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Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests

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Technical Editor

Hugh C. Black, forest wildlife biologist, was National Program Manager, Animal Damage Control, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, Oregon, from June 1988 until January 1991. He retired from the Forest Service in January 1991 and continued working on this volume as a Forest Service volunteer until its completion.

Cover photo: **Black bear damage in a young Douglas-fir stand in western Oregon. Trees with yellow or red crowns were killed by bark peeling during the current season; silver (defoliated) trees died after barking 1 or 2 years previously. (Photo courtesy Mark Gourley, Starker Forests, Inc., Corvallis, Oregon.**

Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests

Hugh C. Black
Technical Editor

U.S. Department of Agriculture, Forest Service
Pacific Northwest Research Station
Portland, Oregon
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Abstract

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This book examines the potential of Silvicultural approaches for managing animal damage in forests at two levels: management of free-to-grow stands and site-specific practices that foster prompt and successful regeneration. Introductory chapters provide a historical perspective of animal damage management in the Pacific Northwest, describe the elements of an integrated approach to forest protection, review the principles of vegetation management and wildlife management, and examine the influence of Silvicultural practices on habitat and animal damage. Individual chapters are devoted to the ecology and control measures appropriate to problem species of wildlife and livestock that damage forest stands. Coverage includes the influence of Silvicultural practices on habitat, populations, and damage. The book focuses on the potential of Silvicultural practices to limit animal damage, but it also includes information on chemical repellents, mechanical barriers, and direct control measures. Other chapters deal with the development of integrated Silvicultural prescriptions, including modeling systems, to limit animal damage. A concluding chapter discusses social, political, legal, and ethical aspects of animal damage.

Keywords: Animal damage management, integrated forest protection, wildlife problem species, livestock grazing, modeling, silviculture, Pacific Northwest.

Foreword

This book was developed to provide a synthesis of published information and operational experience relating to the application of silvicultural practices to limit animal damage. It is intended as a resource for forest-land managers and others concerned with animal damage management in the Pacific Northwest and other regions. Silvicultural methods for the indirect management of animal damage are still under development; therefore, this book examines both the practicality and the potential of various silvicultural approaches for managing animal damage in forests. The book focuses on two levels: management of free-to-grow stands and site-Specific practices related to securing prompt and successful regeneration.

This assessment of silvicultural approaches to the management of animal damage complements and supplements "Assessment and Management of Animal Damage in Pacific Northwest Forests: An Annotated Bibliography" (Loucks and others 1990). That bibliography is a comprehensive reference guide to published information pertaining to the assessment and management of animal damage in the Pacific Northwest and other regions. It includes citations and abstracts from more than 900 papers indexed by subject and author.

These two publications (the bibliography and the present volume) are timely, because forest managers and the public increasingly are concerned about the management of entire forest ecosystems and the need to use environmentally sound approaches to the management of animal damage. Although there are some drawbacks to the application of silvicultural practices on stand and landscape bases to limit animal damage, some very effective, practical, and cost-effective methods can be applied to avoid or limit animal damage and help secure prompt and successful regeneration on a site-specific basis. This also is an arena where additional research is needed.

Chapters that discuss the ecology and appropriate control measures for the principal species of problem wildlife and livestock in the Pacific Northwest were written by specialists who are recognized experts with first-hand field experience in dealing with their assigned topics. Technical editor Hugh C Black and William H. Lawrence, author of the executive summary and synthesis (Chapter 1), are wildlife biologists and resource managers. Both have been deeply involved in the development of many of the current practices directed at controlling animal damage to Pacific Northwest forests.

Charles W. Philpot
Station Director
Pacific Northwest Research Station

Preface

How animal damage to trees should be managed in a forest ecosystem is a significant issue for forest managers to consider in their efforts to prevent or limit resource losses Because of deficiencies in the information available for making animal damage management (ADM) decisions, forest managers often lack specific criteria for determining the long-term effects of animal damage and the need for treatments, the degree of protection needed, and the efficacy and risks associated with specific treatments. Without sufficient information, managers may fail to respond to an animal damage problem in time, or they may unnecessarily act and thus expend resources unproductively.

Forest managers increasingly must take a proactive approach to ADM to prevent or limit losses to forest resources rather than react when animal damage problems are identified (by which time unacceptable levels of damage may already have occurred), Education of forest managers and the public must be expanded to include ADM as an integral part of forest management.

This book is for both the practitioner and the planner. Its 20 chapters (each with an abstract) contain state-of-the-art information on ADM in the forest, and chapter 1 is a summary and synthesis that distills the significant contributions of each author and provides a coordinating framework for the information in this book. It is followed by chapters that discuss the ecology and appropriate control measures for the principal species of problem wildlife and livestock in the Pacific Northwest.

A group of nine chapters deals with a broad spectrum of background topics ranging from a historical review of ADM in the Pacific Northwest to the potential application, in the near future, of computer models and data bases to predict the occurrence of animal damage and recommend courses of action to reduce economic losses. Other chapters deal with economic and silvicultural considerations that must support planning for ADM programs. Included with this group is chapter 7, which describes improved regeneration processes that can reduce the impact of animal damage in plantations. The importance of documenting animal damage problems and control practices for future planning purposes is stressed in chapter 3, which introduces the concept of integrated forest protection (IFP). Important social and ethical considerations relating to animal control are treated in the final chapter.

Supporting information can be found in the literature-cited section within each chapter and in the glossary of technical terms provided at the back of the book. A list of scientific names for the plants and animals mentioned in the text and conversion factors for metric equivalents also are appended to this volume.

The pocket affixed to the back cover contains the following items: pocket cards that summarize planning steps for IFP and that provide information regarding the steps in the regeneration process, and a computer-disk copy of three ADM prediction models.

The general concept of limiting animal damage with multipurpose silvicultural practices is well developed. The most common strategies are vegetation management during site preparation and the use of robust, "animal proof" planting stock.

Marked improvements in forest regeneration systems in the last 20 years have lessened the overall impact of animal damage, but it remains a significant local problem on many forests. ADM is becoming more difficult and controversial with

restrictions on the use of pesticides and other methods of directly controlling animal damage. Slash burning, for example, has been greatly curtailed because of recent changes in air quality regulations.

"New Forestry," which involves new approaches to forest regeneration and stand and landscape management, including practices that increase habitat suitability for problem species and other wildlife, also will have a mapr impact on ADM in the future. Mountain beaver and pocket gopher populations and damage, for example, may increase in shelterwood stands and other stands harvested with New Forestry practices. New Forestry's greater reliance on natural regeneration also may renew concerns over the impact of seed-eating mammals and birds. New Forestry is likely to improve habitat conditions and potential for increased damage by most of the wildlife species that cause damage to forest stands (the species with which this book is concerned). New objectives of resource management with greater emphasis on noncommodity resources, however, may reduce the economic costs assigned to animal damage because of reduced or delayed timber yields (especially on public lands). We do not know, however, how these impacts will change or how their significance will be assessed in the future.

The principal goal of this book is to consolidate knowledge about silvicultural applications that limit animal damage and to identify additional work needed to increase our understanding of animal damage problems and their management. The book's central focus is the potential for silvicultural practices to limit animal damage, but it necessarily includes information on the use of chemical repellents, mechanical barriers, and direct methods of control that limit the impact of animal damage—all of which are important components of integrated forest protection and progressive ecosystem management.

Hugh C. Black
Technical Editor

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Support for this book was provided through cooperative agreements among the Washington Office of the U.S. Department of Agriculture, Forest Service (Timber Management and Fish and Wildlife Management), the Pacific Northwest Region, and the Pacific Northwest Research Station, with funding principally from Timber Management. The final volume is an expression of the knowledge and insights of many people, in addition to the authors.

I thank the Planning Committee for their help in organizing the book and identifying prospective authors. Members of this committee, which I established in September 1988 and chaired, included Robert J. Anderson, Wildlife Research Biologist, Weyerhaeuser Company; Mark Gourley, Reforestation Forester, Starker Forests, Inc.; William C. McComb, Assistant Professor, Department of Forest Science, Oregon State University, Steven R. Radosevich, Professor, Department of Forest Science, Oregon State University; John Tappeiner, Professor, Department of Forest Science, Oregon State University; and John D. Walstad, Professor and Head, Department of Forest Resources Management, Oregon State University. I especially thank John D. Walstad for his valuable counsel and encouragement. This committee contributed importantly to the success of this effort.

I also thank the Editorial Committee, which exercised overall review of manuscript preparation and contributed in other ways to this volume. This committee, which I set up in November 1989 and chaired, included key members of the Planning Committee (McComb, Radosevich, and Walstad), and Martha H. Brookes, technical publications editor, Research Information Service (RIS), Pacific Northwest Research Station. Brookes served on this committee until December 1990. Karen Esterholdt, Staff Director, RIS, participated on the committee from December 1990 until the book's completion. Special thanks are due to William C. McComb who provided in-depth reviews of each of the wildlife chapters (chapters 8-16) and made other contributions. Special thanks are also due to Steven R. Radosevich for his review of the layout proofs of the entire manuscript.

I especially wish to recognize the important contributions of William H. Lawrence, Senior Science Advisor, Weyerhaeuser Company (retired) who freely shared his expertise and good counsel in support of the successful completion of this book In addition to compiling the executive summary and synthesis (chapter 1) and coauthoring the overview of animal damage management in the Pacific Northwest Region (chapter 2), Lawrence reviewed each of the manuscripts and provided valuable commentaries to the authors regarding the organization and content of their papers.

I especially thank our editor, Max G. Geier, Department of History, Oregon State University, who expertly and promptly edited the entire volume. He also prepared the index.

I thank Merline Carter, PNW Station, who provided secretarial support during the preparation of the book and Dawn Peterson, Printed Page Graphics, Portland, Oregon, who prepared the manuscripts for publication. I also thank Delbert Thompson and Ruth Ann Nicklin, RIS, for helping to produce this book.

This book was much improved by the many helpful reviews and constructive commentaries for each of the chapters. Experts in their fields, the reviewers were selected from the USDA Forest Service, other Federal and state agencies, universities, the forest industry, and others, including many of the chapter authors, who themselves contributed expert reviews of other manuscripts in this book.

To the authors who prepared their manuscripts on top of already full schedules and often on their own time, I extend my sincere thanks.

Hugh C. Black
Technical Editor

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SECTION ONE
INTRODUCTORY OVERVIEW

Chapter 1
Summon/and Synthesis

WILLIAM H. LAWRENCE

Abstract

Each of the 20 chapters in Silvicultural Approaches to Animal Damage Management in Pacific Northwest Forests is the original contribution of the authors. This first chapter summarizes the significant contributions of each author and provides a coordinating framework for the state-of-the-art information in this book It also presents, in the synthesis, an independent appraisal of the feasibility of a Silvicultural approach to ADM.

Effective ADM must include a proactive planning phase. ADM should not be a disaster control procedure initiated after wildlife damage is reported. Monitoring of the application of ADM practices is critical to the development of efficient, cost-effective measures of control for future applications.

The potential for Silvicultural control of animal damage to forest resources currently is limited to the regeneration phase of forest management Combinations of site-specific Silvicultural practices, such as site-preparation techniques (selection of logging practices, mechanical scarification, and use of fire), vegetation management, and use of robust planting stock, are effective ADM practices that reduce the adverse impact of feeding injuries from wildlife problem species on newly established plantations.

WILLIAM H. LAWRENCE, senior science advisor (retired), Forest Environmental Sciences, Weyerhaeuser Company, Centralia, WA 98531

In certain situations, silviculturally based ADM must be augmented by control measures, such as the nursery application of foliar repellents before outplanting, tubing seedlings in plastic mesh, supplemental feeding (to control tree damage by black bear, for example), trapping, and the use of toxic baits for pocket gopher control. The development of high-quality, robust planting stock that can withstand light-to-moderate feeding injuries from wildlife is one of the most significant contributions to the reduction of animal damage.

The application of silvicultural practices on a landscape level to reduce the carrying capacity of forested habitats for problem species may have limited value, because public scrutiny of forest management practices and wildlife-population interactions are increasing. It is unlikely, therefore, that the public would accept such an approach in ADM. These concerns and the ethical aspects of ADM are discussed in the synthesis, and an annotated table summarizes the impact that 10 groups of problem animals have at various stages of forest development.

Keywords. Animal damage management, planting stock, site-specific silvicultural practices, ADM ethics, wildlife problem species, vegetation management, computer modeling, integrated forest protection.

Introduction

This executive summary is a technical review and a synthesis The technical review summarizes management topics addressed in the other 19 chapters of this book. The synthesis is concerned with future expectations from an evolving, indirect approach to animal damage management by application of silvicultural practices in forests of the Pacific Northwest The issue of managing animal damage to forest trees is complex, and it involves the economics of stand management and recognition of public concerns about wildlife resources in the managed forest Public policy on the management of our heritage of forests and unique wildlife is still evolving.

Historical Background

This book provides a state-of-the-art assessment of animal damage control as practiced in the forests of the Pacific Northwest It is a compilation of published information and reports based on operational experience. The book's central focus is the potential for silvicultural practices to minimize animal damage, but it necessarily includes information on the use of chemical repellents, mechanical barriers, and direct control measures to minimize the impact of animal damage.

Concurrent with the preparation of this book, a symposium on silvicultural approaches to animal damage management in Pacific Northwest forests was cosponsored by Oregon State University in cooperation with the USDA Forest Service and the Society of American Foresters. The conference was held October 23-24, 1990 in Corvallis, Oregon. This was the third symposium dealing with animal damage management in this forest region. Oregon State University sponsored the first two symposia in 1968 and 1973 (Black 1969,1974) during a period of growing concern by forest managers over the economic losses caused by wildlife damage to forest stands.

After the passage of nearly 20 years and in view of growing concern over wildlife in the forest, it seemed timely for a report on the status of animal damage management in the forests of the Pacific Northwest The symposium provided our authors with the opportunity to present their contributions to a discerning and responsive audience before publication of their work in this book.

Black and Lawrence review in Chapter 2 the nearly 100-year history of animal damage management (ADM) in the Pacific Northwest. During the period immediately after World War II (after 1945), attention increasingly focused on prompt and successful regeneration of harvested stands. Many acres of brush-covered and understocked lands had accumulated on public and private lands, and forest managers demanded that something be done to protect stands of all ages from damage caused by wildlife feeding. The 1968 and 1973 symposia dealt with such topics as surveys to assess economic losses and the importance of specific animals, identification of animal damage, improved control methods, and research needs. By the second symposium, much progress had been made in organizing and funding research on improved repellents to protect newly planted seedlings and in conducting bioassays of more lethal toxicants for direct control programs. Novel delivery systems were developed to improve the efficacy of direct control treatments for specific target species. New and expanded laboratory facilities were provided, and research centered on the evaluation and development of a host of new synthetic compounds for animal damage control.

This indeed was the "chemical period" when new compounds (toxicants and repellents of all sorts) were field-tested for agricultural and forestry uses with little appreciation for their far-reaching environmental impacts. Researchers conducted these field trials not because they were indifferent to these long-term consequences, but because the impacts of "parts per billion" were unknown and scarcely measurable with the technology of the day.

By the third symposium, in 1990, the period of chemical-control methods of forestry had passed. Federal regulations to safeguard human health and reduce environmental hazards from chemical residues eliminated the new synthetic chemicals as useful tools for forest management. The technology of animal damage control reverted to earlier practices, such as trapping, hunting, area fencing, and strychnine baits.

Some progress was made, however, in the development and registration of nontoxic contact-repellents to protect newly planted seedlings. The demands of intensive forest management on industrial lands required prompt and successful regeneration to meet thinning and harvest schedules designed to optimize return on financial investments. Animal damage still caused economic loss. New and novel approaches were needed to lessen the impact of animal damage to forest crops.

One indirect strategy to mitigate animal damage was suggested at the 1968 symposium. It called for manipulation of the habitat so as to reduce its carrying capacity for the problem species. This strategy would have required more long-term research to evaluate its effectiveness. The potential of the chemical approach to provide quick solutions to the problem of animal damage was more attractive to forest managers. Intensive research, therefore, never was initiated to explore this ecological approach to controlling animal damage, although the idea remained attractive.

The organizers of this book and the 1990 symposium expect that exploration of the potential for silvicultural approaches to animal damage management will stimulate further research on this topic and encourage the practical work necessary to put current knowledge into practice. Full evaluation of this ecological approach to solving a major problem of forest management must build on these initial steps.

Animal Damage Management

All wildlife is a publicly owned resource. State agencies are responsible for most wildlife resident on public and private forest lands in the Pacific Northwest. The control of damage from forest wildlife is further complicated by the game or nongame status of problem-causing species. The U.S. Department of the Interior, Fish and Wildlife Service has management responsibility for migratory wildlife and threatened and endangered species; however, habitat management frequently is delegated to managers of state and public land. These wildlife species usually are of little concern to forest managers unless practices of forest-stand management impact the habitat of endangered or threatened species. An environmental assessment must be made in compliance with guidelines for direct control of nongame species under the National Environmental Protection Act (NEPA). Public concern regarding the future status of all forest wildlife is an issue discussed in Chapter 20

Integrated Forest Protection

Integrated Forest Protection (IFF) is a management concept based on Integrated Pest Management (IPM), which was developed for agriculture purposes. The concept of IPM was first proposed by R.W. Stark in 1979 to focus attention on the resource rather than on the problem.

IFP is a holistic approach to attaining forest management objectives while maintaining forest health and productivity. A broad range of biological and environmental factors must be considered in preparing an integrated program of wildlife damage control Biological factors that must be considered, for example, include the stage of forest development to be protected, the population level of problem species, and the duration of the damage period over which the control measure(s) must remain efficacious. The biology and ecology of the target species bear on the method of control required. Environmental factors to be considered include the impact of the control program on nontarget animals, site-specific characteristics that influence accessibility and ease of treatment, and public awareness.

Implementation of the IFP process requires a disciplined approach to planning animal-control programs. Walstad and Norris (in Chapter 3) identify the necessary steps to be followed:

1. Define resource management objectives and constraints.
2. Characterize the potential for damage problem(s) on a site-specific basis within the criteria of step 1.
3. Develop an array of alternative solutions
4. Evaluate alternative control-measures and select the approach consistent with step 1
5 Implement and monitor the control program.
6. Evaluate and document results

The last step is easily overlooked in the press of ongoing work. It is critically important, however, to the success of future planning for animal damage control. Carefully recorded data from current ADM activities provides important input for the development and testing of models for predicting the occurrence of future problems and evaluating possible solutions. The application of modeling systems to ADM is fully described in Chapter 19.

Effective ADM must be proactive and provide a forest manager with reliable information, such as stand-hazard potential, timing and duration of damage, species involved, control alternatives, probability of success, and anticipated cost. Once an animal damage problem is detected, frequently, it is too late to attempt control. This is especially true of ADM problems in newly established plantations. The Integrated Forest Protection process will ensure that ADM is a proactive management tool.

The overall goal of IFP, to paraphrase Logan Norris (1988), is to manage the forest to achieve specified objectives, and ADM is relevant only as it relates to these objectives. Chapter 3 provides a more complete discussion of IFP.

Supportive Forest Sciences

The potential for animal damage in the managed forest is highly variable and dependent on stand conditions and the occurrence and abundance of potential problem species. Population levels of wildlife mostly are controlled by the quality of their habitat, which can be expressed as carrying capacity (number of animals per unit or numbers per acre). The stage of stand development—regeneration, saplings and poles, or mature timber—determines the characteristics of the vegetation matrix, which in turn influences the quantity and quality of forage available for wildlife. The occurrence and intensity of animal damage also is controlled by these same habitat factors. Understanding how these complex interrelations may affect ADM is the province of silviculture, vegetation management, and forest wildlife management.

Silvicultural practices—Traditional silviculture is the science and the art of managing established, free-to-grow forest-stands. The scientific discipline of silviculture defines the biological parameters within which management regimes must operate to stimulate forest growth. The concepts of "New Forestry" include new approaches to forest regeneration from traditional silvicultural practices. Its application will have a major impact on ADM.

This book examines the potential of silvicultural approaches for ADM at two levels of forest management: management at the macrolevel for free-to-grow stands (fertilizer/thinning regimes and harvest methods) in the context of landscape-management considerations, and management at the microlevel that employs site-specific practices related to securing prompt and successful regeneration. Landscape management is concerned with the timing of various silvicultural practices and the pattern of stand conditions those methods produce within the managed forest. Chapter 6 explores silvicultural approaches to ADM at the landscape level.

Microlevel management includes the development of site-specific prescriptions for regeneration and vegetation management that are relatively recent additions to current practices (since the 1960s) of intensive silviculture Important considerations in ADM are the selection of appropriate combinations of planting stock (seedling characteristics of 1-1, 2-1, etc.) and techniques of vegetation management. These ADM tools can significantly affect the probability of occurrence or intensity of animal damage on plantations. Plantation establishment, currently, is the regeneration practice of choice throughout the Pacific Northwest. These two silvicultural practices are critically important for ADM and intensive forest management, and they are treated as individual chapters (see Chapters 4 and 7).

Stand and landscape m anagem ent—A broad spectrum of silvicultural practices are available, but this book primarily focuses on methods that support management of Pacific Northwest forests: clear cutting in Douglas-fir forest-types and partial-harvest (selective and group cutting) in the mixed-conifer forest-types. Emmingham and his colleagues (Chapter 6) provide an overview of the principal silvicultural practices for stand management in the PNW.

In spite of the historical prominence of silvicultural research, very little research has focused on the impact of silvicultural treatments on wildlife populations. The old saw that "good forestry is good wildlife management," in fact, seems to say it all. Hunters provide ample anecdotal justification for this statement. Game can be found in harvested areas and in thinned and fertilized stands. Visibility is an important factor in hunting, but the carrying capacity of these managed areas for game species is much improved over the undisturbed, mature forest.

The forest wildlife (both game and nongame species) that cause serious problems in managed forests are herbivores ecologically associated with natural disturbances that may devastate or totally destroy forest stands Such destruction results in ideal conditions for the establishment of the intolerant pioneer plants that are preferred foods for these animals. "Good forestry," in reference to the above aphorism, concerns prompt (artificial) regeneration after harvest and thinning/fertilizer regimes. These management practices initiate forest succession and create openings in the canopy that, with fertilization, can increase the nutritional level of forage plants consumed by herbivores. These silvicultural practices are designed to regenerate, stimulate, and maintain stand vigor. "Good forestry" practices (silvicultural practices), therefore, effectively increase the potential for current and future animal-damage problems.

The impact of current silvicultural practices on free-to-grow stands and ADM in the managed forest is, perhaps, best considered from a landscape point of view.'
In other words, the habitat conditions (carrying capacity) of an area surrounding a site will influence the potential for damage at that location. Historic considerations are important in any evaluation of the impact of current silvicultural practices on ADM. The current landscape pattern of any managed forest is the result of past management practices and the impacts of natural events. Certain forest managers, consequently, may find they have inherited a mosaic of stand conditions with proposed regeneration units that are predisposed to animal damage problems.

Shifts in management philosophy (for example, a modification in silvicultural practices to manage animal damage) may result in new and different forest management objectives. Managers, in such cases, can only respond in the short-term (that is, implement the initial stages of a shift to a new landscape pattern for ADM). Any significant change in the landscape pattern of forest-stand characteristics takes place slowly over a time-period that frequently exceeds the tenure of the responsible manager or even a series of managers.

' Portions of the following discussion of the potential of landscape management in ADM are based on an unpublished report entitled "area management—stand management at the landscape level" presented by R J Pedersen at the third ADM symposium

At present, there are no designed and field-tested landscape-management prescriptions for ADM, but there is much speculation concerning the potential effectiveness of such an extensive approach to the problem of site-specific damage. A critical problem that must be solved is the matter of scale and the disparity in the extent of home ranges for major problem species, such as snowshoe hare, mountain beaver, black bear, and elk. Small rodents have home ranges of less than one acre, but larger animals range over hundreds of acres. An adjunct to this problem of varying scale is the seasonal movement of problem species between summer and winter ranges (as with porcupines, deer, and elk, for example). Other difficulties with the landscape approach to ADM pertain to the integration of specialized managment methods with harvest planning driven by economic considerations of the marketplace.

Landscape management prescriptions that support ADM are currently lacking, but some forest scientists believe that spatial models in association with Geographic Information Service (GIS) and temporal (stand-growth and yield) models may provide the analytical tools needed to develop practical and effective prescriptions. Management of the pattern and timing of silvicultural treatments can alter the habitat quality of managed stands to lessen the potential for animal damage during the regeneration phase of stand development. Economic considerations and pertinent biological and ecological data for problem species could be incorporated into the model to better define the landscape-management prescription that best meets the objectives of integrated forest protection (IFP). Chapters 5 and 19 present detailed information on wildlife ecology and modeling.

Stand establishment—the most vulnerable stage in forest-stand development occurs during regeneration when seedlings become established and free-to-grow. The literature is replete with published reports of plantation failures caused by wildlife feeding that injures young trees (Loucks and others 1991). A variety of standardized techniques prepare the planting sites with logging systems, slash burning, mechanical scarification, and herbicides, either individually or in various combinations. These methods, however, create an attractive habitat for herbivores that feed on planted seedlings.

The extent of damage to the new plantation is dependent upon two important factors: the rate at which the planting site recovers and the rapidity with which the population of problem animals on the site rebuilds. Problem-causing animals inhabiting the surrounding forest stands are attracted to the improved habitat conditions after harvest, and they augment existing populations of animals that survive site preparation This describes, broadly, the sequence of events that initiate a potential problem of wildlife damage (important biological factors relating to population increases due to improved habitat are treated in Chapter 5). Silvicultural practices such as thinning/fertilizer regimes applied to surrounding stands, therefore, may be contributing factors that increase the severity of wildlife damage to newly established plantations.

The demand that developed in the Pacific Northwest (after World War II) for prompt and successful regeneration to meet the scheduled requirements of intensive forest management prompted an extensive review of all current regeneration practices. Wildlife damage control was only one of many topics carefully studied to identify opportunities for improvement. This broad-based examination (by the forest industry and federal and state forest managers) disclosed the critical need for an overhaul of the entire process of growing, handling and packaging, storing (at the nursery and under field conditions), and planting forest-tree seedlings. Former nursery and

planting practices were inadequate to the task of producing and planting seedlings by the millions.

The first and most significant step toward improvement was to relate the field performance of outplanted seedlings to the growing and storage practices at the nursery. Nurseries now produce high-quality planting stock that can be grown for specific planting-site conditions. A joint research effort of forest scientists has developed a total regeneration system from nursery bed to the microsite selected for the planted seedling.

P.W. Owston and colleagues (Chapter 7) have developed a flow chart outlining the major steps of a coordinated regeneration system that may extend over a period of 20 years or more. Ten or more years might pass before seed could be generated to match outplanting requirements. This problem has been overcome, however, through the development of forest-tree seed banks. Animal damage management, therefore, may be necessary for the entire period of plantation maintenance (12 years or more). The final stage on Owston's flow chart is an evaluation of the plan's effectiveness. This task is critical to identify the need, if any, for future improvements in the regeneration system. There are two basic strategies for stand establishment to ensure prompt and successful regeneration: the more rapidly that seedlings become established and grow beyond a vulnerable size, the less damage they may sustain; and the larger the seedlings planted (2-1 for example), the more resistant they are to certain types of wildlife feeding injury. Planting site conditions (droughty and rocky soils) may preclude the use of large planting stock, so individual tree-protection barriers may be necessary where animal damage problems are likely.

The dramatic improvements in regeneration systems employed in intensive forestry in the Pacific Northwest, arguably, are the most significant developments in ADM to date. The constant production of high-quality seedlings in nurseries, the improvements in planting-site preparation, and the improved handling of bare-root planting-stock in the field has made this progress possible ADM must become an integral part of reforestation planning to be an effective, proactive program in an integrated forest protection plan

Physical preparation of the planting site is an important initial step in the regeneration process, but control of competing vegetation during plantation establishment period is essential. The following section examines this final topic of silvicultural practices.

Vegetation management—Silvicultural practices in intensely managed forests no longer are limited to management prescriptions for maturing stands of free-to-grow trees. The science of silviculture now includes site-preparation standards and vegetation-management strategies to secure the prompt and successful regeneration of harvested stands. Site-preparation standards governing the use of fire, scarification by machine or by hand, or the application of herbicides ensure the creation of appropriate microsrte-conditions for planting. Herbicides and other selective, vegetation-management practices maintain favorable microsite-conditions until the planted seedlings reach the free-to-grow-stage. The principal objective of vegetative management in support of plantation management, therefore, is to permit seedlings to capture the site as quickly as possible Once young trees control the site, competition with vegetation and animals is reduced. Site capture reduces the kinds and abundance of problem wildlife species, but animal damage (bear) also can occur in the maturing forest.

This discussion primarily focuses on the vegetation matrix that develops during a regeneration phase that may extend up to 10 years. The duration of this critical period of stand formation depends on the quality of the site and on the composition and structure of the vegetation that competes with young seedlings for nutrients, soil moisture, and growing space (light). Higher quality of sites correlates with better growth response from seedlings. Increased fertility of high-quality sites, however, may result in greater competition from surrounding vegetation. Optimal habitat conditions for many of the problem animals prevail during this period of stand establishment.

The first three years after planting are the most critical for seedling survival. During this establishment period (and the first year is the key), nursery-grown seedlings readjust to the field conditions of the planting site. As the plantation is becoming established, competing vegetation also develops with the potential to fully capture and dominate the plantation site.

The familiar elements of growth suppression in plantations concern competition in the rooting zone for soil moisture and nutrients and aboveground competition for light and space to develop a fully formed crown. One form of this competition is called allelopathy, or the release of toxic or growth-inhibiting substances by invading plants to eliminate their competition. The presence of allelopathic plants is recognized in Douglas-fir plantations, but their impact on seedling survival is not fully known.

McDonald and Radosevich (Chapter 4) argue that proper vegetation management during the critical period of plantation establishment eliminates much of the need for future treatments to release the young trees. Careful early planning is cost-effective.

The composition of the vegetative matrix of a plantation has much to do with the site's attractiveness to wildlife. Foraging activities of animals may mitigate the intensity of plant competition and may be the principal source of growth suppression. Controlled foraging by livestock, however, can be an effective form of vegetation management under certain conditions. Treatments that reduce plant competition may be used to modify habitat and reduce its suitability for wildlife. Herbicide treatment to control broadleaf herbs, for example, can reduce the suitability of the regeneration site for pocket gophers (see Chapter 10). In the rehabilitation of poorly stocked forest stands that support high populations of mountain beaver, mechanical site preparation in combination with slash burning and herbicide application is an effective prescription to control these problem animals before planting (see Chapter 11). Chapter 4 includes a more complete discussion of vegetation management and the nature of plantcompetition.

Forest Wildlife Management

It has been said that "as the vegetation is, so the animals are." This is a highly simplistic statement regarding the distribution of wildlife in the forest. The simplicity of the statement, however, disguises the importance and complexity of understanding the successional pattern of forest vegetation and its influence on the distribution and abundance of wildlife.

Two principal approaches to ADM currently are available to forest managers: (1) Direct measures control populations of problem species of wildlife directly with baiting, trapping, or shooting, or limit wildlife-feeding injuries through the use of mechanical or chemical barriers (area fencing, screening individual seedlings, or application of foliar repellents). (2) Indirect approaches employ silvicultural practices (including the production of site-specific planting stock and vegetation

management) to alter habitat conditions and thereby reduce the presence of wildlife or reduce the susceptibility of seedlings to damage by wildlife within the treated area. Detailed information on the biology of problem animals and their ecological relation to the pattern of forest vegetation is essential to an integrated forest protection plan for ADM, regardless of the approach selected. Foresters, essentially, manage the habitat of wildlife, and the silvicultural approach is the principal thrust of this book. Operational ADM, however, will continue to be a blend of direct and indirect measures of control.

McComb and Hansen (Chapter 5) have prepared a thorough review of the principles of forest-wildlife management, and they link these concepts to various silvicultural practices. They include a conceptual framework for ADM that includes habitat manipulation, site-specific strategies to protect target stands or plantations, and other control measures (Chapter 2 and chapters covering individual problem-animals)

The home range (habitat) of any animal must provide food, cover, and water. These are basic requirements for survival, and the pattern of availability for each of these factors varies with the problem species Large animals, such as bear or a herd of elk, have home ranges that extend over many square miles, while mountain beaver or voles may range over less than an acre. Readily available water and the quality of food and cover are important factors in determining the population level and extent of the animals' home ranges. Other site-specific characteristics that also may influence the local occurrence of wildlife damage are discussed in Chapter 19.

Various silvicultural practices affect key elements of wildlife habitat The range of practices covered in this book include even-age and uneven-age management, regeneration systems (including species selection), site preparation, vegetation management, and thinning. The results from designed studies that assess the impact of these various practices on specific problem animals mostly are lacking. Reliable inferences, however, can be made for some animals on the basis of the impacts that various silvicultural practices have on habitat conditions (see the section on animal damage management for a more complete discussion of silvicultural treatments and their impact on individual animals).

The development of an ADM plan to deal with the potential of an overlapping pattern of damage caused by species with widely divergent home ranges is complex and, perhaps, best handled with a model. Expert models have been developed that summarize current knowledge of selected species important to ADM. This type of model (a static model based on current data) is, in effect, a list of facts to aid planning. These models, therefore, are most useful for planning short-term, site-specific control-programs, such as protection of a plantation during the establishment period. Assessing the potential of a landscape-management approach for ADM, however, will require the modeling of alternative patterns of stand-management treatments over time and by location to seek the best fit in an action plan for integrated forest protection (a dynamic modeling approach). Great strides have been made in the development of ADM models, but operational models are not yet at hand for field use (see Chapter 19 for an update on the status of ADM modeling).

McComb and Hansen believe that thoughtful stand and landscape management offers the best long-term solution to animal damage problems This approach can actually inhibit the development of large populations of problem species of wildlife or produce a forested landscape with acceptably low levels of problem species and a

diverse assemblage of other species. The success of this approach depends on a thorough understanding of the relation between the animal and its habitat. Much basic long-term research on the habitat relations of problem species within the managed forest is needed, however, to achieve success with this approach. Animal damage problems, meanwhile, will continue to plague the forest manager. What can be done in the interim?

Two key elements of action plans for integrated forest protection are monitoring and documenting results. If these elements could be recorded in a consistent manner with a format suitable for data input for computer analysis, then preliminary models for ADM on a landscape-management basis could be developed more rapidly. Research data over time could be used to fine tune the practical models now in use. Biological data pertaining to problem animals can be found in the chapters referring to individual animals.

Animal Damage Management

Silvicultural practices and the size, spacing and scheduling of harvest units can effectively improve habitat conditions for a broad spectrum of forest-wildlife species. The periodic application of fertilizer (urea) in conjunction with thinning improves the quantity and quality of forage for herbivores such as deer, elk, mountain beaver, and porcupines. Fertilized trees also attract bears. Intensive methods of Silvicultural management that enhance stand health and vigor generally improve habitat conditions for many species of forest wildlife.

Mineral soil and full sunlight with a minimum of vegetative competition during the establishment period are critical requirements for successful regeneration of Douglas-fir. Site-preparation practices that favor the establishment of Douglas-fir seedlings also initiate forest succession. The early serai stages of forest development provide ideal habitat conditions for most species of-problem wildlife. The problems faced by the ADM specialist, therefore, are compounded by the very management practices that represent current Silvicultural practices in the Pacific Northwest.

Problem Species of Wildlife

Ten chapters of the book deal with the problem species of primary concern in ADM. Individual chapters present pertinent data on the life history, habitat preferences, nature of damage to trees, and methods of control for ADM. Chapter 17 specifically addresses the potential impact that grazing by livestock may have on plantations. Table 1 summarizes problems of animal damage from 10 groups of problem species in relation to various stages of forest development and problem species of wildlife. The discussion that follows presents information specific to each group of animals.

Seed-eaters—Application of toxic baits or repellent-treated seed to control losses to seed-eating birds and mammals was never consistently effective as an ADM measure. Planted seedlings have replaced direct seeding as the regeneration method of choice in the Pacific Northwest to ensure prompt and successful regeneration after harvest. Plantation management facilitates effective regeneration with improved seed. Chapter 2 describes the history of research on seed protection. In Chapters, West provides a comprehensive table of the seed-eating birds and mammals of PNW Forests. The deer mouse, for example, is a major consumer of seed shed by forest trees, and it is a difficult animal to control.

Table 1—Animal-damage problems and ADM control measures

	Stage of forest development			ADM control measures	
Problem species	Seed to plantation establishment	Established plantation (seedling to sapling)	Poles to mature timber	Silviculture[8]	Direct[6]
Seed-eaters	x			None	
Voles	x				
Pocket gophers	x	x	x	×	×
Mountain beaver	x	x	x	×	×
Snowshoe hares	x	x		x	x
Deer and elk	x	x		x	x
Tree squirrels		x	x	x	
Porcupines	x	x	x	×	×
Black bear			x		x
Livestock	x	x		Herd management	

[3] Silvicultural control is manipulation of habitat conditions with silvicultural practices that reduce the carrying capacity of that habitat for a problem species
[b] Direct control is the protection of trees with nonsilvicultural techiques of control, such **as** toxic baits, trapping, foliar repellents, plastic-mesh tubing, drift fences, etc

Voles—Conifer forests also provide suitable habitat for the (usually less evident) voles *(Microtus, Phenacomys,* and *Clethrionomys}.* The latter two generally are of no consequence in ADM, because they inhabit mature forest stands and their feeding activities are not injurious to trees. Askham, in Chapter 9, identifies three species of *Microtus* (Oregon vole, long-tailed vole, and montane vole) as potential problem species in plantation management *Microtus* habitat generally consists of grassy openings in forest cover, herbaceous stream margins and open, understocked brushfields. Local populations of *Microtus* periodically become irruptive. Voles, in such cases, literally cover the ground, and the population becomes stressed and may completely girdle thin-barked conifers and hardwoods at the root collar. These irruptions in vole populations are not predictable, nor are they controllable. The population peaks are not sustainable and the population naturally crashes. After a crash, voles are difficult to locate. During the growing season, voles feed on green vegetation (grasses and forbs) and they shift to roots, rhizomes, bark, and cached foods during the winter. Tree barking is more prevalent during winter months. Voles pose a more serious threat to agricultural operations than to forest plantations.

The biggest problem with *Microtus* damage in the Douglas-fir region occurred during the conversion of abandoned agricultural lands (principally pasture land) to forest-tree plantations. Conversion requires total site preparation and seedlings planted in furrows invariably are girdled, which causes heavy mortality. Scarification followed by herbicide treatment usually is needed to control grasses and other competing vegetation. Planting should be delayed for 1 year to ensure the destruction of the grass cover and voles. Maintenance treatments generally are needed until seedlings reach crown closure and control the site.

Pocket gophers—Control of pocket gophers is a major problem in plantation management in the mixed-coniferous forest-types east of the Cascade Mountains. Root pruning, basal stem barking, and stem clipping are the types of injury that cause mortality in plantations. Small, newly planted seedlings may be pulled underground into active tunnels during root pruning. Larger seedlings, saplings, and small poles may sustain basal barking injury under snow. If snow cover is deep and persistent, then barking on the bole and large branches may be 6 or more feet above ground-level. This type of injury can be confused with similar damage caused by porcupines and snowshoe hares. When snowcover melts, foraging tunnels in the snow are apparent from the pattern of burrow casts on the ground that are formed as voles excavate soil and push it into tunnels through the snow.

Effective ADM incorporates silvicultural practices (vegetation management) with direct control measures (toxic bating). Toxic baits either are placed by hand in active tunnels underground or in artificial tunnels constructed by a burrow-builder machine. Pocket gophers incorporate these artificial tunnels into their active network of foraging tunnels. Marsh (Chapter 11) provides a detailed discussion of control strategies for voles.

Mountain beaver—The mountain beaver is the analogue of the pocket gopher in the westside of the Douglas-fir forest. Mountain beaver construct extensive networks of tunnels, but foraging primarily is an aboveground activity. Clipping of the lateral shoots and main stem of seedlings and the barking of saplings and small poles characterizes damage from mountain beaver. Clipping injuries to seedlings can be confused with similar damage caused by snowshoe hares. Hares, however, seldom clip stems over 0.25 inch in diameter, whereas mountain beaver clip stems up to 1 inch in diameter. Hares regularly deposit flattened ovoid droppings while feeding. Mountain beaver, in contrast, defecate in fecal chambers underground. Basal barking of conifers by mountain beaver occurs on trees 3 to 16 inches in diameter at ground level, but it is more common in sapling stands ready for stocking control. High populations of mountain beaver can cause extensive damage within plantations and create unacceptable stocking levels. They frequently clip seedlings at the ground line but do not eat them. Excavation of active burrows show that the animal uses many seedlings for building nests. Effective ADM incorporates silvicultural controls through methods of site preparation and direct controls with methods such as trapping and protection of individual seedlings with Vexar' tubing. Site-specific silvicultural practices include mechanical site preparation, slash burning, and vegetation management. Chapter 11 (by Cafferata) provides a complete discussion of ADM strategies for mountain beavers.

Snowshoe hares—Snowshoe hares may be found in all forest types in the Pacific Northwest. Local populations of this hare are subject to periodic fluctuations in population levels. Peak populations of hares can devastate newly established plantations planted with small stock. Newly planted seedlings clipped by hares can be confused with those clipped by mountain beaver. The differences in these two types of damage are described in the above section on mountain beaver.

' Mention of a commercial or proprietary product does not constitute endorsement by the U S Department of Agriculture

Effective ADM must include silvicultural practices and direct controls. Site-specific silvicultural treatments (such as slash burning and mechanical site-preparation followed by vegetation management) can produce less than optimal habitat for hares during a plantation-establishment period of 3 to 5 years. Direct control currently is limited to tubing the seedlings with Vexar netting. Chapter 14 (by Giusti and others) provides further information on snowshoe hares, rabbits, and pika (essentially a high-elevation mountain-rabbit).

Deer and elk—Browsing by deer and elk consistently has been the most widespread form of animal damage to plantations in the Pacific Northwest. Deer and elk damage affects the terminal leader of seedlings. Repeated annual browsing of terminal shoots converts seedlings into a bushy growth form that effectively suppresses height growth. Such delays can lengthen the rotation period for the developing stand. Browsing produces a ragged break on the terminal shoot in comparison with the clean-angled cut of clippings by hare and mountain beaver Deer and elk travel in herds, so trampling damage may occur in newly established plantations. This is not the case with deer, which travel in smaller family groups. Examination of the size of droppings helps to identify the presence of these two problem animals.

The most effective silvicultural practice in the broadest scope of the term is the consistent production of high-quality, robust seedlings (seedlings that can sustain moderate browsing pressure and maintain vigorous growth). Direct-control measures include the placement of drift fences to deflect elk from plantation sites and the application of a natural-product repellent. An effective, foliar big-game-repellent (BGR) is commercially available for nursery application before seedlings are lifted for outplanting. Contact repellents only protect treated foliage. New growth in the spring is susceptible to browsing damage. Rochelle, in Chapter 16, discusses the potential of other silvicultural approaches to control damage by deer and elk.

Tree squirrels—Tree squirrels of concern to foresters belong to the genus *Tamiasciurus.* The Douglas squirrel may be found in the coastal Douglas-fir forests, and the red squirrel may be found in coniferous forest-types east of the Cascade Range. Squirrels feed on a variety of material gathered from trees, such as foliage buds, succulent elongating shoots, pollen-bearing and seed-bearing cones, and phloem and xylem (when the sap is flowing in the spring). Feeding injuries from squirrels usually take place out of sight, but their occurrence and type can be determined from discarded tree-parts littering the ground under the crown. Barking injuries can be detected readily from the short strips of bark (1-3 inches in length) that squirrels peel from the upper bole and branches. Feeding injuries by squirrels, seemingly, are of little consequence to the tree. Damage occurs when barking injuries adversely impact forest management plans.

The barking by red squirrels on the upper bole and on principal branches in juvenile stands of lodgepole pine is a serious problem in south-central British Columbia. Deformed, spike-topped trees result from this injury, and this reduces expected yields in cases where stands sustain heavy damage. Preliminary findings from ADM research suggest that a silvicultural approach may prove useful in reducing the severity of the problem. Precommercial thinning to reduce stand density appears to reduce the incidence of damage from barking. Additional research on stocking levels is underway. Sullivan further reports (in Chapter 13) the development of a damage-

forecasting model. Direct control measures are not currently being considered. Chapter 13 also contains recommendations for ADM to control upper-crown girdling caused by wood rats in sapling to pole-sized conifers in the Douglas-fir region. The control of damage caused by stream beavers also is briefly discussed.

Porcupines—Porcupines, traditionally, were considered the "lost traveler's" meal and were not to be harmed. When on the ground, they are easily captured despite their quills. Porcupine, however, is indeed starvation fare. Porcupines may be found throughout the Pacific Northwest in forests, on agricultural land, and in high desert. They seldom are found, however, in old-growth forest stands.

Porcupines feed on the bark and sapwood of all age-classes of conifers. Injuries to older trees occur on the unplated bark of the upper bole and crown. On seedlings and saplings, injuries from barking may occur at any point from the ground upward. Repeated injuries to older saplings and to poles frequently result in death of the crown. Poor growth-form results in reduced yields of lumber. Basal girdling kills the seedlings. Feeding injuries are characterized by horizontal and oblique tooth marks (1/8 in. wide) in the sapwood. The presence of quills shed by the porcupine and a scattering of oblong fibrous droppings (up to 1 inch or so in length) are conclusive signs that porcupines are present. During the growing season, lush herbaceous, ground vegetation is the preferred source of food. After the first killing frost, materials gathered from trees are the primary source of food for porcupines.

ADM includes some logical, yet untested silvicultural approaches and the highly effective method of direct control by hunting. Removal of large, overstory roost-trees and control of ground vegetation may reduce the attractiveness of a plantation to porcupines. The prompt burning of large piles of windrowed slash and the accumulations of logging debris at landings and sorting points, conversely, prevents porcupines from occupying those sites as winter dens. On the other hand, shelterwood harvest systems may encourage porcupines by leaving potential roost trees in the vicinity of plantations. ADM measures include trapping at den sites, and construction of 2-foot-high drift-fences around plantations. Hunting, however, remains the most effective species-specific method of control. Knowledge of the seasonal uses of preferred habitat is essential to the planning of effective hunts. Dodge and Borrecco, who have extensive field experience in porcupine control, prepared Chapter 12.

Black bear—Black bear can be a significant forest-management problem in young to intermediate-aged forests throughout the Pacific Northwest. They are the single species that consistently damages stands with trees of 15 to 50 years of age, regardless of the forest type. Douglas-fir is the species preferred by bears in coastal forests, and western larch, Engelmann spruce, and lodgepole pine are the species preferred in intermountain forest-types.

Bear damage trees by stripping bark from the trunks of rapidly growing, vigorous trees to expose the sapwood. In spring, when bear damage usually occurs, the phloem and sapwood are full of wood sugars and other carbohydrates. This is a nutritious food for bear recently emerged from hibernation. Tree damage is sporadic throughout the range of the black bear, so it is thought that feeding on trees is a learned behavior passed from females to their cubs. This reviewer, however, believes that trees are a normal source of supplemental food that bear can and do utilize,

and feeding on trees is not some specially acquired trait. The mosaic of stands sustaining bear damage and stands free from damage also may indicate certain, as yet unrecognized, nutritional deficiencies in other food sources utilized by bear. Bark stripping may only partially girdle the tree at the first feeding, but repeated visits in succeeding years may completely kill the tree. Teeth marks are clearly evident on the exposed sapwood of trees damaged by bear.

Bear damage that continues in a given stand represents a slow attrition in the potential yield of forest products from that stand. Damage in any single year may be tolerable, but the accumulated mortality of crop trees can be an economic disaster. The control of bear damage, therefore, is an ongoing program.

Silvicultural practices, such as thinning and fertilizer regimes to enhance and maintain stand vigor are important factors that contribute to the pattern of bear-damaged stands. Silvicultural practices aimed at controlling bear damage, however, have not been explored. Direct control to remove problem bear is the most practical method at hand. This is accomplished through the removal of nuisance bear by hunting or snaring specific problem animals. Supplemental feeding of bear in problem areas is currently practiced on a limited basis in the Douglas-fir region and in other bear-damaged areas A proprietary, pelleted bear-food is available from the Washington Forest Protection Association in Olympia, WA. Preliminary results from feeding trials in problem areas appear to reduce the incidence of bear damage in test areas.

Livestock—Chapter 17 (by Graham and others) is unique in this book in that it addresses the management of the impact that a privately owned resource (livestock) can have on publicly owned forest resources. Grazing on public forest lands is a "privilege" permitted if it does not interfere with other resource-management objectives. Grazing by domestic livestock continues to be an important use for public forest lands in the West. The term "livestock" includes both cattle and sheep.

Plantation damage is caused by cattle trampling, browsing, and rubbing against sapling-sized trees. These activities potentially may degrade the site, because soil compaction and soil displacement follow prolonged grazing of areas with plantations. Positive aspects of grazing include the control of competing vegetation and, consequently, the conservation of soil moisture for seedlings. Both cattle and sheep can be used in this form of vegetation management.

Livestock damage to naturally occurring regeneration and to plantations can be minimized by controlling the number, distribution, season, and duration of use by grazing animals on a given area. These essentially are administrative decisions that must be made cooperatively by forest managers and livestock owners. The techniques to protect specific regeneration sites involve the placement of salting areas, installation of drift fences, employing range riders and herders (for sheep), and monitoring livestock in the area of concern. Integration of livestock into a Silvicultural prescription for regeneration potentially may be a useful tool for vegetation management that enhances plantation establishment.

Models as Silvicultural Management Tools

William C. McComb (Chapter 19) defines models as

> … abstractions of real processes and relationships. They can assist land managers in making wise decisions by allowing managers to test land management strategies and follow the results through time and by synthesizing pertinent information that would not otherwise be readily available. Given the complexities of multiple-use management and multiple wildlife species, models will see more and more use in land management planning to produce healthy forest for the future.... Models are fallible. The quality and performance of a model is dependent on the quality of the information used to develop the relationship and their applicability to specific circumstances.

Forest resource managers already use a variety of standard models in the course of their daily work. Familiar management tools, such as maps, the geographic information system (GIS—a computerized mapping system), stand tables, and growth and yield forecasts are among the models more commonly used. This executive summary, in part, is a model of this book in that it attempts to condense into a single chapter those salient points described in greater detail in other chapters.

Advances in electronic technology have revolutionized the collection of qualitative data under field conditions. Researchers can now record observations directly from the subject of research study and input field data directly into a computerized model for analysis, or they can directly record individual measurements and observations in the field with hand-held computers and subsequently transfer those data to fixed computers for final analysis. Most natural events that take place in the forest can be modeled, and ADM is no exception. The above admonition by W.C. McComb, however, should be recognized.

An accurate data base of the impact that various Silvicultural practices have on problem species is critically needed for ADM. More effective planning models for ADM that apply to site-specific regeneration problems could be developed from such a data base and a preliminary model could then be constructed for evaluation of potential Silvicultural approaches to ADM with stand and landscape management.

Knapp and Brodie (Chapter 18) describe a structured approach to preparing a Silvicultural prescription applicable to ADM planning that is not unlike the planning process for integrated forest protection (Chapter 3). Monitoring results and providing timely feedback are key activities by which the reliability of predictive models for ADM can be improved. These authors observe that "the management of animal damage is not an independent process.. . Silviculturalists should be concerned about animal damage only in the context of land and resource (management) objectives." Wildlife-feeding injuries occur throughout a managed forest, but if such injuries are of no consequence to management objectives, then they should not be considered problems that require control. This point is examined more closely in the following case history of ADM.

Evaluation models for Silvicultural management—Knapp and Brodie describe an analytical method used to evaluate the worth of individual seedling protection on the Siuslaw National Forest in Oregon. Plastic tubing (Vexar) and netting were used to

protect seedlings from damage caused by mountain beaver. Individual-seedling-protection techniques proved so successful that this practice became a standard regeneration procedure on the Siuslaw National Forest.

Data collected during preplanting surveys, however, described certain environmental conditions and enabled resource biologists to successfully predict the probable occurrence of damage. ADM plans were adjusted to distinguish between high-risk and low-risk regeneration sites, and resource-management objectives were met at a substantially lower cost. Knapp and Brodie refer to adjustment in standard, ongoing practices as "adaptive management." This is another term for the flexibility that experience has demonstrated to be an essential component in natural resource management.

If a regeneration-interaction model for mountain beaver had existed that incorporated the identification of high-risk and low-risk planting sites for use in ADM, then site-specific prescriptions for the control of mountain beaver damage could have been developed. With such a model, the standard practice of tubing all seedlings in all plantations may not be necessary. The distinction between controlling animal damage and meeting a resource-management objective (protecting plantations in the Siuslaw for example) is not just subtle semantics; substantial differences in treatment costs may be involved.

A hypothetical economic analysis comparing the gains obtained from multiple ADM practices merits study. In the course of this analysis, Knapp and Brodie describe the utility of several other modeling systems that may be of value to the ADM specialist. The Scheduling and Network Analysis Program (SNAP) that develops harvest and treatment patterns and identifies specific stands and treatment units is of particular interest. It has the capability to schedule silvicultural treatments over time and to deal with problems related to the management of contiguous stands. This latter capability, in combination with damage-prediction models, would be useful for testing silvicultural approaches to ADM at the stand and landscape levels.

Wildlife management models—Chapter 19 is unique in this book, because McComb has provided three examples of ADM models on the enclosed computer disk with instructions on how to install the programs on a personal computer. McComb recommends that forest managers first read the chapter to understand what the models portray. The examples provide "hands-on" experience, and the chapter describes an array of different types of models appropriate for use in ADM and provides a useful list of references.

The first step in the development of any ADM model is to assemble all pertinent information regarding the biology and ecology of the problem species. An excellent source document is the literature survey on animal damage in Pacific Northwest forests compiled by Loucks and others (1991) McComb provides a flow chart outlining the basic steps for development of an "expert" model that relates existing habitat conditions to the habitat preference of the problem species. Once these relations are developed and analyzed with the GIS data bank, appropriate action plans can be formulated for identified high-risk situations. Habitat-association models can be combined with growth and yield simulations and harvest plans to develop a more sophisticated approach to predicting the occurrence of animal damage problems over time. This dynamic type of model, however, has yet to be developed for Pacific Northwest forests

As modeling becomes more commonplace in the management of forest resources, this reviewer's concern is that the output from computer simulations may well become the world of reality for administrative staffers. The apparent precision and finality of quantitative results produced by a model can easily mislead. Such a view must be tempered by what goes on in nature. In other words—to paraphrase Louis Agassiz—study nature, not computer simulations.

Ethical Aspects of Animal Damage Management

Forest management practices are under closer public scrutiny today than at any time in the past. Local, state, and federal agencies exercise more jurisdiction over forest lands and silvicultural practices on both public and private ownerships, and people unattached to forestry or land ownership are demanding and receiving a role in defining acceptable forest practices. Failure by forest managers to heed these concerns in their decision-making process frequently leads to court-imposed modifications or total abandonment of a program. The public will be heard.

The inclusion of this chapter (Chapter 20) on societal concerns regarding forest-management practices is timely. In the Pacific Northwest, an often acrimonious public debate is underway regarding the fate of the northern spotted owl and the harvest of commercially valuable old-growth timber. The ancient forest is the habitat for this endangered owl. At jeopardy are both the owl and the economic stability of timber-dependent communities throughout the region. Resolution of this issue is still uncertain, and it may become the biopolitical issue of the decade. This debate over the northern spotted owl and old-growth forests reinforces the comments of Schmidt and his colleagues regarding the role that an urban public can exert on forest-management objectives.

ADM in the managed forest easily could become a major public issue in the near future. The USDA Forest Service publicized in 1944 the management concept of multiple-use forestry (Sustained Yield Forest Management Act). The management of most publicly owned forest lands (with the exception of national parks) now is predicated on this principle. How the public will react to ADM programs on a landscape basis remains to be seen The public has attributed multiple use value to wildlife, which has always rated high for its scientific, aesthetic, and recreational values. Manipulating the forest habitat to reduce populations of problem species might be viewed with concern, especially where big-game species such as deer, elk, and black bear might be adversely impacted.

Hunters, historically, have wanted wildlife managers and foresters to maintain maximum populations of deer and elk in forest habitats. This attitude may limit the future application of ADM on a stand or landscape basis; however, hunters are subject to criticism for killing wildlife for pleasure

The application of short-term, site-specific damage-control in conjunction with regeneration projects should be a high priority Several non-lethal ADM techniques are available that would generate less criticism of undesirable impacts on nontarget animals. The added expense of such methods of damage control is unlikely to be of great concern to the public.

The status of all wildlife in managed forests is in a state of flux. There is a growing public awareness that forests should be managed as an entire ecosystem and that all components of the forest are of equal importance This public attitude will require a reconsideration of the role of ADM in the managed forests of the future.

Synthesis

The Concept of Silvicultural Control of Animal Damage

Genesis of the concept—Natural catastrophes have played an important role in the regeneration and maintenance of the ancient coniferous forests of the Pacific Northwest. These forests have evolved through a history of disastrous insect outbreaks, blowdowns, and lightning-caused fires. A natural mosaic of forest stands in various stages of growth resulted from the random occurrence of these natural catastrophes. With the initiation of forest succession, a host of pioneer plants and coniferous seedlings (from seed shed by surviving trees) revegetate receptive sites. A wildlife component in these ancient forests was comprised of herbivorous species that benefited from the abundance of herbaceous food plants and browse characteristic of early serai stages of forest succession. As habitat conditions improved, the populations of herbivores increased. Many of the wildlife species that benefited from the renewal process are the problem species that plague many forest managers today.

The modern forest manager substitutes, in part, harvesting and vegetation management for the wildfires of the past to prepare a site for regeneration. Plantations of genetically superior seedlings replace the haphazard germination of wild seed. Some species that respond to the natural process of forest renewal by rebuilding their population levels also respond in like manner in managed forests. This is the genesis of animal damage problems.

The hypothesis—A silvicultural approach to controlling wildlife damage is predicated on the question if current silvicultural practices improve habitat conditions for problem species, then can silvicultural practices be devised and employed to at least maintain or reduce the carrying capacity for these species while meeting other resource-management objectives? The answer is equivocal: both "yes" and "no," depending on which of the problem species is of concern and the extent of the silvicultural treatment to be applied.

Conceptual application—The concept of silvicultural applications to control animal damage is that the habitat of problem species can be manipulated through silvicultural practices applied to individual forest stands on a landscape basis to reduce the potential, if not the severity, of wildlife damage. The review of current silvicultural practices in Pacific Northwest forests (Chapter 6) and the status of modeling strategies to control wildlife damage (Chapter 19) indicate that this approach remains a challenge to be met.

There are four formidable constraints on the implementation of this concept as an operable management practice on a landscape level: (1) the problem of dealing with diverse ownerships, each with forest management objectives that may be incompatible with silvicultural management plans, (2) the diversity in the size of home ranges for problem animals, (3) the lack of management tools (models) based on pilot-scale trials testing the concept, and (4) acceptance by the public and by wildlife management agencies of what might be perceived as negative silviculture to control forest-wildlife populations The constraints posed by concerns (2) and (3) can be resolved through research, whereas (1) and (4) are sociological and ethical problems with uncertain solutions. Their resolution will require a new understanding of forests and forest management. The practicality of silvicultural controls on a landscape level is uncertain, although the application of selected silvicultural practices to meet site-specific needs for prompt and successful regeneration can be effective.

Current application—Field results clearly indicate that silvicultural practices relating to stand establishment are most likely to be effective in ADM. These practices include selection of logging system, slash burning, mechanical site-preparation, vegetation management, and the production of high-quality planting stock.

These silvicultural management tools are flexible and can be adapted to meet special site-specific requirements. They often operate synergetically when applied in appropriate combinations. Seasonal timing is an important factor in determining the duration and effectiveness of the treatments. Silvicultural practices are standardized, but silvicultural prescriptions must be developed for site-specific applications. (The ADM case-history in Chapter 18 includes a pertinent discussion of the necessity for this distinction.)

Wildlife-damage problems on regeneration sites are localized in areas where the home ranges of problem species lie entirely within the regeneration site. The home ranges of small mammals such as mountain beaver, pocket gophers, and wood rats, for example, are less than one acre in size. Modification of habitat conditions with silvicultural practices that work to the disadvantage of these species is efficacious and economical. The significant factors are the relatively short duration of protection needed, the localized area for treatment, and the small home ranges of the problem species.

Preplanting surveys, in some situations, may indicate the need for supplemental protection provided by baiting, as in the case of pocket gopher control or seedlings tubed with Vexar netting for protection from mountain beaver and snowshoe hares. Trapping may be necessary with extremely high populations of mountain beaver (in excess of 15-20 animals/acre). Supplemental protection usually is necessary when brush fields are converted back into forest stands.

With problem species such as deer, elk, black bear, and porcupines (with large seasonal home ranges), proven silvicultural controls are not available. A variety of damage-control measures are available and in practice, as outlined in the species accounts (Chapters 12,15, and 16). Most of the nonsilvicultural control measures, unfortunately, are labor intensive.

Research needs—Research needs can be organized into three generic categories as follows: (1) ecological studies to improve the basic knowledge regarding individual problem-species and to assess the long-term impact of animal damage on stand productivity, (2) species-specific, integrative studies of the impacts of silvicultural practices as prescribed by authors reporting research pertaining to individual problem animals, and (3) development of computer simulations to examine the feasibility of a silvicultural approach for management of animal damage on a landscape basis.

The research needs identified in categories (1) and (2) are best met by applying a research overlay to ongoing, operational practices, particularly silvicultural practices employed in reforestation. Much of the pertinent information can be collected by monitoring regeneration projects, and a host of new research projects are not required. Field observation should be recorded in a standardized format for computer analysis and for subsequent construction of expert models. Study of interactions between silvicultural practices and wildlife habitat in relation to regeneration would have immediate utility.

The research project identified in the last category, doubtlessly, is a modeler's delight. In the sense of the original concept, however, it may have limited practical utility because of the poor public acceptance of such an approach to wildlife damage control. Dynamic landscape models, however, would provide a broader understanding of the factors that control the distribution of a variety of wildlife species in the managed forest. With this understanding, forest-management plans could be developed to maintain species diversity in the managed forest, although this is a different application than first envisaged.

Environmental concerns—Forest managers are well aware of the growing popular interest in the management of this nation's public and private forest lands. There are numerous examples of the power of public opinion forcing modification or abandonment of certain forest-management plans. The application of silvicultural practices to modify forest habitat on a landscape level and thus control wildlife damage would be a prime target for public concern.

In contrast to the landscape approach for ADM, the public might better comprehend the need to protect the process of forest regeneration from destruction by wildlife if it is integrated with other desirable aspects of forest management. This, after all, is the renewal phase for managing the renewable natural resource that forests represent.

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SECTION ONE
INTRODUCTORY OVERVIEW

Chapter 2
Animal Damage Management in Pacific Northwest Forests: 1901-90

HUGH C. BLACK AND WILLIAM H. LAWRENCE

Abstract

Animal damage was recognized as a hazard to forest regeneration and other resources in the Pacific Northwest from the beginning of artificial regeneration efforts in the early 1900s. Conifer seeds, saplings, and older trees are subject to injury by many animals during stand development. Feeding activity by birds and mammals is primarily responsible for seed destruction, cone severing, browsing, clipping, budding, seedling pulling, tree cutting, and barking. Damage from deer browsing is most common, but pocket gophers cause the most damage to reforestation in the region, especially among pines and mixed conifers. Surveys of animal damage on private and public forest lands have documented problems since the late 1950s. A 1988 survey of National Forest System lands reported treatments to control animal damage on one-quarter of all reforestation and timber stand improvements.

Planting was the favored method of regeneration until after World War II, despite some successful direct seeding efforts in the early 1900s that included prebaiting with strychnine-treated grain baits to control deer mice and other rodents. Protection from animal damage for seedlings planted between 1901 and 1950 relied on direct control of problem species by poison baiting with strychnine or by trapping. With the availability of two new acute rodenticides (compound 1080 and thallous sulfate) after World War II, the development of two new seed protectants by the U S. Fish and

HUGH C. BLACK is wildlife biologist (retired), Pacific Northwest Research Station, USDA Forest Service, Portland, Oregon, and WILLIAM H. LAWRENCE is senior science advisor (retired), Weyerhaeuser Company, Centralia, Washington.

Wildlife Service (tetramine and endrin), and the advent of helicopters, direct seeding was widely practiced from the 1950s to the early 1970s. Restrictions on the use of endrin and other toxic chemicals as conifer seed treatments in the early 1970s marked the end of most operational reforestation by direct seeding.

The U.S. Fish and Wildlife Service conducted chemical screening from about 1950 to 1980 in a search for better rodenticides and repellents that would prevent animal damage to trees and seedlings. That massive search identified many formulations that effectively protected seeds and seedlings, but because of the cost of registering new compounds, restrictions on their use, and other factors, only a few of the identified corn-pounds currently are available. Thiram, an animal repellent, currently is used in limited quantities to protect seeds in nurseries from small mammals, and to protect seedlings from hares, rabbits, and deer. Big-Game Repellent (BGR) was developed by the Weyerhaeuser Company and the Fish and Wildlife Service in the 1970s and is widely used to protect seedlings from browsing by big game.

Animal damage research diminished in the 1980s partly because of improved reforestation practices that greatly increased plantation survival. Several new formulations for protecting seedlings from animal damage are under development but are not in operational use. Physical barriers for protecting individual trees were developed during the 1970s and are widely used to protect seedlings from browsing by big game and damage by other animals. Animal damage prediction-models that provide better assessments of damage have reduced expenditures for damage control and have improved treatment-effectiveness. Silvicultural approaches to animal damage management also are gaining emphasis.

Keywords: Animal damage management, integrated forest protection, wildlife problem species, livestock grazing, modeling, Pacific Northwest, silviculture.

Introduction

This chapter provides nearly 100 years of historical perspective on the need for animal damage management in the forests of the Pacific Northwest, and it examines significant developments in the effort to control such losses. **Animal damage, in simplest terms, is the result of any kind of animal activity that causes economic losses by reducing or delaying forest yield.** Conifer seeds, seedlings, saplings, and older trees are subject to various kinds of injury by many animals during stand development. Every injury does not cause economic loss, and trees may sustain repeated injuries from feeding with little or no long-term effect, Excessive feeding by animals on seeds, seedlings, or saplings, however, can prevent or delay successful reforestation, or it may destroy valuable crop-trees in maturing stands. The latter type of loss takes the form of an annual attrition of crop trees.

Pacific Northwest Region

Our definition of the Pacific Northwest Region encompasses northern California, Oregon, Washington, southern British Columbia, Idaho, and western Montana. About half of this area is forested. The Cascade Range runs north and south to divide the region into eastern and western areas with distinctive climates, vegetation, and wildlife. These areas commonly are referred to as "east side" and "west side" in Oregon and Washington. Our description of this region is based on Franklin and Dryness (1973) and others who have described the forest types, environments, and vegetation of the Pacific Northwest; on Burns (1983) who summarized Silvicultural systems for major forest types in this region, and on Ingles (1965) and others, who give accounts of the wildlife species.

Forest Types and Silvicultural Systems

Western area of the Pacific Northwest Region—The Douglas-fir region extends from northern California through Oregon and Washington to central British Columbia. It includes most of the west slope of the Cascade Range and extends westward nearly to the coast. Douglas-fir and its principal associates, western hemlock and western redcedar, grow in areas with mild and humid climates, dry summers, and heavy precipitation that mostly occurs at higher elevations in the form of snow. The Douglas-fir zone extends from sea level to about 1,500 feet in the northern part of the range to about 6,000 feet in the southern part, and it merges into the mixed conifer zone in the south.

Even-age timber management (clearcutting, seed tree, or shelterwood harvest) is the Silvicultural system primarily practiced in the Douglas-fir region and throughout the Pacific Northwest. Uneven-age (harvest of timber by either single-tree selection or group selection) and even-age systems.are used with other forest types in the region, however, and uneven-age management is gaining greater emphasis on public lands throughout the Pacific Northwest and particularly on forests in the eastern part of the region

Staggered and progressive patterns of clearcut logging generally predominate in the Douglas-fir zone. Logging slash typically is broadcast burned after cutting, and sites usually are planted with Douglas-fir. Much of the forest land in the western parts of Oregon and Washington is in second-growth stands that have develped after timber harvest or wildfire. The acreage of young-growth stands developing from plantations now greatly exceeds that of stands developing from naturally or artificially sown seeds.

Harvest or removal by wildfire of mature stands of Douglas-fir and other conifers profoundly affects wildlife habitat. Populations of deer, elk, and many small mammals such as mice, pocket gophers, wood rats, rabbits, hares, and mountain beaver may markedly increase after removal of mature stands Wildfires and the Silvicultural practice of clearcutting in the Douglas-fir region have greatly increased the productivity of habitat for big game and most other problem species, and that increase has caused serious problems of ongoing animal damage during reforestation of those lands.

Several other forest types, such as the true firs (red fir and white fir) and the mixed conifer types, also occur in western Oregon and Washington but are less widely distributed than the Douglas-fir type. Mixed-conifer stands occur at low elevation in the Coast Range and from mid- to high-elevations in the southern Cascade Range. Seasonal cycles of climate in the zone range from cool and moist in winter to hot and dry in summer. Precipitation is less than in the Douglas-fir zone, and most of it occurs as winter rain. Mixed conifer stands vary in composition, but always include two or more of the following species: Douglas-fir, incense cedar, sugar pine, white fir, and ponderosa pine. These forest types also include several minor species and hardwoods such as madrone and tanoak. Animal damage, particularly by pocket gophers, is important in true fir and mixed conifer forest types of southwestern Oregon and northern California as well as in the eastern part of the region, but the problem is smaller in scale than in the Douglas-fir forests.

Eastern area of the Pacific Northwest Region—Forests in the eastern part of the region are more diverse and are often interspersed with open rangelands. Important forest types include lodgepole pine, ponderosa pine, interior Douglas-fir, and several

mixed conifer types (true firs, western larch, and Engelmann spruce). Interior ponderosa pine and interior Douglas-fir types include pure stands of ponderosa pine or Douglas-fir, or mixtures of these two species and their major associates: grand fir, western larch, and lodgepole pine. These types of forest cover are widely distributed in the eastern parts of Oregon and Washington, and in Idaho and western Montana. Distribution of ponderosa pine and Douglas-fir is strongly influenced by climate and available soil moisture. Pure or nearly pure stands of lodgepole pine are also widely distributed throughout forested areas in eastern Oregon and Washington, southern British Columbia, Idaho, and western Montana. The climate is characterized by dry hot summers and cold winters. Precipitation is fairly low, except at higher elevations. Much of the annual precipitation occurs as snow. Even-age and uneven-age management systems are both used in these forest types. Natural regeneration is gaining importance, but plantation-management techniques developed for east-side conditions are increasingly employed.

Wildlife Problem Species

Many wildlife problem species, including deer mice, porcupine, deer, elk, and bear, occur on forest lands throughout the entire region, but some differences exist between the problem species of the eastern and western parts of the Pacific Northwest. The principal problem species of wildlife in the western part of the region include the black-tailed deer, Roosevelt elk, black bear, mountain beaver, pocket gopher, snowshoe hare, brush rabbit, and wood rat. The mountain beaver's distribution in the Pacific Northwest principally is limited to the Douglas-fir region of western Oregon and Washington and to the mixed-conifer region of southwestern Oregon and northwestern California In the eastern part of the region, the most important problem species of wildlife is the pocket gopher, which occurs in all forest types from lodgepole pine to true firs. Other important problem species of wildlife include the mule deer, white-tailed deer, Rocky Mountain elk, black bear, porcupine, jack rabbit, snowshoe hare, and the red squirrel, which is of particular concern in the lodgepole pine forests of interior British Columbia. Domestic livestock are also an important source of damage to forest plantations in this area.

Deer and elk in the eastern part of the region, unlike their related subspecies in the West, typically migrate from winter range at lower elevations to summer range at higher elevations and return to lower elevations in the fall. These movements affect patterns of browsing damage on plantations on or adjacent to the winter ranges of big game. Seasonal migrations of deer and elk are short or unnecessary in the western part of the region

Greater snowfall and prolonged snow cover in the eastern part of the region and at higher elevations in the West may limit the exposure of seedlings and saplings to animal damage, particularly at higher elevations. Pocket gophers and voles damage trees under snow, however, and porcupines and red squirrels may damage mature-tree crowns and saplings exposed above the snow

Significance and Characteristics of Animal Damage in Pacific Northwest Forests

Animal damage to forests in all stages of growth has been recognized as a problem in the Pacific Northwest Region from the beginning of artificial regeneration efforts in the early 1900s. Forest-dwelling herbivores always have fed on conifers. These natural feeding activities are a serious problem only in managed forests, where they affect projected yields and length of stand rotations. Feeding activity by birds and mammals mostly is responsible for damage to forest trees that involves seed destruction, cone severing, browsing, clipping, budding, seedling pulling, tree cutting, barking, and root pruning, but movement of big game and livestock also causes trampling and breakage of young trees.

Description of Animal Damage to Forest Stands

Animals sometimes destroy the reproductive buds of conifers before seeds are formed, and they consume the mature seeds of many species on the parent tree and on the ground after natural seedfalls or artificial seeding. Seed destruction in nurseries and seed orchards is a special problem that concerns managers of these facilities. Several species of resident and migratory seed-eating birds, such as juncos, grosbeaks, and mourning doves, are important consumers of tree seeds in this region. Mice (especially deer mice), shrews, chipmunks, and tree squirrels, also consume large quantities of seeds, and birds and small mammals clip newgerminants of many tree species.

Damage to growing trees may occur at any point of development from seed germination through maturity. Voles and related rodents damage seedlings and small saplings by barking stems aboveground and roots belowground. Tree squirrels may also clip and bark small trees, but they more commonly bark upper boles of saplings and poles. The most important cause of damage to reforested stands of pine and mixed conifer east of the Cascades, however, is the pocket gopher. Pocket gophers cause serious damage to new plantations, because they feed on the roots, bark, stems, and foliage of seedlings and saplings of many species and either reduce the vigor of young trees or kill them outright.

The mountain beaver is another burrowing rodent that damages seedlings and saplings by clipping stems, foliage, and occasionally roots. It also damages larger trees by barking the root crowns and basal portions of the bole. Mountain beaver are mainly found in the Douglas-fir region of western Oregon and Washington, where they are the most important damage-agent affecting regeneration efforts in that area.

Brush rabbits, snowshoe hares, black-tailed jack rabbits, and pika are widely distributed throughout the Pacific Northwest Region, and they cause damage similar to that of rodents (mainly clipping and barking). Damage from these sources, however, is unevenly distributed over time and place. Porcupines, are most abundant in pine, mixed conifer, and other more xeric forest types where they damage trees by clipping the stems of seedlings and by barking saplings, poles, and mature trees

Deer browsing is the most common type of animal damage in the Pacific Northwest. Black-tailed deer, white-tailed deer, and mule deer all browse on seedlings and small saplings and cause damage during growing and dormant seasons. They also may cause minor damage by trampling and rubbing their antlers on saplings. Black-tailed deer mainly occur in the Douglas-fir region where they are the most important cause of damage to conifer plantations. Mule deer and white-tailed deer mainly occur in the eastern part of the region and cause less damage than black-tailed deer.

Roosevelt elk and Rocky Mountain elk both cause problems that resemble deer damage by trampling and rubbing their antlers on young trees. Elk, however, may browse on larger seedlings than deer, and they more commonly pull seedlings out of the ground without browsing. Rocky Mountain elk occur in the Cascade Range and throughout the eastern part of the Region. Roosevelt elk occur throughout western Oregon and Washington and northwestern California, but most of the damage that they cause occurs in Douglas-fir plantations in western Oregon and Washington.

Black bear damage saplings, poles, and larger trees by stripping bark in spring to eat the newly formed sapwood. Bear damage occurs throughout the Pacific Northwest, but it is most common in northwestern California, western Oregon and Washington, and Idaho.

Damage Identification

An important monograph by Moore (1940) provided the first comprehensive description of the mammals and birds that damage trees and the impact of that damage on reforestation in the Douglas-fir region of Oregon and Washington. Moore's detailed descriptions have aided foresters in the identification and assessment of damage caused by these animals. Smith and Aldous (1947) provided accounts of conifer-seed consumption by mammals and birds, including records of the number of seeds consumed or destroyed by various species. They listed a total of 44 mammals and 34 birds found to eat conifer seeds. Only a few species, however, are important to conifer regeneration: tree squirrels, chipmunks, deer mice, and a few species of fringillid birds (chiefly, grosbeaks, finches, sparrows, and juncos). A bibliography of species that cause seed losses also is available (Pank 1974).

Identifying the causes of damage is especially important in planning and implementing appropriate control measures. Lawrence and others (1961) published a widely used guide to wildlife-damage identification that illustrates the types of feeding injuries these animals cause.

Surveys of Animal Damage

Industrial tree farms—Lawrence (1958) and others recognized that controlling animal damage on a regional basis requires a coordinated effort that marshalls Federal, State, and private resources. They also recognized that the full dimensions of the problem needed to be assessed. Lawrence estimated that wildlife damage to Douglas-fir stands on tree farms owned by the Weyerhaeuser Company in Oregon and Washington cost $875,000 in 1958. Extrapolated to the Douglas-fir region of the Pacific Northwest, the total annual damage by wildlife was estimated to be between $12 and $15 million (Besser and Welch 1959). Although animal damage problems had been recognized for some time (Moore 1940), these figures underscored the scope of the problem, alerted forest managers to the economic impact of animal damage in the region, and energized ADC research efforts. Lawrence made a prescient observation when he recognized that "the real challenge of controlling forest wildlife damage is not in the field of chemical control, but in gaining understanding of ecological factors involved and in putting this knowledge into practice."

Cooperative animal damage survey (CADS) In Oregon and Washington—Many other studies and surveys were conducted in the Pacific Northwest to determine the extent of animal-damage problems and their control One of the most comprehensive studies, the Cooperative Animal Damage Survey of coniferous plantations in Oregon and Washington (Black and others 1979, Brodie and others 1979), evaluated the impact of animal damage on survival and growth in plantations of Douglas-fir and ponderosa pine established in 1963-64 and then observed for 5 to 10 years. Browsing by deer and elk and clipping by hares, rabbits, pocket gophers, and other rodents occurred extensively and repeatedly during stand establishment. This damage caused significant tree mortality and reduced height-growth. An economic evaluation of these data showed that a 3-percent rate of loss from animal damage would reduce the total value of the forest resource in the two States by $1.8 billion and a 6-percent rate of loss would result in a reduction of $230 million (Brodie and others 1979).

Other surveys in Oregon and Washington—Other surveys in Oregon and Washington in the 1970s were aimed at determining the nature and extent of problems caused by porcupines (Evans and Matthews 1972), pocket gophers (Northwest Forest Pocket Gopher Committee 1976), and mountain beaver (Mountain Beaver Subcommittee, Northwest Forest-Animal Damage Committee 1979). These surveys confirmed that damage caused by these species was widespread, significant, and increasing. Owners and managers of forest lands in Oregon, Washington, and northern California, for example, reported mountain beaver damage on about 275,000 acres in 1977.

National Forest System (NFS) lands in Oregon and Washington—In the late 1960s, Crouch (1969) made the first comprehensive assessment of animal damage on NFS lands in the Pacific Northwest Region (Oregon and Washington). This questionnaire survey described in detail the kinds of injuries occurring on NFS lands and the animals causing that damage. Foliage browsing was the most common type of damage, followed in order by barking, root pruning, clipping, trampling, and loss of trees. Problem animals in order of importance were deer, porcupine, pocket gophers, hares, rabbits, elk, livestock, small rodents, mountain beaver, and bear. Animal damage was more common on National Forests in Oregon than in Washington, and most problem areas were in western Oregon. Crouch noted that about 25 percent of all reforestation work in the Region had to be redone in 1969 principally because of animal damage.

NFS lands in four western Regions—A questionnaire survey of animal damage on NFS lands in four western Regions from California to Montana was conducted in 1984 by the Forest Service and showed that animal damage was a serious problem that affected forest regeneration and other resources. The Northern Region (mainly, Montana and Idaho), for example, reported that animal damage, chiefly by pocket gophers, was the major cause of plantation failure from 1976 to 1983. The principal causes of damage in order of importance were pocket gophers, big game (deer and elk), hares and rabbits, voles, porcupines, and mice.

National Forests in these four Regions conducted animal damage control (ADC) in 1984 to protect trees on about 100,000 acres. The cost of this direct control exceeded $5.5 million. Replanting of another 8,000 to 10,000 acres was required principally because of animal damage, and it cost an additional $3 5 million.

All NFS lands—A comprehensive questionnaire survey of National Forests in 1988 indicated that ADC was conducted on 208,000 acres of reforestation and older stands. Nearly all this acreage was in the West, and the annual cost of these control efforts was about $9 million (Borrecco and Black 1990). About one-quarter of all reforestation and timber-stand improvements were treated for ADC (no attempt was made to estimate the amount or cost of replanting required because of animal damage) Sixty-two percent (128,600 acres) of the acreage treated and 49 percent ($4.3 million) of the ADC costs were in the Pacific Northwest Region (Oregon and Washington). Most of the Forests in all regions except Alaska rated animal damage to reforestation and older stands as very important or moderately important. One-third of the Forests rated damage as increasing, approximately two-thirds of them rated damage as about the same, and only 6 percent of the respondents rated damage as decreasing. The survey found that damage to forests stands was caused by a wide variety of animals, including livestock, but pocket gophers were the most destructive group of species on NFS lands. More than half of the Forests reported animal dam-

age to structures and campgrounds or animal-related health hazards such as rodent-borne diseases. Beaver were a minor problem in all regions, and they reportedly caused damage in about one-third of the Forests. Half of the Forests in all regions except Alaska reported bear depredations and nuisances, and they reported significant and increasing damage to young stands by black bears.

Regional assessments of animal damage and other state or regional surveys- Two regional assessments of animal damage in the 1980s provided in-depth analyses of animal damage to conifer regeneration in southwestern Oregon (Evans and others 1981) and western Oregon (Campbell and Evans 1984). The 1981 study emphasized the need to quantify the impact of animals on forest regeneration. The 1984 study was based on a survey of more than 100,000 acres of reforested public and private commercial forest lands and it provided a synthesis of published information and operational experience in animal damage control in the region

Many other state or regional surveys have investigated animal damage on forest lands. An annual questionnaire survey in California, for example, is based on questionnaires sent to state, Federal, and private foresters, companies, and agencies (Guisti and Schmidt 1989). Respondents to one survey conducted in 1989 by the California Forest Pest Council's Animal Damage Committee reported animal damage on 252,000 acres of forest lands.

Management of Animal Damage in Pacific Northwest Forests

Seed and Seedling Protection: 1901-50

The USDA Forest Service and the Bureau of Biological Service (now the USDI Fish and Wildlife Service) took the lead in efforts to develop direct methods of seeding and planting during these early years. Reforestation was given priority, because many National Forests were largely created out of cutover, burned-over, and unstocked forest lands (Cox 1911). Direct seeding was emphasized because of the vast acreages involved (an estimated 7.5 million acres of NFS lands required artificial reforestation in 1911) and because it was much less costly than planting.

The USDA Forest Service, in cooperation with the Bureau of Biological Survey, conducted intensive studies in 1910 of rodent damage to direct seeding. These studies of caged rodents indicated that one chipmunk consumes up to 600 Douglas-fir seeds per day and one deer mouse consumes up to 300 Douglas-fir seeds over the same period. Prebaiting with strychnine-treated grain before seeding also was tested as a method for controlling small seed-eating mammals, especially deer mice.

Isaac (1937) studied natural Douglas-fir seedfall and estimated that "practically all of the seed is consumed by birds and rodents during years of light to medium crops." He also reported that deer mice consume seeds and seedlings (germinants).

Moore (1940) rated deer mice as the most important consumer of tree seeds in the Douglas-fir region because of their abundance and ubiquitous distribution. He provided the first detailed accounts of the life histories of these species and he noted the preferences of deer mice for conifer seeds. He also identified shrews as important seed-eaters. Moore rated brush rabbits and snowshoe hares as the species most destructive to planted seedlings and he studied the effect on small-mammal populations of forest-management practices such as slash burning.

Seed protection—Direct seeding had been tried with mixed results in Europe, but was first tried in the United States in 1901 with seeds broadcast or spot-seeded on the San Bernardino Forest Reserve in California (Cox 1911). The experiment was a total

failure because rodents destroyed the seeds. Seeding trials were later attempted with several conifer species on other National Forests in the West, but all were unsuccessful until 1905, when the first successful direct seeding was accomplished in the Black Hills National Forest in Nebraska (ponderosa pine seed was broadcast and seeded with a corn planter). This was followed by successful direct-seeding on the Oregon National Forest (now the Mount Hood NF), the Suislaw National Forest in Oregon, and other National Forests in the West from 1909 to 1910. Six thousand acres comprising the Soleduck Bum within the Olympic National Forest in Washington were successfully broadcast-seeded from the ground in 1909 with Douglas-fir seed coated with red lead, and about 14,000 acres were direct-seeded in 1910 on National Forest System lands in the West.

An excellent paper by Willis (1914) was subtitled "A Study in Failures" despite the reported successes of 1909 and 1910. Willis described tests of 20 poisonous and distasteful substances (including strychnine) that were used to protect Douglas-fir seeds from mice. All were judged unsuccessful. Willis pessimistically concluded that "the future must decide whether control of rodents is possible or whether we must depend on planting for reforestation."

Pearson (1913) reported in a review of silvicultural practices that

> … because of the destruction of seed and young seedlings by rodents and to a lesser extent by birds, direct seeding has been a total failure throughout the district (National Forests in Arizona) in almost every instance in which it has been attempted So persistent and uniform have been the failures due to this cause that it is the consensus of opinion throughout the district that direct seeding is almost hopeless unless the rodent evil can be eliminated.

Methods employed to protect pine-seed included coating the seeds with red lead, prebaiting with strychnine-treated grain, and installing protective screens over seed spots. Seed coating was ineffective, baiting showed promise for controlling rodents but not birds, and screens were effective against both birds and rodents but were too costly.

About 84,000 acres representing two-thirds of the 125,000 acres reforested on NFS lands in the West by 1915 were direct-seeded, and 41,000 acres were planted. Results showed that direct-seeding was successfuFon favorable sites if rodents were controlled and if weather was favorable for 2 or 3 years after seeding. Prebaiting with strychnine-treated grain had already become a standard procedure.

Garman and Orr-Ewing (1949) reviewed direct-seeding work in British Columbia from 1923 to 1949 and concluded that direct seeding was impossible without rodent control. This summed up the prevailing philosophy. Direct-seeding was not considered operationally feasible until after World War II and planting was favored as a means of artificial reforestation until after the war because of the unsatisfactory control of seed-losses to rodents and birds. Research during this period sought methods for protecting seeds either indirectly, by controlling small-mammal populations, or directly, by protecting seeds with repellents or screens.

Seedling protection—Animal damage to naturally regenerating seedlings and saplings also posed a problem for early artificial regeneration efforts. W.H. Babbitt, for example, wrote an article in 1913 regarding "Porcupine Devastations" in California-

> Porcupines are doing an astonishing amount of damage to reproduction and young timber on this district (Tahoe National Forest) and I would like to stir up all of our force against these pests.... It is very aggravating to ride over an old burn that seems to be restocking when viewed from a distance, only to find that 90 percent of the trees have been ruined by porcupines.

Protection of planted seedlings from animal damage during this entire period (1901-50) mostly relied on direct control of small mammals by baiting with strychnine or by trapping. Repellents, fencing, and other methods had been tested but were seldom used because of cost or unsatisfactory results. An excellent paper by Lantz (1909) discussed pocket gophers with an emphasis on damage to fruit and forest trees and methods of controlling damage by baiting, trapping, and fumigation. Baiting with fresh fruit or grain treated with strychnine sulfate was the recommended practice for controlling gophers in large areas. These procedures were essentially the same as those of modern hand-baiting. Detailed procedures for controlling pocket gophers with strychnine-treated sweet potatoes or carrot baits were outlined in an early report on reforestation on the National Forests (Tillotson 1917). Similar procedures were described for controlling wood rats, cottontail rabbits, and jack rabbits. Tillotson also mentioned the use of fencing to protect planted seedlings from rodents in California but noted that it was both expensive and inefficient.

Prescriptions for the direct control of ground squirrels, jack rabbits, pocket gophers, mountain beaver, and other farm and forest pests were developed by Gabrielson (1921) and other Bureau biologists. They were based on strychnine-treated grain or fresh baits. Similar methods that were developed primarily for controlling rodents on farms and rangelands were later used to control these species on forest lands. Baker and others (1921) reported extensive damage by snowshoe hares in natural stands and plantations of conifers in Utah They provided a detailed description of hare damage to fir, pine, and spruce seedlings and saplings. They also outlined procedures for direct control by baiting with strychnine-treated alfalfa or oats, and they recommended fencing for the protection of small, highly valued plantations where complete protection was desired.

Life history studies—Life histories of important species of forest pests were compiled during this period, including an outstanding monograph by Scheffer (1929) on mountain beaver that included methods of control. Scheffer noted that reforestation is retarded on sites heavily infested with mountain beaver He developed control methods based on trapping (steel-jaw trap or box trap) or baiting with fresh apple, carrot, or clover treated with strychnine alkaloid Trapping remains one of the two principal methods of direct control (conibear traps have supplanted steel-jaw traps) and apple-based (pelleted) strychnine is now the only bait registered for the control of mountain beaver.

A treatise by Crouch (1933) on pocket gophers described and illustrated methods for their control that included poisoning, trapping, fumigating, flooding, and shooting. Poisoning and trapping were recommended as the most practical and efficient methods for controlling pocket gophers. Procedures for baiting with fresh vegetable, grain, alfalfa, or clover baits were based on use of strychnine alkaloid. The author emphasized that a combination of two or more methods (integrated pest management) is often necessary for control

Seeds and Seedling Protection: 1950 to Present

ADM practices before 1950 failed to effectively control animal damage, and a large backlog of nonproducing forest lands consequently had accumulated over the preceding 50 years as old, poorly stocked burns and clearcuts became brushfields. The 360,000-acre Tillamook Burn in Oregon, and other large wildfires, added significantly to the backlog of reforestation needs after World War II that increased the pressure for research and development of more effective methods of reforestation and protection of seeds and seedlings from animal damage. Recognition that second-growth forests are the forests of the future and that all forest lands should be regenerated promptly after harvest stimulated and intensified the efforts of researchers and practicing foresters to develop new and improved methods of regeneration and animal control.

Ample funding for significant increases in ADC research consequently became available in public and private sectors after 1950, and a number of cooperative groups (such as the Northwest Forest-Animal Damage Committee) were formed to coordinate and focus expanded efforts to deal with problems of regeneration, tree damage, and associated wildlife species. New ideas to control animal damage were solicited from all quarters and no suggestions were dismissed without a review by the appropriate cooperative group.

Regeneration efforts initially focused on direct seeding after broadcast-distribution of toxic baits containing the newly available rodenticides. Direct seeding on a large scale began in Oregon and Washington in the early 1950s, but primarily on private land (Payne 1964). Before that time, conifer seeds and seed germinants mostly were protected from small mammals with strychnine and two highly toxic rodenticides newly available in the late 1940s: sodium fluoroacetate (compound 1080) and thallous sulfate. These rodenticides were applied to wheat and other cereal grains that were then broadcast over forest lands before the area was seeded with conifers. A buffer strip up to 0.25-mile wide frequently was treated in conjunction with the area to be seeded. By about 1950, two baits (1080 and thallous sulfate) commonly were applied together, each at a rate of 0.25 to 0.50 pound per acre, and the site was then aerially seeded. Successful regeneration was limited, however, and the method required two separate operations: baiting and seeding. Initial reduction of small mammals was nearly complete after prebaiting in this manner, but it was temporary. Deer mice and other small mammals rapidly repopulated areas from which the resident population was removed, and researchers recognized that it would be better to protect seeds from mice without eliminating the resident population.

Experimental seeding projects conducted by Federal and State agencies and private companies showed by the mid-1950s that successful seeding is not possible without effective control of seed-eating mammals. Many compounds were tested as potential repellents, but none was effective. Poison baits applied before natural seedfall or before aerial seeding had only limited success. Baiting with wheat treated with thallous sulfate, compound 1080, or a combination of both, provided good, initial control of resident populations of small mammals, but baited areas were rapidly repopulated and regeneration was only partially successful.

Strychnine, zinc phosphide, compound 1080 (sodium fluoroacetate), thallous sulfate, tetramine (tetramethylenedisulphotetramine), sodium arsenite, and many other rodenticides control small mammals and protect tree seeds or seedlings. Most of these compounds no longer are commercially available, however, because they are

secondary poisoning hazards and cannot be registered. Only zinc phosphide, thallous sulfate, and strychnine currently are registered for use as rodenticides on forest lands, and strychnine may be used only belowground.

Helicopters and more effective methods of dispersing toxic baits and tree seeds enabled the wider application of this method of regeneration, and it especially facilitated the regeneration of large burns and clearcuts. Over 1.5 million acres in Washington, Oregon, and California were seeded for conifer regeneration from the late 1940s through 1972, and nearly all of those acres were seeded to Douglas-fir. Direct seeding in these three States peaked in 1970 when over 140,000 acres were seeded, but that method rapidly became less common for silvicultural reasons. Even with improved methods of seed protection, rodents rapidly repopulated the treated areas, and seed losses continued. A new approach to reforestation obviously was needed.

In the early 1970s, planting replaced direct seeding as the regeneration practice preferred for silvicultural reasons, because the establishment of plantations was an important step toward the development of thinning regimes for controlling the spacing of stands and the selection of crop trees. The random spacing that results from direct seeding poorly suits the more intensive approach to stand management that thinning and fertilization regimes require.

Methods for controlling and limiting damage by deer and elk on NFS lands (Borrecco and Black 1990) included the use of rigid plastic tubing, repellents such as Big-Game Repellent (BGR), netting, bud caps, habitat modification, and special hunts. Pocket gophers mainly were controlled with strychnine-treated grain placed by hand or machine. Habitat modification, planting of above-normal numbers of seedlings, and protective plastic tubing (applied aboveground and belowground) also were used. Plantations were protected from livestock with electric and other fencing, and herding practices were controlled. Repellents, such as thiram, plastic tubing, and habitat modification, protected seedlings and saplings from clipping by hares and rabbits.

Roughly half of all repellents and rodenticides applied to NFS lands for reforestation purposes are used in the Pacific Northwest Region (Oregon and Washington), and their use has increased with the growth in reforestation programs. Those programs used 4,210 pounds of Big-Game Repellent (BGR, or putrescent egg solids) and thiram in FY 1988. This included treatment of about 3.5 tons of seed sown in nurseries with 31 pounds of thiram. In addition, 3,376 pounds of strychnine were used for direct control of pocket gophers in conifer plantations.

Chemical methods of seed protection—The Fish and Wildlife Service began an intensive program of chemical screening in the 1950s at the Denver Wildlife Research Center (DWRC) to find better rodenticides and repellents for preventing animal damage to tree seeds and seedlings. Kverno and Spencer were coleaders of this program (Kverno 1954). The FWS and its predecessor, the Bureau of Biological Survey, had sought safer and more effective materials to control animal damage. Screening of chemicals for biological activity was mostly an empirical process of evaluating compounds against a standard. Two types of compounds were sought: effective, species-specific lethal agents and broad-spectrum repellents. Environmental safety was another important parameter The screening program focused on compounds with chemical structures similar to those with known biological activity

and on unregistered chemicals that originated from the chemical industry. The Fish and Wildlife Service took the lead in this research, in cooperation with chemical companies, the forest industry, and other State and Federal agencies, because development costs and limited markets for forest-animal repellents precluded the development of such products by the chemical industry (Besser and Welch 1959, Kverno and others 1965).

Spencer (1958), who concluded that "the traditional means of removing offending species via direct control is only a stopgap measure," led the DWRC's search to find chemicals that can be translocated into living trees by treatment of the seeds, spraying of the foliage and roots, or application in the soil. Research initially focused on systemic seed-protectants rather than seed coatings, because larger rodents cut through coated seeds with their incisors without ingesting any repellent. Systemic insecticides (chemicals that are translocated within the plant) were first introduced during World War II. Most were snort-lived, however, because although they are toxic to mammals after a single application, that characteristic did not meet the need for long-term protection of seeds and seedlings that most forestry applications require.

Spencer (1958) and coworkers at the DWRC in 1951 located a promising seed-protectant chemical, tetramine, which is a highly toxic, acute rodenticide. Unlike previous chemical seed-treatments, tetramine is nonphytotoxic; therefore, it could be applied directly to the tree seed and thus eliminated the need for baiting before seeding. The chemical acts as both a poison and a repellent. Mice that ingest a sublethal dose of tetramine-treated seed either develop an aversion to the seed, or they continue to eat it and are poisoned. Three years of field trials demonstrated the efficacy of tetramine. The new product attracted great interest, and it was successfully used on thousands of acres of operational tests in the Douglas-fir region of Oregon, Washington, and British Columbia in the 1950s.

Tetramine (tetramethylenedisulphotelramine) demonstrated potential as a systemic seed protectant, although it had low water solubility. It was equal to or better than endrin, which later replaced tetramine as the treatment of choice. Endosperm of tree seeds treated with tetramine that acquired sufficient amounts of the compound would be repellent to deer mice and lethal to meadow mice. The compound primarily was used as a rodenticide, although mice that ingested sublethal doses of tetramine-treated seeds either developed an aversion to the seeds, or they continued to eat the seeds and were poisoned. Treatment of seeds or seedlings with tetramine was discontinued in the late 1950s, because the compound is acutely toxic to nontarget mammals and poses a high risk for humans.

Endrin, a nonphytotoxic chlorinated hydrocarbon, replaced tetramine as the seed treatment of choice. Endrin is an insecticide with excellent rodenticidal properties, but it is not a repellent. It is, however, toxic to small mammals at very low levels, and sublethal exposures to endrin-treated seed produces temporary aversion in mice. Endrin also is suitable for use as a coating on conifer seed. It is nonphhytotoxic at the recommended treatment levels.

The endrin seed-coating treatment was developed by the DWRC in 1956 and became the standard seed protectant during the 1950s and 1960s. The registered formulation for the endrin seed-treatment was 50 percent wettable powder applied at the rate of 1 to 2 pounds per 100 pounds of seed for a concentration of active endrin of 0.5 to 1.0 percent based on the weight of the treated seed. The endrin formulation

included thiram as a second active ingredient. Thiram is a fungicide with repellent characteristics for both rodents and birds, and it was added to enhance the repellency of the seed treatment. The formulation also contained a neutral adhesive with aluminum powder or green dye that deterred feeding by birds, and it aided the identification of treated seeds by coloring them as a safety precaution. Direct-seeding trials with Douglas-fir seeds demonstrated the efficacy of the endrin treatment as a seed protectant. Seedling-to-seed yields with treated seeds were significantly greater than with untreated seeds. Fate-of-seed studies by Black (1969) and others showed that the treatment was effective in protecting Douglas-fir seeds but ineffective in protecting ponderosa pine seeds from ground squirrels.

Regeneration was more successful with endrin seed-treatments than with other methods of prebaiting with acute rodenticides, but seed-eating rodents still caused many failures. Endrin in combination with thiram (the recommended formulation) significantly reduced Douglas-fir germination. Thiram, however, was subsequently eliminated from the formulation because of its phytotoxicity to germinating Douglas-fir and its failure to protect seedlings from damping off and other fungi. Deer mice also accept endrin in sublethal doses, so there is a small but constant attrition of available seeds. Various modifications of the original formulation were tried, therefore, including the impregnation of seeds with endrin, but none were significant improvements (Crouch and Radwan 1975). The continued consumption of endrin-treated seeds by rodents and birds, moreover, was a recognized shortcoming of operational practices of regeneration That shortcoming was addressed with the application of several anticoagulants (Warfarin, chlorophacinone, and diphacinone) that are useful in controlling commensal rodents. These anticoagulants were field tested with limited success.

The U.S. Department of the Interior banned, in 1970, all uses of endrin and several other toxic chemicals on Interior Department lands, and endrin was discontinued soon after the USDA Forest Service restricted its use as a treatment for conifer seeds in 1972. Endrin no longer is registered by the Environmental Protection Agency (EPA), because it is a hazard to nontarget wildlife. The discontinuance of the endrin formulation effectively marked the end of artificial seeding on Federal lands. Direct seeding on State and private lands in Oregon and Washington, however, continued into the 1980s Only 950 acres of public and private lands in Oregon and Washington were direct seeded in 1988 in comparison with about 375,00 acres planted that year.

Seed protection with anticoagulants—Warfarin and other anticoagulant rodenticides have been used successfully since 1948 to control commensal rodents. Continued feeding on Warfarin, which is slowacting, is necessary to cause death. Multiple feedings may also require the use of bait stations, and this generally is an impractical method for controlling small mammals in forest lands. Second-generation anticoagulants, such as chlorophacinone and diphacinone, are faster acting and require fewer feedings to cause death. They also cause no discomfort that the animal can relate to the bait, and the possibility of bait shyness is therefore reduced.

Hooven (1975) and others showed that prebaiting with an anticoagulant bait (with chlorophacinone as the active ingredient) reduces the population of seed-eating rodents and further improves the effectiveness of the endrin treatment in protecting individual seeds. The effectiveness of prebaiting with an anticoagulant, however, is of short duration. Rozol-treated wheat (Rozol is a commercial rodenticide first marketed

in the late 1960s with chlorophacinone as the active ingredient) aerially applied as a prebait at the rate of 2 pounds per acre, for example, sharply reduced small mammal populations, even though they rapidly recovered.

Fate-of-seed studies—Evaluation of the fate of seeds disseminated naturally or by artificial seeding is difficult but necessary for understanding the causes of seed loss and evaluating methods of seed protection. The success of seeding mostly is measured by indirect methods that evaluate seedling survival on the basis of stocking surveys. Direct methods based on the surveillance of individual seeds or seed spots also have been used from the beginning of direct seeding (Gashwiler 1967, for example). The advent of radio-tracer methods in the early 1960s permitted the relocation of unrestrained, radio-tagged seeds in the field without disturbing the soil surface (Lawrence and Rediske 1962, Black 1969). These methods help in the collection of quantitative data about the causes of seed loss and the sequence and duration of destructive biotic agents. Fate-of-seed studies helped in the development of improved procedures of direct seeding by measuring seed loss during the germination period and rating the relative importance of agents that cause seed loss.

In an early study of the survival of naturally disseminated tree seed in western Oregon, Gashwiler (1967) found that ground-feeding birds and small mammals cause 63 percent of Douglas-fir seed loss, and other agents cause 25 percent of such loss. Nearly all seed loss caused by invertebrates or fungi occurred during seed germination. Only 12 percent of the Douglas-fir seed survived from the beginning of seedfall until the end of germination in late spring of the following year. Birds and small mammals took many more Douglas-fir seeds than seeds of western hemlock and western redcedar, both of which are smaller than Douglas-fir seeds. Of seeds destroyed by animals, small mammals, chiefly deer mice, took about two-thirds; birds one-third; and a few were eaten by insects. The most common ground-frequenting resident birds were juncos, song sparrows, and white-crowned sparrows. The deer mouse was the most abundant small mammal.

Lawrence and Rediske (1962) relocated Douglas-fir seeds in the field by tagging the seeds with scandium 46, a radioisotope. They determined by this method that 46 percent of untreated seeds were lost before germination, and they found that rodents were responsible for about one-quarter of the losses. Seed-rotting molds, ground insects, and other invertebrates also destroyed seeds. Later field studies indicated that fungi and insects do little damage to Douglas-fir seeds in the field (Gashwiler 1967, Black 1969, Crouch and Radwan 1972). Damping-off, a fungal disease, was the principal cause of germinant mortality in seedlings.

Black (1969) also used radio-tracer methods to assess the fate of untreated and endrin-treated Douglas-fir seeds on the Oxbow Burn in western Oregon. On units aerially seeded with untreated Douglas-fir seed a few months after the fire, 70 percent of the tagged seed were eaten, principally by deer mice, within 4 weeks of placement. Prebaiting or trapping and removal before seeding did not reduce later seed losses. Attrition of tagged seeds continued, and animals had destroyed about 93 percent of all tagged, untreated seeds by the start of germination in mid-May. Only 52 percent of endrin-treated seeds were eaten by small mammals and birds during this same period. Losses of tagged, endrin-treated seeds that were aerially seeded one year later after vegetative density had greatly increased were significantly less, particularly

in the first 4 weeks after seeding. Losses of endrin-treated seeds continued after seeding; however, and animals took nearly 40 percent of the tagged seeds by mid-June.

Fate-of-seed research showed that protection of individual seeds with toxic coatings or repellent materials does not ensure the reliable regeneration of harvested stands. The failure to provide a consistent, one-time only approach to the regeneration of forest lands by direct seeding with treated seed or with area baiting was a consideration that simulated the predominant use of planted seedlings rather than direct seeding as the favored regeneration practice. Other factors that influenced the shift to plantation management were the increasing difficulty of registering toxic chemicals for forestry use and the recognition that the initial spacing of trees in intensively managed second-growth stands was silviculturally important. The randomly spaced clumps of young trees that resulted from direct seeding did not accommodate designed thinning schedules. The result was underutilization of the site and poor growth form of surviving trees in many instances.

Chemical methods of seedling protection—The DWRC conducted a chemical-screening program for seedling protection that determined repellency ratings and measured feeding reactions in bioassays with test animals. Efficacy of candidate repellents was based on repellency, lack of phytotoxicity, and persistence. This last characteristic determines the effective field life of a repellent, and it is important because retreatment of forest-tree seedlings is seldom feasible. The program included laboratory screening to identify potential candidate compounds, pen studies to evaluate repellent compounds on pest species, and field evaluation under operational conditions. Each step in this sequential series of evaluations was designed to provide more detailed information on the properties, efficacy, and potential hazards associated with each candidate compound.

Pen studies were conducted at the center's field station in Olympia, Washington. Repellents were tested in separate enclosures with black-tailed deer and snowshoe hares. Douglas-fir seedlings (2-0) were standard carriers for the repellent compounds, which were tested during the dormant season. Thiram (at a 6-percent concentration of the active ingredient) was used as the standard for comparing candidate repellents. These tests were followed by field tests conducted in cooperation with other Federal and State agencies and the forest industry

Three repellent formulations were identified early in the program for development and testing by the DWRC. The active ingredients of these compounds were trinitrobenzene-aniline complex (TNB-A), zinc dimethyldithiocarbamate cyclohexamine complex (ZAC), and tetramethylthiuram disulfide (TMTD). All three subsequently were formulated commercially. Both ZAC and TMTD were formulated so that active ingredients made up 10 percent of an aqueous suspension, an acrylic resin adhesive made up another 10 percent, and the remainder included small amounts of suitable thickening, defoaming, and dispersing additives. A 3-year study (1953-56) in western Washington demonstrated that both ZAC and TMTD reduced damage by about 80 percent. TNB-A was equally effective, but it was discontinued from testing and commercial application because of its phytotoxicity.

Seedlings in nursey beds were treated with repellent by spraying them at the rate of 1 gallon per 2,000 seedlings and, less frequently, by dipping bundled seedlings after lifting. This procedure became operational by 1960, when most Douglas-fir seedlings

planted in the Pacific Northwest were treated with TMTD to protect them from hare and deer damage during their first dormant season ZAC primarily was used to protect against deer damage, although results were inconsistent in different regions. The repellent action of both compounds fails under heavy feeding pressure, and animals feed on the treated seedlings. In some instances, seedlings were retreated in the field with backpack sprayers.

ZAC is no longer used and is unavailable TMTD (thiram) currently is used in limited quantities to protect seedlings from hares, rabbits, and deer. Potential health hazards to exposed nursery workers and tree planters were reported in the mid-1970s and concern over those reports limited the use of thiram. The availability of more effective repellents, such as BGR, also limited the interest in thiram.

Several thousand chemical compounds were evaluated before the DWRC screening-program was discontinued in the 1980s The DWRC screened 891 compounds during 1963 and 1964, for example, and 509 were rated sufficiently active to warrant further testing. About halt of these compounds (254) were accepted for further testing after bioassay; 39 as lethal agents and 203 as repellents After laboratory and pen tests, 10 toxicants and 14 repellents were identified for further field evaluation.

The results of this costly, long-term, chemical-screening effort were limited. All the nine candidate-repellents field-tested in 1964-65, for example, proved as effective as the TMTD standard repellent, but none of these was significantly better. The program was discontinued, because promising compounds, such as "Gophacide" (an acute rodenticide for pocket gopher control) and ZAC (a deer and hare repellent), became unavailable, registration procedures became more restrictive, and the cost of registration for new compounds became prohibitive for a limited forestry market One notable exception was the program's role in identifying and testing a repellent formulation based on putrified fish that the Weyerhaeusaer Company later developed into a commercial repellent.

Systemic repellents—Field tests performed by the DWRC early on in the evaluation of contact repellents (which provide surface protection only to treated foliage) showed that foliage sprays and dips might provide good repellency during winter dormancy, but the treatment consistently failed to protect seedlings during the spring growing season. A repellent that could be incorporated directly into the foliage of seedlings and translocated into newly emerging shoots would be ideal. The repellent would have to be nonphytotoxic and persistent through several growing seasons so as to provide long-term protection. The concept of developing a systemic wildlife repellent was attractive, because naturally occurring compounds in certain plants were known to cause avoidance in the feeding patterns of livestock on open ranges. Livestock, for example, avoid lupine growing on seleniferous soils, and elk and deer avoid foxglove.

The first systemic materials that the DWRC evaluated were a series of organophosphate insecticides. Singular results had been obtained in the systemic control of agricultural pests by application of this new class of chemicals to foliage and soil, but little was known about whether or how these insecticides might affect forest mammals. The DWRC initially selected systemic insecticides that were not phytotoxic to Douglas-fir seedlings and then bioassayed treated seedlings with those insecticides against selected forest mammals. The need for operational treatments for seedlings was recognized as a major problem because of the high mammalian toxicity of most

organo-phosphate compounds. Naturally occurring compounds also were evaluated in the DWRC program and in the industrial ADM research program. Many, unfortunately, were found to be phytotoxic at effective levels.

In a novel experiment, Kvemo (1959) planted 2-0 Douglas-fir seedlings in tetramine-treated soil. After one growing season, the tetramine had translocated from the soil into the foliage in amounts that were lethal to captive snowshoe hares that were fed cuttings from the seedlings. New growth from these same seedlings was bioassayed in the second growing season with the same result. Screening of toxic trees (to exclude nontarget animals) and establishment of small (3 ft^2) toxic feeding stations that would exclude deer but permit access by hares also were considered.

Radwan (1967) showed that tetramine does not penetrate leaves upon foliar application, is immobile in plants after absorption by roots, and is metabolized by Douglas-fir seedlings. Adequately protecting tree seedlings with tetramine, therefore, would require continuous presence of the chemical in the root zone of the trees during the period requiring protection. Application of such large amounts of tetramine would be hazardous to man and could cause toxicity in some associated plant species. This approach was abandoned.

Rediske and Lawrence (1962) reported that selenium (a toxic, nonmetallic element and a natural systemic material) was absorbed and translocated by Douglas-fir seedlings and caused repellency, but it was phytotoxic to Douglas-fir at concentrations too low to provide repellency. They also found that if it was applied to Douglas-fir seedlings as a contact repellent at high concentrations (0.5 percent), then it was not phytotoxic and it was more effective than thiram in pen tests with snowshoe hares This compound, however, was never developed as a commercial repellent.

Allan and others (1984) reported that time-release, selenium-containing tablets placed with seedlings at planting cause the trees to exude a malodorous (garlicky) gas that repells deer. Preliminary tests showed that this method reduces deer-browsing of Douglas-fir by up to 80 percent with no apparent effect on tree growth-rates, and the treatment remained effective for 3 years. Field tests of this chemical by the Fish and Wildlife Service in Olympia, Washington, in 1984, however, failed to confirm that selenium-treated seedlings adequately repel deer.

Rediske and Lawrence (1964) demonstrated the potential of octamethylpyro-phosphoramide (OMPA: a highly toxic organic phosphate insecticide) as a systemic animal-repellent for Douglas-fir seedlings. OMPA is readily translocated up and down the stem when applied to the roots or foliage of seedlings, and it is nonphytotoxic. Bioassays show that OMPA effectively repels snowshoe hares. OMPA was never developed for use as a commercial animal repellent, however, because it is a hazard to humans and nontarget animals.

Toxic-tracking compound—One of the most innovative approaches to animal-damage management was developed by Lawrence and others (Oita 1969). They concluded that conventional baiting and trapping methods are inefficient for controlling mountain beaver and other burrowing animals, so they sought a safe, effective, long-lasting control technique that is independent of bait acceptance by mountain beaver and other species. They developed a toxic-tracking compound containing OMPA and a dispensing system for injecting foam into burrows. The toxicant was

incorporated in a liquid formulation that expanded to more than 30 times its liquid volume. A small amount of material placed in a mountain beaver burrow thus expands sufficiently to cause animals to contact the poison as they move through the treated material. This system proved highly effective in controlling mountain beaver during operational field tests in Washington during the late 1960s, but it did not become commercially available, because OMPA was not approved for registration, and alternative toxicants were unsatisfactory.

Big-Game Repellent (BGR)—The Weyerhaeuser Company, in 1969, initiated research to find an improved repellent (Rochelle and others 1974). They reviewed the potential repellency to big game of essential oils from unpalatable plants, pheromones of black-tailed deer, and extracts from putrified fish or egg. The DWRC had identified a fraction of the putrified fish mixture with high repellency, but the supply of raw material was uncertain and the handling and processing of the mixture posed other problems that limited its operational use. Weyerhaeuser scientists substituted an egg-based product for putrified fish and subsequently developed a practical, nontoxic repellent that reduced big-game browsing on conifer seedlings by about 80 percent and exceeded the level of protection provided by the commercially available repellents.

Weyerhaeuser Company licensed the McLaughlin Gormley King Company of Minneapolis, Minnesota, to further develop and market the product. Two liquid formulations containing putrified egg solids as the active ingredient were registered with the Environmental Protection Agency (EPA) in 1977. A third powdered formulation was registered later. Big Game Repellent (BGR) is premixed and must be used promptly to minimize deterioration of the active ingredient. Deer Away-L is a storable alternative that can be mixed onsite. Both of these liquid formulations must be applied to dry tissue. Deer Away-P (powdered) was developed as a third alternative for use during wet weather, and it requires damp tissue for application. These repellents are registered for the protection of conifer seedlings (Douglas-fir, noble fir, grand fir, and ponderosa pine) from black-tailed deer and Roosevelt elk in the Pacific Northwest.

Recent developments in seedling protection—Several new products for protecting conifer seedlings became available during the 1980s or are under development. These include acute rodenticides and synthetic predator odors (area repellents).

Repelliff is the trade name of a big-game repellent that contains a 1:1 mix of epidihydroandrosterone and androsterone. It was developed and marketed in Norway and reportedly is effective as a perimeter repellent to red deer and roe deer. The active ingredients are incorporated into strips of micropore plastic about 12 inches long. The strips are bunched into tassels of about 40 strips that are placed at 20-foot intervals around the perimeter of a plantation. Tests of this product by DeYoe and Schaap (1987) and others in this region, however, failed to prevent deer or elk from entering Repelliff-staked plots, and browsing of Douglas-fir seedlings was not reduced by this method.

ANI-PEL is the trade name of a new repellent product containing denatonium benzoate manufactured by Ani-Pel Silviculture, Ltd. of Surrey, British Columbia. This product is marketed in Canada (since 1988), but it is not registered for use in the United States. It is available in tablet or spray form and is claimed to function as a systemic repellent that protects Douglas-fir seedlings from deer, rabbits and

other species. The company has provided no data to verify these results. The active ingredient, denatonium benzoate, is a nontoxic, extremely bitter, and inert compound. A closely related compound, denatonium saccharide, is the active ingredient in ROPEL, a commercial deer repellent that is less effective than thiram or BGR. Starker Forests, Inc. of Corvallis, Oregon conducted preliminary field tests of ANI-PEL and ANI-SPRAY in 1989-90. In those tests, ANI-PEL tablets were pushed 3 inches into the ground next to the root systems of recently planted Douglas-fir seedlings. The tablets provided limited protection against deer browsing for about 3 months during the growing season. The application of ANI-SPRAY to actively growing western redcedar seedlings during the fall also provided limited, short-term protection against deer browsing. Both tests were conducted in western Oregon (personal communication 1990, Mark Gourley).

Sullivan and others (1988) showed that certain synthetic predator odors repelled snowshoe hares, several species of voles, northern pocket gophers, and red squirrels. They also showed that synthetic predator odors reduced damage to tree seedlings Predator odors that originate from feces, urine, or anal scent-gland secretions of short-tailed weasel and red fox elicit a "fear" response from prey species that detect the odors. Synthetic predator odors also produced significant avoidance-responses in the above-named species when used as an area repellent. The synthetic compounds are dispensed in small capillary tubes attached to trees. The tubes protect the compounds from weathering, control the release of odors, and maintain the odor around the base of test trees. Field tests of this new area repellent are currently in progress in forest plantations in British Columbia.

QUINTOX is the trade name (Bell Laboratories, Inc., Madison, Wisconsin) tor a new commensal rodenticide that contains cholecalciferol, which was registered by the EPA in 1987 for the control of Norway rats, roof rats, and house mice. Cholecalciferol (vitamin D3) acts differently than conventional acute and chronic rodenticides. It metabolizes calcium from bone matrix to plasma and causes target animals to die from hypercalcemia This chemical reportedly differs from other acute rodenticides in that no bait shyness is associated with consumption. All food intake ceases once the lethal dose is consumed, although death may be delayed for 3 to 4 days. Preliminary studies indicate that cholecalciferol has potential as a rodenticide for controlling pocket gophers and ground squirrels.

Field-efficacy tests performed in 1988 with QUINTOX (pelleted grain baits) on the Targhee National Forest, Idaho, were not promising. Initial results showed a 35-percent reduction in pocket gopher activity on the QUINTOX-treated plot compared with a 75-percent reduction on the plot treated with strychnine oat baits. Preliminary tests in 1988 on the Umatilla National Forest in Oregon were inconclusive. Poor bait acceptance may have adversely affected the results of both tests. Field trials in 1989 on the Umatilla National Forest showed that reduction in pocket gopher activity on QUINTOX-treated plots (by about 70 percent) is comparable to that obtained with standard strychnine oat baiting.

Tuneberg and others (1984) developed multikill baits tor pocket gopher control. This new concept in pocket gopher control is based on two behavioral traits of gophers-their rapid invasion of unoccupied burrow systems and their use of existing food stores, including baits left by previous gophers. A long-lasting (durable) pocket gopher bait was designed so that it would last for several months in the burrow

system before deteriorating. This approach was intended to make it possible to control gophers with one bait or with a single baiting. It was designed for situations where the locations of all burrow systems are difficult to determine during hand-baiting and where gopher invasion from the surrounding, untreated area is a problem. Preliminary tests with paraffinized wheat baits containing bromadiotone, which is a potent, second-generation anticoagulant, were promising. Second-generation anticoagulants produce death in many rodent species after one or or two feedings, unlike first-generation anticoagulants that are effective only after multiple feedings. In this test, gophers moved the baits to the nest area for feeding; gophers that fed on the bait were killed, and other gophers rapidly invaded the abandoned burrow systems and fed on the residual bait.

In 1987, J.T. Eaton and Co., Inc. of Twinsburg, Ohio, applied the multikill concept to the development of a paraffinized grain bait with a 0.5-percent concentration of diphacinone (a first-generation anticoagulant) for pocket gopher control. Preliminary field tests with this product, trade-named "Eatons Answer," were promising, and they provided the basis for full registration with the EPA.

The Rogue River National Forest in Oregon used Eatons Answer operationally in 1988 for pocket gopher control on about 6,000 acres of forest land. Preliminary results showed excellent bait-acceptance (95%) and about a 60-percent reduction in pocket gopher activity, based on open-hole surveys conducted 2 to 3 weeks after baiting. Durable bait blocks are less restricted by weather and soil-moisture conditions than strychnine oat baits, but they are also twice as costly. Results of an administrative study of Eatons Answer in Oregon by the Rogue River, Fremont, and Winema National Forests in 1989 were inconclusive. Baiting with Eatons Answer caused no significant reduction in pocket gopher activity. Errors in formulating the Eatons Answer baits (both treated and untreated, paraffinized bait blocks) may have caused the erratic results obtained with this product.

Life-history studies and problem analyses—Edward F. Hooven, biologist, Oregon State University, conducted numerous field trials of rodenticides and repellents that protect tree seeds and seedlings. His most important contributions, however, were studies of small-mammal populations in forest habitats and especially the deer mouse (Hooven 1958). Hooven's studies of the wood rat, mountain beaver, porcupine, and pocket gopher led to a better understanding of the ecology of these species and provided information useful for controlling these animals where they were a problem.

Two important problem analyses that shaped the course of animal damage management and research were Lawrence's (1957) comprehensive review of damage caused by porcupines in the pine region and Barnes' (1973) review of literature on pocket gophers relating to damage, species biology, control methods, and research needs. Lawrence examined the life history, ecology, control practices, and research needs relating to porcupines, and he outlined a plan for an ADC program that emphasized monitoring, damage appraisal, and feedback to ensure program effectiveness and that served as a model for other types of ADC programs.

Radwan, of the Forest Service laboratory in Olympia, Washington, summarized, in 1963, the literature regarding the protection of forest trees and tree seeds from wildlife (172 references). This was an important historical review that gave a complete account of pertinent work to date.

Nonchemical approaches to ADM—Approaches to ADM by nonchemical methods have included fencing and other physical barriers, silvicultural modifications, and habitat modification. Physical barriers have included area fencing and cages for individual seedlings. Modification of food availability for problem species has involved the provision of supplemental sources of food plants and the control of vegetation to eliminate food plants and reduce the carrying capacity of an area for problem species.

Physical barriers—The successful use of animal-proof exclosures of varying sizes for protection of study plots suggests that such an approach might be effective in protecting plantations of forest trees. This, historically, was not an important research approach to ADC, but it was tried in a number of situations as an operational practice. These cases demonstrated that exclusion of forest rodents (including hares and rabbits) from relatively large areas is not practical or cost-effective. In addition to fencing costs, toxic bait stations were needed to control those animals confined within the exclosure. Constant maintenance, furthermore, was necessary to maintain tight fences capable of excluding burrowing rodents. The exclusion of deer and elk, however, was much easier to accomplish.

Area fencing to control big-game damage evolved into the construction of open-ended drift-fences that were relatively simple to maintain. This approach is more effective with elk, which follow established travel patterns, than with deer, which are more sedentary It is also expedient, in some situations, to leave logging slash in place for the protection of planted seedlings. The concentration of big game in wintering areas, however, remains a problem for foresters and ranchers. Wire or nylon fencing provides effective protection, but it is too costly for most operational uses. It also requires regular maintenance. Various types of physical barriers for complete protection of individual trees and for terminal-only protection are available.

Several systems for protecting entire seedlings after planting or for protecting only the terminal shoot of a seedling also have been tested. Campbell and Evans (1975) published the results of a 6-year, cooperative study with DuPont, Inc., that developed and evaluated "Vexar" (a rigid polypropylene-mesh tube) as a protector for conifer seedlings. This popular publication stimulated wide use of several types of Vexar protectors in the Pacific Northwest, although previous experimental methods of protecting Douglas-fir seedlings from browsing by deer and elk and from damage by hares, rabbits, mountain beaver, pocket gophers, and other animals had involved the use of Vexar and other plastic-mesh tubing. Rigid, plastic-mesh tubing is used extensively where severe damage is expected, where damage occurs during all seasons, and where damage by several species of wildlife is expected. Vexar provides effective protection over the short and long term that is superior to protection provided by available animal repellents. It is the most widely used physical barrier for complete tree protection. Various problems with plastic tubing have been experienced, however, that mostly involve interference with tree growth. The high cost of installation and maintenance, moreover, has curbed the use of these products in recent years.

Several types of physical bud protectors have been developed that effectively protect terminal leaders from browsing damage by big game during the dormant season, but these methods are largely ineffective against summer browsing by deer and elk or winter clipping by hares and rabbits. A detailed evaluation of physical barriers for protecting Douglas-fir seedlings from deer browsing (DeYoe and Schaap 1984) showed that budcaps (of waterproof paper or spun polyester) are as effective as staked Vexar tubes at one-third the cost. (Vexar tubes cost more than $250 per acre

to install.) An advantage of total-tree protectors in comparison with terminal-only protectors is that tubing the entire tree also provides protection from clipping or barking by animals such as hares, rabbits, mountain beaver, pocket gophers, and grouse.

Silvicultural modifications—Lawrence (1964) noted the historical emphasis on controlling animals with chemical protectants, suggested that "we should investigate thoroughly the practicality of ecological (silvicultural) control for animal damage," and asked whether we "can manage the pattern of vegetation to lessen the impact of wildlife on forest regeneration." Controlling vegetation and planting preferred forbs are promising techniques for managing animal damage that have not been fully explored. Howard (1967) observed:

> In some situations there is every reason to believe that the intensity of undesirable browsing of young conifers by deer might be substantially reduced by increasing the amount and availability of alternate and more preferred species of browse. Such an increase in food supply will not necessarily result in a corresponding increase in deer numbers, nullifying this benefit.

Site preparation to reduce vegetative competition with planted seedlings is a common practice, but it is much less commonly used to control animal damage.

Planting large seedlings, planting less preferred species (such as spruce and fir), planting as late in spring as allowed by other reforestation requirements to avoid periods of heavy animal-use, and breeding for less palatable genotypes, all are examples of methods that silviculturists occasionally use to limit animal damage. One of the pioneers of this approach was Harry D. Hartwell, biologist, Washington Department of Natural Resources, who conducted numerous field trials of repellents, acute toxicants, and other methods of protecting tree seedlings (such as planting with large nursery stock). Hartwell (1973) demonstrated, for example, that animal damage can be substantially reduced by planting with large Douglas-fir stock (3 to 4 ft high). Stock of this size seldom was used, but Hartwell's findings led to the widespread use of large (2-1) seedlings in sites exposed to heavy animal damage.

Prevention is probably the single, most important silvicultural procedure for alleviating animal damage. Prompt regeneration after clearcutting, therefore, can minimize opportunities for wildlife populations to reach damaging proportions.

Habitat modification—Barnes (1973) reviewed methods of reducing pocket gopher damage to conifer seedlings and concluded that vegetation management had the most potential for accomplishing long-term control, because vegetation largely controls the size of pocket gopher populations. Teitjen and others (1967) showed that pocket gopher populations decline after perennial forbs are reduced with herbicide. Barnes (1974) found that the serai vegetation that develops after logging, the productivity of these plant communities, and the abundance of gophers on or in proximity to harvested areas all affect pocket gopher response to timber harvests. He also found that site preparation returns plant communities to a lower serai stage and creates more favorable habitat for pocket gophers. Barnes proposed leaving uncut "buffer" strips of timber (500 ft wide) or direct control before logging as methods for controlling population buildup of pocket gophers on harvested areas. He also suggested using selective-harvest systems as an alternative to clearcutting in lodgepole pine forests

as a method that could limit the buildup of pocket gopher populations. Black and Hooven (1977) showed that pocket gopher activity and damage to conifer seedlings declines sharply in response to control of herbaceous vegetation with herbicides, and their research demonstrated that the greatest reduction in pocket gopher activity and seedling damage occurs on areas where all vegetation (grasses, forbs, and shrubs) is completely controlled.

A unique experiment by Campbell and Evans (1975) showed the feasibility of establishing palatable native forbs as forage for big game by fall-seeding several species of forbs on burned or scarified Douglas-fir plantations in western Washington. This approach to reducing summer deer browsing was based on the prompt introduction and establishment of native forbs as preferred foods. The method has not been fully evaluated or used operationally, but it may offer a promising means of alleviating summer-browsing damage.

The Suislaw National Forest in western Oregon helped develop alternative practices of forage seeding that have been used operationally to enhance habitat for big game and to reduce damage to tree seedlings. Treatments that favor early establishment of-preferred forage species (grasses and forbs) include early season slash burning, seeding or planting forage species before tree planting, and mulching residual vegetation without the use of fire. Cool-season species (species that grow actively in cool seasons) were best suited to reduce browsing on tree seedlings, because forage quality is most limiting during the fall through early spring throughout most of the Pacific Northwest. Commonly seeded, cool-season perennials include ryegrass, orchard grass, and white clover. The Forest has successfully managed grazing in combination with the establishment of alternate forage to control undesirable competition from shrubs and to manage heavy grass-cover.

Supplemental feeding—Tree damage by bears occurs shortly after bears emerge from hibernation and when nutritious food is scarce. Flowers (1987) tried supplemental feeding in 1985 as a possible solution to this tree-barking problem. He developed a food pellet containing sugar, protein, calcium, and other nutrients attractive to bears. The results of this method for reducing tree damage, however, are inconclusive Erickson and Hansen (1987) observed that bears promptly adapted to deterrent feeding stations, and they concluded that the method warrants further study. They noted, however, that bears using the feeding stations became accustomed to human presence, and the positive association of man with food could lead bears to develop nuisance tendencies

Improved reforestation practices—Concurrent with continuing work on improved repellents during the 1960s and 1970s, foresters began to critically examine regeneration practices. The regeneration phase, until that time, was largely considered a closeout activity that followed the stand harvest. In many instances, there was a delay before the land was actively regenerated. Cutover acres were placed in a regenerating land pool, creating a "reforestation backlog" on public lands that partly depended on natural regeneration. Bumper seed crops, however, occur about once every 7 years for Douglas-fir and about once every 10 or more years for ponderosa pine.

Habitat conditions during this waiting period supported optimum populations of wildlife problem species. When artificial regeneration was attempted, consequently, the results frequently were less than satisfactory and stands were at best understocked.

The regeneration practices of direct seeding and planting required site preparation to control competing vegetation, but this only aggravated animal-damage problems. As normal food plants were reduced, wildlife shifted to heavy feeding on the nursery-grown planting stock and often destroyed plantations before growth began.

The use of nursery-grown planting stock is a long-standing regeneration practice, but before the 1970s it was usually under local control and was not based on an integrated and standardized system of quality controls. Only when forest managers began to view regeneration as the initial phase for managing the young-growth forest did the production of nursery planting stock become a fully integrated system from seed collection to seedling storage in preparation for planting in prepared field sites.

Contact repellents provided only short-term protection and partial success, and systemic repellents failed to gain approval for operational use. Emphasis, consequently, shifted to the development of robust seedlings that were "animal damage proof." Maintenance of seedling vigor and the development of nursery and field-planting practices to maintain this vigor have significantly improved field survival. Prompt regeneration after logging, together with site preparation and the application of ADM measures on an as-needed basis, also has reduced the adverse impact of animal damage.

The principal key to successful plantation management in the Pacific Northwest was the recognition of the need for an integrated system of managing nurseries and planting sites that could maintain seedling vigor in the face of moderate animal damage. The use of registered repellents and toxicants on an as-needed basis added to the success of this strategy.

Greatly improved regeneration practices and better management of animal damage have significantly increased plantation survival. One measure of improved regeneration practices is the development of containerized seedlings that facilitate prompt regeneration of physically difficult planting sites and high-elevation sites where planting and growing seasons are short. About 0.9 million containerized seedlings were produced in 1970 in private and public nurseries in Oregon and Washington, compared with 37.2 million containerized seedlings produced in 1988. Bare-root seedlings and containerized seedlings also are transplanted in nursery beds for one or more growing seasons before they are lifted for forest planting. This produces larger seedlings that can sustain more injuries from wildlife feeding and that establish themselves faster to reduce their exposure to animal damage.

Many other silvicultural practices of only limited application in the 1950s are now conducted each year on tens of thousands of acres in the region. Site preparation for planting and seeding, timber-stand improvement (release and weeding), fertilization, precommercial thinning, and related practices (including tree improvement and improved nursery and seedling-handling practices) all may affect the occurrence and severity of animal damage. Timber-stand improvement (TSI), for example, may expose stands to increased damage by mountain beaver or black bear. This practice was negligible in the 1950s but increased to include 372,000 acres on all private and public forest lands in Oregon and Washington in 1988. This is comparable to the 375,000 acres artificially reforested on such lands in 1988. Animal-damage control was conducted for reforestation purposes on about 69,000 acres of National Forest System lands in Oregon and Washington in FY 1988.

Improvements in all phases of forest regeneration, including tree-selection practices in the nursery, seedling handling and planting, site preparation, vegetation management, and ADM, have greatly increased plantation survival. First-year survival for all species on NFS lands in the Pacific Northwest Region (Oregon and Washington) during the 1980s averaged about 90 percent, and third-year survival averaged 70 percent. By limiting mortality caused by wildlife and by limiting the exposure of seedlings to animal damage during stand establishment, the overall impact of animal damage has been reduced. The concern with managing animal damage also has diminished, because forest regeneration in the region generally is successful.

Animal Damage Management Research

The FWS established the Forest Animal Damage Control Research Project in 1955 to develop methods of controlling damage by forest wildlife and to support the DWRC's chemical screening program The USDA Forest Service also established an Animal Damage Control Research Project in 1965. Both projects were located at the Forest Service's Pacific Northwest Research Station, Olympia, Washington.

During the 1960s and 1970s, the Fish and Wildlife Service, Forest Service, State forestry agencies, Oregon State University, Weyerhaeuser Company, and others were actively involved in ADM research. These efforts were sharply cut back in the 1980s, however, because the increasing cost and time required to register new toxicants and repellents and the growing success of improved systems of artificial regeneration influenced decisions to reduce funding and shift research priorities The USDA Forest Service terminated their Animal Damage Control Research Project at Olympia in 1975 ADM studies continue with support from the National Agricultural Impact Assessment Program (NAPIAP) and other funds, but no comprehensive ADM research has been conducted by the Forest Service since 1975.

Funding and staffing of the Fish and Wildlife Service's Animal Damage Control Project at Olympia decreased for several years before the project was closed in 1985. After transfer of the ADC program from the FWS to the USDA Animal and Plant Health Inspection Service (APHIS) in 1985, the project was reactivated in 1986. The current forest ADC research program of APHIS at Olympia and at the DWRC is beginning to expand after a period of reorganization and rebuilding.

Only a limited amount of ADM research has been done during the past decade by State, Federal, and Provincial agencies, universities, or the forest industry The APHIS program at Olympia is now focused almost entirely on the development of data required to maintain current registrations of strychnine baits for the control of pocket gophers and mountain beaver. That program also is cooperating with the USDA Forest Service, Pacific Northwest Region, in an evaluation of Eatons Answer for pocket gopher control.

Future Directions in Animal Damage Management

Animal-damage prediction models are providing better damage assessments that reduce damage-control expenditures and improve treatment effectiveness Researchers are placing more emphasis on the development of silvicultural prescriptions that integrate the responses of wildlife problem species with vegetation and stand growth as a silvicultural approach to animal damage management. ADM will become less of a reactive procedure to save threatened plantations and more of a proactive effort within an integrated regeneration system It will emerge as a fully integrated system of forest protection, and it also will be an important facet of "new forestry" as it evolves during the 1990s

Conclusion

This review provides nearly 100 years of historical perspective on the need for animal damage management in the forests of the Pacific Northwest, and it examines significant developments in the effort to control such losses. The ADM program was broadly supported, and it reached its apogee during the decade from the mid-1960s to the mid-1970s. Forest management objectives during this period were sharply focused on reforestation of a continuing backlog of poorly stocked forest lands in public and private ownership. Selected species of forest wildlife, such as deer, elk, and bear, were recognized to have important recreational value as game animals, but the value of nongame problem species, such as pocket gophers, mountain beaver, porcupine, hares, rabbits, and mice, was largely ignored.

Pesticides have been under increasing government regulation since 1910, when the Federal Insecticide Act was passed, but the first major constraint that affected the use of forest chemicals (repellents, mammalian toxicants, and herbicides) developed in the early 1970s. Concern was growing at that time over the use of potential carcinogens and their residual effects on the environment, particularly where domestic water supplies and foods were obtained from the forest. With the new toxicants, especially compound 1080, the potential for secondary poisoning of nontarget wildlife was a demonstrated hazard. Amendment of the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) in 1972 emphasized protection of public health and the environment, and more rigorous registration requirements were established for new chemical agents. Restrictions also limited the extension of registrations for existing chemicals for use in forest management. The registrations of many of the systemic insecticides under consideration as systemic repellents or toxicants were totally withdrawn, under FIFRA, as amended, thus cutting off this approach to seedling protection.

Workers in the ADM field had a sense of *deja vu* by the 1980s, because virtually the only control practices available were those of the 1960s and earlier. These included strychnine baits for burrowing animals (pocket gophers, mountain beaver, and ground squirrels), traps for mountain beaver, hunting for porcupines, and contact repellents (thiram and the nontoxic BGR) to protect seedlings from damage by hares, rabbits, deer, and elk. An environmental assessment also was often required for compliance with the National Environmental Policy Act (NEPA) before toxic baits could be used for ADM on public lands.

The backlog of understocked forest lands was nearly eliminated by the 1980s on both public and private lands, but the real key to this success story was the development of a vastly improved regeneration system that produced robust, "animal-damage proof" seedlings that survived outplanting and rapidly reached the free-to-grow stage. This was accomplished by matching seed-sources with planting sites that had similar physiographic and ecologic conditions, by careful preparation of planting sites, and by improved nursery practices that ensured seedling vigor during growth and in storage before outplanting. These methods required full appreciation of the importance of selecting favorable microsites for planting individual seedlings, of following weather guidelines for planting, and for conducting quality-control checks of tree-planting performance. The role of ADM is to assess the potential hazards of animal damage and to recommend appropriate control practices. These are all steps needed to ensure the success of a regeneration program.

Management planning is again in a state of flux, at least on public forest lands. The public is demanding that forest types be managed on an ecosystem basis that preserves and maintains inherent biodiversity. The management tools to accomplish this

"new forestry" presently are in an evolutionary stage. An essential component of this new approach presumably will be a plantation system that ensures prompt and effective regeneration after the harvest of mature timber. This is particularly true if the full benefit of an increase in the growth and yield of "new" forest stands is to be realized from the intensive, regional effort in forest-tree improvement currently underway. The only practical way to secure full value from the use of genetically superior planting stock is to employ a plantation system for regeneration.

Creating environmental conditions appropriate for the successful establishment of plantations, particularly for Douglas-fir, requires some form of site preparation to expose mineral soil and to control competing vegetation for seedling survival. These are the same site-preparation conditions required in nature for the production of the ancient forests that exist today. Those conditions were produced by natural catastrophes that destroyed previously existing stands through a combination of widespread fires, insect attacks, and blown-down timber.

The conditions that initiate natural patterns of forest succession in the Pacific Northwest are the same as those that create the preferred habitat for most of the wildlife problem species of concern for ADM. An important ADM concept is the recognition of this similarity in the evironmental and habitat conditions required for the establishment of plantations and for the development of preferred-wildlife habitat. Douglas-fir and problem species of wildlife both are products of disturbed forest conditions. The understanding that this dual relation exists is critical to planning effective ADM and securing prompt and effective regeneration of harvested stands. Any delay in the establishment of plantations after the first growing season after harvest gives the burgeoning populations of problem species an unwarranted advantage, and increases the difficulty of implementing an effective program of ADM. Regeneration programming and operational planning for ADM must be an integrated team effort.

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SECTION ONE
INTRODUCTORY OVERVIEW

Chapter 3
Animal Damage Management in the Context of Integrated Forest Protection

JOHN D. WALSTAD AND LOGAN A. NORRIS

Abstract

Methods for minimizing animal damage to seedlings, saplings, and mature trees traditionally have focused on direct control of populations of wildlife problem species. Methods for reducing or preventing damage to valuable tree species in the Pacific Northwest have included special hunts, trapping, toxic baits, repellents, fences and cages. Indirect methods for controlling animal damage, such as habitat manipulation, also have been utilized on occasion.

Direct and indirect methods for controlling animal damage generally are effective, but they have not completely satisfied the concerns of either the public or forest resource managers Better integration of such practices within the overall context of silviculture and forest protection, rather than continued dependency on reactive, "quick fix" solutions to animal damage problems, is a more holistic management approach that could provide relatively "animal-proof" forests.

JOHN D. WALSTAD is professor and department head, Department of Forest Resources Management, College of Forestry, Oregon State University, Corvallis, OR 97331. LOGAN A. NORRIS is professor and department head, Department of Forest Science, College of Forestry, Oregon State University, Corvallis, OR 97331.

This chapter describes the elements of an approach to forest protection that integrates basic ecological knowledge with technological advances to prevent, minimize, or eliminate adverse effects of animal damage to forest trees. This integrated approach involves defining resource management objectives and constraints, characterizing potential animal damage problems, developing potential solutions, evaluating and selecting alternatives, implementing selected alternatives, and evaluating and documenting the effectiveness of the program. These six steps, when integrated and coordinated into the entire silvicultural system, will foster the development and maintenance of healthy and productive forest-ecosystems with minimal need for intervening methods of animal damage control.

Keywords: Animal damage management, integrated forest protection, forest health, direct control, indirect control.

Introduction

Many species of vertebrates, ranging in size from mice and pocket gophers to deer, elk, and bear, damage seedlings, saplings, and mature trees as a normal consequence of their search for food and habitat in the forest. Forest managers, therefore, have come to expect and accept some level of damage by wildlife. When the extent of damage to a stand exceeds or threatens to exceed acceptable levels, however, foresters seek to prevent or minimize damage through a variety of direct and indirect methods of damage control that are often costly, ineffective, and sometimes unacceptable to the public. Recent concern over the management of forest resources suggests the need for progressive and integrative approaches to controlling animal damage to stands of forest trees.

Conflict over an increasing array of values associated with various forest resources raises difficult management issues. Deer, for example, are highly valued by hunters and wildlife enthusiasts, but they sometimes severely browse tree seedlings and thereby hamper efforts to successfully reforest and assure stand development in certain areas. Direct control of animals in such situations may be unpopular with animal preservationists, whereas hunters and wildlife managers may favor opportunities to harvest surplus animals via special hunts (Ives 1969). Other alternatives, such as protecting individual seedlings with cages or repellents, often are too expensive and unreliable to satisfy foresters. Accommodating the desires and demands of various interest groups, therefore, can be difficult.

As our society becomes more environmentally sensitive and as human interests diversify, we can anticipate more conflicts over the allocation, use, and management of forest resources. Livestock, for example, are sometimes managed in concert with timber production. This is an attractive proposition for ranchers and foresters, but herds of cattle and sheep consume forage in amounts that could reduce browse available to deer and result in an unpopular outcome for wildlife enthusiasts. Excessive grazing also may damage seedlings if livestock are not managed properly, and this is an unsatisfactory outcome for foresters. The ramifications of various management strategies and tactics, therefore, are manifold and complex.

Public tolerance of methods for directly controlling populations of wildlife problem species (such as measures specifically aimed at reducing their number) is decreasing, and many methods and programs have been challenged and stopped. Trapping is often considered inhumane. The use of toxic baits, repellents, and sprays has been restricted or preempted because of environmental concerns Even seemingly innocuous control measures such as nontoxic repellents and fences are disparagingly labelled "unnatural."

Managers, nevertheless, are increasing their efforts to reduce damage caused by pest animals because of the seriousness of such losses. A survey of animal damage to coniferous plantations in Oregon and Washington by Black and others (1979), for example, found that 30-percent of all unprotected Douglas-fir seedlings were browsed, clipped, or otherwise damaged by animals during the first 5 years after planting. Brodie and others (1979) projected that such damage would lead to a 13-percent reduction in eventual yield and a loss in potential timber value of up to a $1.83 billion across the region. As the land base of commercial forest continues to shrink and the demand for forest products continues to grow, seedlings and trees become more valuable and less damage is tolerated. The need is great, consequently, to carefully evaluate the destruction caused by animals, and to minimize or eliminate it where appropriate.

The rapidly rising cost of methods for direct control, their occasionally erratic performance, and their growing disfavor with the public, all dictate a new approach to animal damage control in Pacific Northwest forests. This new approach should stress preventive rather than corrective measures. It should encompass both direct and indirect control techniques, but it also should be based on sound ecological principles, silvicultural knowledge, and practical experience. The new approach should be an ongoing consideration in the management of forest resources, and not just an emergency response to particular problems when they occur. It should embrace a comprehensive perspective of resource values and interactions, and it should rely on thorough planning and analysis to ensure that economical and socially acceptable approaches are developed. In short, the new approach calls for an integrated program of forest protection analogous to programs of integrated pest management (IPM) already adopted in agriculture. This chapter outlines the components of such a program.

Historical Development of Integrated Forest Protection

Integrated forest protection (IFP) is a holistic and systematic approach to maintaining forest health and productivity within the overall context of forest resource management. A brief history of the development of contemporary concepts of integrated forest protection illustrates the significance and distinct features of this approach.

Animal damage control in forests of the Pacific Northwest originated in the 1940s and 1950s when the effects of excessive damage on forest regeneration were first observed (Moore 1940, Mitchell 1950, Lawrence 1958). Before that time, animal damage went largely unnoticed or was generally considered inconsequential because of the relatively low values placed on young forest stands. Greater investment in new regeneration practices such as direct seeding and planting, however, warranted closer monitoring and protection of new stands and plantations in the Pacific Northwest by the 1950s. The widely used "Guide to Wildlife Feeding Injuries on Conifers of the Pacific Northwest," for example, was produced during this period (Lawrence and others 1961). Numerous qualitative and quantitative assessments of the scope and economic importance of such damage appeared in later years (Black and others 1969, Dimock and Black 1969, Teeguarden 1969, Black and others 1979, Brodie and others 1979, Evans and others 1981, deCalesta 1982). The thrust of these publications was to help foresters identify and evaluate particular types of damage and to establish which levels of damage were not acceptable.

Identification and assessment of animal damage accompanied efforts to control it. Early measures relied on natural and cultural methods that reduced problem species of wildlife with predators and prescribed fire. Research and operational trials developed numerous direct control measures such as trapping, poisoning, shooting, and otherwise reducing the numbers of problem animals (Radwan 1963, Dodge 1969, Black and Hooven 1978, Campbell and Evans 1984. Timm 1983, USDA Forest Service 1988). These techniques were applied widely as foresters reclaimed brushfields and converted tow-value hardwood stands that harbored high populations of problem animals.

Public sentiment and regulatory pressure to prevent killing of animals, particularly with toxicants, grew during the 1960s and led to the development of an array of nonlethal methods. Chlorinated hydrocarbon seed-coatings, foam sprays of organo-phosphate rodenticides, aboveground strychnine baits, and other pesticide applications were prohibited during the 1970s. Sport hunting and commercial trapping became more restricted, and some occasional nuisance animals such as beaver and bear were protected in many areas. These restrictions shifted the emphasis of development efforts to protective measures such as BGR (big game repellent), feeding-barrier devices like Vexar tubes, and specifically formulated and carefully placed toxic baits designed to avoid damage to nontarget organisms.

The rising cost and occasional ineffectiveness of direct control measures prompted the development of indirect control measures in the late 1970s and 1980s (Raedeke 1988). Animal habitat was manipulated with various methods of site preparation, such as mechanical clearing, prescribed fire, and herbicides. These methods reduced populations of wildlife problem species and fostered seedling development. New plantations were seeded with forage plants preferred by deer and elk in an effort to reduce browsing pressure on conifer seedlings. Feeding stations were established as a means of reducing damage caused by bear to young stands.

The severity of animal damage in young stands and plantations has diminished in many locales with the passage of time. This is because the rehabilitation of many brushfields and hardwood thickets allows foresters to concentrate on the reforestation of recently logged areas where animal problems usually are not so great. Steady improvement in the quality of seedlings used in reforestation has also reduced their vulnerability to damage. Foresters, finally, have developed a better appreciation for the ability of seedlings, trees, and stands to recover from damage; what was once thought to be severe damage has sometimes turned out to be inconsequential by the second or third decade of stand development.

Animal damage, nevertheless, continues to plague forests of the Pacific Northwest, and annual expenditures to reduce its impact total millions of dollars. Despite significant advances in both direct and indirect techniques of damage control, however, foresters, wildlife-management specialists, and the public increasingly are dissatisfied with current approaches to the problem. Four significant factors contribute to this growing dissatisfaction:

1. Accepted thresholds of damage are poorly defined. In many cases, therefore, we are unsure about when and how much protection is needed.
2. Long-term consequences of damage to trees and stands are not known, so we cannot reliably forecast the long-term effects on resource values that result from various levels of damage, particularly when it occurs in young stands.

3. Many direct control strategies that involve killing large animals such as bear, deer, and elk, or poisoning rodents, are increasingly unacceptable to the public even though they are highly effective. Public attitude, indeed, often shapes contemporary debate over methods of forest resource management, including animal damage control.
4 Current strategies of indirect control are expensive and difficult to implement, because they sometimes require conventional tools, such as herbicides and fire, that are not always viable.

Methods of animal damage control, historically, have been somewhat direct and simplistic. Recently, however, forest researchers, specialists, and managers have begun to develop new, integrative approaches to animal damage control as part of a larger effort called integrated forest protection—a concept dealing with all forest pests, including animals, diseases, insects, weeds, and abiotic factors such as fire and environmental stress.

The emerging base of knowledge is sufficient to begin integrating direct and indirect methods of animal damage control into comprehensive silvicultural packages. Just as the discipline of forest entomology progressed from simplistic, direct-control measures to a more holistic program of integrated pest management, so too is the field of animal damage control ripe for an integrative approach that focuses on long-term management of animal populations and habitat rather than relying on immediate suppression and other corrective measures. Developing an integrative approach to animal damage control requires comprehensive knowledge of forest ecology, wildlife biology, population dynamics, and management parameters. Reliable information on the response of problem animal species to various silviculturai systems, therefore, is essential. Solid data, practical experience, and intuitive wisdom all are needed to construct "expert" models that will facilitate decision making in this arena.

Perfecting such integrated models requires much additional research, but with a rigorous and thorough understanding of the relations involved, it should be possible to develop and implement efficient systems of forest management that protect all the resources at stake and also ensure the periodic renewal and sustained productivity of the forest. The rest of this chapter describes basic steps toward an integrated approach to the prevention and control of animal damage.

Components of an Integrated Forest Protection System

The six basic steps of an integrated system of forest protection are:

1. Define resource management objectives and constraints;
2. Characterize potential animal damage problems on a site-specific basis in terms of the objectives and constraints;
3 Identify or develop an array of potential solutions, if unacceptable damage is projected;
4. Evaluate alternatives and select the optimal solution that is consistent and compatible with objectives and constraints;
5. Implement the selected alternative(s); and
6. Evaluate and document how effectively the program achieves management objectives. Make adjustments to current and future programs as needed.

Clear definition of management objectives and constraints is crucial to the success of the IFP process This step involves defining the resource values to be developed, protected, or otherwise managed, explicitly identifying relations and interactions among these values, and establishing the level of resource production to be achieved within the constraints that are necessary A case example might be that the forest is to yield a certain volume of timber per acre at a given age while maintaining deer populations at specified levels The obiectives and constraints are key parameters, because they are the guide for determining whether potential damage would be unacceptable, for deciding which control strategies should be used, and for measuring the success of selected strategies

Characterizing animal damage problems involves recognizing what constitutes a "problem species" and anticipating when and where such problems are likely to occur An understanding of wildlife-population dynamics and ways to measure them is crucial to this phase of the operation Prediction and detection of problems or potential problems, identification of the causal agent, and quantification of economic damage-thresholds are other key ingredients in the process of characterization Knowing the conditions under which deer browsing can become a significant problem in young plantations, for example, is crucial to developing an appropriate control strategy Deer browsing could cause low rates of seedling survival or loss of dominance to competing vegetation, and that would delay or reduce yield at harvest or require additional expenditures for reforestation and treatment of competing vegetation to avert a long-term loss in site productivity

Identifying or developing effective solutions to unacceptable animal damage entails formulating various methods to contain the problem species or reduce or tolerate its damage This step should include comparison of various control methods to determine their relative strengths and weaknesses Research, pilot testing, and operational validation are key steps in the process of developing a sound database to support accurate estimates of the effectiveness and reliability of proposed methods under actual field conditions In the case of a deer problem, for instance, researchers might explore the relative effectiveness of Vexar tubes, repellents, alarm pheromones or scents, and special hunts as methods to control levels of potential damage from deer browsing Novel approaches to managing deer populations might test, for example, the adoption of different silvicultural regimes, the manipulation of key habitat, the augmentation of natural predators, or introduction of unpalatable tree species Methods for increasing tolerance to damage might include establishing initially dense levels of stocking, planting large stock and a variety of species, or promptly replanting the area These examples merely suggest the wide range of approaches that should be considered in developing an array of management options

Selecting an alternative or array of alternatives from the range of available options involves an evaluation of cost-effectiveness, health and environmental risks, and other practical constraints such as timing, public acceptability, and probability of success This step generally should include the development of a detailed prescription that will be operationally feasible and compatible with other components of the resource management plan The prescription also should include a contingency plan to deal with unanticipated situations or developments, and it should consider the short- and long-term influence on other potential pest problems The optimal scheme for one situation involving deer, to continue the earlier example, might be to install Vexar tubes at the time of planting, but the management of vegetation to reduce an

area's attractiveness to deer might be more useful in other situations. Rational analysis of the risks, costs, and benefits of applicable options as they relate to the overall cycle of the management scheme should determine the optimal approach in either case. Integrated management methods constantly challenge managers to seek and compare new and existing alternatives.

Implementing selected alternatives involves detailed planning and execution of ADM operations. The development of logistical plans, crew training, publicity, and quality control are part of this step in the process. The application of BGR to selected plantations, for example, might involve forecasting deer movement, contracting for the application of repellent, obtaining permits, training and supervising applicators, notifying adjacent landowners and the public about the operation, and developing contingency plans for coping with potential problems.

The final step of evaluating and documenting program effectiveness entails monitoring the results of the program, analyzing its'success, and recording results for use in future decisions about ADM. This step requires careful sampling, analysis, and documentation to determine if objectives have been met and whether future operations will require any modifications or improvements. Evaluation, in the case of deer browsing, might determine that closer monitoring of deer populations and patterns of movement would be needed before problem plantations could be selected. The analysis, alternatively, might show that managing both timber and deer populations within a given area requires a broader perspective at the landscape level.

Integrative Nature of Forest Protection

How do the aforementioned six steps—objective setting, characterization of problems, development of solutions, selection of alternatives, implementation, and evaluation—differ from classical approaches to pest control? Many of these steps, after all, were used in programs of animal damage control during the 1960s, 1970s, and 1980s. We believe the principal distinction lies in the way the steps are integrated with one another and with other components of the forest management enterprise.

R.W. Stark (1979) proposed the term "integrated forest protection" as a means of focusing attention on the resource rather than on the pest. Our overall goal is to manage the **forest** to achieve specified objectives. What is done to pests is relevant only as it relates to those objectives (Norris 1989).

Integrated forest protection (IFP) builds on the premise that many forest animal damage problems originate from forest or wildlife-management practices that fail to recognize the fact that organisms we sometimes call pests are usually endemic inhabitants of the forest. Solving problems of animal damage, therefore, often involves improving overall management practices rather than directing quick-fix solutions solely at the problem species. Integrated forest protection is analogous to a comprehensive health care system as opposed to traditional ADM methods that are more analogous to bandaids. Regular exercise, good nutrition, periodic checkups, and other preventative measures, to continue the analogy with medical care, are as important as first-aid and corrective surgery in assuring a healthy, vigorous, and productive existence.

Successful IFP, which includes animal damage management as an important component, requires integration at all steps of the process. Those who set the objectives should consider and include multiple resource-values. Characterization of the problem requires an integrative knowledge of potential problems from animals, and of

the resource values to be protected. Wildlife biologists and forest managers must work together to consider whether animals are likely to inhibit the achievement of management goals and whether these animals respond to various silvicultural conditions. The identification of possible solutions for problems of animal damage requires the integration of control strategies and tactics with silvicultural regimes and practices. The wildlife biologist should work in concert with the silviculturalist and other specialists to determine which approaches to a problem are feasible, how solutions can be packaged most effectively, and whether they are likely to produce unwanted side effects. Integration of information-gathering and decision-making is also needed to assess tradeoffs between costs, benefits, and risks, and to select optimal approaches. The collective wisdom of an interdisciplinary team and analysis with "expert systems" facilitates this decisionmaking.

Careful planning and logistical coordination are also needed during implementation of the selected alternatives. Preventive and corrective precautions needed for the successful application of measures to control animal damage should be identified and implemented with close cooperation among field crews and technical-support personnel to ensure safe, effective, and socially acceptable operations. Integrated assessment of the project or program for controlling animal damage in terms of specified management objectives should continue during the evaluation and documentation phase. Once again, an interdisciplinary team should evaluate all aspects of the program to determine whether it achieved intended objectives and whether the results call for any adjustment, additional research, or work. This evaluation should encompass all aspects of the program and include recommendations for future action.

Thoughtful use of this integrated approach will help forest-resource managers protect and produce desired resource-values in a cost-effective manner acceptable to the public. It focuses attention on anticipating and preventing problems and reduces reliance on remedial control. This may increase efficiency and will almost certainly reduce conflict and controversy.

Summary

The process of integrated forest protection should be viewed as a systematic approach that is heavily dependent upon close interaction among specialists and managers representing several disciplines for the purpose of developing sound strategies of ADM. Interlocking relations among animals, vegetation, and people dictate the need for a comprehensive and integrated health care system to ensure efficient and sustained productivity in a manner that is ecologically sound and acceptable to the public. Animal damage management should be part of that integrated system.

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SECTION TWO
PRINCIPLES OF PLANT AND ANIMAL ECOLOGY

Chapter 4
General Principles of Forest Vegetation Management

PHIUPM-McDONALD AND STEVEN R. RADOSEVICH

Abstract

The saying "As the vegetation is, so the animals are" illustrates the role of vegetation in animal damage management Species that achieve vegetative dominance in young plantations up to15 years (the setting for this chapter) are often the first species that establish themselves or grow faster than competitors on such sites This chapter presents five regeneration strategies (persistent seed banks, persistent seedling banks, windblown seeds, vegetative expansion above-ground, vegetative expansion belowground) that set the stage for outlining some fundamentals of plant succession. Plants from all five regeneration strategies often begin life together and compete for dominance. Animals are part of this early community, and they increase in numbers and diversity along with the plants. The role and importance of competition as a major force that shapes the composition and structure of the early plant and animal community are discussed in detail. The interaction of animals and competition is particularly intriguing. The chapter closes with 16 general principles that constitute a silvicultural basis for vegetation management in Pacific Northwest forests.

Keywords Vegetation management, succession, competition, regeneration strategies

PHILIP M. MCDONALD is research forester, U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station, 2400 Washington Avenue, Redding, CA 96001
STEVEN R RADOSEViCH is professor, College of Forestry, Oregon State University, Corvallis, OR 97331

Introduction

A conifer seedling rarely exists by itself. Other species of trees, shrubs, forbs, and grasses (fig. 1) almost always compete for site resources (soil moisture, nutrients, light). The inevitable presence of undesirable vegetation among crops has been noted since Biblical times, and Van der Zweep (1981) effectively quoted an 1867 passage by the German poet Finger to illustrate the idea:

"One farmer sows the barley soon
His neighbour sows them late,
But both see the charlock grow
As was their father's fate."

Figure 1—A 2-year-old snowbrush seedling is in position to compete with the ponderosa pine seedling for nutrients and water

A plant is considered undesirable primarily when it denies site resources to crop species, and the desired crop, for the purpose of this chapter, is conifer seedlings. Undesirable species in effect are competing species. Suppressing competing species of plants, therefore, is the basis for vegetation management

Vegetation management has become more than just the tactical elimination of weeds, although it is a fairly recent term often substituted for "weed control." It now is recognized as a more encompassing concept that embraces an array of preventive and corrective measures, linked to other cultural practices, for optimizing the entire crop production system (Walstad and Kuch 1987). Forest vegetation management is a major component of integrated forest protection—a promising management concept often mentioned in this book.

Vegetation management is part of nearly all the activities that make up forest management It is used, for example, to enhance timber production, increase water yield, create pleasing views, encourage wildlife, provide forage for grazing animals, and

stabilize soil. This chapter focuses on managing competing vegetation to enhance the growth of conifer seedlings and reduce animal damage, but much of the information also is applicable to these other uses. Vegetation management often includes manipulating crop species and competing species until the crop is harvested. In this chapter, however, vegetation management is restricted to the control of competing species for the first 10 to 15 years of plantation life. The first few years are critical for the establishment and growth of conifer seedlings (McDonald and Fiddler 1986). It is during these first years that many of the principles of vegetation management apply. Grime (1979) noted the necessity of examining the strategies adopted during two different periods in a plant's life history: the established (mature) phase and the regenerative (immature) phase. The principles of vegetation management described in this chapter mostly will be directed to the regenerative phase of plant life.

This chapter presents information, therefore, on the regenerative strategies of plant species that attempt to dominate a disturbed area within the first 10 to 15 years after the event. Sometimes species dominate simply because they are the first to become established on disturbed ground. This information is the basis for presenting current theories of plant succession, describing succession in plantations, and relating the influence of vegetation management practices to plant succession. Competition is a major factor in species relations, and this chapter considers in detail the role and importance of competition in forest regeneration. The role and influence of animals is considered throughout the chapter, which closes with a summary of the main points dealing with vegetation management in young conifer plantations.

Reasons for Vegetation Management in Forest Regeneration

The need to manage vegetation in forests of the Pacific Northwest (including northern California) during the regeneration phase is constant and nearly ubiquitous over a wide range of site qualities. Vegetation management is critical when the conifer seedling is young, and it remains important after the seedling becomes a sapling.

Managing competing vegetation is important, because the abundance of vegetation can determine the growth rate of newly planted conifer seedlings. Much observational and some empirical evidence demonstrates that the initial vigor of a seedling determines its subsequent rate of growth. Conifer seedlings in nurseries receive amounts of nutrients, light, and water that are nearly optimal for their planted density. After planting in the field, and if free of competing vegetation, these conifer seedlings generally grow vigorously. Seedlings that must compete with other vegetation, however, often are not as vigorous and grow slower in subsequent years. A root-shoot acceleration theory (McDonald and Fiddler 1986) may explain this phenomenon: In the absence of competition, conifer seedling roots rapidly extend vertically and horizontally. They increase in size and length, number of root tips, and water absorption capacity. By increasing the volume of soil exploited, they also increase the amount of water and nutrients available for rapid growth. The resources stored in or acquired by the expanding root system contribute to additional, exponential growth both above- and belowground.

When conifer seedling roots encounter those of competing vegetation (from shrubs or grasses that activate root growth at lower soil temperatures for example), the conifer roots extend into areas of previously exploited soil that not only contain less water and nutrients, but also harbor inhibiting chemicals given off as byproducts by shrub or grass roots. The conifer roots, consequently, are denied the resources necessary for rapid expansion. Lack of initial resources can lead to lower carbohydrate production, decreased exploitation of soil, less resource collection, poor growth, and increased

susceptibility to attack from animals and insects (McDonald and Fiddler 1989). Studies in southern Oregon support this theory. Douglas-tir seedlings in one such study were planted in an area where competing vegetation was mostly sprouts of canyon live oak and greenleaf manzanita. Manual and chemical treatments created conditions of heavy, light, and essentially no competition. After five growing seasons, excavation showed that seedlings in the control and lightly treated areas had produced almost no new roots and had the same shape of root system as that when planted. Moreover, seedlings that were essentially free-to-grow had 9 times more root biomass than seedlings in lightly treated areas and 22 times more root biomass than seedlings in areas of heavy competition (S.D. Tesch, Oregon State University, personal communication).

Container-grown and bare-root seedlings of Douglas-fir in another study were underplanted beneath treated and untreated trees of Pacific madrone, giant chinkapin, and tanoak. Sixty percent of the hardwood canopy was killed by herbicide injection. After five growing seasons, the dry weight of container-grown seedling roots in treated stands was 8.7 times that of seedling roots in untreated stands, and the dry weight of bare-root seedling roots in treated areas was 6.7 times greater than in untreated areas (Helgerson 1990). Competition clearly reduced the root biomass of Douglas-fir seedlings.

Vegetation management continues to play an important role as conifer seedlings and competing vegetation grow larger. Competition negatively affects conifer growth on poor and good sites, but in different ways. Shrubs on poor quality or harsh sites threaten the very existence of conifer plantations and exert a negative influence on growth for many years. Five years after a 16-year-old plantation of ponderosa pine was treated, for example, the average annual d.b.h., height, and stem volume growth were significantly greater in plots where competing shrubs were removed. Overall annual production of pines actually rose 7.3 ft^acre, for a 29-percent increase in production over untreated shrubs (Oliver 1984). Close spacing of trees did not restrict shrub growth, but increasing shrub density decreased ponderosa pine growth (W.W. Oliver, Pacific Southwest Research Station, personal communication). In a related study on a site of good quality, ponderosa pine was planted at five spacings ranging from 6 feet by 6 feet to 18 feet by 18 feet with half of each plot maintained in a shrub-free condition and half with naturally occurring shrubs. Over all of the spacings after 15 years, competition from shrubs reduced the periodic annual increment (PAI) diameter at breast height by 31 percent, and it reduced height by 29 percent and stem volume by 51 percent (McDonald and Oliver 1984). Comparison of the two studies showed that loss of growth was proportionally greater on the poor site, but growth loss in absolute terms was greater on the good site.

Plant Regenerative Strategies

Most plants in new plantations have a sexual or a vegetative reproductive process, and many plants posses both. Plants with abundant seed production often have only slight capability for vegetative propagation, and plants with copious vegetative reproduction often are associated with reduced seed output. In either instance, a drain on the resources of the parents takes place. Grant (1971) noted that gene recombination occurs through the sexual process of cross-fertilization and meiosis. Gene recombination is the chief source of hereditary variations in a sexually reproducing species, and such variations are the raw materials necessaiy for the species to respond to ever-changing environments. It is not surprising, therefore, that sexually reproducing species tend to be most successful in unstable or changing environments, and that vegetatively reproducing species are found in stable environments to which they already are well adapted.

Conifer plantations characteristically occupy areas that have been severely disturbed by timber harvests where slash was piled and perhaps burned, and where most remaining vegetation was uprooted and removed. Soil surfaces in these areas often are bare and temporarily devoid of most plants and many animals. Available site resources, however, are high because large quantities of organic material are incorporated into the soil through harvesting and site preparation operations, and large quantities of moisture are absorbed by organic material in the soil. Warm temperatures and added moisture cause a rapid buildup of microorganism populations that decompose organic material and liberate nutrients. In this changed and somewhat unstable environment, plant species of both reproductive processes become abundant and compete effectively by utilizing different regenerative strategies.

Regenerative strategies fall into two main groups: those involving the *reproductive* potential of plants, and those that affect potential plant *growth.* Strategies that affect reproductive potential include persistent seed banks, persistent seedling banks, and windblown seeds (Grime 1979). Strategies that affect growth potential include vegetative expansion aboveground and vegetative expansion belowground.

Species with reproductive strategies involving persistent seed banks, persistent seedling banks, and windblown seeds have the advantage of being among the first to colonize and monopolize a site. The success of these strategies depends on little or no competition with other species and a high level of available site resources.

Persistent Seed Banks

Plant species with this strategy generally produce seeds that are incorporated in the litter and soil in a dormant condition for at least 1 year. The seeds almost always have dormant embryos and hard seedcoats that prevent imbibition of water. The seeds tend to be small. Length of time in the soil may range from decades to hundreds of years. Species involved may include trees and shrubs (fig. 2) and annual and

Figure 2—After 7 years, deerbrush seedlings grown from seed are taller than this 4 8-foot-tall Douglas-fir seedling in the Klamath National Forest, California

perennial forbs and grasses. Families of plants with representative species in young plantations in Pacific Northwest forests include Compositae, Cruciferae, Graminae, Polygonaceae, Ranunculaceae, Rosaceae, and Scrophulariaceae. The amount of seed in a persistent bank may vary greatly for any given species, but it generally is largest after a bumper seed crop. A primary trend is for seed amount to decrease with soil depth; a secondary trend is for bulges of seeds to be present in the soil in years of bumper crops.

Factors that cause germination of dormant seeds include increased heat, light, and diurnal temperature fluctuations that may result from removal of foliage, litter, or humus layers. Grime (1979) noted that many species with persistent seed banks tend to exhibit polymorphism in their germination requirements. Seeds produced by individual plants, or even by the same population of plants, often show considerable variation in response to changes in light and temperature. The risk of mortality is high in disturbed habitats, so polymorphism in germination requirements provides for regeneration in a range of different spatial and temporal niches. Polymorphism also ensures a reservoir of viable seeds in the soil.

Persistent Seedling Banks

Shade-tolerant plants, which often are initially lower in stature than vegetative associates, persist in the understory in this strategy and accumulate for many years. Shoot growth is slow or even negative because of dieback, but root systems expand slowly and may include rudimentary burls that serve as food-storage organs (McDonald and Tappeiner 1986). Surviving for long periods under unfavorable circumstances ensures that the potential for regeneration is maintained until gaps open in the overstory, or until the entire overstory is removed by senescence, insects, disease, windfall, fire, or harvest. After release, the seedlings receive more site resources (including light) and grow at a faster rate.

In Pacific Northwest forests, tanoak provides a good example of the seedling bank regenerative strategy. Inherently shorter than the conifers with which it often grows (McDonald and Tappeiner 1987), this species regenerates both from root-crown sprouts (see section on vegetative expansion aboveground), and from seedling sprouts. Seedlings (from acorns) almost always die back to the root crown, then sprout and become seedling sprouts (stems arising from stumps less than 1 inch in diameter at ground line). Capability to sprout has been observed to occur within 7 days of emergence on hundreds of tanoak seedlings in a large plantation (McDonald 1978). Detailed examination of growth rings above and below the burl, which forms at about age 3, reveals that tanoak seedling sprouts may be up to 62 years old and less than 85 inches tall. Sprouts on each stump have died back and sprouted several times by this age, and stem age just below the burl is much greater than sprout age above the burl (Tappeiner and McDonald 1984). The number of sprouts per stump ranges from 2 to 14, and the number of seedling sprouts may exceed 10,000 per acre. After release by cutting or burning, the seedling sprouts die back, sprout, and grow vigorously, fueled by intake from the root system and augmented by food reserves stored in the burl.

Wind Dispersed Seeds

The relatively bare ground of new conifer plantations serves as a near-perfect medium for colonization by species having small seeds with large wings, plumes, or pappus designed for aerial dispersion. Both woody and herbaceous species regenerate with this strategy They often produce huge amounts of seed that can be carried long distances by the wind to saturate an area (fig. 3). Herbaceous species of the family Compositae are common windbourne invaders in the forests of the

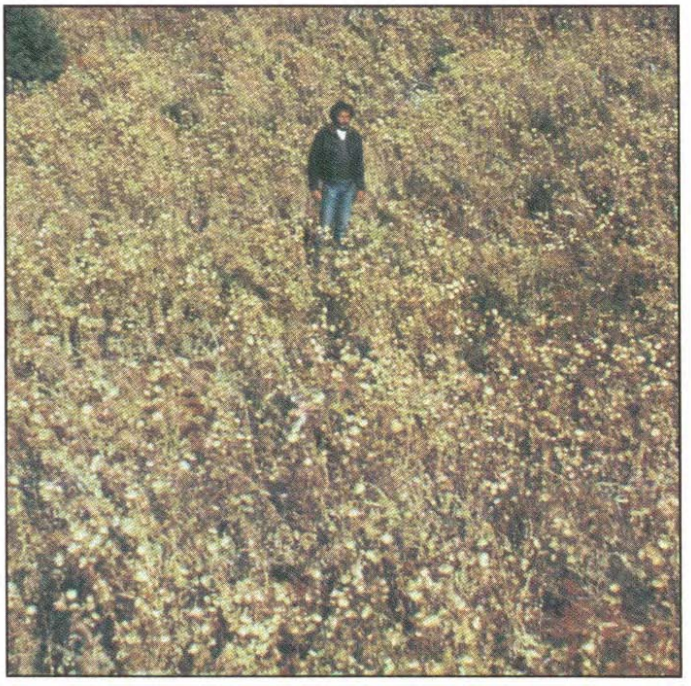

Figure 3—Over 20,000 bull thistles occupy each acre in a plantation in the Plumas National Forest, California

Pacific Northwest. Genera often observed in new plantations are *Cirsium, Madia. Epilobium, Stephanomeria, Hypochoeris,* and *Senecio.* Small seeds often mean meager reserves of stored food reserves, short viability timespans, and low competitive capability for the seedlings. Species with wind-dispersed seeds often circumvent these shortcomings with biennial cycles. Their seeds blow in on the wind in fall, germinate after the fall rains, punch a taproot into the soil for a few inches, and overwinter as short, inconspicuous plants. These plants resume growth in the spring when soil temperatures are still cold enough to inhibit root growth of conifer seedlings. Fueled by the underutilized resources in the plantation area, and with their photosynthetic apparatus already in place, these plants bolt, grow vigorously, and complete their life cycles. Populations of windbourne species usually peak after 2 to 4 years, and become a formidable drain on site resources. Peak density of bull thistle in a new plantation on a good site in the northern Sierra Nevada of California was 34,000 seedlings per acre (McDonald and Tappeiner 1986).

Vegetative Expansion Aboveg round

Many species in Pacific Northwest forests dominate by vegetative expansion aboveground. This strategy primarily is accomplished by root-crown sprouts of hardwood trees and woody shrubs that originate from dormant buds on a burl located at or just below groundline. Representative genera include *Quercus, Acer, Arbutus, Lithocarpus, Arctostaphylos, Ceanothus. Rhamnus,* and *Castanopsis.* Nearly all of these species occupy an environment in which fire is a common phenomenon. In a mixed conifer-hardwood stand, fire kills the conifers outright and burns the hardwoods back to groundline. Enriched by the food reserves and root system of the parent plant, sprouts grow rapidly to as much as 4 or 5 feet in height after one growing season. After three growing seasons in northwestern California, sprouts of bigleaf maple were 12.8 feet tall; sprouts of Pacific madrone were 10.1 feet tall; and sprouts of tanoak were 6.8 feet tall (Roy 1955). In the northern Sierra Nevada of California,

McDonald (1978) found that root-crown sprouts of California black oak, Pacific madrone, and tanoak averaged about 15 sprouts per clump and were over 20 feet tall and 10 feet wide after 10 years. Rapid growth and capture of available resources by the sprouts caused mortality and overtopping of more than half of the conifers in the plantation.

Trailing stems that root freely are another form of aboveground expansion. Species of this nature that are common in local plantations include common whipplea, pinemat ceanothus, and spreading snowberry.

Vegetative Expansion Below/ground

An outstanding attribute of vegetative expansion belowground is the low risk of mortality to offspring. Location belowground and attachment to a food source practically guarantees survival and establishment. Plants with this strategy, consequently, often are found in harsh environments or areas with dense vegetation or litter layers, and where establishment from seed is difficult because of chronic destruction or consumption. Rhizomatous species in plantations in Pacific Northwest forests include thinleaf huckleberry, salmonberry, salal, woolly nama, low dogbane, morning-glory, Modoc morning-glory, broad-leaf aster, milk kelloggia, and western bracken fern. Such species often form dense patches and suppress the growth and regeneration of other plant species.

Root sprouts are another form of belowground expansion. Species that regenerate by this means are not extensive in Pacific Northwest plantations. Sierra plum, however, is one such species that is common to plantations in southern Oregon and northern California. Attachment to the parent is particularly long-lasting for this species.

Risks in genetic uniformity and ecological range are associated with regenerative strategies that are wholly sexual or vegetative, and many plant species, consequently, have both processes. This gives them the flexibility to prosper in a wide range of habitats. Flexibility is greatest when well adapted genotypes replicate either by vegetative or sexual means on an alternating basis. Asexual propagation locks in changes to the environment while sexual propagation allows retention of genotypic variety. Bearclover is an example of a species with multiple regenerative strategies that inhabits thousands of acres of forest land in northern California. It is a vigorous competitor to conifer seedlings (fig. 4) because it regenerates from seed, sprouts from the root crown, and produces rhizomes that give rise to new plants (McDonald and Tappeiner1986).

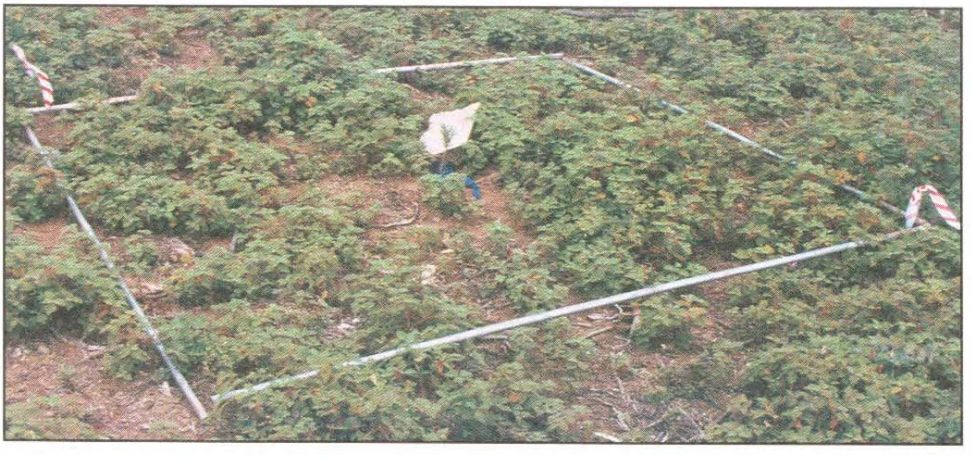

Figure 4—Sprouting bearclover is stunting growth and threatening survival of a ponderosa pine seedling in northern California

Succession

Plant succession often is described as primary (occurring on heretofore unvegetated land) or secondary (revegetation after a disturbance). Secondary succession typically occurs in forest plantations. Succession is a complex phenomenon in the productive environment of plantations that involves the regenerative strategies and dispersal efficiencies of plants and their capability to progressively modify the soil and microenvironment. Knowledge of succession is vital because vegetation management often sets an initial point (bare ground) through site preparation, and imposes a narrow range of environmental conditions, that lead, in turn, to a particular animal and plant community.

Odum (1969) noted that ecological succession may be defined by three parameters:

1. Succession is an orderly process of community development that is reasonably directional and therefore predictable.
2. Succession results from modification of the physical environment by the community. It is community controlled, even though the physical environment determines the pattern, the rate of change, and often limits the extent of development.
3. Succession culminates in a stabilized ecosystem in which maximum biomass and symbiotic function between organisms are maintained per unit of available energy flow. Table 1 presents ecological attributes characteristic of succession for early and late stages.

Theories of Plant Succession

Connell and Slatyer (1977) described several mechanisms by which succession may take place (fig. 5). Species having the strategy of wind dispersed seeds generally are the first to occupy an empty space after a major disturbance, provided that no competing species survive belowground or that no large seed bank responds to the disturbance. Wind-dispersed species rarely grow well in the presence of living adults of their own or other species. The kind of plants following these earliest species may be determined by one of three mechanisms. Species with a "facilitation" mechanism require earlier species to modify the environment for their entry and growth. Facilitators can colonize only after suitable changes in the microenvironment. Where later species tolerate inhibiting chemicals or lower levels of resources than earlier ones, however, the "tolerance" mechanism causes a predictable successional sequence in which later colonizers invade and grow to maturity in the presence of those that preceded them. The "inhibition" mechanism, finally, operates where all species, even the earliest, resist invasion by competitors. The first occupants preempt space and exclude or inhibit later colonists. Later colonizers become established and reach maturity only after the first become damaged or die. Morris and Wood (1989) found that pioneer species can both facilitate and inhibit subsequent invaders.

Succession in Plantations

The mechanism of succession that is typical of plantations in northern California, southern Oregon, and perhaps elsewhere in the Pacific Northwest was examined in a northern California study that took place in a clearcutting on a site of good quality. Slash and remaining vegetation were pushed into piles and windrows and burned. In this instance, conifers regenerated from natural seed fall, although planting was a viable alternative.

Origin of species—The first plant species present in the cleared area were those already present before the harvest. Logging and site preparation removed most aboveground plant parts, but those belowground remained largely intact. Belowground plant parts retained mechanisms for regrowth, even though they may

Table 1—A tabular model of ecological succession: trends to be expected In the developmental stage of ecosystems"

Ecosystem attributes	Developmental stage
Community energetics:	
Gross production/community respiration (P/R ratio)	Greater or less than 1
Gross production/standing crop biomass (P/B ratio)	High
Biomass supported/unit energy flow (B/E ratio)	Low
Net community production (yield)	High
Food chains	Linear, predominantly grazing
Community structure:	
Total organic matter	Small
Inorganic nutrients	Extrabiotic
Species diversity-variety component	Low
Species equitability component	Low
Biochemical diversity	Low
Stratification and spatial heterogeneity (pattern diversity)	Poorly organized
Life history:	
Niche specialization	Broad
Size of organism	Small
Life cycles	Short, simple
Nutrient cycling:	
Mineral cycles	Open
Nutrient exchange rate between organisms and environment	Rapid
Role of detritus in nutrient regeneration	Unimportant
Selection pressure:	
Growth form	For rapid growth ("r selection")
Production	Quantity
Overall homeostasis:	
Internal symbiosis	Undeveloped
Nutrient conservation	Poor
Stability (resistance to external perturbations)	Poor
Entropy	High
Information	Low

'Adapted from Odum (1969)

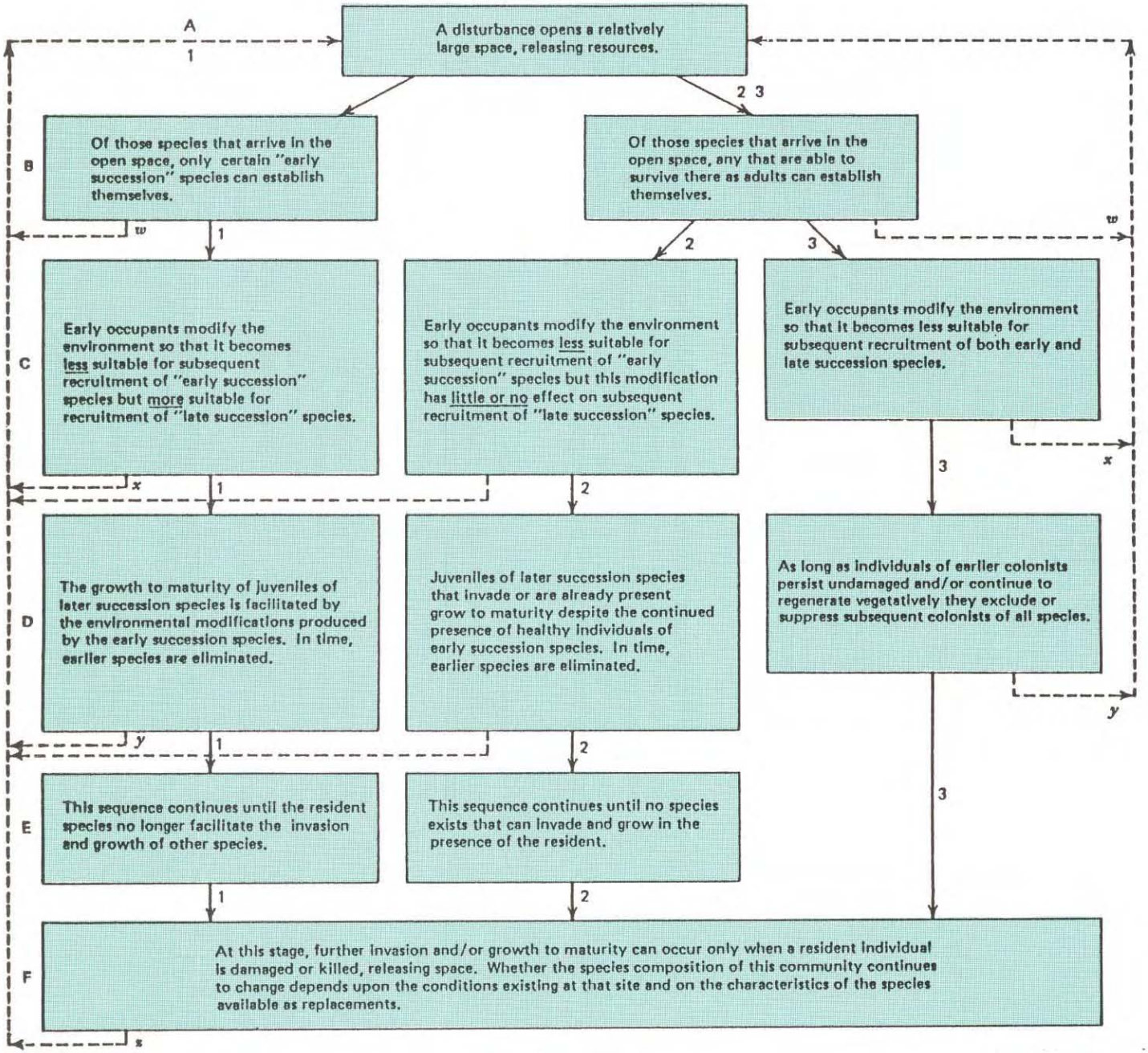

Figure 5—Three models of the mechanisms producing the sequence of species in succession The dashed lines represent interruptions of the process in decreasing frequency in the order *w, x, y,* and z The numbers 1,2, and 3 refer to facilitation, tolerance, and inhibitory models (From Connell and Slatyer 1977, copyright 1977 by the University of Chicago)

have been damaged. These early species benefitted from dormant buds on root crowns and burls of hardwoods and shrubs, from nodes on the rhizomes of poison-oak and bearclover, and from the reproductive capability of severed pieces of roots, as in the case of bracken fern. Shoots from these sources rapidly extended above-ground and expanded in height and crown width. Sprouts from the roots and the root crowns of hardwoods and shrubs were common, as were patches of bracken fern. Logging and site preparation did not greatly disturb some animals (deer mice, pocket gophers), but others (hares, rabbits, tree squirrels, and some large animals), although displaced, nevertheless continued to feed in the area.

In this study, ponderosa pine and, less commonly, Douglas-fir and incense-cedar produced light to medium cone crops. Seeds from these crops were dispersed into the study area in the fall. Seeds from many other species also blew into the clearcutting and germinated soon after the first rains. By late fall several thousand plants per acre had become established. Representative species were bull thistle, willow herb, smooth cat's ear, prickly lettuce, gumweed madia, and wirelettuce. After germination, the shoots grew slowly, but roots extended several inches betowground. Rapid growth during the following spring was characteristic. Animals continued to be scarce.

Plants that originated from dormant seeds in the soil became established in the spring, but more importantly, these species mostly were woody shrubs like manza-nita, deerbrush, and coffeeberry that have strong capability to dominate disturbed areas in parts of summer-dry southern Oregon and northern California. Other plants, including some forbs and grasses, also became established and vied for resources at this time.

Chronological development—Plentiful soil moisture and abundant nutrients (from decomposition of organic material remaining after harvest) supported various plant species during the first summer. Shallow depressions in the soil, however, often served as catchments for large numbers of seeds, and here many plants competed for resources and room to grow Animals were few and scarcely noticeable.

By the second fall, or 1 year after site preparation, many grasses and forbs had grown quite tall and had produced seeds. The plantation by then had an environment with cover and foodstuffs that small animals (particularly deer mice and pocket gophers) found favorable. High reproductive rates of resident animals and dispersion of animals from outside the plantation increased animal populations in the community. Deer foraged on tender new growth of conifers and other shrubs and forbs, including many species that became unpalatable a year or two later. High nutrient content and tender foliage apparently made these species desirable.

In the following spring, more ephemeral species were established from seeds that were either windblown or produced by previously established plants. Plants also were established from dormant seeds in the soil. Sprouts of all species and plants from dormant or recently deposited seeds competed aboveground for space and belowground for resources, particularly soil moisture. The variety of animal species and the number of animals in the community both increased during this period.

Processes that started in the previous spring intensified during the second growing season, and species diversity and population sizes increased. Species diversity of plants increased further after three growing seasons, and the diversity of animals also

increased somewhat. The number of plants and animals of many species had become much larger, and the size of many individual plants had increased. The number of interactions involving plants and animals also had increased manyfold. Competition by roots from sprouts of several hardwood and shrub species and from shrub seedlings also limited the resources available to conifer seedlings. Fewer, shorter, and lighter colored needles on pine seedlings became noticeable for the first time.

Plants occupied much of the cleared area after 5 years. They were dense in some places and scattered in others. Over 150 species of plants were identified. Foliar cover, which provides a conservative estimate of horizontal development, was 6 percent forbs, 8 percent grasses, 30 percent shrubs, 1 percent widely scattered hardwoods, and 8 percent pines. After 10 years, hardwood sprouts were 16 feet tall, shrubs were 8 feet tall, ponderosa pines were 7 feet tall, grasses were 2 feet tall, and forbs were about 1 foot tall.

Influence of Vegetation Management on Succession

The effect of vegetation management on succession is determined by the physiological state of the treated vegetation, the role of allelopathy, the time the treatment is applied, and the type of treatment.

Physiological state of treated vegetation—Sousa (1984) noted that modern-day species that characteristically take advantage of disturbance have been doing so for millennia and are accustomed to wide changes in the degree of disturbance and to concommitant variations in temperature and moisture. The acclimatization of an evolutionary species to the environmental stresses it encounters is an ongoing process. The degree of disturbance brought about by vegetation management, however, can cause fluctuations in the physical environment that may exceed the limits for an effective physiological response by the treated plants. This may cause initial reductions in growth and reproduction, but organisms will die if the stress becomes severe enough. The number of organisms killed in this manner varies from a few individuals to entire populations. In northern California clearcuttings with intense site preparation, for example, spring browsing by migratory deer nearly eliminates early successional species such as prickly sowthistle and yellow salsify.

Role of allelopathy—Allelopathy or the process whereby a plant species releases a chemical substance that inhibits the presence or growth of another plant in the same or nearby habitat (Muller 1966), and its influence on succession in plantations in the Pacific Northwest is poorly understood and poorly demonstrated. Tukey (1969) noted that plant-to-plant chemical interactions take place via four transport pathways: leaching, volatilization, decomposition, and formation of root exudates.

Hall (1977) suspected that something in ponderosa pine litter apparently inhibited pine growth and suggested that periodic underburning might destroy this substance. McConnell and others (1971) found that pine litter impeded root growth of various grasses and forbs. Del Moral and Gates (1971) noticed that in greenhouses the litter extracts of Pacific madrone, Cascades azalea, vine maple, European red elder, and several other common shrubs inhibited radical elongation in germinating Douglas-fir seeds. Stewart (1975) showed that senescent fronds of bracken fern hindered germination of western thimbleberry and delayed germination of salmonberry. Rose and others (1983) found that bracken influenced mycorrhizae development to varying degrees. Their study on in-vitro growth of four mycorrhizal fungi showed that bracken stimulated one, inhibited two, and did not affect the fourth.

Timing of treatment—The timing of vegetation management treatments mostly affects how soon succession can resume. The capture of resources during the first year is so important to the buildup of fine-root biomass in conifer seedlings that coexistence with competing vegetation is not desirable. Treatments that *prevent the* presence of competing vegetation, therefore, are desirable for the establishment of conifer seedlings (McDonald and Fiddler 1986). Preventive treatments may include broadcast burning before harvest to stimulate the dormant seeds of shrubs. Shrub seedlings are then killed by subsequent bums or application of pre-emergent herbicides. Herbicides also are available to kill plants emerging from dormant seeds in the soil, seeds carried on the wind, and sprouts of most shrubs and hardwoods. These preventive treatments, however, seldom change the composition or magnitude of species in secondary succession. Succession simply begins anew after 1 to 3 years, but this extra time provides the conifer seedlings with at least an even start.

Type of treatment—Site preparation before planting is an important tool for manipulating vegetation. It includes mechanical and manual methods, chemical applications, fire, and combinations of these techniques in ways that may strongly influence succession. Mechanically piling slash tends to aid the establishment of manzanita, for example, and broadcast burning favors ceanothus species (Gratkowski 1962). Cool, spring burns that leave an inch of duff on the surface protect the soil, preserve nutrients, and inhibit the germination of dormant shrub seeds. If piled and windrowed slash is burned, prickly lettuce rapidly and almost exclusively occupies the burned areas (McDonald and Fiddler 1989) and becomes a seed source for broader colonization. Some herbicides effectively target and control individual dominant species of competing vegetation. Bracken fern and tanoak, for example, were substantially reduced with herbicide applications in specific plantations in California and Oregon. After these treatments, succession reverted to an earlier stage with many more species of lower stature and greater need for sunlight.

Plantation release after planting is another important vegetation management tool capable of changing the composition of the ensuing plant community and affecting the growth rate of some species. This management technique is most effective if keyed to *minimizing* the effect of competing vegetation with herbicides, manual techniques (grubbing, slashing), grazing animals (cattle, sheep), mechanical methods (large "mowing" machines), and mulches (McDonald and Fiddler 1986). This practice almost always involves applying a treatment after one growing season. Most available propagules of competing species are committed to germination or growth by that time, and plants are young, small, and vulnerable. Mulch placed in a radius of 3 to 5 feet around a newly planted conifer seedling can effectivly control herbaceous vegetation or shrub seedlings for a few years. Succession in mulched space usually favors species bordering the mulch at the time it loses effectiveness. Manually grubbing entire areas or radii of at least 5 feet around conifer seedlings, usually after competing plants are 1 year old, also generally minimizes the effect of undesirable species. The only significant result of this treatment is that it delays succession for 1 year. Application of herbicide would similarly limit competing species and also affect sprouting shrubs or hardwoods. Herbaceous vegetation would replace shrubs and hardwoods, and succession on treated ground would be set back dramatically.

Unwanted vegetation also can be reduced by encouraging or introducing less competitive vegetation. A rapidly growing, shallow-rooted, perennial forb that inhibits germination of shrub seeds is desirable. Naturally occurring woolly nama is a

good example. A short-statured, shallow-rooted legume like subterranean clover is another example of an introduced plant that furnishes nitrogen to the system and could be desirable. Horticultural varieties of dwarf grasses also fit into this category. Biological control such as these often delay normal succession until conifer crowns close and shade out the introduced species.

Grazing animals and mechanical methods usually are not applied to minimize competing vegetation. The vegetation present after only 1 year seldom is sufficient to support grazing, and grazing rarely is sufficiently intensive to lessen competition belowground. Mechanical methods often are used in situations where the competition is mostly from mature shrubs and hardwoods. Chronic grazing by cattle or sheep hastens the elimination of highly palatable species (usually forbs) that are then replaced by grasses or other forbs of lower palatability. Palatable shrubs that are the primary browse species develop more slowly than unbrowsed counterparts, but eventually they become too tall to be affected. Slower development of shrubs often provides a longer timespan for herbaceous plants to grow well and produce seeds.

Minimizing the effect of competing plants in plantations of 2 to 5 years of age is more difficult because of inaccesibility and factors like inadequate money or lack of permits, and the effect of treatments on succession is much more complicated. Treatment alternatives are all possible, but their effect is more contingent on correct timing and application than in instances where the competing vegetation is younger and smaller. Methods of treatment and the makeup of vegetative communities being treated also should be considered. The abundance, size, and dominance of plant species, and the effect of animals, all determine how treatment affects succession.

Shrubs and hardwoods from 6 to 15 years in age almost always resprout after mechanical treatment or cutting. The sprouts have a large and well-established root system from which to draw resources, hence they grow rapidly and their height and crown-spread resemble untreated counterparts within a few years. The effect of these treatments on plant succession is small, but if herbicides are applied and the sprouts are killed, succession begins anew by plants from dormant seeds in the soil and from windblown seeds.

Site prepartion and plantation release, because of their effect on succession, provide opportunities to establish, maintain, and study biodiversity in manipulated stands. They also constitute a beginning point for evaluating long-term effects on the ecosystem.

Role of Competition in Forest Regeneration

Competition is a complex ecological process, although it often is described in simple terms. The study of competition requires an understanding of various biological, environmental, and proximity factors that interact when plants grow together over time (Radosevich 1984).

Intensity of Competition

Influence of density and size—Those who conduct and interpret experiments involving competition among species should consider the effects of plant density, proportion, arrangement, size, age, and growth rate, as well as timing of biomass production for each species. A study of a medium-to-poor site in northern California, for example, quantified the growth of ponderosa pine relative to various densities of woody shrubs (McDonald and Oliver 1984) After 18 years, average stem height

and diameter of pine differed significantly among shrub density classes, and they increased as the intensity of competition from shrubs decreased (table 2). "Light" shrub density caused moderate losses in pine growth and medium shrub density caused major losses. Subalpine needlegrass began to invade the area five years after planting with pines (fig. 6), and needlegrass density was inversely related to shrub density after 18 years (table 2). Once the shrubs were eliminated in the no-shrub plots, moreover, new shrubs did not re-establish despite the virtual certainty that seeds were present in the soil and were constantly disseminated from nearby sources by birds and animals. Interference by needlegrass, whether chemical (allelopathy) or physical (denial of resources), prevented germination of shrub seeds.

Table 2—Relation of pine parameters and needlegrass density to shrub-density class 18 years after planting near Mount Shasta, CA

Shrub-density class	Pine diameter	Pine height	Needlegrass density
	Inches	*Feet*	*Number per acre*
None	5.1	16.5	50,000
Light	3.9	12.0	17,600
Medium	2.9	9.3	8,200
Heavy	1.4	5.8	533

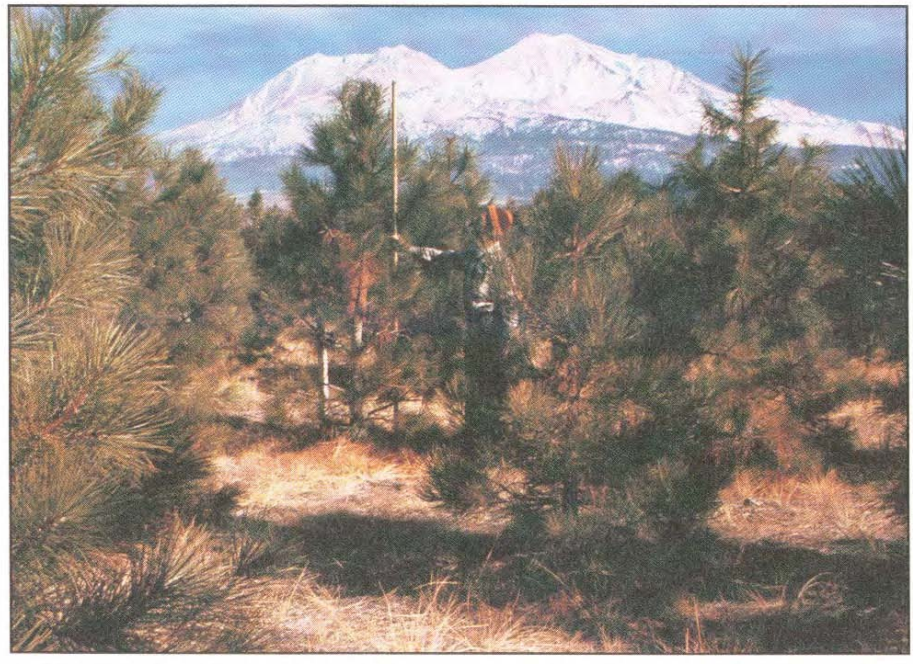

Figure 6 - Needlegrass is rapidly covering the ground in plantation near Mount Shasta, California.

Wagner and others (1989) noted that growth of ponderosa pine seedlings increases as the abundance of shrubs or herbs decreases (fig. 7). Other studies have reported similar relations with ponderosa pine (Oliver 1984), Douglas-fir (Cole and Newton 1989), and loblolly pine (Burkhart and Sprinz 1984) grown with various densities of other plant species.

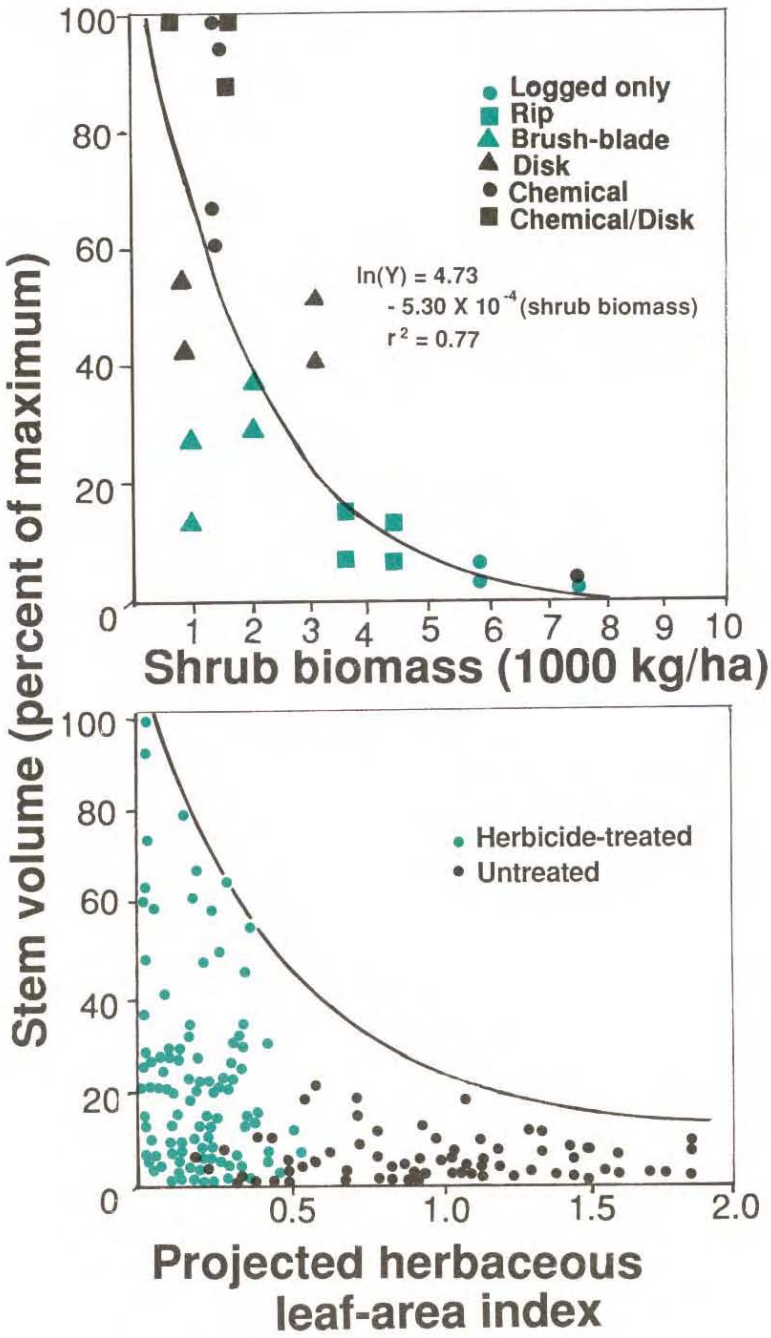

Figure 7—Percentage of maximum stem volume for **(A)** 8-year-old ponderosa pine seedlings growing with various levels of shrub biomass in south-central Oregon after six site-preparation treatments, and **(B)** individual 3-year-old pine seedlings surrounded by vanous amounts of herbaceous vegetation (projected leaf area index) from western Montana (Wagner and others 1989)

Thresholds—Competition thresholds, or the levels of vegetation abundance at which the rate of tree survival or growth markedly increases or decreases, are especially valuable to forest managers because they often serve as decision points. Thresholds often involve a critical and quantitative evaluation of tradeoffs between techniques of vegetation management and the corresponding responses of conifer seedlings. The direct effect of a particular technique on the abundance of competing vegetation, and the indirect response of the conifer seedling to this abundance, both constitute biological responses to a treatment and should be integrated with other data that guide management decisions.

Thresholds also are valuable in a more general sense. As noted earlier, almost any competition by vegetation for the space that conifer seedlings require for maximum growth early in life is potentially too much. Three long-term spacing studies in ponderosa pine plantations on poor, medium, and good sites in northern California indicate possible thresholds of competition. Regression equations from one study on a good site suggest that any amount of shrubs restricts the diameter growth of pine, and shrubs dominate where cover exceeds 30 percent (Oliver 1984). Two studies indicated competition thresholds when foliar cover by shrubs was 15 to 21 percent on medium sites and 10 to 15 percent on poor sites (McDonald and Fiddler 1986). These studies suggest rule-of-thrumb thresholds of competition with foliar cover of 10 to 20 percent on poor sites and 20 to 30 percent on good sites. Shrub amounts beyond these values markedly inhibit pine growth.

Competition thresholds for vegetation management probably are higher (more competition) for survival of conifer seedlings than for growth. Tree survival in the study by Wagner and others (1989), for example, remained constant and relatively high (fig. 8) at weed levels that limited stem volume (fig 7). Survival did not decline until competition reached levels where stem volume was reduced to less than 25 percent of the observed maximum (figs. 7 and 8). These observations are consistant with those of Burkart and Sprinz (1984) for survival of loblolly pine relative to the basal area of hardwoods. The probability of mortality apparently increases when environmental resources are depleted beyond the levels at which conifer seedlings maintain minimum growth.

Importance of Competition

Competition among species for the environmental resources (light, water, nutrients, gasses) necessary for photosynthesis and respiration, is primarily responsible for the negative interaction between conifer seedlings and other vegetation. Over 200 studies in the United States have demonstrated that incremental increases in the density or biomass of competing vegetation lowers seedling survival or growth (Stewart and others 1984).

Many reasons other than competition, however, explain why seedlings live, die, or grow on reforestation sites. Figure 8 shows the individual response of seedlings plotted against the level of competition. The best growth, notably, occurs when competition is absent, and the poorest response results when competition is present. At least some of the seedlings with strong competition, however, responded like those without competition. This suggests that other factors must control the growth of these seedlings.

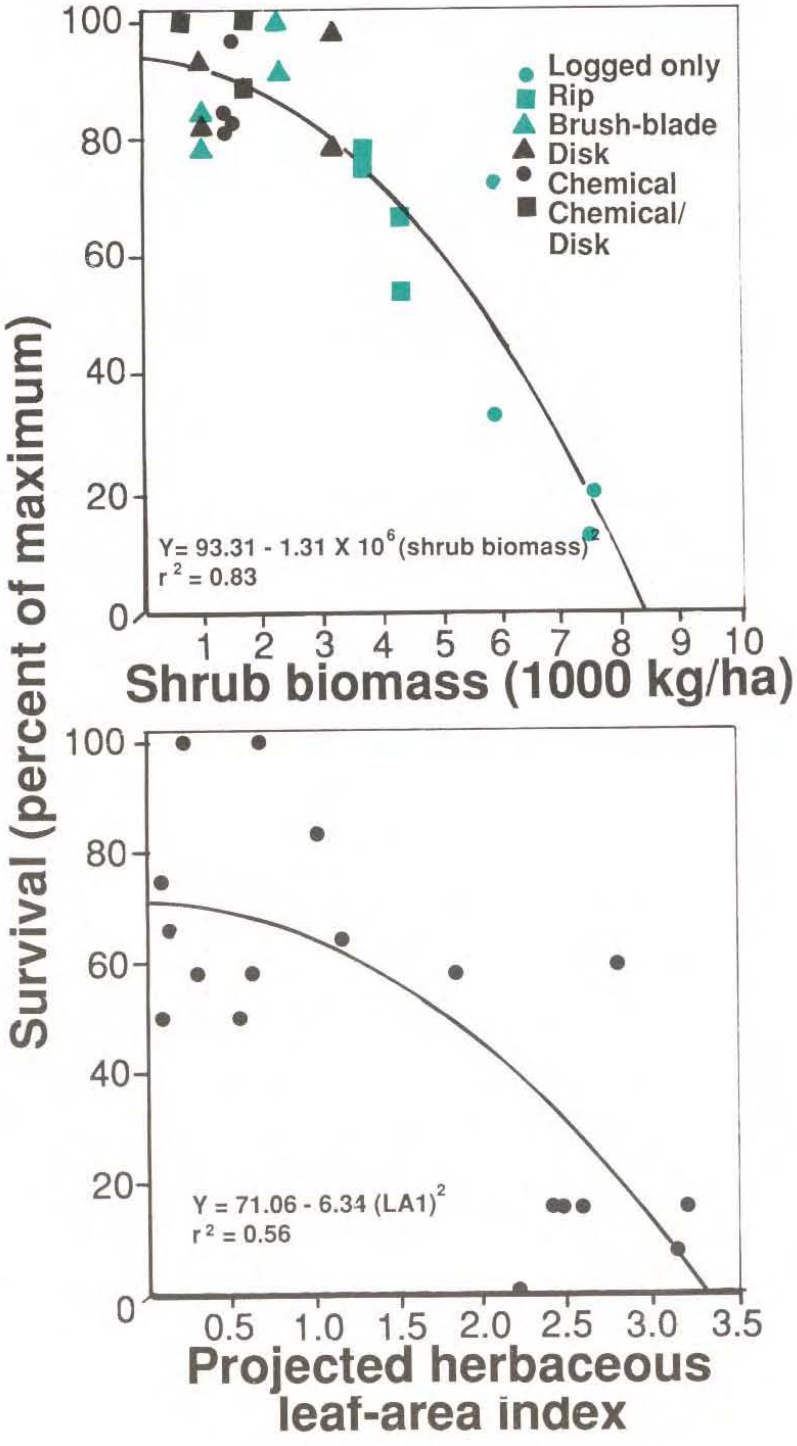

Figure 8—Percentage of maximum survival for **(A)** 8-year-old ponderosa pine seedlings growing with various levels of shrub biomass in south-central Oregon after six site-preparation treatments, and **(B)** 1-year-old pine seedlings growing with various levels of herbaceous vegetation in western Montana

Influence of ablotic and biotic factors—Radosevich and Osteryoung (1987) indicated that either abiotic or biotic (actors can influence conifer regeneration (table 3). Figure 9 describes how abiotic (environmental) and biotic (animal) components affect competition between two plants (a tree and shrub, for example). The interactive process depicted in figure 9 probably results in a range or hierarchy of tree sizes (as in fig. 8). Browsed seedlings, for example, have less biomass for producing subsequent growth than unbrowsed seedlings. Poorly adapted species, weak planting stock, poor planting procedures, or establishment in unfavorable microenvironments can all limit growth potential. Grazing and poor seedling performance reduce growth potential for the following year because later growth is partially a function of achieved growth. Differences in the size of conifer seedling, therefore, are magnified over time and depend on the frequency and extent of the biomass initially removed. This loss of growth potential may be exacerbated by competition, or the lack of competition may compensate for some animal damage. Fast-growing seedlings in a weed-free environment not only are less susceptible to the effects of damage by animals, but they also may gain from an improved microenvironment.

Table 3—Important factors of the environment

Factor	Important aspects
Climatic factors:	
Light	Intensity, quality, duration or photoperiod
Temperature	Degree, fluctuation, duration
Precipitation	Amount, frequency, distribution
Humidity	Degree, duration
Wind	Velocity, duration
Gases	Carbon dioxide, oxygen, pollutants
Edaphic factors:	
Origin and classification of soil	
Topography, slope, and exposure of soil	
Physical properties of soil	Structure, texture, aeration, moisture, temperature, slope
Chemical properties of soil	pH, minerals, organic compounds, base exchange capacity
Biotic properties of soil	Organic matter, plants, animals
Biotic factors:	
Humans	Clearings, drainage, fire, cultivation and other cultural treatments
Insects	Defoliation, stem and root feeding, disease transmission, pollination
Plants	Competition, parasitism, symbiosis
Animals	Grazing, mechanical damage

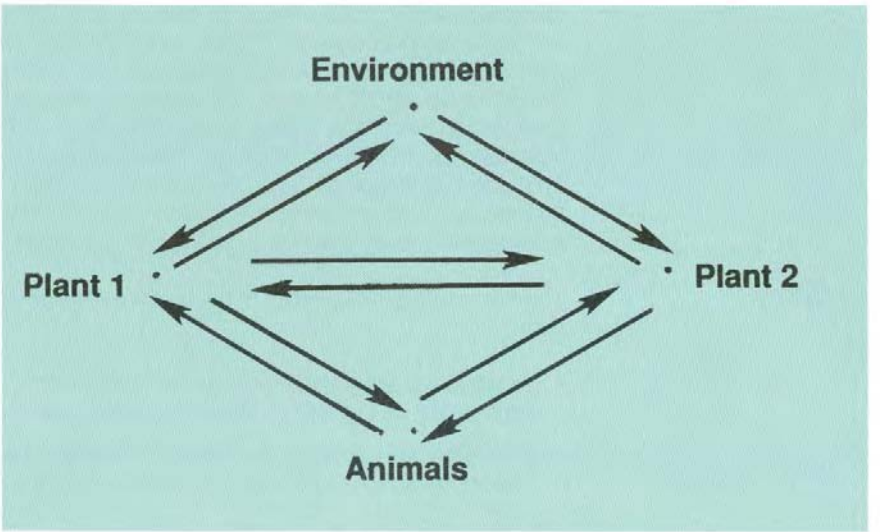

Figure 9—Schematic relation among plants (competition), animals, and environment

Interaction of animals and plant competition—Many studies document the effect and relation of competition, environment, and animals on seedling size, but most only consider these factors separately rather than as an interactive system. Animals may either mitigate or intensify the effect of competition from plant species on the survival and growth of conifer seedlings. They lessen competition by limiting the size and density of competing plants, by eliminating some species, and by modifying habitat in favor of conifer seedlings. Animals increase the effect of competition by utilizing the shoots and roots of conifer seedlings or by modifying the seedling environment by removing less competitive species and liberating resources for more competitive ones.

Animals also may interact with competing vegetation in ways more detrimental than the impact of either single factor. In northern California, for example, a large burned area planted with conifer seedlings was invaded by several grasses and forbs, and the pocket gopher population increased. Today, the area contains only a few conifer seedlings and numerous grasses, forbs, and pocket gophers. Subsequent plantings have failed, and plantations outside of the burn also have come under increasing pressure from pocket gophers. Crouch (1979) noted that effectively controlling herbaceous vegetation lessens the competitive impact of the plant cover and the gophers that depend on it.

The amount and timing of animal damage depends on many factors involving the interaction of habitat and animal populations. Some plants that could be major competitors simply are not palatable, and animals have little effect on their ability to compete. Some nonnutritious plants that seemingly would not be palatable are consumed by ruminants, however, because they are symbiotic with their rumen microbes (Longhurst 1976). Nutritious plants, in contrast, can remain highly competitive when other factors in the habitat reduce populations of plant-eating animals to low levels. More work is needed to evaluate whether planting or seeding plants that attract wild and domestic animals ("ice cream" plants) would divert such pests away from conifer seedlings.

In many plantations, the level of competition is set by the growth of conifer seedlings relative to competing plants Conifer seedlings with mycorrhizae generally survive and grow better than seedlings without mycorrhizae. Interaction with small mammals and mycorrhizal fungi, for example, enhances conifer seedling viability. Small mammals consume subterranean fruiting bodies of the fungi and egest viable spores that establish mycorrhizae on seedlings. These mycorrhizae are necessary for the survival and growth of the seedlings on which they are located (Maser and others 1978). Mycophagous (fungi-eating) mammals thus fulfill a vital function within the forest ecosystem by making conifer seedlings more competitive.

Summary

The following points summarize the general principles of forest vegetation management:

- Vegetation management generally is practiced for only a short period, but it has a major effect on the long-term development of the stand.
- Understanding the responses of plant species to treatments and relations between tree performance and competition is necessary for good forest vegetation management.
- Species with several regenerative strategies begin together in most conifer plantations, and if present for the first 5 years, they also are present for the next 5 years, albeit in smaller numbers and usually with smaller stature.
- Early successional species compete effectively for light, soil moisture, and nutrients, but they do not necessarily compete simultaneously for all these resources.
- The amount of time and inputs required to shift dominance in favor of conifer seedlings significantly increases with the length of time that competing vegetation is present.
- The absence of competing vegetation equates with no growth loss, a light amount of competing vegetation equates with moderate growth loss, and a moderate amount of vegetation often equates with complete loss of the plantation.
- Vegetation management shifts resources to conifer seedlings by minimizing competition.
- Minimizing the amount of competing vegetation often creates an unfavorable habitat for animals that cause problems for regenerating conifers, and also allows seedlings to grow rapidly and avoid damage.
- Combined competition from weeds and animals is worse than the effect of either alone (negative synergism).
- Conifer seedlings grow in an accelerating manner if high levels of resources are provided in the field, but if high resource levels are not provided in the field, seedlings adopt more conservative growth strategies that they follow for some time with resulting losses in growth.
- Conifer seedlings do not make up for growth lost in earlier years unless rotations are extended.
- The first year and probably the first 3 years are critical for conifer seedlings. Proper vegetation management during this period usually eliminates the need for further treatments.

- Where several species with different regenerative strategies are present, dominance accrues to those species that become largest first. Species that become dominants usually originate from established root systems.
- The population of dormant seeds rarely is exhausted after one disturbance, because germination requirements often are polymorphic. This suggests that more than one silvicultural treatment may be necessary for control.
- Competition in young conifer plantations becomes significant when foliar cover exceeds 10 to 20 percent on poor sites and 20 to 30 percent on good sites.
- Controlling weeds is less important after the first 3 years. Less aggressive plants, in fact, should be allowed to invade and prosper, particularly if they interfere with the establishment of more competitive species.

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SECTION TWO
PRINCIPLES OF PLANT AND ANIMAL ECOLOGY

Chapters 5
An Introduction to Forest Wildlife Ecology

WILLIAM C. McCOMB AND ANDREW J. HANSEN

Abstract

Wildlife species are integral components of forest health Managing forests to produce a desirable mix of forest resources, including timber and wildlife, requires an understanding of how animals respond to habitat. Management strategies aimed at long-term population change are most likely to succeed if they alter habitat quantity, quality, or availability. Manipulation of habitat to reduce populations of one species, however, also changes habitat quantity or quality for other wildlife species.

Species inhabiting Pacific Northwest forests are adapted to the natural forest-disturbance regimes in the region. Some species colonize after large, recent disturbances, others recolonize after the forest develops; and still others appear in late successional stages, with territories that may include small patches of early serai stages. Some colonizers of early serai stages are more abundant now than ever before. They include many herbivores that can influence the trajectory of ecological succession within a stand, particularly where the size and distribution of early serai stages optimize rates of population growth and colonization.

WILLIAM C. MCCOMB and ANDREW J. HANSEN are wildlife biologists, Department of Forest Science, Oregon State University, Con/allis, OR 97331.

Consideration of the type of silvicultural system chosen for a location in relation to the natural-disturbance regime for the region can aid the management of wildlife species. Habitat needs for many species encompass several stands, so it is important to consider the arrangement of stands within the landscape. Treatments that maximize effectiveness over space (stand and landscape) and time (years and rotations) while minimizing adverse impacts on other species, therefore, require careful consideration. A high density of small (10-20 acres) clearcuts scattered over a landscape increases habitat quality and quantity for deer and elk for several decades. Lowering the density of harvest units or creating large clearcuts that are more widely spaced over the landscape, conversely, may reduce habitat quality and availability for ungulates. Some uneven-age management systems may maintain late serai-stage characteristics in stands and reduce the potential for colonization by voles and other species associated with grass-forb conditions. A combination of silvicultural systems employed across an entire landscape probably would allow land managers to meet timber and wildlife objectives.

Keywords: Animal demography, energetics, habitat, landscape ecology, wildlife research.

Introduction

This chapter provides a conceptual framework for wildlife ecology and habitat management that forest managers can consider when taking actions to manage wildlife habitat and, ultimately, wildlife populations and communities. That framework builds on a common understanding of several terms: Habitat is the place where a species lives. It includes the physical resources necessary to support a viable population over space and through time. Each species and each population has its own habitat requirements. References to "wildlife habitat" are meaningless, therefore, unless particular wildlife species are identified, because everything is habitat for something. Populations are self-sustaining assemblages of individuals of one species over space and through time. Communities, by contrast, are assemblages of many species over space and through time,

There are two common approaches to management of forest habitat for wildlife: management for (or against) key species and management for (or against) communities. The focus of this book is key-species management; however, forest disturbances change the abundance of individuals in most populations, and those changes also affect the composition of wildlife communities. Management for key species, therefore, has consequences for other species in the community occupied by the key species. Management for mule deer, for example, probably would benefit pocket gophers and Wilson's warblers but not tree squirrels or pileated woodpeckers.

Some species are common regardless of management activities. Vegetation management by forest-land managers, however, is probably the greatest factor influencing the abundance and distribution of animals in our forests. The growing populations of deer and other species associated with early serai stages in the Oregon Coast Range (Wrtmer 1985) demonstrate this fact, as does the response of cavity-nesters to strategies of stand management that leave snags in clearcuts (Schrieber 1988). Many concepts of stand management have been proposed and applied for maintaining or increasing desirable species. These same concepts also may be useful for reducing the abundance of pest species. Just as the quantity and quality of habitat for cavity-nesters in stands can be enhanced, the quantity and quality of habitat for certain pest species can be decreased by altering specific habitat components important to them.

A land manager who embarks on a program to manipulate vegetation to reduce animal damage must first understand the habitat requirements of the wildlife problem species, the requirements of associated wildlife species that share the community with the problem species, and the scale over which habitat manipulation should occur. Habitat quality for any species varies over time and space; consequently the value of habitat to a population continually changes.

This chapter introduces concepts of habitat function, population change, and habitat patterning. It then links these concepts to illustrate how silvicultural systems and habitat patterning can influence demographic patterns of animals over large forest areas. The result, finally, is a conceptual framework for solving forest-wildlife problems by combining three primary approaches: habitat manipulation, manipulation of the target trees or plantations, and direct animal control. Some of these solutions require a detailed understanding of the biology and life history of the relevant animal species that can only be gained through basic research. This information, like that presented elsewhere in this book, can be used to develop a strategy for identifying and managing desirable habitat features. Applying these methods and monitoring their effectiveness in an adaptive management process is probably the best approach for managing forest wildlife through habitat manipulation.

Habitat Function

Habitat is the environment in which a population gains energy from food resources and conserves energy by exploiting cover resources. Excess energy increases the population's fitness (growth, reproduction, body weight, survival). The rate of net primary production is fixed over large areas and time, because there is a solar constant. Herbivores in forests exist in a sea of energy, but food quantity may not be as important as food quality. Animals require the digestible energy in food, but undigestible portions of food (for example, cellulose, lignin, or bones) or compounds in the plants that inhibit digestion (tannins and other phenols) reduce food quality (fig. 1). Net energy available after metabolism increases the animal's fitness (fig. 2).

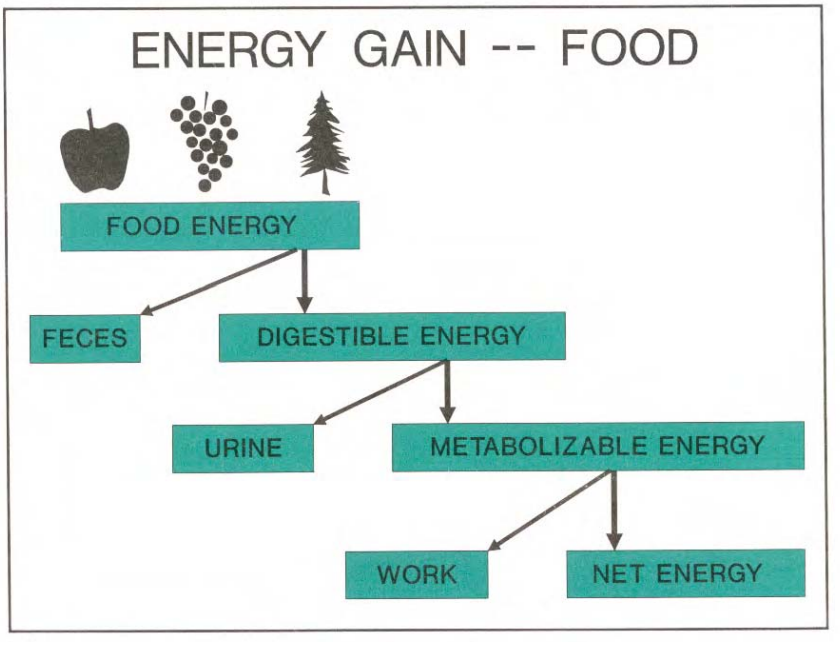


Figure 1—Digestibility of neutral detergent fiber (NDF) fed to deer as a function of lignin and cutin content (from Robbins and others 1987)

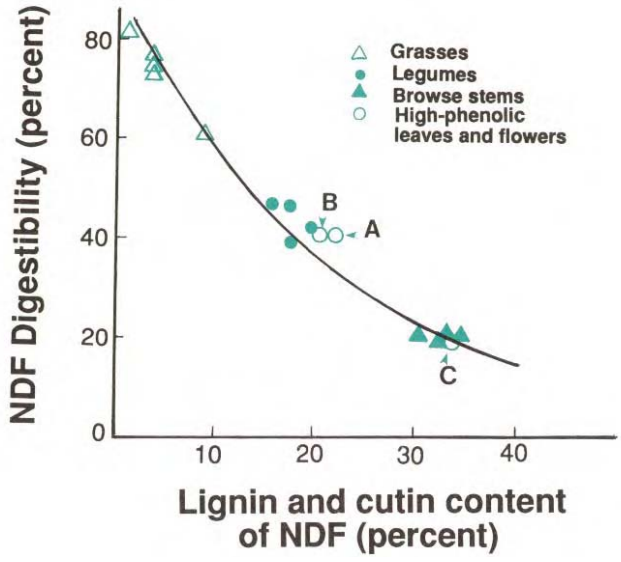
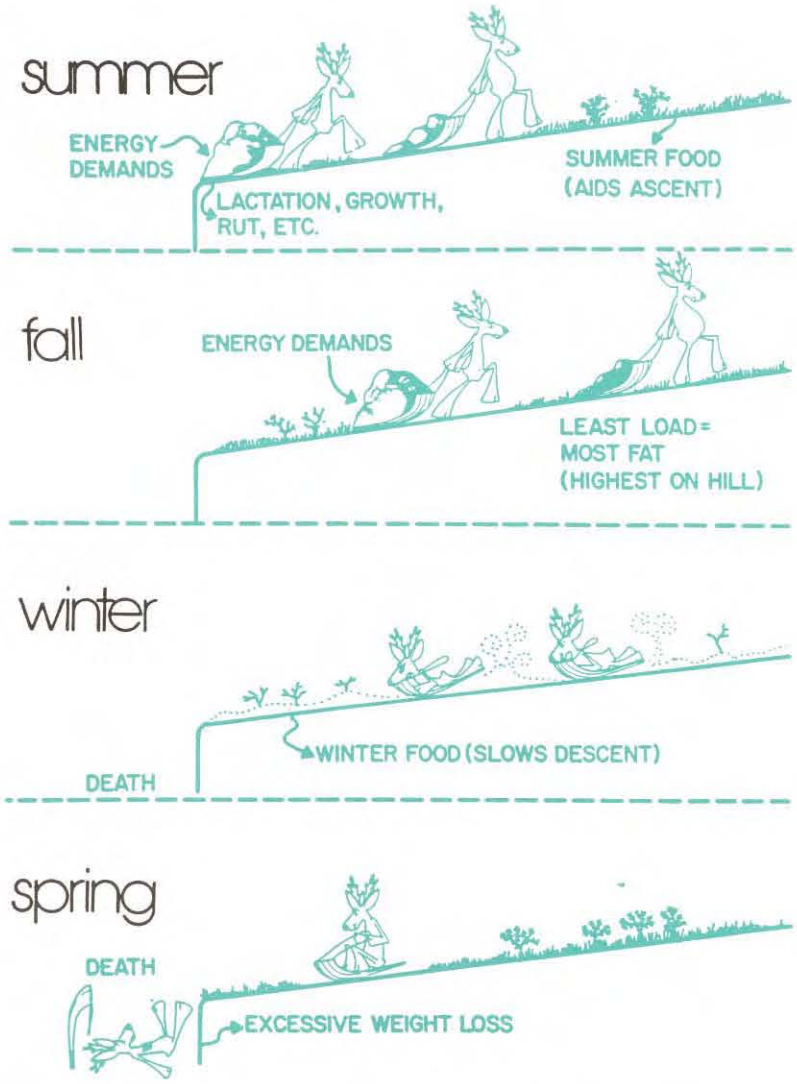


Figure 2—Partitioning of gross energy into fecal energy, digestible energy, urine energy, methane energy, metabolizable energy, unne energy, methane energy, metabolizable energy, work of digestion, and net energy (based on Mautz 1976 325)

Many of the browse species eaten by mule deer, notably, contain high levels of phenols that reduce the digestibility of these plants for many other herbivores, but mule deer saliva contains a substance (prolene) that binds with the phenols and reduces their effectiveness (Bobbins and others 1987). Some plants, therefore, may have high levels of compounds that reduce digestibility for some species, but the coevolution of plants and herbivores has resulted in plant defense mechanisms that are less effective for some herbivores

Food availability can be altered with barriers (spines, thorns, and prickles are natural barriers). One aspect of energetics that affects animal fitness is the amount of time that an animal must search for and handle a food item relative to the energy the animal receives from that food item. If the energy an animal receives from food A, for example, is less than the net energy it gains (or could gain) from food B, then that animal should avoid or ignore food A unless it is the only food available. Increasing the energy that an animal expends to find, handle, and digest a food reduces the chance that the food will be eaten, because if these expenditures of energy exceed potential gains, then the animal loses its saved energy and may go bankrupt. Bankruptcy, in the case of a wild animal, results in death (fig. 3).

It is advantageous for an animal to conserve any energy that it acquires. Mammals and birds that maintain a constant body temperature expend a large amount of energy to maintain that temperature. Energy expenditures to maintain body temperatures are minimized in an animal's thermal neutral zone (fig. 4). Any departure from the thermal neutral zone results in increased expenditure of energy, so animals often select habitat that reduces climatic extremes. There are upper and lower critical temperatures (temperatures beyond those limits are lethal). Cover from overheating is especially important to large animals such as elk that may find it particularly difficult to release excess heat unless water is available to aid in evaporative cooling. Cover that allows an animal to stay within an acceptable range of temperatures (particularly temperatures that approach the thermal neutral zone) is important to maintaining a positive balance of net energy.



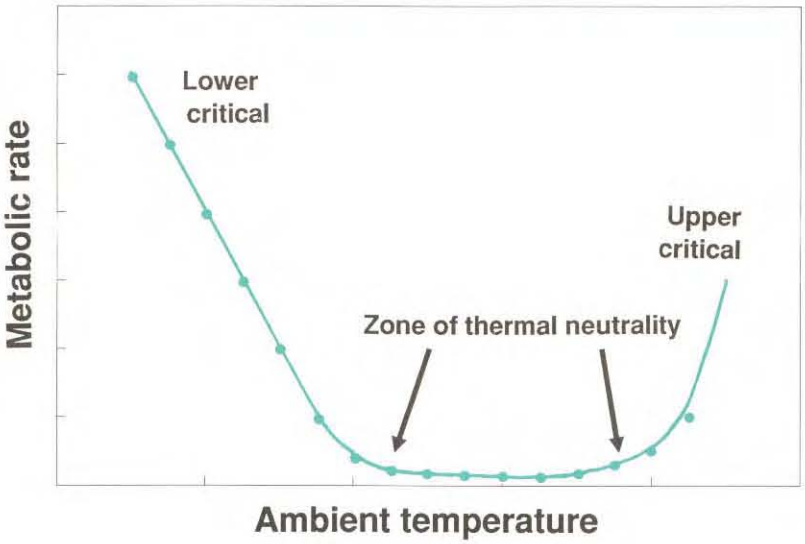
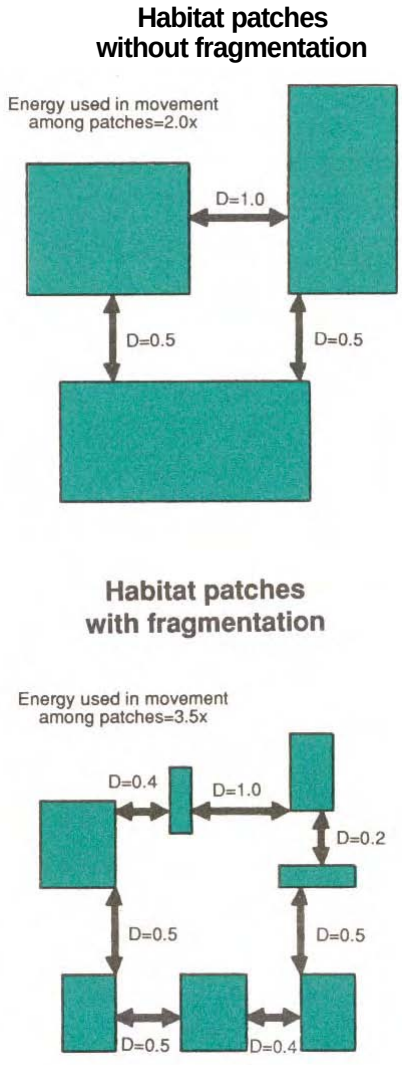


Figure 3—*Above*. Influence of energetics on the fitness of a vertebrate (from Mautz 1978: 343).

Figure 4—*Left*. Metabolic rate (energy use) in relation to environmental temperature.

Cover can also refer to the portion of habitat that an animal uses for nesting and escape from predators. Restricting the availability of cover by means of barriers is a technique that rarely is used to control wildlife problem species. The effectiveness of nest box programs tor wood ducks and bluebirds, however, demonstrates that manipulation of the quantity, quality, and availability of cover resources can be an effective management technique. Land managers can manage habitat to control a problem species by reducing food quality, quantity, or availability while also reducing the quality, quantity, or availability of cover. This strategy can lead to drastic reductions in habitat quality for the pest species.

Water is differentially important to animal species. Some require free water or high humidity (mountain beaver, for example have a primitive uretic system). Others species obtain most of their water from their food (for example, pocket gophers). Some species use water as a form of cover to enhance evaporative cooling or to escape predators. Management practices for species that require free water or high humidity could be designed to alter moisture availability. Management of free or atmospheric moisture in combination with manipulation of food and cover resources may particularly reduce habitat quality for a target species.



The size of habitat is an important determinant of its suitability for a species. Habitat must be sufficiently large to provide energy inputs and conservation features in order to sustain a population. Habitat may occur in one large unit, but it more commonly is distributed in patches through other less suitable habitat. If these habitat patches are too widely distributed, then the animal expends more energy moving among patches than it receives from those patches (fig 5). The amount of habitat, therefore, and its quality and distribution are all interrelated. Reducing the amount and quality of habitat, and distributing habitat widely over the landscape reduces the energy available to the population and leads to low populations of a species. Increasing any or all of these attributes of habitat increases the net energy available to animals that use this energy to maintain body temperature, move to food and cover, and reproduce.

Figure 5—Energy use in relation to the distribution of patches of resources in space D = distance moved between patches, fragmenting the landscape leads to increased factors associated with movement

Population Growth

Populations can be indirectly manipulated by modifying habitat or directly manipulated by altering death rates. The linkages between animal demography and habitat are complex, but some understanding of these relations is necessary for successful wildlife management. Each species has its own potential for population increase, and this potential is described as the intrinsic rate of natural increase (r). This rate of increase (r) = N1+1 / N((t), where N(= the population at time t, and N,+1 = the population at the next time interval.

One breeding pair of a species that lives 1 year (such as a rodent) and that produces 6 young per year (each of which produce 6 young/year) would result in 6 new animals at the end of one year, by which time the original pair would have died, so r = 6 / 2*1, or r = 3. Another species (for example, an ungulate) that produces 1 young per year and lives 3 years would produce 3 young in 3 years, so r = 3 / 2*3 or r = 0.5. The rodent has a rate of increase of 300 percent, while the ungulate has a rate of increase of 50 percent. If we assume that resources within a habitat are unlimited and that a population is introduced to that habitat, then the population will grow at an ever-increasing rate proportional to its biotic potential (N = N + (r*N)) at each time interval (fig. 6). In 2 years, the rodent population could grow to 806 individuals, but the ungulate population would only have risen to 5.4 individuals.

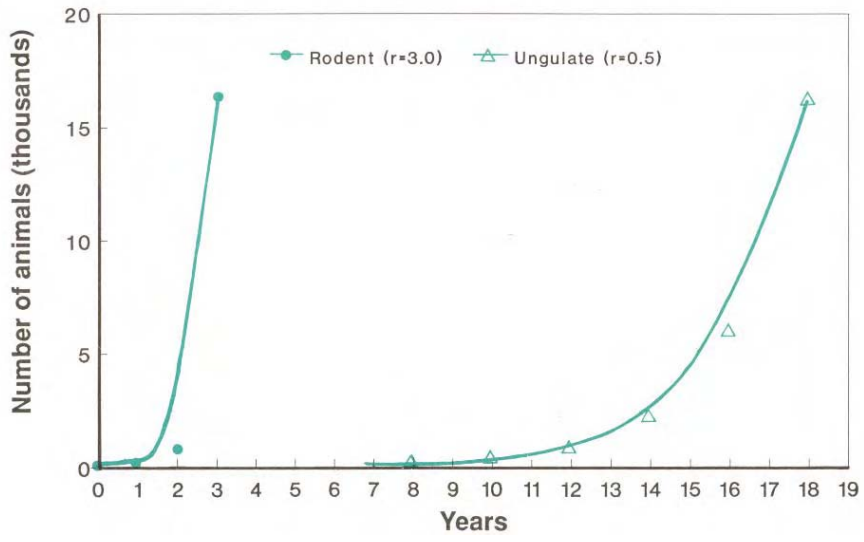


Figure 6—An example of exponential growth for two hypothetical species; r = intrinsic rate of natural increase

This exponential growth may be approached by some populations early in the colonization of a recently occupied site, but we know that resources are limited. There is, after all, a solar constant, so energy available to animals is limited. Food, therefore, becomes scarcer or of poorer quality as the population grows, cover is occupied by animals, diseases and parasitism increase, and surplus animals must use suboptimal cover (fig. 7). As food, cover, or other resources become limiting, the population growth rate decreases, because mortality increases or because reproduction decreases. This is termed logistic growth. If we assume that resources are constant, then the population reaches a point where births equal deaths and growth becomes 0. This point is termed the carrying capacity of the habitat for the population.

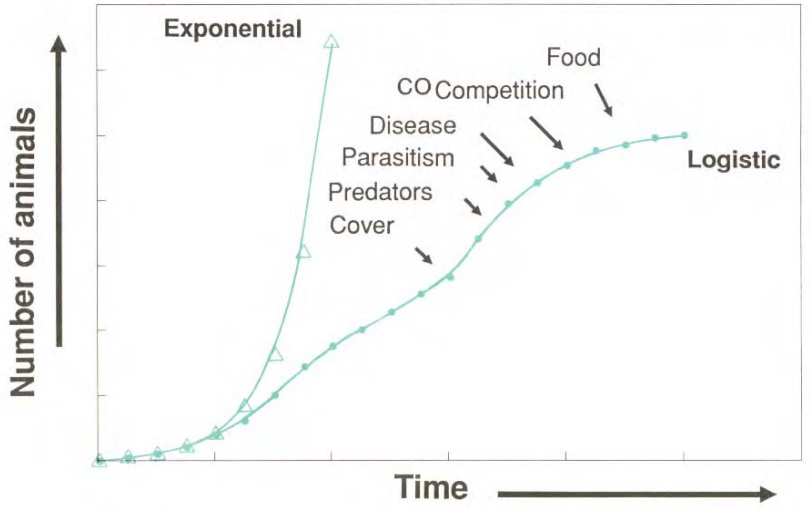


Figure 7—Examples of exponential (from biotic potential) and logistic (sigmoid growth) population growth Exponential growth is suppressed to carrying capacity by resource restrictions This results in reduced natality and increased mortality.

A carrying capacity (K) of 100 can be assumed for the rodents (100 per acre) and the ungulates (100 per section) in the above example, and population growth (change in N over change in time) can then be calculated as r*N* [(K-N) / K]. Early in the growth of a population, N is very low, so the term [K-(N / K)] is quite high (0.98 for N = 2 and K = 100) and approaches exponential growth. As N increases, (K - (N / K)) decreases (0.01 for N = 99 and K = 100), bringing the term (K - (N / K)) closer to 0. When the term reaches 0, carrying capacity (K) is reached.

The time that it takes for the rodent to reach K (4 years) and the time it takes for the ungulate (19 years) are shown in figure 8. A rodent population reduced to 50 animals per acre by direct control methods would return to 95 animals 1 year after control ended. Similar direct control of the ungulate population would result in a return to 62 animals per section 1 year after control ended. Population control of species with high r has an effect over a shorter period than for species with low r. Reducing habitat quality (reducing K) has the most significant effect over the long run on the density of both species.

The above example assumes that resource availability remains constant over time. We know, however, that resources are not constant; they are daily, seasonally, and annually dynamic. Carrying capacity, consequently, is always changing. The concept of carrying capacity is useful to land managers, because it provides the link between habitat quality and population growth. Attempting to control a pest population by inflicting direct mortality is only likely to be successful in the short term. As population size is reduced below carrying capacity, net reproduction or survival increases and eventually raises the population back up to carrying capacity. This outcome may be acceptable to land managers interested in controlling damage to seedlings for only a few years, until the trees outgrow the reach of wildlife problem species. Habitat manipulation, however, is the clear choice for long-term manipulation of wildlife populations.

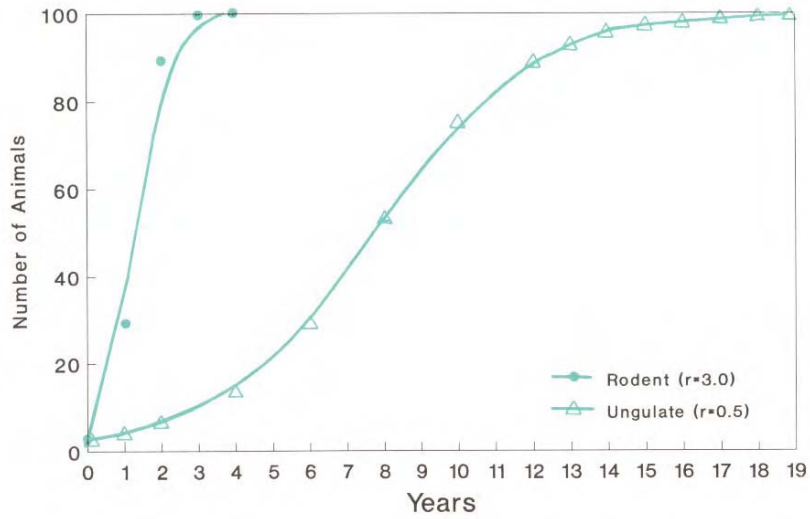


Figure 8—An example of logistic growth for two hypothetical species, r = intrinsic rate of natural increase

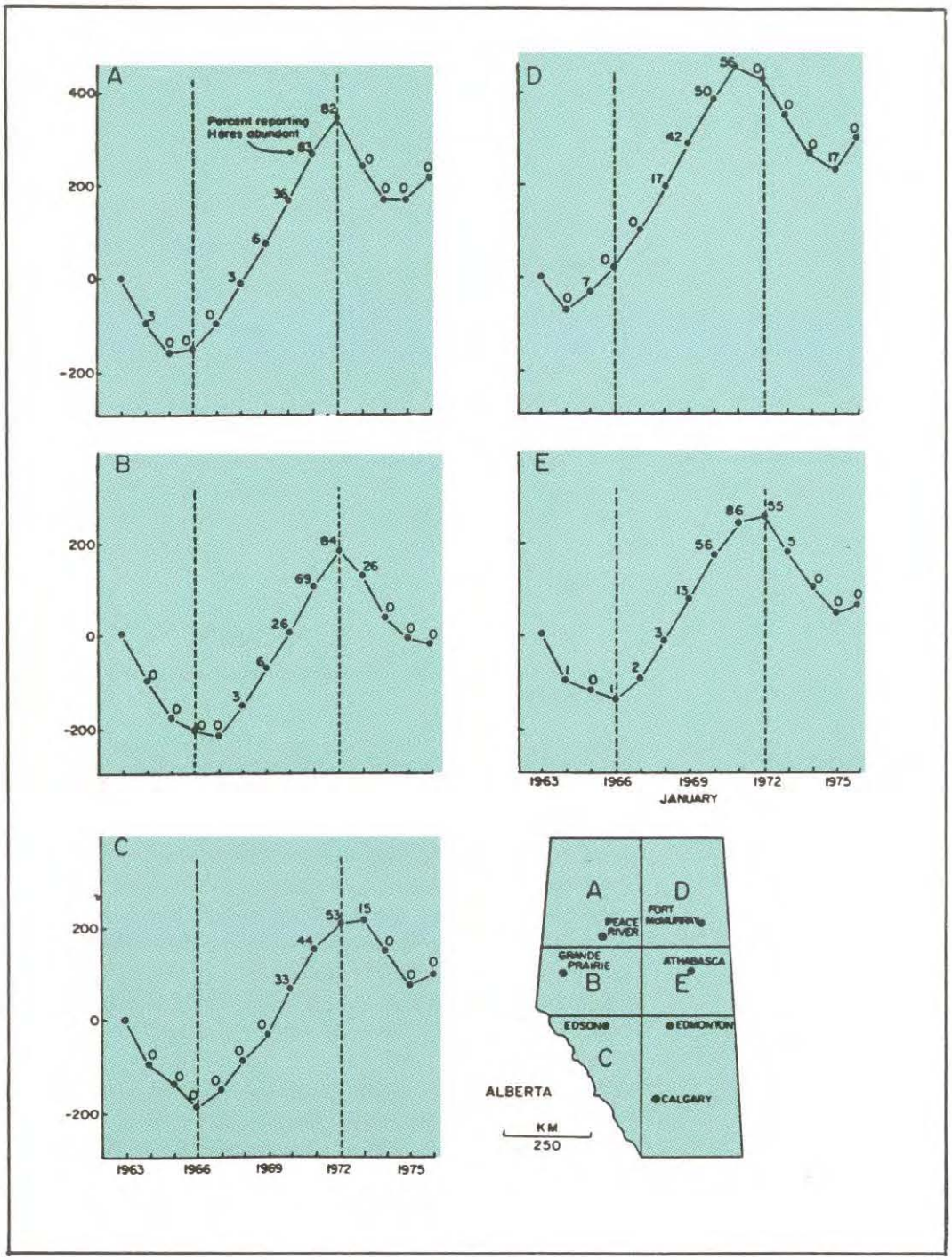
Cyclic Populations

Populations do not always reach carrying capacity in relation to habitat quality. Some, notably some species of voles, hares, and grouse, follow a "boom and bust" population pattern. Populations grow for about 3 to 6 years and then rapidly decline for another 3 to 6 years. High-quality habitat usually increases the highs and decreases the lows of a population cycle, but habitat probably does not directly mediate these cycles, because they occur throughout the range of species (Keith and Windberg 1978, fig. 9). Responses of these species to habitat manipulation must be monitored relative to the stage in the population cycle. A rapid decrease in a population following a treatment, for instance, may result from the treatment or from natural decline after a population peak. The latter case might indicate that no treatment was necessary.

Animal Movements

Animals move for a variety of reasons, but movement to and from food and cover is the most obvious daily requirement of any species. This distance is very short for some species (such as mountain beaver), while others (such as mule deer) may move from one stand type to another. The arrangement of food and cover in an area can affect energy costs associated with movements from one resource to another (fig 5).

Another type of movement, dispersal, results from overcrowding. As a population approaches carrying capacity, individuals move out in search of acceptable habitat. Dispersal can be influenced by habitat quality. The rate of movement (R) and the probability of survival (Ps) in various habitat types during dispersal for a simple example are shown in figure 10. The time in which a species with a low dispersal rate (R = 10 m per day) and low-quality intervening habitat (Ps= 0.80 per day) could disperse from a source to a target (one plantation to another) 200 m away is 200 /10 = 20 days. The probability of surviving dispersal is 0.80^{20} = 1.2 percent. If intervening habitat is higher in quality (Ps = 0.95 per day), then Ps for dispersal = 35.8 percent. Ps for dispersal of a species with high rates of movement (R = 20 m per day) and high-quality intervening habitat (Ps= 0.99 per day) is 60 percent.



$$P = S_x^{W/D}$$

P=STAND PERMEABILITY INDEX
S_x=DAILY SURVIVAL PROBABILITY IN HABITAT 'X'
W/D=WIDTH/DAILY MOVEMENT=RATE OF MOVEMENT

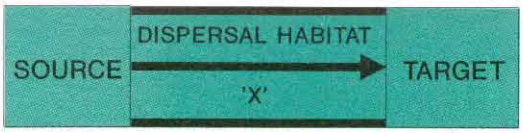


Figure 9—*Above.* Geographic synchrony in trends of snowshoe hare populations in January for five regions (A, B, C, D, and E, as indicated on outline map) of Alberta, Canada, showing a uniform, cyclic, population pattern (from Keith and Windberg 1978).

Figure 10—*Left.* Calculation of the probability of successful dispersal across a simple landscape from a source habitat to a target habitat.

These figures indicate that either habitat management or direct population control without consideration for potential dispersal from surrounding habitat may be doomed to failure, particularly in cases involving highly mobile species with high-quality habitat surrounding the managed stand. Habitat management or direct control should extend into adjacent habitat for a distance sufficient to influence the probability of dispersal to the target stand.

Population densities can vary with seasons, largely because many animals move from one habitat type to another. Some populations of elk, for example, are migratory, but others are not. Problems associated with elk damage in plantations often are caused by seasonal occupancy. Plantations located at low elevations in the Cascades are more likely to suffer winter elk damage than summer elk damage. Damage to a similar plantation in the Coast Range, however, may occur at any season. Habitat quality for migratory species, therefore, may often require separate consideration as summer range and winter range.

Predators and Prey

The perception that predators control or eliminate their prey has resulted in widespread killing of many predators assumed to be responsible for declining game populations. Predators can exert a significant influence on prey populations by removing weakened, young, old, and otherwise less fit individuals in numbers disproportionate to their availability in a population. Predators also kill healthy animals, but the most fit prey are more likely to occupy the best cover and be more able to escape capture.

Predators, as well as parasites, disease, and competitors, exert an influence on prey populations (fig. 7), but they almost never completely eliminate a prey population from an area. Prey populations, through their availability as food, may in fact control predator populations. Predators that eliminate their prey, are themselves eliminated or forced to seek other, less available prey.

Prey population dynamics sometimes reflect the presence and absence of predators. Whole-tree exclosures, for example, allow spruce budworm populations to skyrocket in the absence of insectivorous birds or ants that are predators of the budworm (Campbell and others 1983). Predators are likely to keep populations from skyrocketing (though eruptions still might occur less frequently), and they should, therefore, be considered part of any integrated forest protection system. Habitat management that increases habitat quality for insectivorous birds, bats, raptors, and mammalian predators can only aid damage-control efforts and may reduce the scale of intensive population control within a region.

Competition

Many animals share parts of their habitats with other species. Chapters in this book, for example, describe how several animal species eat common tree species. Sharing food or cover, however, can go only so far. Consider, for example, two populations that both have only one type of food available to them and are both very low in number. Both populations grow as long as food is not a limiting factor, but as food availability declines to where there is not enough to support both populations, several things might happen:

1. Both populations could reach carrying capacity with neither population changing in size. This condition probably would not persist for long, because other requirements (cover, for example) would enable one of the two species to more readily survive environmental fluctuations.

2. One population could increase and dominate the site, while the other decreases (because only one population survives environmental fluctuations). The decreasing population may become locally extinct.

3. A predator may keep one or both populations below carrying capacity. If both populations remain below carrying capacity, then food or cover are not limiting, and available resources are shared (fig. 11). If one species is kept below carrying capacity, then the other population can rise to a new and higher carrying capacity.

The concept that two species do not fully share the same resources when resources are limiting is termed "competitive exclusion."

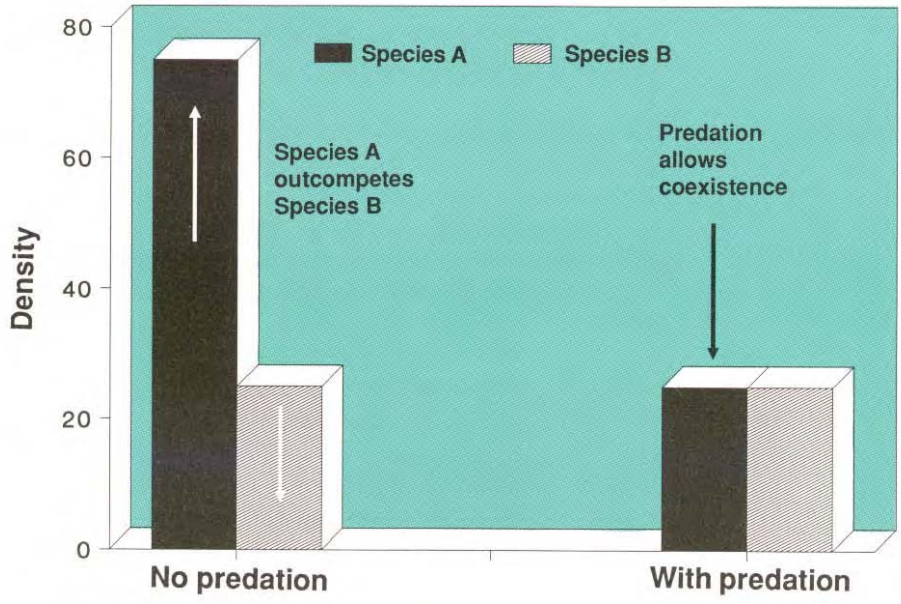


Figure 11—Theoretical response by two competing species to predation

What does all of this mean to the forest manager? First, to avoid competition, animals have evolved in ways that minimize sharing of resources. Forest managers should consider resource partitioning among pocket gophers, deer, and porcupines. All these species eat woody plants, but gophers primarily eat the roots and lower portions of the stems, deer eat the twigs and leaves, and porcupines eat the bark. This is partitioning of plant parts as food resources. Douglas-squirrels and flying squirrels, as another example, share many of the same foods, but Douglas-squirrels feed during the day and flying squirrels feed at night. This is partitioning of resources over time.

What one competitor eats in a plantation may influence what is left for subordinant species to eat If species A devours a highly preferred food of species B, then species B may begin eating less desirable foods (tree seedlings), because they become more available. The solution to this problem, therefore, might be to control species A to reduce damage by species B.

A similar relation can occur among individuals of the same species. Some dominant individuals in a population, for example, can force subordinate individuals out of optimal habitat and into suboptimal habitat, and the population of subordinates per

unit-area can exceed that of the dominants. Optimal habitat is termed "source" habitat and suboptimal sites are termed "sink" habitats. Tom Sullivan provides an excellent example of source-sink relations for squirrels in chapter 13 of this volume.

Competitive interactions rarely are interpreted so easily, however, and the complexity of competitive interactions among species or between sexes or age cohorts within a species emphasizes the need for careful selection of treatments. Taking management actions that influence the target species and its competitors is probably the best approach, but we have much to learn about competitive interactions among forest herbivores (Anderson 1987).

Plant-Animal Interactions

We have already described how some plants have chemical and physical defenses against herbivory (Farentinos and others 1981). Plants also respond to animal herbivory by altering growth rates. Growth responses can be complex, and ecologists continue to debate their adaptive significance. Among many grasses, forbs, and some shrubs, moderate levels of herbivory can actually stimulate growth above the levels of either undisturbed or heavily grazed or browsed plants (Belsky 1986, du Toit and others 1990). It is widely assumed that this compensatory growth occurs at the expense of reproduction and that herbivory, therefore, results in decreased seed production or smaller seed sizes. The opposite has been demonstrated, however, for some desert annuals (Paige and Witham 1989).

The effects of vertebrates browsing on coniferous trees of the Pacific Northwest are not well known. Compensatory growth from browsing by vertebrates may occur (see chapter 13 in this volume, and Anderson 1987) High levels of browsing certainly inhibit growth and survival of seedlings, but the effects of low-to-moderate levels of browsing on tree growth over the rotation have not been fully studied It is not known whether damage to seedlings continues to hamper growth through maturity, especially if foresters are more concerned with the productivity of the plantation than with individual-tree productivity. Moreover, animal damage to some trees may elicit a "thinning" response and elevate productivity of the stand.

Herbivores affect forest systems in ways other than by eating plants They aid in the dissemination of seeds, and they may help maintain site quality Some plants are well adapted to dispersal on animals (for example, bedstraw, dock, or lopseed). Other plant species (such as dogwoods and cherries) are well adapted to scarification that results from passing through animal digestive systems and "direct-seeding" in a packet of fertilizer. Many fencerows, consequently, are dominated by cherries, hawthorns, and dogwoods because birds often perch on fences after eating the fruits of these plant species.

Mycorrhizal fungi aid plants in the uptake of water and nutrients, and they can be particularly important to early plant growth and survival on harsh sites (Perry and others 1989) These fungi produce fruits underground, unlike most other fungi, and they do not, therefore, rely on aerial spore dispersal as do other fungi They seem, instead, to be well adapted to animal dispersal Some fungi known as truffles are important components of the diets of some small mammals, particularly red-backed voles These animals eat fruits and ingest spores, which then pass through the digestive system in a few days and are deposited at a new site (fig 12). A new fungal mat may then grow from this site and ensure the presence and widespread distribution of mycorrhizae in the soil (Cork and Kenagy 1989). Mixing organic matter in the soil by these burrowing animals also is likely to influence decomposition rates and soil characteristics

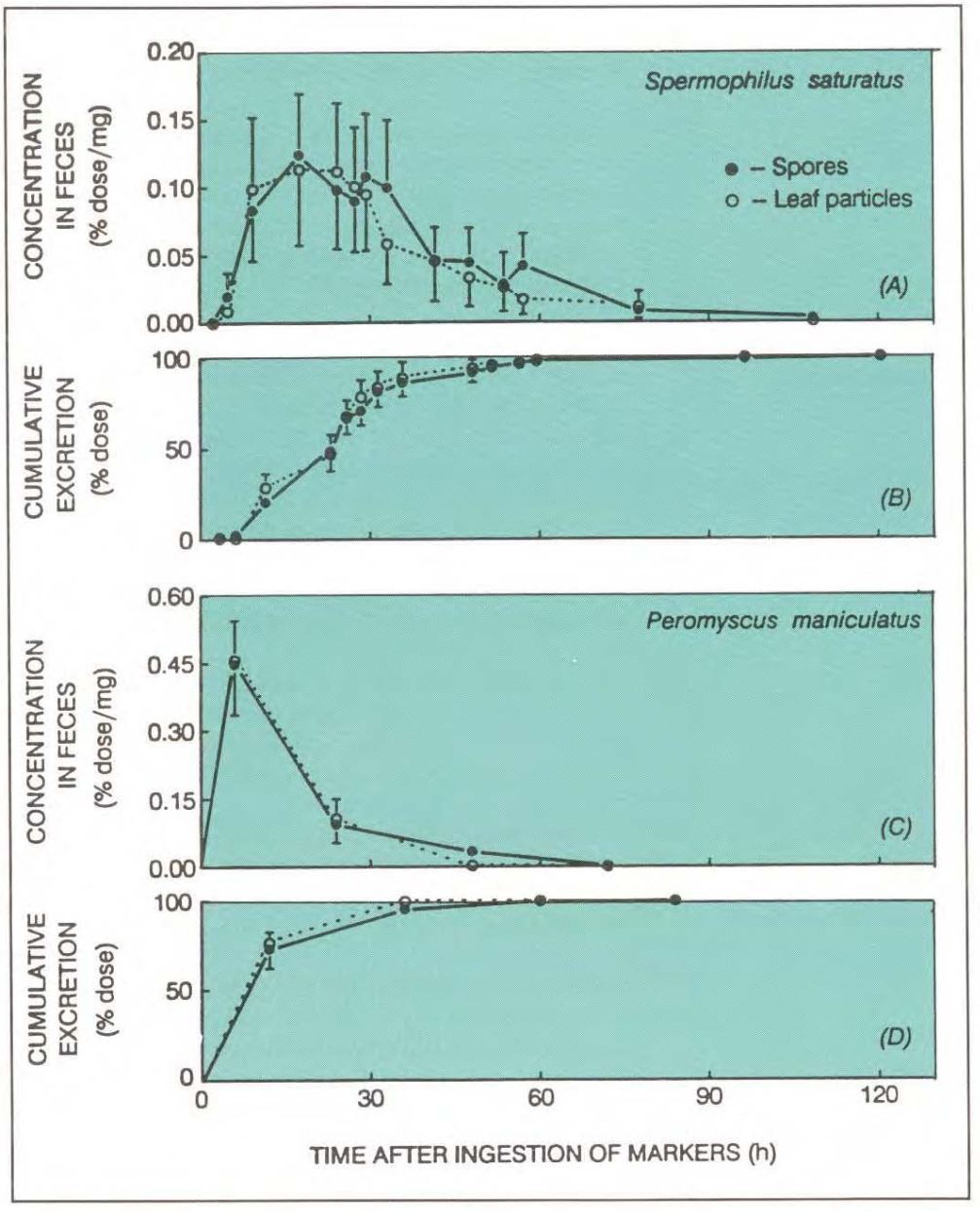


Figure 12—Cumulative excretion of spores of the hypogeous fungus *Elaphomyces granulatus* in ground squirrels *(Spermophilus saturatus)* and deer mice *(Peromyscus manicutatus)* (from Cork and Kenagy 1989)

The activities of some herbivores can have tremendous impact on habitat tor other species (Naiman 1988). The activities of American beaver, for example, create early serai-stage riparian forest and pool habitat that can be important to other species. Other examples include bears that kill patches of trees in plantations, gophers that eliminate regeneration in patches, or elk herds that browse heavily next to riparian zones. All these activities create patchiness or heterogeneity in affected sites, and those patches can be important habitat for other species (insectivorous birds, for example).

Forest managers that employ management practices that eliminate or reduce the impacts of these species on stands must consider long-term impacts on other members of the wildlife community that might benefit from the disturbance. There should be a balance between total control of one animal species and a "hands-off" policy for management of all species, but long-term impacts on forest health (the health of all forest resources) should be considered.

Spatial and Temporal Scales of Habitat

Habitat typically is characterized by physical setting (soils, aspect, elevation, climate) and by the structure and composition of vegetation occupying the site. One attribute of habitat is its size. A 1-acre patch of habitat may be more than sufficient for a mountain beaver but inadequate for a deer or elk (fig. 13). Habitat is also dynamic. It is affected by the geomorphic setting that slowly changes, by the weather that changes daily, seasonally, yearly, and over centuries, and by plant-community succession, which is rapid in the early stages and slower in the later stages. Vegetation management can alter the composition and structure of habitat and the direction of plant succession. Forest managers, therefore, must think of habitat over a range of spatial and temporal scales. One convenient way of dealing with these scales is to visualize a hierarchy of small patches of habitat that serve as building blocks within stands, which in turn serve as building blocks for forests. The present discussion of habitat begins with a consideration of how habitat functions at the stand level, and then discusses how habitat functions in aggregates of stands at the forest or landscape scales.

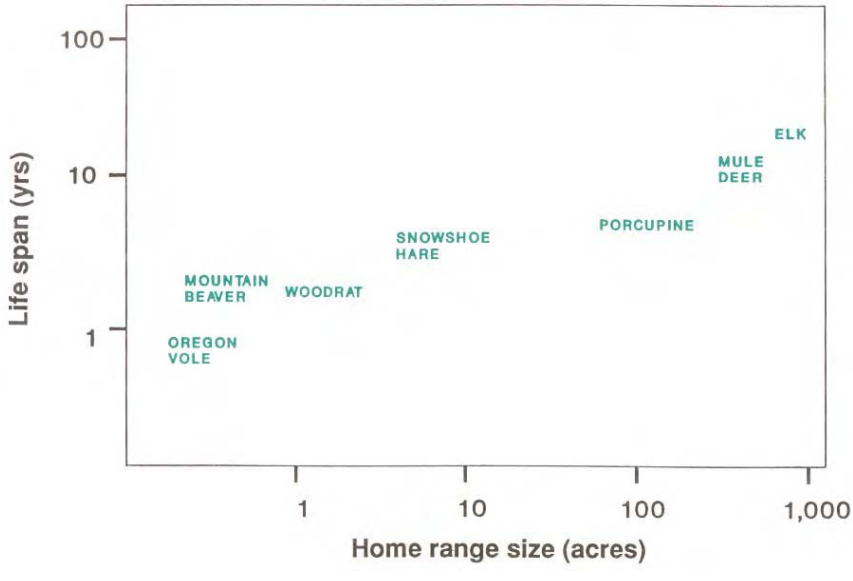


Figure 13—Relation between the home-range size of some common Northwest forest vertebrates and the life expectancies of the same species

Spatial Scales of Habitat—the Stand

Thomas (1979) and Brown (1985) characterized stand conditions (grass-forb, shrub, open pole, closed pole, small sawtimber, large sawtimber, and old growth) within plant communities in western forests. They used these descriptions of habitat, in combination with specific habitat features (snags, logs, rocks [talus], riparian areas) to predict what species of vertebrates could occur in a stand. This system provides a simple means of characterizing the potential quality of habitat in a stand for a wide

range of species (see chapter 19 in this volume). The versatility of each species is described as the number of combinations of stand conditions and plant communities in which a species occurs. Most pest species mentioned in this book have high versatility (table 1). Changing stand conditions, therefore, may have less effect on these species than on others with lower versatility ratings. Habitat management may not be very effective for species with high versatility (deer mice, for example).

Table 1—Versatility Indices, maximum reproductive rates, and home-range sizes for selected wildlife species

Species	Versatility index	Reproductive rate	Home range
		Max. young/year	*Acres*
Potential problem species:			
Beaver	24	3	500
Black bear	36	5	3,200
Black-tailed deer	40	2	640
Botta's pocket gopher	16	10	0.1
Bushy-tailed woodrat	37	12	80
Camas pocket gopher	14	5	0.1
Deer mouse	42	54	4
Douglas-squirrel	26	6	1-2
Dusky-footed woodrat	28	8	46
Elk	32	1	6,000
Long-tailed vole	24	45	10
Mountain beaver	28	4	0.5
Northern pocket gopher	18	10	N/A
Oregon vole	36	40	0.2
Porcupine	32	1	300
Snowshoe hare	33	21	0.6
Townsend's vole	28	50	N/A
Western pocket gopher	20	6	N/A
Selected nonproblem species with low versatility:			
Red tree vole	14	4	0.1
Heather vole	14	8	N/A
Water vole	10	21	0.5
Spotted owl	12	4	3,000
Marbled murrelet	6	2	N/A
Osprey	10	4	3,500
White-headed woodpecker	12	7	20
Spotted frog	11	2,400	1-8
Olympic salamander	13	16	N/A
Tailed frog	14	50	0.4

N/A = not available
Source Brown 1985

The methods described by Thomas (1979) and Brown (1985) for characterizing stands as habitat for a group of species that could occur there are good predictors of the presence or absence of species in a stand. Other features not described by their system, however, may influence the abundance of a species in the stand, and this may be more important to land managers. Soils, burrows, basal area, stand density, and grass cover are habitat components that may influence the abundance of pocket gophers, for instance.

Stand exams are common practice for foresters concerned about the growth and survival of plantations. Modifications of stand exams to include habitat features important to key wildlife species or to an array of species may be useful. One feature of a stand that is measured for timber management is tree-species composition and size of trees in the stand. Habitat quality for some species may be evaluated with these features (fig. 14, McTague and Patton 1989), but this method may insufficiently measure habitat quality for other species. Additional information about the value of a stand for a particular species might be needed. Habitat features require as much consideration as competing vegetation, tree growth, and other, more traditional timber objectives, if forest managers wish to effectively manage stands to affect habitat quality for key species. It is particularly important to collect this information to support decisions regarding methods of vegetation management (perhaps guided by a model—see chapter 19) and to monitor animal responses to the treatment. Modifications to vegetation management may be necessary to realize desired results.

Stand density index

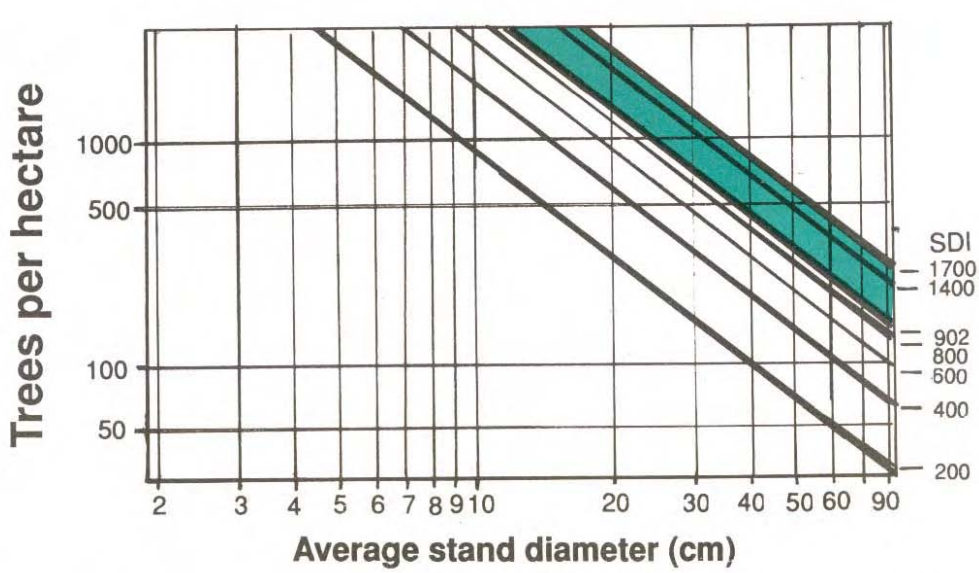


Figure 14—Stand density index with a reference diameter of 10 inches. The shaded area represents the area of suitable thermal cover for elk in stands of lodgepole pine (from McTague and Patton 1989).

Consider, for example, the types of information needed to evaluate a stand's risk of damage by mountain beaver:

1. Geographic location—is it within the range of mountain beaver?
2. Elevation—low-elevation sites are better habitat than sites > 5,000 feet in elevation.
3. Dominant type of understory vegetation—food quality of ferns > shrubs > trees > grasses.
4. Understory vegetation coverage in the stand—higher coverage means more food is available.
5. Proximity of the stand to free water—mountain beavers have a high demand for water.

Knowledge of each of these factors may allow managers to predict the likelihood of problems from mountain beaver in stands. Adding additional habitat items during a stand exam (snag and log abundance, overstory cover, basal area of hardwoods and conifers, and species of shrubs) also may facilitate evaluation of habitat quality for desirable species (for example, some species of nongame birds, mammals, reptiles and amphibians). Some habitat features that are not important to animal pests can be left at little or no extra cost and could tremendously increase use of the stand by more desirable species. Snags, for example, are used by woodpeckers, nuthatches, wrens, and swallows, but these dead trees also provide perching sites for hawks and owls. Predators such as hawks seldom control prey populations within a stand, but they may contribute to the control realized through other practices.

Spatial Scales of Habitat—the Landscape

Stands do not exist in isolation. Each stand is surrounded by other stands, corridors of vegetation, water courses, and other features. All these features comprise a landscape. A landscape is the mosaic of vegetation and geomorphic features that occur across an area (Forman and Godron 1986). The elements of the landscape pattern that are important to wildlife include the types of patches that make up the landscape, the sizes of those patches, the length of surrounding edge, and the nature of corridors or barriers between patches. All these landscape elements interact to determine the suitability of habitats over the landscape for various plant and animal species. It is often better, therefore, to view forest and wildlife management strategies at the multi-stand or landscape scale, rather than at the stand level. Large animals such as elk, for example, use space at the landscape scale (Lindstedt and others 1986). They forage in some types of stands and rest in others. Habitat management in one stand, therefore, must be considered relative to all other stands available to elk. This approach may not be appropriate for species like mountain beaver that may occur wholly within one stand.

Animals clearly differ in the types of habitat that they require. The total amount of each stand type across a landscape, accordingly, strongly influences the kinds of species found on that landscape. Managers can manipulate stand kinds and distribution across the landscape to influence the abundance and distribution of species within the planning area.

The arrangement of stands over a landscape determines the amounts of edges present. "Inherent edges" are created by proximity to another plant community (an upslope-riparian edge, for example). "Induced" edges are more common and result from disturbance, such as fire or clearcutting (fig. 15). The type of edge (inherent or induced), the composition and structure of the two stands forming the edge, and the abruptness of the edge all contribute to its importance to certain wildlife species. Aldo Leopold (1933:131), in reference to certain game species, stated that the abundance of a species requiring two or more cover types is proportional to the sum of the adjacent type peripheries. Any management activity, such as creating edges, benefits some species but not others. An unwritten corollary to Leopold's edge effect is that the abundance of species requiring the interior of one cover type may be inversely proportional to the sum of adjacent type peripheries.

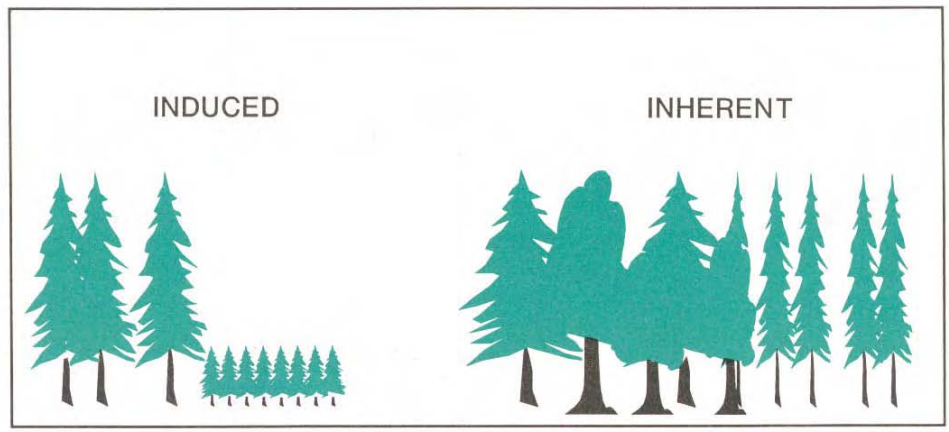


Figure 15—An example of inherent and induced edges (based on Thomas and others, 1979 54)

The land manager, consequently, must decide whether to reduce edge (create large units) to decrease the influence of herbivory within the stand by deer (an edge species), or to enhance edge to increase the effectiveness of predators (some are also edge species). Each management activity, however, results in differing responses among the myriad of vertebrates present in a stand or along edges, and some of these vertebrates are desirable species.

Stand conditions and species compositions are important, but the size of stands and their arrangement on the landscape also influences habitat quality for some species. Large stands that provide forage may be adequately protected from browsing at their interior, because animals are reluctant to forage too far from cover. Stands that provide cover but are located far from food resources, conversely, do not provide quality habitat for some species.

Nonproblem species also may be influenced by stand arrangement on the landscape. Species that require forest-interior (core) habitat may be adversely impacted by the proliferation of edges within the landscape. Forest fragmentation is the process by which large contiguous blocks of habitat are broken into smaller, isolated blocks. Animals that move among these blocks expend increasing amounts of energy, while the availability of forest-interior habitat decreases (fig. 16) (Temple 1984, Franklin and Forman 1987). Management activities to reduce habitat quality for problem species should be considered relative to their impacts on the entire wildlife community.

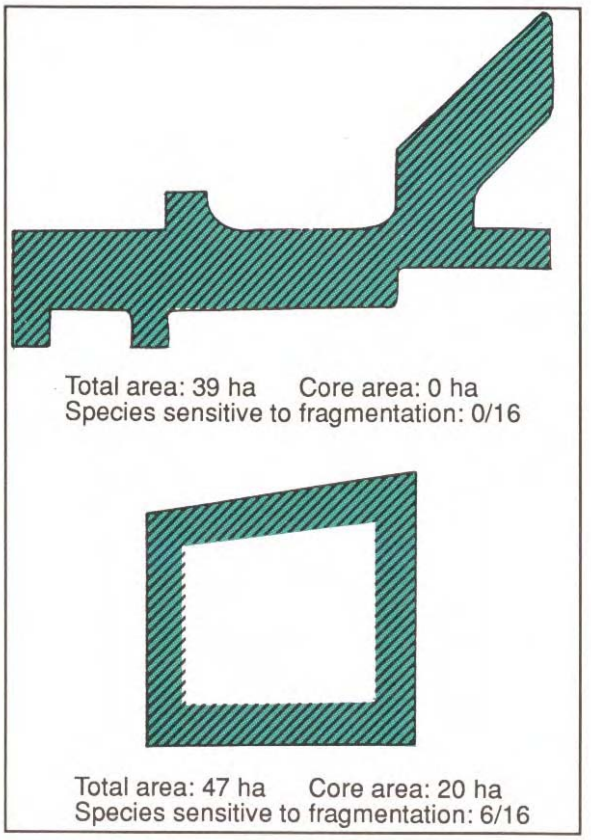


Figure 16—Comparison of the occurrence of birds sensitive to fragmentation in two forest fragments with similar areas but markedly different core areas (from Temple 1984 304)

Linkages or connections among stands influence the types of animals that may inhabit these areas. Some species are better able to disperse to new habitats if corridors are available. Riparian systems are good examples. It seems reasonable to expect mountain beaver and elk to use riparian systems to move from one stand to the next. This should provide clues regarding where direct-control measures should be focused. Identification and modification of corridor habitats may reduce colonization rates on newly planted sites. It is imperative, however, to consider the effects of these activities on the entire wildlife community.

Temporal Scales of Habitat Disturbance Regimes

The rate at which habitat changes and the spatial scale of habitat differ among species in much the same ways. Ecological succession is the process of change in vegetation composition and structure and in associated habitat and wildlife communities after a disturbance. Each change in succession produces a new assemblage of resources that causes some species to drop out of the community and encourages the addition of others (fig. 17).

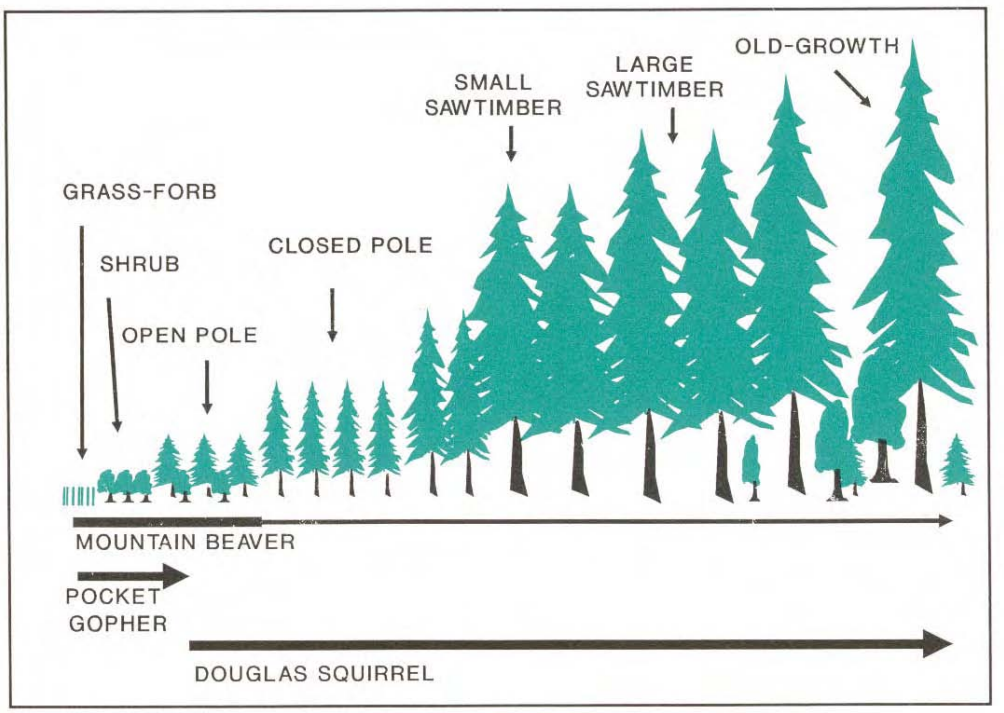


Figure 17—Speaes occurrence along an ecological sere in a Douglas-fir forest (based on Brown 1985)

Before human alteration of forests in the Pacific Northwest, natural disturbances, such as f.ire, windthrow, root rot, insect outbreaks, and individual tree mortality, produced patterns on the landscape of varying size and frequency (Spies and Franklin 1988). The frequency of catastrophic and widespread wildfire, for instance, averaged once every 150 to 400 years, and frequency was higher in the southern and eastern portions of the region (Morrison and Swanson 1989). Ground fires were more frequent, but often less widespread. Root-rot pockets occur during stand development and are localized. Individual tree mortality occurs very frequently, but is restricted to a small area on the ground that the tree crown influenced.

An inverse relation generally describes, therefore, the spatial scale and frequency of natural disturbances (fig. 18). Animals inhabiting this region are well adapted to surviving and even benefitting from disturbance scales and frequencies.

Effects of Silvicultural Treatments on Habitat

Silvicultural activities have largely replaced natural disturbances in managed forests. Forest managers can select the types and rates of disturbances that will meet specific resource objectives. Some animal damage problems that foresters face in the Pacific Northwest may result from insufficient consideration of the size, frequency, intensity and patterning of Silvicultural disturbances on the landscape. There is a range of management decisions that can be made on any given site that will result in stand conditions and plant communities that support only certain species (fig. 19). Consider, for example, an Oregon Coast Range site managed with the following combination of decisions: clearcut, no legacy (retention of logs, snags or green trees), no site preparation, natural regeneration, no vegetation management, and no precommercial thinning. The result would probably be a hardwood-shrub plant-community of small stature. Now consider the same site managed with the following decisions: clearcut,

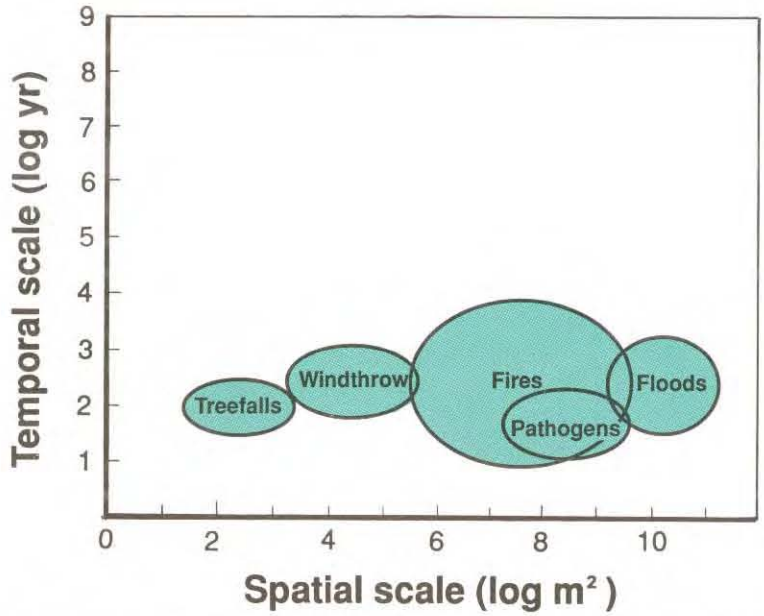


Figure 18—Relation between size of a disturbance and the frequency of occurrence of the disturbance on the landscape (from Urban and others 1987).

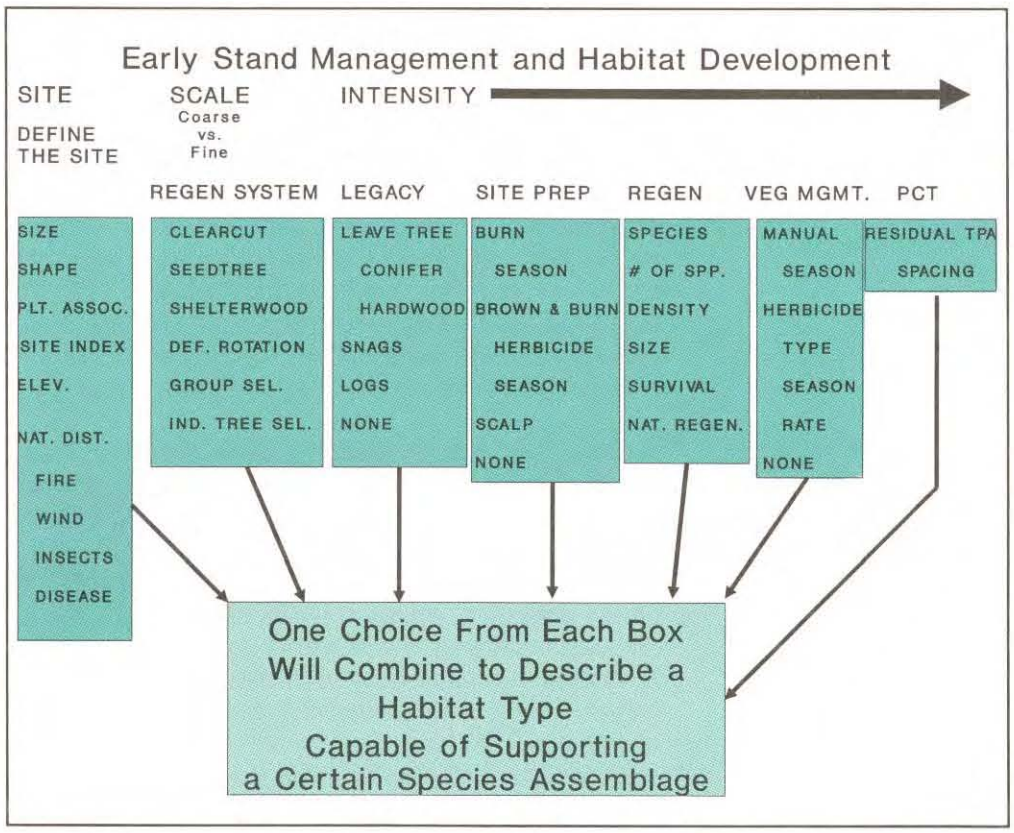


Figure 19—Example of the array of choices available to land managers in Northwest forests. Each set of decisions results in a different habitat condition that is capable of supporting a different assemblage of wildlife species.

snag legacy, spray with herbicide and bum (brown and bum), plant Douglas-fir and western hemlock, spray with glyphosate at year 1, and thin to 300 TPA. The result would probably be a conifer-dominated stand condition with a grass-forb understory (sparse shrubs) during the early stages of development.

Some generalizations can be made regarding the effects of silvicultural practices on habitat structure and composition, with some exceptions depending on site quality and plant communities. Described below are some general effects of certain silvicultural practices on key elements of habitat.

Even-Age Management

Clearcut and plant regeneration is the system most frequently used in the Pacific Northwest, but there are other options. Seed-tree and shelterwood systems are useful on certain sites and with certain species. The deferred rotation system described by Smith and others (1986) is an alternative that benefits certain species of animals by leaving large trees to grow through two rotations. Whichever system is chosen, the stand usually proceeds through site preparation, stand re-establishment, vegetation management, and stand-density management before it is ready for harvest at the end of the rotation. Decisions at each stage influence stand character and affect habitat quality for the wildlife species present at various stages of stand development.

Regeneration system —The selection of a regeneration system affects stand structure during the early stages of stand development. Seed-tree and shelterwood systems leave vertical structures (important to some birds and arboreal mammals) that remain in the stand until the seed trees and overwood are removed. Duration of the grass-forb stand condition is usually shorter and shrub conditions in the stand are more predominant with these systems than with traditional clearcutting (depending on vegetation management). Deferred rotation systems offer the advantage of some vertical structure remaining in the stand throughout the rotation Even-age management, however, often results in the creation of sharp, induced edges (depending on the stature of adjacent stands), and the potential for forest-fragmentation effects, therefore, is high (table 2). Plant species associated with these regeneration systems are often shade intolerant, although this can be adjusted with shelterwood systems and artificial regeneration.

Legacy—At harvest and before site preparation, the land manager may decide to leave certain structural components of the previous stand on the site and into the next rotation (table 2) Snags are the most visible type of legacy left on sites on many federal lands these days. Logs and living conifers and hardwoods left on the site, however, can provide structural and compositional features that create conditions in the new stand more typical of those found after natural disturbances. Animal communities associated with stands that include these features probably would be more complex than communities in stands that lacked similar components. These features, however, may interfere with site preparation, vegetation management, and growth rates of the new stand, so they may only be desirable where land-management goals include resources besides timber (table 3).

Table 2—Generalized comparison of wildlife-habitat characteristics resulting from use of even-age and uneven-age management in Pacific Northwest coniferous forests

Habitat feature	Even-age			Uneven-age
	Early[a]	Middle[b]	Late[c]	
Vertical structure	Low	Low	Moderate	High
Edge effects	High	High	Variable^	Low
Fragmentation	High	High	High	Low
Horizontal patchiness	Low[0]	Low	Low	High
Hiding cover	Low	High	Low	Moderate
Browse	High	Low	Low	Moderate
Shade tolerance of tree species	Intolerant	Both	Both	Tolerant
Snags and logs	Variable^	Variable	Variable	Variable
Belowground impacts	Moderate	Moderate	Low	High

[a] Grass, shrub, and open-pole stand conditions
[b] Closed-pole, small-sawtimber stand conditions
[c] Large-sawtimber stand condition"
[d] Dependent on ad)acent stand conditions
[6] Dependent on stocking density; may be high at low density
' Dependent on land manager's objectives

Table 3—Suggested management activities that might influence habitat quality for selected groups of wildlife species

Silvicultural system	Early serai-stage species	Late seral-stage species
Even-age:		
Stand size[3]	Large	Small
Reserve trees	Few	Many
Snags and logs^	Variable	Many
Harvest system	Variable	Cable or helicopter
Site preparation	Variable	None, light burn, or chemical
Regeneration	Intolerant	Mixed species
Seedlings/acre	Low	Variable density
PCT	- Aggressive	Variable spacing
Commercial thin	Aggressive	Variable spacing
Rotation	Short	Long
Uneven-age:		
Cutting cycle	Short	Variable
Target tree d.b.h.	Small	Large
Reserve trees	Few	Many
Snags and logs	Variable	Many
Group size[3]	Large	Small
Thinning	Aggressive	Variable

[a] Relative to the home range of the species—see table 1
[b] Dependent on species—see Brown (1985)

Site preparation—Site preparation ranges from very intense (mechanical scarification) to none. Mechanical scarification may significantly affect the belowground structure of the stand by removing burrows and compacting soils. It also may affect plant communities that develop after the disturbance. Mechanical scarification may be desirable if the goal is to restrict the habitat of burrowing animals, but it also may significantly affect nontarget species important to the system (Anderson 1987). Intense scarification, burning, or some herbicides (such as glyphosate) may reduce shrub development in succeeding stands. Light fires may proliferate the sprouting of shrubs and reduce the presence of grasses and (orbs in an early stand. The choice of site preparation influences not only the trajectory of the plant community that develops on the site, but also the level of residual "legacy" that remains after the treatment. Intense bums or mechanical scarification, for example, reduces levels of dead wood on the site. This may be a desirable method for manipulating the habitat of some problem species (such as mountain beaver), but it also may have adverse consequences for a group of other species.

Stand re-establishment—Land managers can determine the composition of developing stands by deciding which species will be re-established after site preparation. With natural advance regeneration, that decision may be unnecessary. Planting seedlings, however, can greatly affect the structure and composition of stands. The structure and composition of a stand that includes several species, with different growth rates, for example, will be more diverse than a stand planted with a single tree species. Density and spacing of the regeneration could also be affected. The size distribution of trees in the stand can be narrow (uniform spacing) or broad (irregular spacing), even in an even-aged stand. If animal damage is concentrated on one species of tree or tree size, then mixed-species planting or variable-density planting can provide heterogeneity in an otherwise more homogenous system (table 3).

Vegetation management—Management of competing vegetation can significantly affect the availability of certain plant species as food and cover. Herbicide applications that release conifers can temporarily decrease the availability of browse during early stages of stand development, but they also can increase the availability of browse when applied in stand conditions of open sapling poles (Newton and others 1989). Intensive control of competing vegetation in Douglas-fir plantations can lead to high seedling survival and rapid growth in areas that are prone to deer damage (Gourley and others 1990). Either chemical or manual vegetation control can influence the heterogeneity of developing stands. Spot control of competing vegetation can lead to a much more heterogeneous stand than possible with broadcast application of a treatment. Manual control of many shrub species can lead to a proliferation of sprouts that increase amounts of available browse.

Perhaps the most profound effect of vegetation management is the influence that such activities have on the composition and structure of developing stands. Lack of any vegetation management in many Coast Range sites may lead to stands with a large component of shrubs or hardwoods (beneficial to some species of wildlife), while intensive vegetation management may lead to a conifer-dominated stand with little shrub development unless stand density is manipulated as the stand develops.

Intermediate treatments—Precommercial and commercial thinning influences the structure and composition of the understory and may influence, consequently, the vertical complexity and quantity of browse in a stand. The plant composition of the

stand is unlikely to be influenced to any great degree at this point of development. Opening the crowns by thinning also influences habitat quality for those species that find cover and food (cones) in tree crowns.

Variable-intensity thinning can produce a wide range of tree diameters and greatly influence the production of small snags early in stand development (table 3). It can also influence the distribution of food and cover in young, pole-stage stands. Small openings (0.1 acre) in second-growth stands of spruce-hemlock in southeast Alaska have allowed access to food in close proximity to cover from snow for Sitka black-tailed deer.

Uneven-Age Management

Uneven-age management usually involves group selection or individual tree selection. These regeneration systems cause a fine-scale disturbance, so stand-level vertical-structure is usually high, edge and fragmentation effects are usually low, and stand heterogeneity is usually high compared to even-aged system (table 2). The decision to leave a legacy of dead wood depends on the objectives of the land manager; retention of green trees normally is part of the silvicultural system, but the allocation of large reserve trees in the stand is also feasible (table 3).

Site preparation is usually minimal in these systems, because they usually rely on natural advance regeneration. Artificial regeneration is feasible, however, and especially within the group selection system. Chemical or mechanical site preparation, therefore, may help ensure establishment and survival in these harvest groups. Mechanical scarification of the harvest groups and compaction of the soils along designated skid trails can significantly affect belowground habitat by reducing the availability of burrow systems and restricting the ability of animals to burrow in the surface soil.

Artificial regeneration in harvest patches with a group selection system provides a significant opportunity to influence the composition and structure of the stand. More shade-intolerant species can be regenerated with group selection than with single-tree selection. Animal damage to regeneration in harvest patches, however, may be high. Regeneration within harvest patches adjacent to well-established groups of trees may be particularly vulnerable to damage by browsers that seek food adjacent to cover. Small-patch, group-selection systems or single-tree selection systems that rely on existing advance-regeneration or large planting stock, however, may eliminate grass-fort stand-conditions and reduce the length of time that a stand remains in a shrub stage. Even if patches are high-quality browse, the stand as a whole may be low-quality habitat for many early serai-stage species. Cutting cycle length, target tree size, and thinning intensity all affect the habitat of early serai species (table 3). The spatial extent of uneven-age management probably also dictates its effectiveness in reducing damage to seedlings.

Deciding Which System To Use

The choice of which silvicultural system to use is determined by the plant community, site conditions, logging constraints, and species of vertebrates of highest interest. Because most damage occurs early in stand development, the following general recommendations suggest strategies that minimize habitat quality for species in specific stages of habitat development. Even-age management strategies that reduce habitat quality for many species of vertebrates typical of early serai stages include managing on long rotations, maintaining high-density stands, and establishing small,

narrow and widely scattered harvest units (table 3). Activities that could simultaneously enhance habitat for species typical of late serai stages include allocation of dead and living trees as structural legacy after harvest, variable-density planting and thinning, and harvesting techniques that minimize soil disturbance (table 3).

Uneven-age management strategies that could reduce habitat quality for many species that inhabit early serai-stage conditions include establishing a large target-tree size, lengthening cutting cycles, minimizing disturbance to the stand during logging with designated skid trails, harvesting with small-group or single-tree selection systems where they are appropriate, managing for shade-tolerant tree-species, and maintaining high-density groups of regeneration. An allocation of dead or large, living trees also would increase habitat quality for many species typical of late serai stages.

Consider, for example, how an animal damage problem might be manipulated over large scales of space and time: Black bears presently cause high mortality rates by stripping bark for food in pole-stage plantations of Douglas-fir in the Oregon Coast Range. Past harvesting strategies have created stand conditions that represent good bear-foraging habitat (shrub stage with high fruit production). This has resulted in increased populations of bears in the region. Resident bears are now more abundant than previously, and they have begun to consume tree bark—a high-carbohydrate food readily available in the stands. Bear damage could be reduced by altering harvest patterns across the landscape to reduce the quality of habitat available for bears. One solution might be to extend rotations through periodic commercial thinning. This method would maintain a large basal area and reduce the percentage of the landscape that includes stands with high-quality food for bears. Initiating an uneven-age management system over much of the area, alternatively, would produce pole-sized trees scattered throughout stands. These trees, moreover, would grow slower than with even-age systems. Uneven-age strategies would have to be carried out over vast areas, however, so they may not be economically effective. Uneven-aged management in small stands, moreover, may not prevent bear damage, because even-age management elsewhere in the landscape could maintain high populations of bears.

Altering the scale or frequency of cutting also might influence habitat quality for several other common forest vertebrates. Imposing a single-tree selection system in a forest with a cutting cycle of 10 to 15 years and target tree-sizes of >20 inches d.b.h., for example, would result in small, widely scattered openings. Species operating at small scales (such as mountain beaver) may cause problems with regeneration, but habitat quality would be low for deer or elk if this cutting strategy were carried out over a large area. On the other extreme, locating 60-acre clearcuts side-by-side within a basin would create huge areas of young serai-stage stands. Colonization of parts of this area by relatively less mobile species would be less likely than colonization by larger, more mobile species, especially with long rotation lengths and low residual populations of wildlife problem species. Both the silvicultural strategy employed and its arrangement in context with other stands on the landscape, therefore, probably influences expected types of animal damage. Foresters should consider more of the silvicultural techniques that would enable them to manage wildlife resources as well as timber.

Approaches to Damage Problems

Strategies for managing animal browsing on trees are diverse. Land managers must first assess the extent to which browsing affects the management objectives of tree productivity and other resource values. If the effects of herbivory are viewed as negative and are sufficient to justify the expense of control measures, then the manager must decide which measure to use. Three major approaches to controlling animal damage should be considered: inflicting direct mortality on the problem population, protecting seedlings from herbivory with protective plastic sheaths or repellents, or habitat manipulation. The value of each method varies from case to case, and some combination of these techniques probably would be most effective.

We believe that thoughtful management at the stand and landscape levels offers the best long-term solution to animal damage problems. This approach can actually inhibit the development of large populations of wildlife problem species. It can also produce a forested landscape with acceptably low levels of problem species and a diversity of desirable species. Successful manipulation of habitat requires a thorough understanding of the relation between animals and habitat. Land managers can specifically consider manipulating the following resources:

- Food—quantity, quality, or availability
- Cover—quantity, quality, or availability
- Distribution of food relative to cover
- Microenvironmental factors (soil compaction, humidity)
- Water—quantity or availability
- Space—stand size and shape
- Movement—travel and dispersal corridors
- Predator habitat—predators might help control populations of wildlife problem species
- Competitor habitat—competitors might control food or cover important to the target species

Basic research is needed to identify important foods, cover, space, or water requirements. Manipulating these factors with silvicultural prescriptions may reduce the severity of animal damage problems. Until that information is available and the prescriptions have been tested, managers must make decisions without adequate information. Adaptive management should be encouraged, and decisions should be made with the best, current information. The results of those management practices must be monitored to determine their effectiveness. Undesirable or unsatisfactory results will suggest modifications for the next prescription. Effective new prescriptions will emerge as basic information is added from research and as the results of adaptive management are monitored.

The correct approach to any problem depends on a consideration of site-specific circumstances as well as the landscape in which the stand occurs. Many species of vertebrate that become pests occur in a wide range of habitat conditions, and habitat management may only reduce the severity of the problem and not eliminate it. The application of a variety of silvicultural prescriptions in a manner that reflects planning at landscape scales probably will be the most effective approach to solving problems of forest wildlife-management.

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SECTION THREE
SILVICULTURAL PRACTICES AND INFLUENCE
ON ANIMAL DAMAGE

Chapter 6
Silvicultural Systems and Stand Management

WILLIAM H. EMMINGHAM, RICHARD HOLTHAUSEN,
AND MARCVOMOCIL

Abstract

Limiting animal damage with silvicultural systems and stand-management practices requires that foresters consider broad scales of time and space. Trees are far more susceptible to animal damage when they are small; therefore, the problem attracts more attention during the regeneration phase of forest operations. The available range of silvicultural systems produces various intensities and sizes of disturbance. As the size and intensity of disturbance decreases in a gradient ranging from clearcutting to single-tree selections, the potential for greater populations of herbivores (such as forest rodents, hares, deer and elk) and associated damage also decreases. These animals all benefit from disturbance and early serai successional conditions. Home-range size and fecundity rates, obviously, are important factors that affect the potential for damage in relation to the scale of management activities.

WILLIAM H. EMMINGHAM is associate professor, Department of Forest Science, College of Forestry, Oregon State University, Corvallis, Oregon 97331. RICHARD HOLTHAUSEN is regional wildlife ecologist, U.S Department of Agriculture, Forest Service, Pacific Northwest Region, Portland, Oregon 97208. MARC VOMOCIL is forester, Starker Forests, Inc., Corvallis, Oregon 97339.

Large unit sizes also may-favor animals that cause damage in young stands (such as squirrels, porcupines, wood rats, and black bears). Large-scale application (thousands of contiguous acres, for example) of a given silvicultural system may be necessary to significantly affect patterns of animal damage from larger, wider ranging species such as deer, elk, and bear. This may be possible, however, only in landscapes with little variation in microclimate and in large blocks of a single ownership where management objectives are stable.

This chapter focuses on whether forest managers can ameliorate problems of animal damage with a variety of silvicultural systems and stand-management activities, such as thinning and fertilization. It outlines the present situation, suggests possible benefits from different silvicultural systems, describes limitations, and suggests perspectives useful for foresters dealing with animal damage in a changing socio-political climate. The chapter builds on a broad definition of silviculture that encompasses the management of forest ecosystems for a broad spectrum of specific resource-objectives, including timber, wildlife, recreation, clean water, fish, and a host of other forest values.

Resource-management actions that disturb the forest ecosystem affect the entire array of forest resources. Animals that damage the timber resource are part of the ecosystem, and their population levels (and amount of damage) respond to manipulation in a fairly predictable manner. There is a continuing, great need, therefore, for an integrative approach by teams of resource specialists skilled in predicting the response of all elements of the ecosystem.

This chapter is intended to be thought provoking. Research trials on how silvicultural systems affect animal damage rarely, if ever, have been carried out. This discussion, therefore, can only provide suggestions or hypotheses and not hard-and-fast recommendations. It, hopefully, will challenge researchers and managers, jointly, to conduct scientifically rigorous trials of silvicultural approaches so that management decisions in the future may be made with more confidence.

Resource managers can predict the results of common silvicultural operations fairly well. West of the Cascade crest, even-age management with clearcut regeneration is practiced widely, and it favors a whole array of animal species that thrive in early successional conditions (Hooven 1973; Hooven and Black 1976). Damage to young Douglas-fir seedlings from high populations of deer favored by nearby clearcuts is predictable. How uneven-age management of the same landscape affects populations of deer, other problem species, and damage levels is far less certain.

Experience with partial-cutting methods in forests east of the Cascade crest has given managers a fair idea of how those forests respond to uneven-age management-regimes. Defoliators or bark beetles, apparently, are greater threats than damaging animals in most such cases, but the need for an integrated approach to forest protection is equally strong. Animal damage will always be variable and predictions will be unprecise, so situations that also require direct methods of control should be expected.

Forest managers must provide for healthy ecosystems and long-term productivity, but their ability to predict the influence of less common methods of management on forested ecosystems is very limited. High levels of animal damage may conflict with management objectives and undermine forest values. Managers, therefore, have a

critical need to understand when their actions create conditions conducive to animal damage. They also must understand the likely long-term consequences of damage and the criteria needed to decide when damage is unacceptable. Some levels of animal damage may be acceptable with a longer-term, broader view of forest management. dumpiness in forest stands injured by mountain beaver or bear, for example, could be accepted as "natural" diversity under some conditions. Injury from animals, insects, and diseases surely has contributed to the diversity of mature or old-growth stands. Not all levels of animal damage, therefore, are negative, but only those that conflict with established objectives.

Keywords: Animal damage, silvicultural systems, diversity, uneven-age and even-age management, stand management, forest types.

Introduction

The present study of silvicultural systems (defined as the whole process whereby forests are tended, harvested, and replaced) and their relation to animal damage management comes at an opportune time in the history of Pacific Northwest silviculture. It is a time of uncertainty and change. Methods of "New Forestry" (Franklin and others 1986), New Perspectives in Forestry (Salwasser 1991), and the high level of public interest in the selection of a silvicultural system, as exemplified by voter initiatives in the 1990 California election, make the practice of silviculture especially challenging at this time. Sih/iculturists and wildlife managers, ironically, are expected to manage forests with unfamiliar treatments and systems. Animal damage of many types (Black and others 1969) is one of the most difficult challenges that these forest managers face in the Pacific Northwest. It is a common and perplexing problem from the early phases of regeneration, when ungulates and rodents damage or destroy small seedlings, to later stages, when bears damage timber that is nearly merchantable. Creativity and vision are needed to develop viable systems of animal damage management at the landscape level from a limited base of knowledge

Allowable harvest levels on national forests are being reduced because of the increasing value placed on wildlife, nonconsumptive forest products, and aesthetics. Direct control of animals on federal land, therefore, probably will fall further into disfavor, and the decreased supply of timber from federal lands will increase the pressure for efficient production of timber on private land and increase the emphasis on animal damage control. Managers, in both cases, will require new and effective methods that avoid direct control or expensive procedures.

Forest Types, Silviculture, and Animal Damage Management

The development of silvicultural schemes that ameliorate animal damage is complicated by the fact that careful and systematic management of the forests of the Pacific Northwest is young. A significant portion of federal lands remain as virgin forests. Silvicultural systems, furthermore, never have been tested systematically in forest types of the Pacific Northwest. The following brief description of silvicultural experience in four major forest types illustrates the limitations of the current base of knowledge.

Forests West of the Cascade Crest

Douglas-fir forests—Douglas-fir forests are dominated by Douglas-fir, and western hemlock or grand fir are the more shade-tolerant, late-successional components of the forest. Douglas-fir produces high-quality wood; therefore, regeneration efforts have focused on securing relatively pure Douglas-fir stands with clearcut regeneration Uneven-age management was considered a promising approach to managing these forests during the 1930s (Isaac 1956, Munger 1950), but the efficiency of extracting large logs and large volumes of (often defective) timber per acre scon led

to acceptance of the clearcut method Many people (McArdle and others 1949) also recognized the similarity between clearcutting and the "natural" sequence of fire and replacement of stands.

This even-age, single-species focus led to many problems with animal damage in some areas (Black and others 1979), especially where successive entries into large blocks of mature timber created extremely favorable habitat for herbivores that often eat Douglas-fir. Deer and elk browsing and clipping by mountain beaver and rabbits are the most common forms of damage. Direct control or protection methods are effective, but costly (Owston and others, this volume). Good site preparation, the planting of large, vigorous seedlings, and good vegetation management alleviate many of these kinds of animal damage (Gourley and others 1990).

The frequency of damage to young pole stands by black bear increased during the last decade Bear frequently bark trees in spring as they strip the outer bark and eat the inner bark and outer sapwood. Fertilization, especially of individual trees, promotes vigorous trees that attract bear Bear damage is most common in poorly stocked stands where loss of trees exacerbates an already marginal situation. Managers cannot be certain that stands are safely established until three decades after planting' Although trapping and shooting works very well for a specific area for a few years, neither direct control by trapping and shooting nor supplemental feeding are entirely successful methods of controlling bear damage to Douglas-fir forests

Upper-slope forests—Upper-slope forests often include Douglas-fir or noble fir, or both, with Pacific silver fir or mountain hemlock as late-successional species. Logging of these forests was delayed because they are less accessible than Douglas-fir forests They eventually were logged, however, with even-aged clearcut methods like those developed for low-elevation Douglas-fir forests. Shelterwood methods of regeneration later were adopted for gentle slopes, because summer frosts created significant problems.

Animal damage in upper-slope forests is minor compared to problems at lower elevations, although pocket gophers and voles cause significant problems in some areas. Deer and elk damage is not a great problem in these forests, perhaps because these animals are present only for the relatively short summer season. Seedling growth, however, is limited by the short growing season, and seedlings in upper-slope forests are susceptible to damage for several years longer than trees at lower elevations.

Forests East of the Cascade Crest

Mixed conifer forests—The mixed conifer forests found on cool and moist sites in mountain ranges east of the Cascade crest include some combination of Douglas-fir, grand fir, western larch, western white pine, lodgepole pine, or ponderosa pine. Incense cedar, sugar pine, or Shasta red fir also may be present in forests of southwestern Oregon East of the Cascades, historically, frequent fires limited the more shade-tolerant, thin-barked species and created relatively open stands of ponderosa pine and larch. Fire control changed the balance in these systems and favored regeneration of the more shade-tolerant species. Past harvest methods included selective high-grading of ponderosa pine and larch, while successive entries progressively took more of the other species. The more shade-tolerant species, such as grand fir and Douglas-fir, consequently, dominate these forests and are extremely vulnerable to defoliation by spruce budworm or Douglas-fir tussock moth. Significant areas of mixed conifer forest are managed with even-aged clearcut methods, and

regeneration success is fair with prompt planting. Vegetation management would help ensure success and promote early growth of seedlings (Emmingham, unpublished data). In the extremely varied forest environments of southwestern Oregon, even-age management with clearcut regeneration has produced varied results. Recent research confirms that vegetation management is an important, almost mandatory ingredient of successful reforestation.

Animal damage to mixed conifer forests is varied but generally minor compared to threats from drought, insects, and diseases. Pocket gophers cause significant problems for both natural and planted seedlings, deer and elk browse or rub seedlings and saplings, and porcupines bark trees and cause death or deformation of ponderosa pine.

Ponderosa pine forests—Ponderosa pine forests are found on drier sites east of the Cascades where drought limits the vigor of species associated with mixed conifer forests. Frequent fire significantly affected stocking levels in pine forests, and fire control promotes natural regeneration, overstocking, and associated problems with bark beetles. High grading and sanitation salvage of high-value pine were common methods of harvest. Regeneration in these partially cut stands seldom was managed; therefore, little is known about how properly executed, uneven-age management-systems would affect these forests. Most silviculturists agree that single-tree selection and uneven-age management would be effective if stocking levels are controlled with careful, selective cutting in all size-classes. Ponderosa pine forests also were clearcut extensively. Ross and others (1986) showed that good site-preparation and vegetation management promote good survival and growth in young plantations.

Animal damage in ponderosa pine forests includes predation by pocket gophers and porcupines, and trampling and browsing by cattle (Black 1969). Deer and elk commonly bark young saplings. Seedlings, in this very dry environment, require several years to become established and start vigorous growth; therefore, they are susceptible to animal damage for prolonged periods.

Preface to the Discussion of Silvicultural Systems

Evaluation of the effects of different silvicultural systems in the Pacific Northwest is particularly difficult. Silviculture, as practiced west of the Cascade crest, almost exclusively consists of even-age management. Regeneration occasionally is adequate with partial cutting, but private landowners are unwilling to accept the brush and mixed hardwood stands that often develop after such logging. East of the crest, partial cutting is common, but it seldom is part of a planned, uneven-age management-system. More often, partial-cutting is risk-rated sanitation-salvage or (far worse) high grading. Managers tend to switch from one system to another over time. Little evidence is available, therefore, for judgments beyond tentative conclusions about the effects of silvicultural systems, and this chapter largely is based on informed speculation.

Selection of a particular silvicultural system requires knowledge of some basic concepts of animal damage management. Factors that must be considered include management objectives, costs of administering the system, plant association, soils, topography, habitat diversity, site potential, and timber species. Legal and regulatory factors also influence the management of our forests, but those concerns often are reflected in management objectives.

oevere animal damage often results when high populations of a damaging species, such as pocket gophers, coincide with a critical silvicultural stage such as regeneration. Climatic disturbance or other factors, conversely, may reduce populations, and timely silvicultural operations may reduce the level of damage. In such cases, regeneration is successful if a unit is planted immediately after harvest and before pocket gopher populations increase Silviculturists should seek to promote or take advantage of favorable mismatches between levels of wildlife population and potential damage.

How or when do these favorable mismatches occur? First, managers can reduce the population of the wildlife species with direct methods of control, such as poisoning or trapping. Second, serendipity plays a role when, for example, bumper seed crops mature as deer mouse populations decline from disease or other causes. Third, silvicultural treatments can create habitat conditions favorable to regeneration but unfavorable to potentially damaging species of wildlife.

Managers have occasionally met their resource objectives with the first and second strategies described above, but they are less inclined to use the first option.' Bumper seed crops, moreover, are all too infrequent. The third strategy, theoretically, is possible, but it requires an uncommon degree of information about animal populations coupled with careful planning and organization. The silviculturalist rarely is able to control the time of harvest to promote a favorable situation.

Important Factors: Cost, Species, and Environment

The cost of managing a forest tract with different silvicultural systems varies widely The costs of more complex systems of management, generally, are higher. Uneven-age management and multistage shelterwood-systems, therefore, have not gained great favor, especially on steep terrain where logging costs escalate with any kind of partial removal

Species and site differences also must be included in calculations of the relative cost of various silvicultural systems. Pine, for example, is the only viable tree species on dry ponderosa pine forests, and regeneration is very difficult to accomplish with clearcuts. The cost of regeneration with intensive weed control may be so high, in such situations, that considerations of animal damage can tip the balance in favor of an uneven-aged system with gradual regeneration at low cost over longer periods. McDonald (1976a, 1976b, 1976c) worked on relatively moist sites and found large differences in the response of conifer and hardwood species to a variety of silvicultural systems. Ponderosa pine, for example, required the open conditions of even-age management, or at least large groups in uneven-age management to attain satisfactory growth rates. Shade-tolerant species such as western hemlock thrive in small openings This indicates a strong interaction between species and environment.

The efficacy of a match between a silvicultural system and a managed species must be judged by a knowledgeable forest manager Efforts to match species, site, and silvicultural systems to avoid or minimize problems of animal damage, however, also require planning and consideration of several other factors (size, timing, and juxtaposition).

'A notable exception here is in control of pocket gophers Direct control with strychnine grain bait is the most common and widespread practice, and the practice is likely to continue as the principal means of control in the foreseeable future

Spatial Factors

Spatial arrangement, scale of habitat, environmental diversity, and scale of silvicultural operations all are important to wildlife population-dynamics and animal damage control. In this chapter. **Alpha diversity** refers to variety within one site or stand; **beta diversity** refers to variety across sites; and **gamma diversity** refers to variety in conditions from one landscape to another. The term **environmental diversity** refers to the spatial pattern of abiotic factors and small-scale climatic-conditions, including (for the sake of simplicity) variation in parent material and soil conditions. **Habitat diversity** refers to the spatial variety in vegetative structure at several different scales. Habitat diversity is affected by environmental diversity and disturbance from natural or human causes. Wildfire, insects, and diseases all contribute to diversity, and will continue to do so despite efforts to control them. Different wildlife species react in various ways to diversity (Hall and Thomas 1979). Resource managers must understand the different types of diversity and how they interact. The following two examples help clarify the concepts.

Environmental diversity is low in the Oregon Coast Range, where the entire landscape is potentially forested, because rainfall is abundant and cloudy weather ameliorates climatic differences between north and south slopes. Forest stands on north and south slopes have similar alpha diversity. Managers, therefore, can only increase alpha, beta, and gamma diversity by clearcutting, thinning, or otherwise manipulating stands (fig. 1).

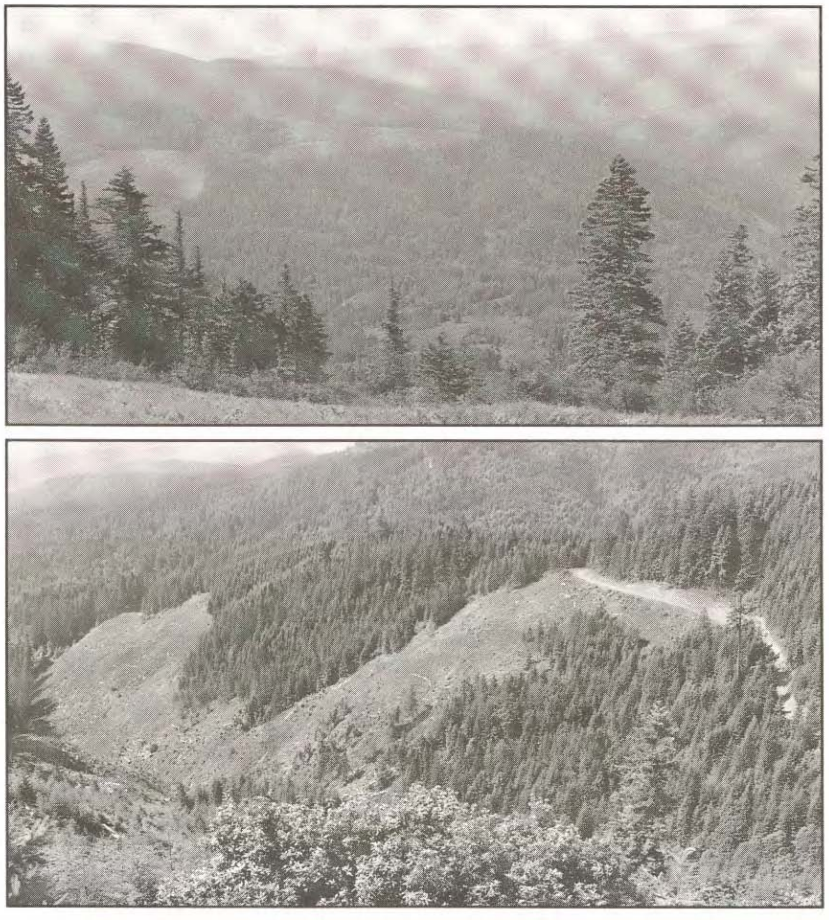


Figure 1—In west-side landscapes, between-stand and landscape diversity can be created by management operations in areas that otherwise would have little diversity.

East-side forest areas, in contrast, generally exhibit large differences in microclimate between north and south slopes, and environmental and habitat diversity are high (fig. 2). Beta and gamma diversity, therefore, are relatively high with or without stand management or harvest operations.

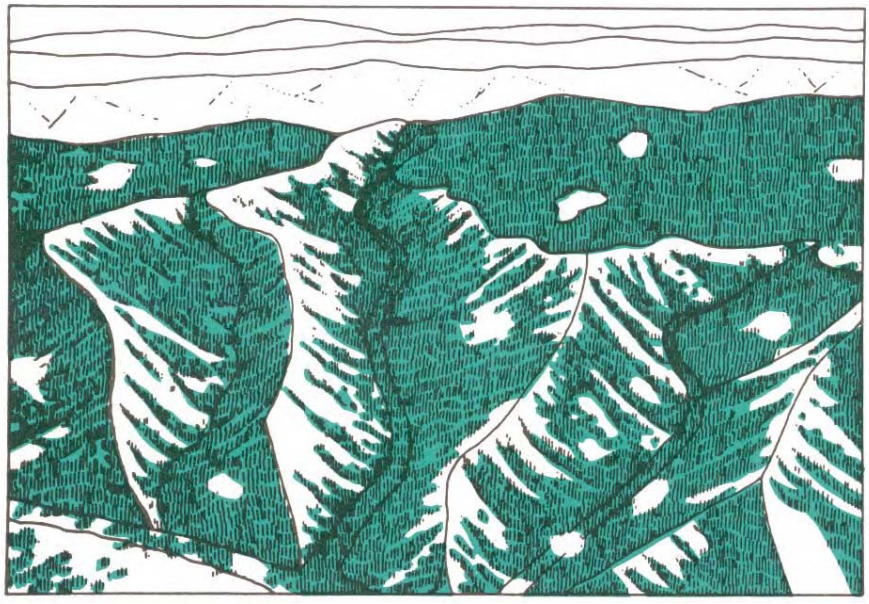


Figure 2—An east-side landscape where forested north slopes and open south slopes provide considerable between-stand and landscape diversity without management operations (Hall and Thomas 1979).

Strategies that limit animal damage must allow regeneration of trees but discourage the buildup of large populations of potentially damaging species of wildlife. This may be accomplished with a silvicultural system on the site that is inherently unfavorable to the wildlife species; with silvicultural systems in a landscape pattern that are unfavorable to the species; or by controlling the location of particular silvicultural practices to avoid areas where the practices would benefit potentially damaging species of wildlife, and by identifying trouble spots that may require direct methods of control.

Management of sites with uneven-age systems that retain some cover of high canopy, for example, might limit the production of herbaceous plants utilized by species such as pocket gophers. Landscapes managed with a uniform, but uneven-age, single-tree selection-system might produce low habitat diversity (beta and gamma) that would result in relatively unproductive conditions for deer and elk (Hall and Thomas 1979; Hall and others 1985). Avoidance of practices that remove all high conifer-canopy and leave slash piles in moist areas would limit the creation of conditions favorable for mountain beaver.

The effect of any measure to limit animal damage is a function of the scale and setting in which it is used. Regeneration success, for example, could be assured by creating a 20-acre clearing within a large 2,000-acre unbroken area of pole and

mature timber. The unbroken stand, in this case, provides limited habitat for deer, elk, or pocket gophers. Potentially damaging populations of wildlife, therefore, would not have access to the area (in the case of deer and elk), or they would not build up with sufficient rapidity (in the case of pocket gophers) to pose a threat to forest regeneration, assuming other conditions for successful regeneration were met. Successful regeneration in a similar-sized clearing within a large 2,000-acre area of young plantations (with a large deer population) would be unlikely. The same concept applies to a variety of wildlife species, and the scale of application would depend on the size of the animal and its ability to travel and reproduce. Conflict may, in fact, arise where one potentially damaging species with a small home range is favored by a practice designed to be unfavorable to another potentially damaging species with a large home range.

Introduction to Silvicultural Systems

Various silvicultural systems have been developed and used throughout the world during the last several centuries (Daniel and others 1979, Smith 1986). It is important to remember that silvicultural systems refers to the entire set of treatments used to regenerate and tend the forest over long periods of time. Silvicultural systems are classified and named in accordance with the harvest and regeneration methods used to establish new stands. Classical systems commonly described in textbooks encompass a wide range of techniques. Modifications of these systems should be described in terms that relate the new practice to the old systems. The snag, woody debris, and high-canopy retention-technique of "new forestry", for example, might best be described as an even-age system with reserve trees and a restricted salvage policy (table 1) or, in other cases, as an irregular shelterwood (Smith 1986).

Table 1—Characteristics of silvicultural systems

Silvicultural system	Comments
High forests:	All trees regenerate from seed Stand tended throughout rotations to control stocking and improve wood quality
Even-age systems—	All trees the same age, plus or minus 10 years
Clearcut	All trees cut at final harvest
Seed-tree	A few trees/acre left for seed production
Shelterwood	Enough trees left to modify seedling environment
Uneven-age systems—	Trees of 3 or more ages or sizes on an area of a few acres
Single-tree selection	Mature trees harvested as individuals Thinning completed in all size classes on each acre
Group-selection	Mature trees harvested in "small" (<2-acre) groups Groups managed with even-age tending and thinning methods
Coppice forests:	Trees regenerate from sprouts and suckers
Coppice	Frequent (every 10-20 years) cutting of all trees
Coppice with standards	Some high-quality trees retained to produce large timber, all others cut at frequent intervals

Source Daniel and others 1979

Ameliorating Animal Damage with Silvicultural Systems

Practical methods of limiting animal damage with Silvicultural systems must promote imbalances between wildlife species of interest and their habitat. Limitations imposed by scale considerations, including the size of area managed with a silviculture system, and the topographic and habitat diversity also must be considered. Roads associated with management and recreational activities also affect behavior of animals such as elk (Skovlin and others 1989).

Even-Age Management

Even-age management produces a successional or stand-developmental sequence much like that which follows catastrophic, stand-replacement events, such as a hot crown fire. Variations in size and location of a unit, degree of woody-debris retention, amount of high-canopy retention^ and length of rotation determine the type and extent of wildlife habitat produced. The staggered-setting approach produces a large amount of contrasting edge with small units of clearcut or shelterwood and greatly increases beta diversity (fig. 3).

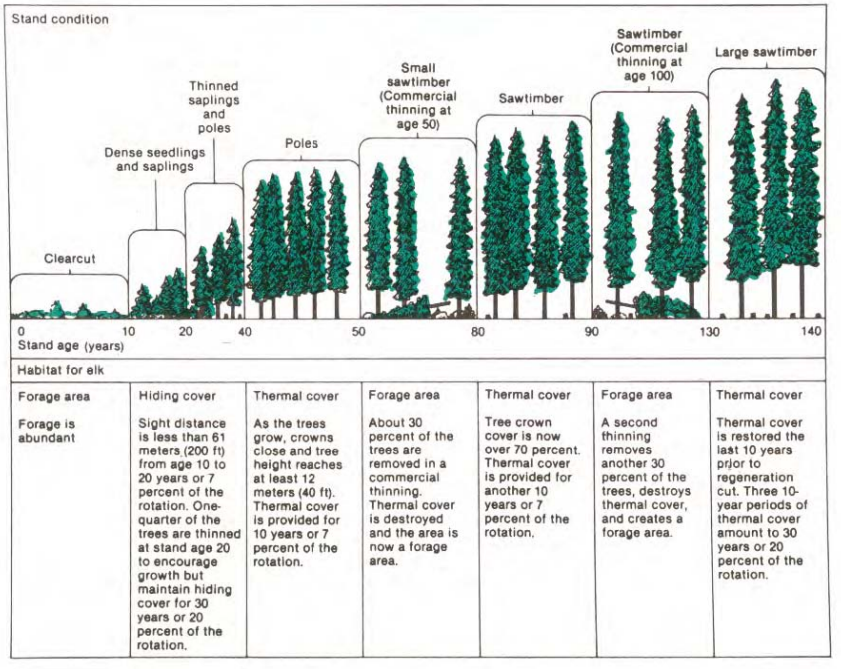


Figure 3—Even-age Silvicultural systems produce a variety of habitat conditions in different-aged units Edge effect and beta diversity are maximized (Halt and Thomas 1979)

The even-age management option encompasses several regeneration methods, including clearcut, seed tree, and shelterwood. Selection of one of these methods can alter wildlife habitat and affect patterns of animal damage. Pocket gophers, for example, are a serious threat to regeneration in portions of southwestern Oregon. The shelterwood method of regeneration has proven more successful than the clearcut method in moderating gopher damage in some areas (Williamson and Minore 1978, Minore 1978). apparently, because the shetterwood environment is less favorable to plants utilized by the gopher. McDonald (1976b) showed that shelterwood trees considerably reduce the growth of Shasta red fir in the understory, probably by producing shade and consuming water and nutrients. Competition for site resources also restricts grass and forb production to the detriment of pocket gophers.

Changing the scale of application of even-age management strategies also can influence levels of damage from wildlife species. Some evidence suggests that very large clearcuts reduce the impact of big game on tree seedlings. As Rochelle (chapter 16, this volume) points out, large harvest units reduce edge effects and increase distance to hiding cover. Both factors discourage browsing by deer and elk. Even though elk (Merrill and others 1983) and (probably) deer travel long distances under extremely open conditions (in the Mount St. Helens blast zone, as an extreme example), damage generally decreases with distance from cover.

Uneven-Age Management

Uneven-age management produces a much smaller pattern of disturbance in a forest stand (high alpha diversity). Such patterns are very heterogeneous when viewed at a small scale but quite homogeneous (low beta and gamma diversity) when viewed at a larger scale. The implications of this habitat pattern for wildlife species depends on the normal scale of interaction (home or forage range) between the species and its environment.

Single-tree selection—Single-tree selection (STS) can produce a forest stand structure similar in many ways to certain old-growth forests if some snags are left or created to provide standing and down woody debris. Such systems could favor mature forest species of wildlife. Under these conditions, natural regeneration of shade-tolerant trees often is abundant (fig. 4). Populations of many species associated with early serai conditions probably would decline in large tracts of forest managed with the single-tree selection method. This includes many of the species that most commonly are associated with animal damage in the Pacific Northwest, such as pocket gophers, mountain beaver, deer, and elk.

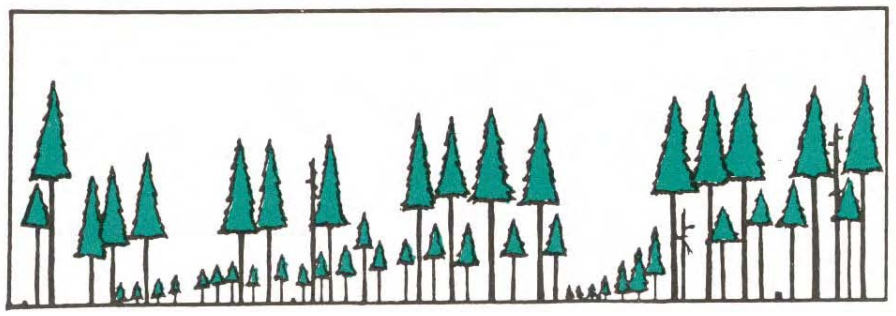


Figure 4—Uneven-aged forest stands provide greater within-stand diversity but less between-stand and landscape diversity

Managers should recognize, however, that STS stands are not closed-canopy forests. Stocking levels in STS stands are maintained at 50 to 75 percent of full stocking to promote individual-tree growth. Unless patches are left unthinned, the canopy is quite open. Each cutting cycle will also disturb the forest at least lightly. The combination of open canopy and frequent disturbance creates habitat conditions more favorable to many wildlife species than conditions found in typical, even-aged saw timber (pole or mature) that has not been thinned. Alpha diversity is high in STS stands, which probably would favor animals with small home-ranges. STS stands would be very open in forests east of the Cascade crest that normally support only low tree densities.

Group selection—The group-selection system produces a mosaic of small openings less than 2 acres in size. Such patterns provide a rich mixture of serai and mature-stand habitat that may be conducive to some wildlife species normally associated with animal damage. Small openings surrounded by seed-producing trees could produce a favorable mismatch between seedfall and seed predators, thus promoting natural regeneration. The timing of harvest and site preparation to coincide with a good seed year and seedfall would help assure success. Groups of pole and mature trees are thinned with this system, so individual trees are vigorous and seed production can be massive, especially when seed production peaks every 7 to 20 years. Normal populations of rodents cannot completely consume all the seed or seedlings produced during peak seed years. Minore (1986) found that rodents are extremely aggressive in finding and consuming seed sown in the Pacific silver fir zone of the central Oregon Cascade Range. Seed protected by plastic berry baskets averaged about ten-fold greater survival than unprotected seed. Musser (personal communication), conversely, found that shelterwoods installed in the plateau south of Mount Hood, Oregon in the same zone were capable of producing enough seed to successfully restock newly prepared sites 3 years after the shelterwood cut. Seed production is enhanced in managed forest stands where stocking levels are reduced by thinning, and the disturbance caused by thinning often promotes natural regeneration.

Group selections within units of 0.25 to 0.5 acre create tremendous amounts of edge that may produce or attract abundant populations of ungulates. Implementation of this system in the Douglas-fir region would favor shade-tolerant species such as western hemlock and grand fir. Both species are less palatable to grazing animals than Douglas-fir, which is favored by even-age methods or selective cutting in larger groups.

As with STS, the effect of habitat conditions created by a group-selection system depends on the range-size requirements of each species. The potential for animal damage varies widely by forest type, and problems are likely to differ by wildlife species. The precise effect of uneven-age management on animal populations and animal damage for Pacific Northwest forest types and species is poorly understood, because forest managers have relatively little experience with this system, especially in Douglas-fir and upper-slope forests.

Coppice management—Coppice silviculture is practiced with sprouting hardwoods, and it is quite feasible in southwestern Oregon and California (McDonald 1978, McDonald and Tappeiner 1987). Species like California black oak, tanoak, big-leaf maple, and madrone are prolific sprouters. Coppice management of sprouting hardwoods (with coniferous species as standards) increasingly is practiced by small, nonindustrial, private forest owners as the value of firewood or other hardwood products increases.

The implications of coppice management for animal damage management are not well known. The system is used in western Europe to promote small and big game, but it is not favored as a method of producing high-quality timber. If practiced over large tracts, this method could alleviate the need for planting, and it could produce abundant forage for wildlife. Only one or two sprouts per clump are needed for a viable timber stand, so browsing may not pose significant problems for simple coppice management. Coppice management is included in this discussion of silvicultural systems for the sake of completeness and to note that even silvicultural systems currently in disfavor should be included in research trials.

Selection of Silvicultural Systems

The silvtoultural system selected for any specific case must reflect all the considerations discussed above and measure predicted outcome against management objectives. The following steps may facilitate the complex process of selecting and applying an appropriate system.

Determine management objectives—Primary consideration must be given to the management objectives assigned to a site. These should include objectives for stand composition and wood production, wildlife, public uses (including aesthetics), diversity, soil and water, and economic expenditures and returns. Management objectives for the site also must be understood in the context of the objectives set for the larger landscape-unit. Management objectives help define the risks and acceptable levels of animal damage for each site.

Determine acceptable levels of animal damage—Resource objectives for a site strongly affect the acceptability of animal damage, and may determine whether one form of animal damage is acceptable while another should be avoided. Substantial levels of ungulate damage, for example, may be acceptable on a site where deer habitat is a primary objective, but high levels of pocket gopher damage on the same site may be unacceptable, because dead trees provide little hiding cover. Similar levels of ungulate damage would not be tolerated in an area managed primarily for wood production. The same levels of damage might be acceptable in other situations with a combination of wood-production and wildlife objectives. Full consideration of resource objectives, therefore, including those for diversity and wildlife, are necessary to help determine which levels and types of animal damage are acceptable and which should be avoided.

Determine the relative severity of various threats of animal damage—Once the objectives relative to animal damage are clear, the types of potential damage must be determined. This assessment should be based on information on the habitat relations of various species; actual surveys of the populations of species in and around the target area; available information on recent population trends of the species; and recent history of animal damage. This information should be synthesized to identify species central to animal damage management. All management activities are likely to benefit one species or another; therefore, it is critical to know which species are of particular concern on the site.

Determine how possible actions will affect the species that pose the greatest threat—Information about species that may cause damage should be organized according to significant habitat associations: important food plants, home ranges, seasonal ranges, and dispersal movements. These data can be used to help predict which silvicullural systems have the greatest chance to succeed in maintaining animal damage at acceptable levels (see table 2).

This habitat information, even at a general level, helps identify how species are influenced by various Silvicultural systems and by the patterns in which those systems are applied across the landscape. Species that prefer early successional habitats with relatively small home ranges obviously benefit from small, closely spaced, even-aged units. Such species include voles, mountain beaver, pocket gophers, and deer mice. It should be no surprise that many species of most concern in the Pacific Northwest are on this list, because this type of silviculture is common in this region. The same Silvicultural systems also benefit species (such as mule deer and black-tailed deer) that range across the landscape to reach a variety of habitats.

Table 2—Important habitat considerations, habitat relations, primary diet, and home-range size for various animals that cause damage

Species or groups	Important habitat considerations		
	Habitat relations	Primary diet	Home range and movements
Mule deer, including blacktail deer[a]	Early and late successional stages	Herbs and shrubs	Large—many miles, sometimes migratory
Tree squirrels[b]	Dense canopies	Cones and seeds	Relatively small-several acres
Pocket gophers[c]	Early successional stages	Herbaceous plants	Relatively small-up to 1 acre
Mountain beaver[d]	Moist sites: edges, large woody debris	Grasses and forbs	Small—up to 0.5 acre
Voles[e]	Early successional stages	Grasses and forbs	Very small—25 - 50 sq ft[5]

[a]Rochelle (this volume)
[b]Sullivan (this volume)
[c]Marsh and Steele (this volume)
[d]Cafferata (this volume)
[e]Askham (this volume)

Species (such as tree squirrels) that prefer closed canopy forests and have relatively small home ranges and movement patterns also benefit from small, closely spaced, even-aged units. They use those units at a later period in time, however, than species that prefer younger successional habitats.

Design a system that allows for acceptable levels of damage —Once forest managers organize information on the species that pose the most serious threat to a particular project, they can proactively design a system that reduces the threat to acceptable levels. The key items to be considered are suitability of the habitats to be created, location of habitats on the landscape, and juxtaposition of habitats.

Determination of habitat suitability is fairly straightforward. Many species that cause the most severe damage in this region are those that prefer early successional habitats and primarily feed on grasses and herbs found in such habitats. These species are less successful in units where the growth of grasses and herbs is restricted. In even-age management, herbicides are effective at controlling ground vegetation and in altering small mammal populations (Borrecco 1972). Uneven-age management, especially through single-tree selection, may help limit populations of these species. The addition of high-canopy retention to even-age systems also may help limit these populations.

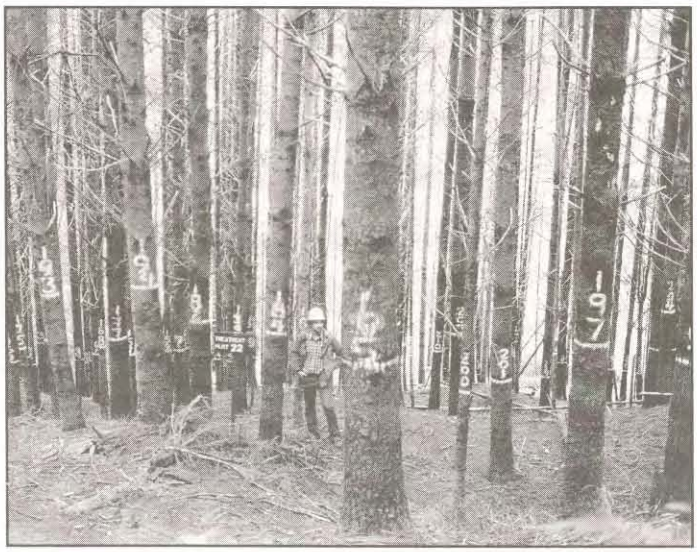
Other species, such as tree squirrels, prefer closed-canopy forests because of the abundance of cones produced in such forests. In these cases, there may be no important differences in the suitability of habitat created by different silvicultural systems. Even-age and uneven-age systems both produce vigorous trees with large crowns—conditions conducive to abundant cone crops. Silvicultural practices such as thinning, however, may affect habitat suitability.

The location of units-on the landscape where these treatments are applied may significantly affect problems of animal damage associated with different silvicultural systems. Mountain beaver prefer moist habitats associated with north slopes and riparian areas. Even-age systems produce favorable habitat for mountain beaver in such sites and may lead to high levels of damage by that species. On such sites, an uneven-age system, or an even-age system that allows retention of high canopy, may help limit the problem. In either case, retention of large, down, woody debris increases population levels and exacerbates damage to regenerating conifers. Direct control by trapping or poison bait, however, will probably be called for with any silvicultural system.

The juxtaposition of treatments across the landscape may provide some of the most intriguing possibilities for controlling animal damage. Silvicuttural systems, quite naturally, often lead to generalized landscape patterns. The choice of a small or large clearcut size in even-age management can produce either a fine-grained or coarse-grained pattern of different serai stages distributed across the landscape. This creates high beta diversity but restricts alpha and gamma diversity. Various management concerns, however, usually have led to a pattern of staggered clearcuts or shelterwoods spread across the landscape in a moderately fine-grained pattern. This pattern produces good to excellent habitat for many of the species that cause animal damage in a variety of environmental settings. Changes in the pattern of application of even-age management would produce different habitat effects. As noted above, large or progressively harvested clearcuts or shelterwoods may produce less favorable habitat for species (such as mule or black-tailed deer) that tend to forage near edges. Isolated clearcuts in large stands of mature forest are less likely to suffer problems of animal damage than more evenly distributed harvest units, but such patterns are unlikely for economic reasons.

Uneven-age management systems also tend to produce characteristic patterns on the landscape. Single-tree selection produces a relatively homogeneous, very fine-grain pattern (high alpha, low beta and gamma diversity), although this can be altered somewhat with various Silvicuttural specifications within large units. Changes in the pattern and size of openings that result from single-tree selection could produce habitat favorable to species such as mule deer that require a mixture of habitat types. This strategy also could make the habitat less favorable for tree squirrels. Single-tree-selection areas managed at lower tree densities probably are less susceptible to tree squirrel damage than those managed at higher densities. Managers may be able to control areas with a mixture of densities to guide populations of tree squirrels away from the most susceptible stands.

A.



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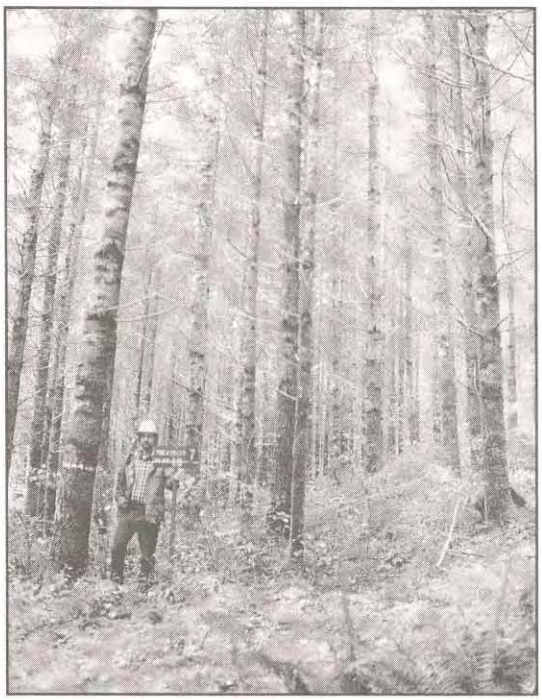

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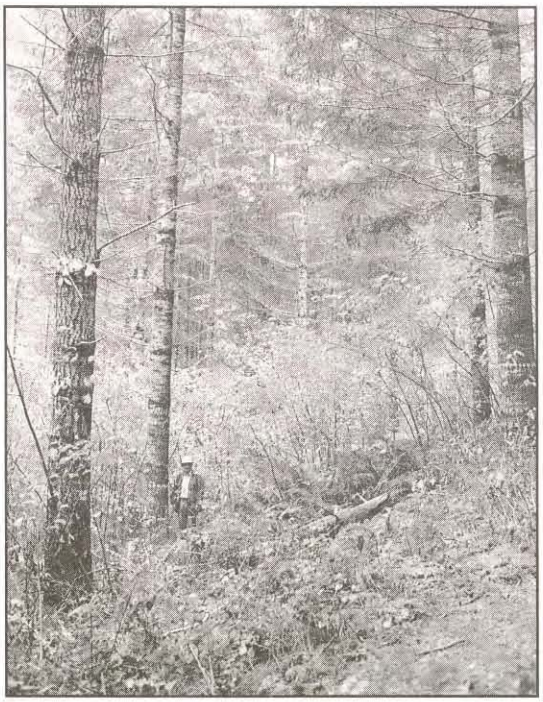

Figure 5—Unthinned stands **(A)** totally lack understory vegetation, while lightly thinned stands have only a few shade tolerant herbs and shrubs **(B).** Heavily thinned stands **(C)** have well-developed understory vegetation. Differences in wildlife habitat will result after final harvest.

Group selection produces a fine-grained pattern of different serai stages. This pattern may be very favorable to species (such as mule and black-tailed deer) that range through moderately sized areas and various habitats. It may be less favorable to elk that favor habitats with a somewhat coarser grain. The pattern also may be favorable to early serai species with small home ranges (such as deer mice, voles, and pocket gophers). Slight alteration of this pattern, however, might affect these species differently. Group selection with very small unit sizes (0.25-0.5 acre, for example), may produce habitat less conducive to the growth of grasses, herbs, and species that feed on them. It also may produce an abundant tree-seed set in those units and lead to eariy regeneration with less opportunity for build up of grass and herb biomass and associated animal species. Such systems, furthermore, probably are less favorable to deer and elk.

Stand management activities must be considered in a long-term perspective with respect to ADM problems during the critical regeneration phase. Stands that have well-developed perennial herb and sprouting shrub understory vegetation will develop more quickly after final harvest (see fig. 5). The animal habitat and potentially damaging animal populations will vary according to thinning regimes carried out long before the regeneration phase.

Status of Research Trials

The effectiveness of operational strategies to control animal damage often is difficult to judge. Carefully planned experiments are needed to determine the true effectiveness of treatments. This is possible but costly for small-scale measures of direct control, because many replications are necessary for dependable results. It is far more difficult to study silvicultural systems. Experiments of the scale and duration required to demonstrate the effectiveness of one silvicultural system versus another rarely, if ever, have been completed. Tree performance in various silvicultural systems has only been compared on a valid, scientific basis in a few areas (McDonald 1976a, 1976b; Baker and Murphy 1982). Literature reporting differences in animal damage in such experiments is thin. Animal damage results from such experiments surely would be invaluable, but the necessary scale would be much larger than the scale for measuring tree response.

In the long run, carefully planned, large-scale experiments that explore the effects of silvicultural systems on animal populations must be conducted, particularly experiments with treatment areas of hundreds if not thousands of acres. These experiments require a scale similar to the scale of experiments now being conducted on the Starkey Experimental Forest in eastern Oregon (Thomas 1989), where an entire (25,000-acre) experimental forest was fenced and silvicultural treatments were installed over hundreds of acres to gauge their effect on animal behavior. Such experiments are long overdue. The consequences of continued ignorance of the effects of different silvicultural systems on management costs and wildlife populations are unacceptably high. The spotted owl controversy is adequate evidence of this point. The best and, perhaps, only practical way to carry out such experiments is to integrate them carefully with ongoing, operational forestry-practices.

Summary

As mentioned in the introduction, this chapter draws on our experience and knowledge of Pacific Northwest forest ecosystems and their management. Many items mentioned above derive from anecdotal data, and confirming experiments would take years to conduct. Some of the ideas stated earlier, nevertheless, must be implemented in hopes of obtaining a desirable result.

Several silvicultural systems, over the long term, will produce a variety of stand structures that favor different wildlife species. An appropriate mix of silvicultural systems for a sizable area may create habitat less favorable to a particularly damaging wildlife species. Management objectives determine the type and intensity of animal control methods. Multiple resource objectives foster more passive strategies of control, while a specific objective of intense timber management engenders direct-control measures Reduction of competing vegetation with herbicides offers a cost effective way to relieve drought stress on young seedlings and to accelerate their growth, effectively getting them out of range of most damaging wildlife (Gouriey and others 1990, Borrecco 1972, Lawrence 1967).

Animal damage management greatly depends on perspectives of time, the ability to predict serious problems, and resource objectives. Imitation of nature remains an important tenet in the regulation of wildlife and forest management. New forestry is an attempt to develop management systems that are based on knowledge of how natural forest systems function. Studies have shown that forest systems, historically, regenerate after a wide variety of disturbances that vary in scale from single-tree blowdown to large scale, catastrophic fire (Spies and others 1991). This suggests that forest managers could use a variety of the silvicultural systems available to them to create the desired stream of habitat conditions, goods, and services from forest areas (McComb and others 1991). Management plans designed for long-term implementation must include recognition of the need for large-scale trials that take into account the home-range sizes of various wildlife species, including but not limited to those species that cause damage. Management with a variety of silvicultural systems will not solve all types of animal damage problems for all ownerships and resource objectives, but it will create conditions that favor tree regeneration and growth. After all, most of the areas currently designated for forest management in the Pacific Northwest were "naturally" covered with tree stands.

Acknowledgments

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SECTION THREE
SILVICULTURAL PRACTICES AND INFLUENCE
ON ANIMAL DAMAGE

Chapter 7
Stand Establishment

PEYTON W. OWSTON, STEVEN P. SMITH/
AND WILLIAM I. STEIN

Abstract

Natural or human-caused disturbances alter existing forest ecosystems, create openings, and provide opportunities for the regeneration of trees and associated vegetation Through their normal activities, animals may help as well as hinder regeneration establishment This chapter discusses the silvicultural practices used in the Pacific Northwest to foster tree establishment and limit animal depredations to tolerable levels Topics covered include key relations, types and causes of damage, methods of harvest and site preparation, establishment of trees and forage crops, and care and evaluation of plantations Influence of tree species and the critically important role of seedling size and quality also are discussed How animals and their habitat are affected by various silvicultural practices is emphasized throughout

Keywords Stand establishment, silvicultural practices, animal damage control, site preparation, planting, Pacific Northwest

PEYTON W OWSTON is plant physiologist, Pacific Northwest Research Station, U S Department of Agriculture, Forest Service, Corvallis, OR 97331 STEVEN P SMITH is habitat biologist, Oregon Department of Fish and Wildlife, Corvallis, OR 97330 WILLIAM I STEIN is plant ecologist (retired). Pacific Northwest Research Station, U S Department of Agriculture, Forest Service, Corvallis, OR 97331

Introduction

Sooner or later, natural or human-caused disturbances alter existing forest ecosystems, create openings and lead to the reestablishment of trees and associated vegetation. Successful regeneration of enough trees for commercial timber production must be achieved despite foraging by animals and competition from residual and colonizing vegetation. Silvicultural methods for establishing regeneration in the Pacific Northwest are briefly discussed in this chapter with emphasis on manipulating vegetation to prevent or reduce animal damage while providing favorable environments for tree seedlings.

Animals impact trees more severely during stand establishment than at any other time; small trees are easier to damage than large ones, and reforestation areas provide ideal habitat for many species that damage seedlings. Several studies have shown that animal damage is a major impediment to reforestation success, and on some sites it is the most likely cause of stand failure or significant lengthening of rotation (Black and others 1979; Borrecco and Anderson 1980; Crouch 1969,1971).

Establishing regeneration is a complex, multistep process (fig 1) that requires careful advance planning (Cleary and others 1986), including a site-by-site evaluation of the potential for animal damage. The damage evaluation may range from simply knowing what to expect from past experience in the vicinity to surveys for animal presence or activity. With information at hand on land management objectives, site conditions, and damage potentials, the planner must decide if it is necessary to prescribe practices aimed specifically at preventing or reducing animal damage.

Removal of the existing stand, usually by harvesting it, is the first step in the regeneration process. Later steps include site preparation, planting or seeding, treatments to prevent or reduce animal damage and vegetative competition, stand maintenance until crowns close or precommercial thinning occurs, and periodic evaluation of results. All steps must be done carefully and in a timely manner to prevent or control animal damage and produce adequate regeneration Prevention or control of animal damage requires an integrated approach. A key requirement is the production, proper storage and shipment, and good planting of high-quality nursery stock suitable in size for the site and the expected plant competition and forage pressures. Planting must be followed by appropriate Silvicultural practices including direct methods of animal control or physical barriers where the potential for damage is high.

Key Relations

Animals depend on plants for food and cover. Anything that alters vegetation, therefore, affects animals and vice versa. Environmental factors interacting from the landscape level to the microsite influence the composition and development of vegetation and the associated animal populations. Plant-community characteristics with a prominent effect on animal populations include variation among communities in the locale, number and size of openings, species composition on specific areas, presence and condition of forage species, density of cover, topography, aspect, and elevation. Animal-population characteristics that influence potential for vegetation damage include species, density, full- or part-time residents, predation levels, and physical condition.

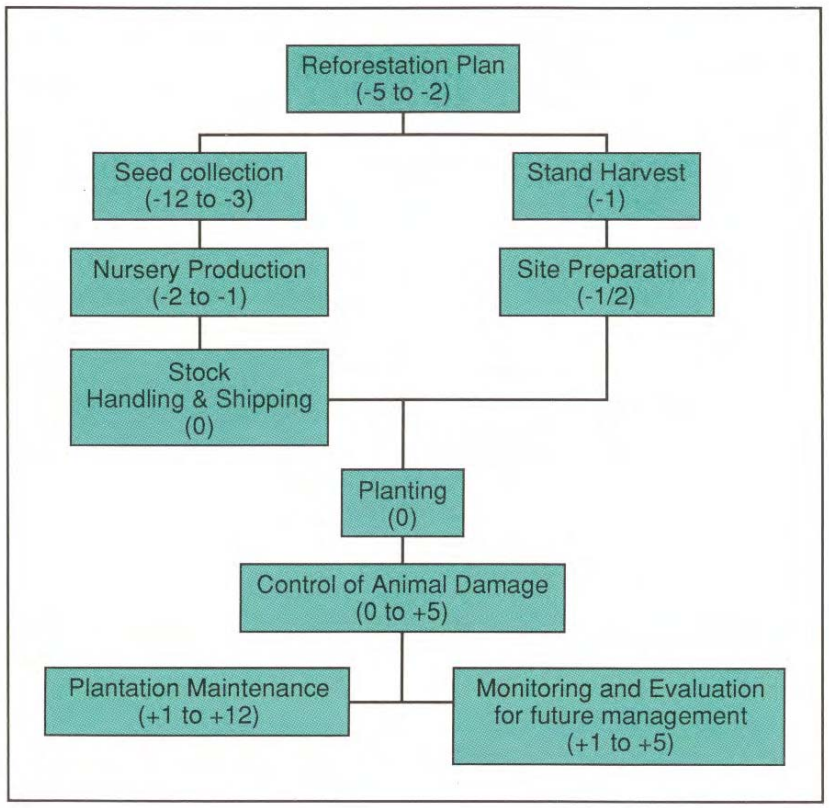

Figure 1—Typical timing and steps necessary to plan and achieve stand establishment (numbers indicate years before or after planting)

Potential for damage to regeneration also is influenced by the preferences developed by individual animals or whole populations, by the species and size of tree seedlings at risk, and by long- and short-term weather patterns that regulate the rate of plant growth and the level of forage and cover needed by the animals. Moreover, relations among these factors are dynamic. Plant composition, animal populations, and forage pressures change rapidly as trees develop and overtop associated vegetation. Managing the vegetation and animal communities on a specific area to successfully regenerate trees, obviously, is complex.

Types and Causes of Damage

Animals inflict many kinds and amounts of damage on seeds and seedlings of desired tree species (fig. 2). Seeds are consumed by small rodents and birds; seedling roots are girdled or clipped by gophers; seedling stems are girdled, barked, clipped, rubbed, or ripped by small rodents, mountain beaver, rabbits and hares, porcupines, deer and elk, and cattle and sheep; small branches, foliage, or buds are browsed or broken by deer, elk, and grouse; and small seedlings are trampled by big-game animals and domestic livestock. The Cooperative Animal Damage Survey, the most comprehensive survey of animal damage ever made in the Pacific Northwest, showed that 30 percent of unprotected Douglas-fir and 15 percent of unprotected ponderosa pine seedlings were damaged each year for the first 5 years after planting (Black and others 1979). Browsing by deer was the most common type of damage.

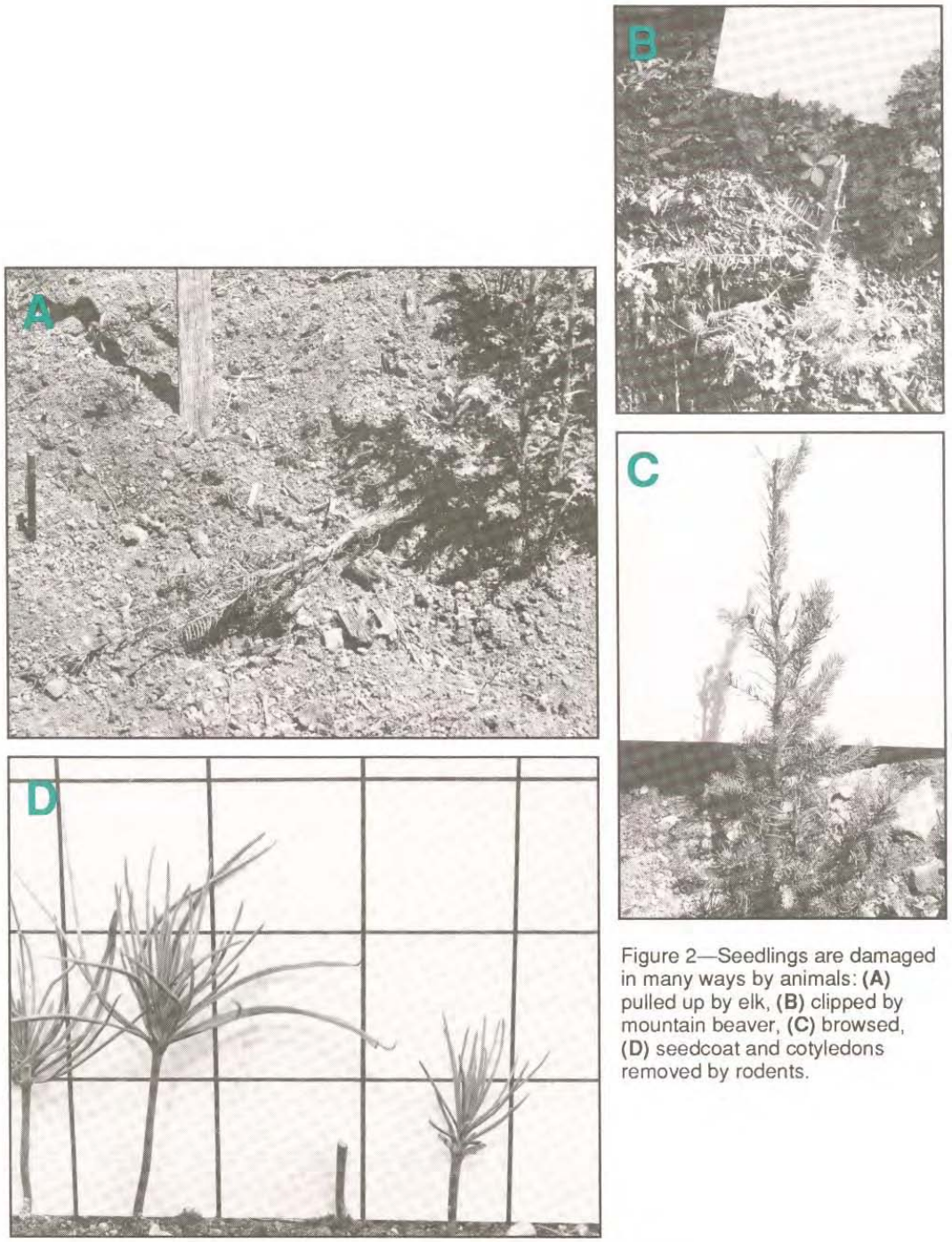

Figure 2—Seedlings are damaged in many ways by animals: **(A)** pulled up by elk, **(B)** clipped by mountain beaver, **(C)** browsed, **(D)** seedcoat and cotyledons removed by rodents.

It is important to recognize that complete elimination of animal damage is neither practical nor necessary Regeneration can tolerate different kinds and degrees of damage without significant mortality or growth losses. Animals play such important roles in forest ecosystems, moreover, that even some mortality and growth losses are acceptable tradeoffs In many instances, concurrent foraging on competing vegetation reduces the need for expensive release of crop trees and may even speed their growth. The control objective is to limit animal damage in a cost-effective manner so that stocking and growth objectives for the new timber stand are met.

Reforestation Practices

Harvest Method

In planning for regeneration, the choice of harvest method depends on the ecological requirements of the desired species and whether the area is to be planted, seeded, or regenerated from natural seedfall. The size and shape of the area harvested governs the length of forest edge created. The proportion of overstory removed affects the amount of light reaching the forest floor and the level of soil moisture available. Light and soil moisture are major factors that determine which plant species will predominate and how fast they will grow.

In their overall effects, the four recognized harvest systems used to foster regeneration—selection, shelterwood, seed tree, and clearcutting—represent a gradient of disturbance in the existing forest and animal habitat. Selection cutting, whereby individual trees are removed, changes existing overstory and understory conditions the least, whereas clearcutting completely removes the overstory and drastically changes the environment to foster regeneration. Shelterwood and seed tree methods provide shade, an abundance of tree seed, and involve time-delayed steps toward eventual removal of the original overstory. As larger fractions of the existing stand are removed, greater amounts of woody debris accumulate near the ground and more unoccupied space is created for establishment of new trees and associated competing vegetation. Favorable habitat is depleted concurrently for some animal species and increased for others. These issues are also discussed in chapter 6.

Site Preparation

Post-harvest preparation of reforestation sites often is done to increase planting efficiency (Zasada and Tappeiner 1988), reduce residual vegetation that would compete too severely with young trees, and create suitable microsites for seeds or seedlings. The kind and intensity of site preparation prescribed also must produce the desired animal habitat, be appropriate for the type and size of seedlings to be planted, and meet environmental and legal requirements. Common methods include prescribed burning, herbicide spraying, and machine or manual clearing and soil scarification. Different methods result in different amounts and composition of vegetation (table 1) and different potential for animal damage (table 2).

Table 1—Relative effects of site preparation on components of wildlife habitat In the Pacific Northwest

	Amount[3] relative to other site-preparation methods			
Component	None	Burn	Scarify	Spray
Dead cover	M/H	L	L	M/H
Bare ground	UM	M	H	UM
Appearance of annuals	L/M	H	H	M
Shrub recovery	M/H	L/M	L	L

[a] The amount is low (L), medium (M), or high **(H)** relative to that resulting from other site-preparation methods for years 1 to 5 post-treatment

Table 2—Relative effects of site preparation on the potential for animal damage In the Pacific Northwest

	Potential damage[a] relative to other site-preparation methods			
Source of damage	None	Burn	Scarify	Spray
Big game	L	M/H	M/H	M
Mountain beaver	H	L/M	L	H
Pocket gophers	UM	M/H	M/H	L/M
Rabbits and hares	H	L/M	L/M	" H
Livestock	L	M/H	M/H	M

•"The potential damage is low (L), medium (M), or high (H) relative to that from other site-preparation methods

Tree and vegetation development and resulting animal habitat progress very differently during stand establishment, depending on the level of site disturbance. If relatively few trees are removed, only a little more light, soil moisture, and bare ground becomes available for new tree or vegetation establishment. Animal habitat sustains only minor changes in these circumstances, and about the same potential for animal damage exists as in the undisturbed stand. When the entire tree canopy is removed by harvest, substantial amounts of soil are bared for plant colonization, but much partly damaged understory vegetation may remain that can quickly recover to dominate undisturbed areas not deeply covered by woody debris. This vegetation mix includes residual tree seedlings, shrubs, and lorbs that existed in the original understory, and interspersed, bare areas will be colonized, primarily by light-seeded annuals.

Application of herbicides adds to the disturbance resulting from harvest by eliminating much of the residual vegetation, thus leaving dead shade and undisturbed soil surfaces. Annuals colonize such surfaces, but they generally do so more slowly and sparsely than on bare mineral soil. Broadcast burning or scarification cause still more disturbance of the post-harvest conditions by virtually eliminating residual vegetation and debris-provided habitat. Scarification also involves substantial rearrangement of surface soil that effectively disturbs belowground habitat of small rodents. In most circumstances, trees establish readily on loose mineral soil and compete with successive flushes of annuals such as fireweeds, groundsels, and thistles, and with resprouting species such as bracken fern, sword fern, maples, salmonberry, and thimbleberry. Successional vegetation and changes in habitat then follow in more or less predictable sequence at site-dependent rates.

Prescribed burning—Broadcast burning has been the most common site preparation method in western Oregon and Washington, because in one operation, it effectively reduces fire hazard and improves access to mineral soil by reducing logging residue, vegetation, and duff. By altering cover, forage, and accessibility, broadcast burning drastically changes the habitat for wildlife, making the site less favorable for some species and more favorable for others (deCalesta 1990, McMahon and deCalesta 1990). Broadly stated, rabbits, hares, and other small mammals that need cover from predators are hampered in their activities until regrowth of vegetation

again yields forage, seeds, and protection. Improved accessibility helps predators find prey and facilitates the movement of big game and livestock. Reductions in woody debris and improved accessibility are relatively long-term changes produced by broadcast burning. Elimination of vegetation may last for several years or as short as 3 months, depending on vegetation type, local climatic conditions, and timing and intensity of the burn (fig. 3). Burning usually alters the composition and quality of vegetation; species that develop are often tender, vigorous, and attractive to big game and other foragers.

Figure 3—Broadcast burning on this coastal clearcut (L) reduced woody debris and fostered a heavy cover of annuals the first year in contrast to the unburned area (R)

Prescribed burning, especially if intense, may temporarily reduce populations of small rodents and mountain beaver (Black and Hooven 1974, Hooven 1977). Tree-survival data from two long-term comparisons of site preparation on the Siuslaw National Forest in the Oregon Coast Ranges indicate that damage from animals may be reduced by broadcast burning (table 3) The difference in survival between trees unprotected or protected from animals by plastic mesh tubing was less on burned than on unbumed sites; this difference appears mainly attributable to how much burning curtailed animal-caused mortality. Differences in total height between unprotected and protected trees on burned sites were equal to or greater than height differences on sites not burned, demonstrating that survival gains achieved by burning were not offset by greater browsing damage. Direct control by baiting or trapping was not used on the study sites. Where it is used, direct control is more effective on burned than on unburned sites, because populations of wildlife problem species are lower, and the location of animal activity (especially for mountain beaver) is more readily detected.

Table 3—Seven-year survival and total height of unprotected trees and those protected by plastic mesh on unburned and broadcast-burned sites In two Coast Range studies

Measure of tree protection	System study		Site-preparation study	
	Unburned	Burned	Unburned	Burned
Survival:		*Percent*		
Unprotected	43	55	53	79
Protected	80	83	70	81
Difference	37	28	17	2
Total height:		*Cm*		
Unprotected	235	263	300	404
Protected	258	285	325	455
Difference	23	22	25	51

Burning of abundant logging debris improves access and thus may increase damage to seedlings by big game and cattle. A regeneration survey on 1,826 acres in northwestern Washington, for example, revealed greater damage from deer and elk, and the average height for planted Douglas-firs on burned areas, consequently, was lower than on unburned sites (Gockerell 1966). Swanson (1970) reported that browsing damage by Roosevelt elk was lowest on steep slopes, in heavy slash, and where slash pattern was uniform on clearcuts in the southern Oregon Coast Ranges. On the other hand, Obermeyer (personal communication 1990) observed that elk are not deterred by heavy logging slash on clearcuts in the central Oregon Coast Range. These different observations are further evidence of the need for site-specific prescriptions that consider landscapes and levels of wildlife population in the vicinity as well as factors on the site.

Small animals such as rabbits, hares, mice, voles, pocket gophers, and mountain beaver may be at low population densities immediately after a fire, but they have the potential to increase to preburn or higher levels within a relatively short period if vegetation recovers quickly. Rapid recovery of vegetation also increases competition among plant species for site resources, which exacerbates the difficulty of stand establishment.

It is important to prescribe and conduct the right burn for a given site and situation. Early season, low-intensity burns, for example, allow grasses, forbs, and shrubs to germinate or sprout within the same growing season. Often it is too late to plant after early season bums; thus, vegetation has one growing season to develop before trees are planted. Late season burns reduce the time between site preparation and planting of seedlings, but they tend to be more intense and the "window" for accomplishing them is short. Higher-intensity burns stimulate germination of snowbrush, gooseberry, and other species with long-lived seeds in the soil. Salmonberry sprouts rapidly even after moderately intense bums. Consideration of animal damage is only one component of a bum prescription, and tradeoffs often must be made, such as accepting improved access for large animals when debris must be burned to improve plantability of the site.

Environmental concerns related to air pollution as well as legal sanctions against burning may severely restrict the future use of prescribed burning. Some organizations have curtailed burning and rely primarily on disturbance during logging to adequately prepare sites for planting. Others seek to burn more selectively by incorporating emerging improvements in burning techniques, emission reduction, and smoke management.

Use of herbicides—Site preparation with herbicides offers more specificity and flexibility, lower costs, and less physical impact on the site than prescribed burning. Herbicides are particularly effective in reducing competition from herbaceous vegetation and small shrubs; therefore, they especially aid conifer establishment on droughty sites (Dimock and others 1983, Gratkowski and others 1979) and on upper slope sites dominated by sedge and bear-grass (Dimock 1981).

Removal of herbaceous vegetation provides the concomitant benefit of reducing seedling damage from small animals such as pocket gophers and meadow voles (Black and Hooven 1977, Borrecco and others 1979, Crouch 1979). In altering pocket gopher habitat, herbicides should be applied 1 year before planting so that the gopher population diminishes before trees are available as food (Marsh and others, this volume). Removal of herbaceous vegetation from old clearcuts, fields, and pastures sometimes is imperative to reduce populations of voles and other small mammals that girdle or clip newly planted seedlings (Borrecco 1973,1976; Borecco and others 1979).

Habitat for big game may be improved by the use of herbicides for site preparation, but their effects on the level of browse damage are uncertain. If grasses and forbs are removed by herbicide treatment, obviously, forage may be temporarily reduced; but if residual shrubs are targeted, their treatment may stimulate grass and forb development and, perhaps, growth of shrub sprouts. Increased use of herbicide-treated areas by deer has been observed but no significant difference in browse damage resulted (Borrecco and others 1972). The net effect is likely to be quite variable from site to site, depending on total forage available and population pressures.

Where woody vegetation predominates, the main use of herbicide in site preparation has been as a preburn treatment to "brown" vegetation and thus facilitate the subsequent slash burn and slow resprouting. The result is a cleaner burn and a more complete change of the existing habitat. Shifts in animal species and densities and in potential for seedling damage will follow in the same manner as already described for prescribed burning.

Mechanical and manual site preparation—Mechanical site preparation involves the removal, chopping, mulching, or piling of logging debris and competing vegetation. Tractors are most versatile for preparing sites mechanically; but for worker safety and preservation of site productivity, tractor use generally is limited to slopes less than 35 percent. Even on gentle terrain, care must be taken to minimize soil compaction by restricting operation whenever soils are compactable. Recent study of Douglas-fir growth in progeny-test plantations in western Oregon showed that soil compaction, humus loss, and overall loss of short-term productivity was greater on machine-piled sites than on broadcast-burned sites (Minore and Weatherly 1990).

On steep terrain, mechanical site preparation involves the use of cable systems to yard and pile large debris. The primary purposes for removing large woody debris have been to reduce fuel loading and improve accessibility for planting. Cable methods also have been used as an alternative to prescribed burning to knock down understory vegetation and expose mineral soil. Soil compaction is a concern within yarding corridors if logs are not fully suspended, and erosion is a threat when much soil is loosened on steep slopes.

Vegetation and wildlife responses to mechanical treatments vary, but they are broadly predictable. In general, small-mammal habitat and populations of mountain beaver, hares, rabbits, voles, and some species of mice are reduced as the intensity and area of scarification increases. Speed of vegetation recovery on bared areas depends on the site, sprouting potential of residual species, invasion by pioneer species, and the foraging pressure of large and small mammals. Resurgence of small mammal populations occurs rapidly, usually before vegetation becomes fully reestablished.

Populations of deer and elk are not reduced by mechanical site preparation. These species are highly mobile, often secretive, and they seek cover adjacent to the treated area. Their presence may actually increase significantly during and immediately after vegetation removal due to improved access and the attraction of disturbance. Dear and elk forage extensively on sprouting and new vegetation.

Manual site preparation requires intensive labor for hand-cutting and, sometimes, piling of slash and competing vegetation. Debris accumulated from the slashing of standing vegetation may impede movement of larger mammals, thus reducing the severity and frequency of browse damage. On the other hand, piles of slash improve cover for small mammals such as hares, rabbits, wood rats, mice, and mountain beaver, which lowers the effectiveness of predators in detecting and capturing prey.

Cutting or lopping residual vegetation induces basal sprouting in many species. Sprouting vegetation provides succulent forage for wildlife, but its availability to large mammals depends on the amount of slash accumulated Little change in plant composition occurs if relatively full stands of resprouting species are cut; but when partial cover or nonsprouting species are cut, changes in plant composition are likely. Resprouting vegetation provides severe competition for tree seedlings unless regrowth is held in check by foragers.

Alternate Forage Crops

If animals remain and preferred forage is limited after intensive site preparation, tree seedlings may serve as primary forage until alternate species become established. The potential for damage to tree seedlings may be reduced if alternate forage species are available at the time of planting (Campbell and Evans 1978) Postharvest activities that favor early establishment of preferred forage species include: cutting or mulching residual vegetation, early season burns, and establishing alternate forage before planting tree seedlings (Hanson and Smith 1970). Sowing and fertilizing grasses, legumes, and forbs is the most common means of providing alternate forage (fig. 4).

Figure 4—Grasses, legumes, and forbs sometimes are seeded to provide alternate forage and, thus, minimize browsing of tree seedlings

Forage seeding is still experimental and often evokes debate. Competition with crop trees for moisture and light, improved habitat for wildlife that results in tree damage, and introduction of non-native plants top the arguments against forage seeding. Moreover, if forage is successfully improved for big game but remains underutilized, damage to trees may occur in the favorable habitat created for voles and pocket gophers. Improved wildlife habitat, fewer undesirable plant species, and less browse damage to tree seedlings are arguments in support of forage seeding. Conflicting viewpoints on forage seeding emphasize, again, the need for establishing well-defined management objectives, integrated evaluation processes, and site-specific practices to meet both timber and wildlife goals.

Although the role forage crops serve in mitigating animal damage to trees is still uncertain, the complexities involved deserve brief discussion. Annuals and sprouting shrubs are the first forage plants to establish naturally after site preparation. Satisfactory establishment of artificially seeded species depends on the quality and type of site preparation—the more mineral soil the better. The timing and method of seeding must be adapted to the terrain and species selected. Because use of farm or rangeland equipment is limited to gentle topography, most forage seeding and supporting fertilization on forest land involves aerial application.

Few guidelines exist for aerial seeding of forage species. The Oregon Department of Fish and Wildlife (Cleary 1972) and the USDA Forest Service (Ramsey and Krueger 1986) cooperated in developing several seed mixtures and application rates for the Coast Range of west-central Oregon. The same methods have produced similar results in the southern Coast Ranges and the western slopes of the Cascades.

Species and amounts of seed vary, depending on site factors such as the potential for moisture stress (table 4). More species and larger quantities of seed sometimes are prescribed on low-stress sites where a plausible additional objective is to occupy the site so fully that shrub development is retarded.

Table 4—Species mix and aerial seeding rates used to establish forage for Roosevelt elk on sites In the Oregon Coast Range"

Species	Pounds of seed per acre when moisture competition is: Expected	Not expected
White clover	4	2.5
Subterranean clover	10	5.0
Big trefoil	2	2.5
Annual ryegrass	0	5.0
Perennial ryegrass	0	2.5
Orchardgrass	0	5.0
Total	16	225

[a] Adapted from Ramsey and Krueger 1986

Species that mature early are needed to enhance forage yet keep competition with trees to a minimum. In western Oregon, such annuals may provide forage during fall, winter, and spring months when the quantity and quality of native forage are most limited (Mereszczak and others 1981). Seeded annuals should die early enough not to elevate moisture stresses for tree seedlings. Biennial forbs have growth habits similar to annuals, but they tend to be deeper rooted and remain available through two growing seasons. Many forbs are highly preferred forage species (Campbell and Evans 1978).

Perennial species provide both forage and competition on a multiyear basis. Commonly seeded, cool-season perennials include ryegrass, orchardgrass, and white clover. Some perennials provide significant competition to tree seedlings if their current growth is not utilized by grazing animals.

Forage species that spread vegetatively by rhizomes or stolons and produce heavy, mat-like ground covers should be avoided. Heavy grass cover can foster high populations of voles. As the vole population grows and green vegetation becomes limiting, tree seedlings are at high risk of girdling damage to stems and roots. Intensive grazing or treatment with herbicide provides the most effective deterrent and control of grass and voles.

Availability and expense of seed has limited the use of native plants (Campbell and Johnson 1981). As collection and propagation of native species becomes an increasing concern on public lands, availability of seed should increase. Many are highly preferred forage plants, and seeding them when forage plants are needed should be encouraged.

Tree Crop Establishment

Natural regeneration—Primary reliance on natural regeneration for the establishment of tree crops in the Pacific Northwest all but disappeared within the past 20 years The need for rapid reforestation made the potential delays and failures of natural regeneration unacceptable Rising costs, partial cutting, and uneven-age management, however, particularly on National Forests east of the Cascades, have renewed interest in natural regeneration

Good seed crops are usually necessary, because seed-eating birds, mammals, and insects generally consume most of the seeds (Gashwiler 1970) Seed predation, furthermore, is most serious when crops are small Good site preparation that exposes mineral soil is also necessary to optimize the chance that seeds that escape predation will produce seedlings

Predation by animals and birds does not end with germination Germinants are damaged by agents that cause little or no damage to larger seedlings Birds and mice, for example, injure or clip cotyledons and terminal buds as they remove adhering seed coats (fig 2) Small seedlings, of course, are more apt to be killed by trampling than are large ones Germinants and older natural seedlings can be protected by barriers or repellents, but the costs are so high that it is usually more economical to protect only planted seedlings that are less susceptible to the wide variety of environmental stresses As natural seedlings grow to equal size, their susceptibility to animal damage is no greater than planted stock

Direct seeding—Broadcast seeding was extensive in the 1950s and 1960s, because it was a relatively inexpensive reforestation technique Its effectiveness often depended on advance rodenticide treatment or coating seeds with animal and bird repellent When available compounds were restricted in the early 1970s because of environmental and health concerns, broadcast seeding ceased to be a viable reforestation tool Seeding is rare today, because seed is very expensive and results are too uncertain relative to those from planting Germinants resulting from direct seeding are, of course, susceptible to the same kinds of animal damage as those from natural regeneration

Planting—Planting is now the primary reforestation method throughout the Pacific Northwest, because it can be done quickly and with relatively reliable results For both economic and ecological reasons, prompt reforestation is essential Prompt reforestation shortens rotations, and seedling establishment cost less if accomplished before competing vegetation gets a firm foothold on harvested or naturally disturbed areas

Dramatic improvements in nursery practices and in seedling handling and planting in the past 20 years are, perhaps, the most significant developments in the management of animal damage These improvements are the product of public- and private-sector research, better technology transfer, and the much greater concern among land managers for seedling performance rather than merely for the number of seedlings planted Nurseries are capable now of producing high-quality stock with reasonable consistence, and ongoing refinements are designed to produce seedlings with characteristics targeted for specific sites (Rose and others 1990) (fig 5) Procedures for testing the quality of nursery stock also have been developed and refined Large-scale tree improvement programs have had a strong positive influence Much of the nursery stock now planted in the Pacific Northwest has been grown from seed representing some level of genetic improvement

Figure 5—Species and sizes ot seedlings can be targeted for conditions on specific sites

When considering potential animal damage, two general principles influence the choice of seedlings to plant: the more rapidly seedlings become established and grow beyond vulnerable size, the less damage from animals will be incurred; and the larger the seedlings, the more resistant they are to most forms of animal damage, because of both their size and rate of growth. The latter point is illustrated by 5-year results of a study in the Oregon Coast Ranges where mortality, ascribed primarily to clipping by mountain beavers, was greater the smaller the initial height and diameter of the planting stock (Stein 1984) (table 5).

Table 5—Cumulative 5-year mortality of different sizes of Douglas-fir nursery stock planted in the Oregon Coast Ranges

Initial stock size		Seedling mortality	
Length	Diameter	Not tubed	Tubed
Cm	*Mm*	*- - - - Percent - - - -*	
37	*7.0*	35	8
29	4.8	41	9
19	4.0	46	13
20	2.6	49	15

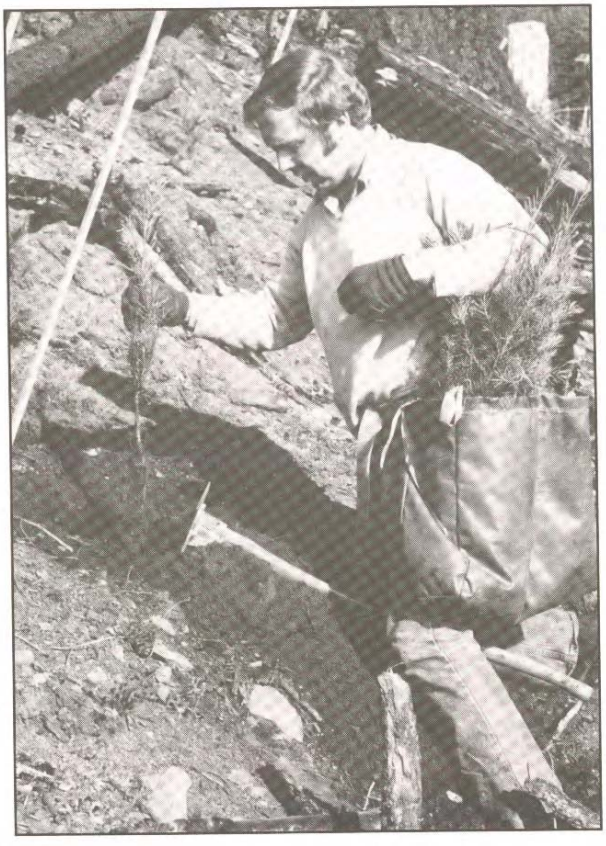

Figure 6—Planting large, high-quality stock is one of the best ways to minimize the amount and length of exposure to animal damage

Vigorous, fast-growing seedlings are best for all reforestation purposes. Guides are available for the production of seedlings (Duryea and Landis 1984, Tinus and McDonald 1979) and the evaluation of seedling quality (Duryea 1985). Research on quality control of nursery stock continues (Owston and others 1990) The objective is to produce seedlings that grow rapidly the first season after planting and that also are genetically adapted for long-term growth on the site. Large stock in good physiological condition (fig. 6) usually is required (Duddles and Owston 1990, Howard and Newton 1984, Owston 1990, Stein 1984). Browsing tends to be proportionally less severe on large seedlings than on small seedlings (Mines 1973). Thus, physiological impacts of browsing decrease with increasing seedling size. Large seedlings also tend to grow more rapidly beyond the reach of browsing animals than do small seedlings.

There sometimes are compelling reasons, however, to plant small seedlings. On droughty sites, for example, a low top/root ratio is desirable (Thompson 1985), and the soil on some sites is too rocky or shallow to plant seedlings with large roots. In these situations, some form of barrier or direct animal control may be necessary to protect seedlings. It is critically important to develop site- and situation-specific prescriptions that fully integrate all influencing factors to prevent animal damage, and follow-up damage surveys are essential to evaluate the need for further action.

Scientists have attempted to reduce feeding damage on Douglas-fir by manipulating the palatability of its foliage through fertilization and by genetic selection (Crouch and Radwan -1981, Dimock 1974, Dimock and others 1976). So far, the effects of such treatments or selections appear too small and inconsistent to be of any practical value. Even if effects were consistent, seedling selection and treatment more likely would be based on vegetative competition or growth considerations than on potential reduction in animal damage. Genetic engineering might be the most promising avenue for development of unpalatable seedlings, but rapid progress is not likely.

Some tree species definitely are more palatable than others, but choice of species usually should be based on objectives other than reduction of animal damage. Knowledge of palatability differences is useful, however, in developing integrated reforestation prescriptions. Barriers or repellents, for example, might be necessary when Douglas-fir, western redcedar, or western hemlock are planted, but not for a less palatable species such as Sitka spruce.

Proper handling and planting of seedlings also are vital aspects of an integrated approach to management of animal damage. Exposure of seedlings to drying conditions or elevated temperatures at any point, most particularly when they are out of the ground, reduces their potential for survival and vigorous early growth. Crushing or rough handling, even of seedling packages, can be deleterious. Planting must be done when weather and soil conditions prevent excessive drying of the seedlings, and roots must be deeply placed with soil packed firmly around them. Several guides" to proper care of tree seedlings are available (DeYoe 1986, Duryea and Landis 1984).

Plantation Care

Vegetation Management

Knowledgeable management of associated vegetation is critical to the success of tree plantations. Inadequate control of competing vegetation leads directly to mortality of crop trees, and thus, to poorly stocked stands. Through competition for site resources, competing vegetation also reduces tree vigor and growth, making the trees susceptible to animal damage much longer than if they were free to grow (Gourley and others 1990). Mulching, manual cutting, herbicide spraying, or grazing are the most common means of preventing or reducing competition from associated vegetation in tree plantations. Responses of vegetation and wildlife populations to release of crop trees manually or with herbicides are similar to the effects already discussed for these treatments under site preparation and planting.

Regrowth of competing vegetation can be prevented or slowed by mulching around crop trees. Several materials are effective, but a heavy kraft paper is most commonly used (McDonald and Helgerson 1991). The mulched area must be 30 inches in diameter or larger to be reasonably effective.

The appropriate use of herbicides is of particular concern to wildlife managers. Many forbs, shrubs, and hardwood trees preferred by wildlife are highly susceptible to herbicides, but through careful and selective use of chemicals, habitat can be temporarily modified enough to release crop trees and even improve forage. Herbicides also are used to induce basal sprouting of oversize browse species, but if the dead vegetation is too dense, much new forage may remain unharvested. Several recent Canadian papers are recommended for those interested in herbicide use; one reviews the effects of herbicides on wildlife forage (Batfour 1989), and the other describes methods for assessing herbicide impacts on small-mammal populations (Ritchie and Sullivan 1989).

Grazing is a biological means of achieving control of vegetation (Doescher and others 1987, McDonald 1986). Control of grazing area, animal numbers, and timing are key factors for minimizing browse damage. Benefits of properly administered grazing include maintenance of high-quality forage longer into the growing season, release of crop trees, rapid recycling of nitrogen, and (sometimes) increased availability of forage species. Terrain limits livestock grazing in some areas, whereas deer and elk feeding is limited more by their need for cover or security.

Proximity to vehicular traffic may directly influence area use by elk that are periodically subjected to hunting (Wisdom and others 1986). When roads are open, animals concentrate their activities near forest edges or on hidden benches, where over-browsing on forage species includes severe damage to trees. Road closures increase the security of animals and encourage browsing over the entire area. Undisturbed animals appear to seek out preferred forage species, thus providing more uniform and effective vegetation control. Damage still occurs where high densities of elk (or deer) are resident on an area or where tree seedlings are the only available forage.

Use of Barriers, Repellents, and Direct Control

The planting of large, vigorous nursery stock and the manipulation of habitat are not always sufficient to keep animal damage at acceptable levels. Physical protection of seedlings with plastic or wire mesh is another option. Studies on coastal sites with high populations of mountain beaver, as well as deer and elk, have shown that plastic-mesh tubes placed around seedlings improve survival and growth of several sizes of nursery stock (table 5) and with different methods of site preparation (Stein 1984,1986,1990a,1990b). Damage also can be prevented with other barriers (such as fences), repellents applied directly to seedlings, or with direct control of animals by poisoning or trapping. Discussion of these methods is not within the scope of this chapter, but guidelines are available for their use (Campbell and Evans 1984, Crouch and Frank 1979, DeYoe and others 1985, Schaap and DeYoe 1986). Once again, we must stress the need for advance prescriptions and integrated management of animal damage based on sound knowledge of the site

Plantation Evaluation

Periodic evaluation of plantation development is critical to success (Stein 1985). Initial examinations evaluate the adequacy of site preparation and planting"; subsequent examinations determine how the new stand is progressing and alert managers to additional or corrective action needed to reduce animal damage and remedy other stand-establishment problems. Plantation development should be evaluated repeatedly for at least the first 5 years. Information from all-examinations also is useful in developing prescriptions for future reforestation projects.

Summary

Successful reforestation is the product of careful planning and a coordinated sequence of silvicultural activities. The major factors that must be considered are: harvest and regeneration methods, site preparation, choice of tree species, seed source, and stock type; production and planting of seedlings; postplanting care and protection of trees; and long-term maintenance and monitoring of the plantation. Several of these factors do not apply to direct seeding or natural regeneration, but more effort may be needed to protect seeds and young germinants. Stand establishment efforts cease when required stocking has been attained and a crop of trees dominates the site.

Both physical and biological site-characteristics must be considered in planning reforestation activities. Existing and potential animal populations are a critically important site characteristic, because small plants (such as tree seedlings) are easily damaged by animals and because created-openings provide ideal habitat for many species that damage young trees. Damage impacts range from minor growth toss from browsing to substantial mortality from such causes as trampling and the clipping or girdling of stems and roots. Planted seedlings are damaged most commonly by deer and elk, mountain beaver, gophers, rabbits, hares, and voles.

Management of animal damage in new plantations has been facilitated over the past 20 years by dramatic improvements in nursery practices and in the handling and planting of seedlings. Efforts to learn how to target seedling morphology and physiological condition to specific sites continue. Planting of large, sturdy seedlings with the potential for rapid growth is one of the best and least expensive ways to avoid or mitigate the effects of animal damage in the Pacific Northwest.

Animal foraging is certain to occur on every site, and some damage to trees must be tolerated. Animals are a valuable component of forest ecosystems, and complete protection of tree seedlings is neither necessary nor feasible. On land allocated to timber production, intervention to prevent damage should be the minimum necessary to achieve adequate tree stocking and growth with the least cost. Integrated consideration of site factors and silvicultural practices are necessary for best results. Damage prevention or techniques of animal control vary with tree species, characteristics of the associated vegetation, and animal populations on the site. When planting is prescribed, it is critically important to use vigorous nursery stock and to handle and plant it with care. On sites where significant animal damage is predicted, large nursery stock with well-balanced tops and roots should be planted.

Changes in vegetation alter animal habitat. All reforestation practices, therefore, affect animal populations either directly or indirectly. Silviculturists must know how vegetation treatments will affect animal habitat, so they can use the treatments to best advantage or integrate them with more direct prevention or control measures when situations or conditions warrant. Forest management practices currently are undergoing change in response to mandates for biological diversity and retention of large trees on reforestation sites. As stand-management objectives change, keeping animal damage to tolerable levels likely will increase in complexity and require even more professional ingenuity than at present.

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SECTION THREE
SILVICULTURAL PRACTICES AND INFLUENCE ON ANIMAL DAMAGE

Chapter 8
Seed-Eating Mammals and Birds

STEPHEN D. WEST

Abstract

Many bird and mammal species consume tree seed and, collectively, they inhabit all stages of forest succession. This chapter discusses the effects of common silvicultural practices on populations of shrews, deer mice, chipmunks, ground squirrels, and granivorous birds that inhabit the primary timber-producing regions of the Pacific Northwest. The natural histories of these species vary considerably, so their relations to silvicultural practices are diverse. Some species increase and others decrease in response to a given practice. Silvicultural procedures that simplify forest environments, such as slash and snag removal or burning, may reduce populations of species (not necessarily seed-eating) that are adapted to structurally complex forests. Populations of many seed-eating birds and mammals do relatively well after such treatments, so it is possible that these procedures favor populations of seed eaters and lead to forest faunas numerically dominated by seed-eating species. The relative importance of seed consumption to stocking levels is not well understood. This relation is affected by a very complex series of events involving variable seed production, weather patterns, plant competition, seed-bed conditions (several factors), and attack by fungi and variable populations of different invertebrate and vertebrate seed eaters. Because tree seed production itself is variable, a given quantity of seed consumption may cause reproductive failures for trees in average or poor seed years, but the same quantiliy may be rather inconsequential in years when seed production is high. Stands resulting from years of good seed production often are overstocked, despite seed consumption.

STEPHEN D. WEST is associate professor, Wildlife Science Group, College of Forest Resources AR-10, University of Washington, Seattle, Washington 98195

Our understanding of this relation will remain obscure until multiyear, replicated field experiments assign losses to agents of mortality throughout the process from seed production to stand establishment. Methods for doing this are available, and they employ various animal exctosures and radio-tagged seeds. Seed losses can be minimized by reducing the consumption rate of individual seed eaters and by avoiding large populations of seed eaters in time and place. Ideas for accomplishing these goals have been suggested, but few have been tested systematically. The rate of consumption can be lowered by concealing seeds from seed eaters, providing alternate foods during seeding operations, and planting tree species with naturally low rates of seed consumption. Large populations of seed eaters can be avoided with uneven-age management methods that create forest stands capable of supporting smaller populations of seed eaters than those usually found on areas after clear-cutting, and seeding operations could take place during low points of seed-eater abundance. The consequences of seed losses could be countered by scheduling harvests during years of good seed production when more seeds are present than animals can consume.

Keywords: Granivory, birds, small mammals, Pacific Northwest, forest regeneration, animal damage.

Introduction

Granivory and Silviculture

The importance of seed consumption (granivory) to successful forest regeneration may vary a great deal, depending upon site characteristics and silvicultural procedures. There are situations (small clearcuts in early stages of succession, for example) where large populations of small mammals can substantially reduce numbers of seed. These losses, coupled with seed mortality from birds, insects, fungi, and drought conditions, can be associated with multiyear delays in forest regeneration. Many studies have documented the destruction of tree seed and assigned the losses to small mammals, and a few studies have partitioned the losses between mammals and birds. Understanding the effect of seed depredation on forest regeneration, however, has proven difficult. Any demonstration that seed depredation controls the rate of regeneration in a given case would require simultaneous investigation of the major mortality agents—a formidable task. Clear demonstration of such a controlling role, in fact, rarely has been done.

During the past several years, as discussed by Black and Lawrence (this volume), silviculturalists have relied more on planting and less on seeding programs for forest regeneration Generally speaking, planting has resulted in more rapid rates of regeneration than obtained by seeding. The difference is striking for some tree species, particularly Douglas-fir, which almost always is planted (Fiske and DeBell 1989). With the trend to planting, concerns over seed losses understandably have declined. Except for recent work in Canada, most research on the question of seed depredation hails from the 1950s and 1960s. At times, however, when survival of planted stock is poor, when costs of planting are prohibitive, or when perpetuation of locally adapted stock is an objective, regeneration from seed may be an acceptable option. Increased interest in natural seeding also may increase as silvicultural alternatives to clearcut harvesting are investigated within the context of "new forestry."

Primary and Secondary Granivores

Seed-eating is an enterprise of interest to many animal species. Some species indicated on table 1 are primarily seed and fruit consumers, while others take seed, but do not require them, and others (shrews for example) cannot survive on them exclusively. Examples of committed mammalian granivores would be deer mice, harvest mice, chipmunks, pocket mice, jumping mice, and tree squirrels

Table 1—Seed-eating mammals and birds suspected of Inhibiting the regeneration of commercial forests In the Pacific Northwest

Common name[a]	Scientific name
Shrews:	
Masked shrew*	Sorex *cinereus*
Vagrant shrew	*Sorex vagrans*
Montane shrew*	*Sorex monticolus*
Pacific shrew*	*Sorex pacificus*
Trowbridge's shrew*	*Sorex trowbridgii*
Deer mice:	
Deer mouse*	*Peromyscus maniculatus*
Forest deer mouse*	*Peromyscus oreas*
Chipmunks:	
Least chipmunk	Tarn/as *minimus*
Yellow pine chipmunk*	Tarn/as *amoenus*
Townsend's chipmunk*	Tarn/as *townsendii*
Sonoma chipmunk	Tarn/as *sonomae*
Red-tailed chipmunk	Tarn/as *ruficaudus*
Lodgepole chipmunk*	Tarn/as *speciosus*
Ground squirrels:	
California ground squirrel	*Spermophilus beecheyi*
Golden-mantled ground squirrel	*Spermophilus lateralis*
Cascade golden-mantled ground squirrel	*Spermophilus saturatus*
Birds:	
California quail	*Callipepla californica*
Mountain quail	*Oreortyx pictus*
Mourning dove	*Zenaida macroura*
Steller's jay	*Cyanocitta stelleri*
Gray jay	*Perisoreus canadensis*
Clark's nutcracker	*Nucifraga columbiana*
Red-breasted nuthatch	*Sitta canadensis*
Rufous-sided towhee*	*Pipilo erythrophthalmus*
Dark-eyed junco*	*Junco hyemalis*
Song sparrow	*Melospiza melodia*
White-crowned sparrow*	*Zonotrichia leucophrys*
Golden-crowned sparrow*	*Zonotrichia atricapilla*
Fox sparrow*	*Passerella iliaca*
Chipping sparrow*	*Spizella passerina*
Red crossbill*	*Loxia curvirostra*
White-winged crossbill	*Loxia leucoptera*
Pine grosbeak*	*Pimcola enucleator*
Evening grosbeak*	*Coccothraustes vespertinus*
Purple finch*	*Carpodacus purpureus*
Cassin's finch	*Carpodacus cassinii*
Pine siskin*	*Carduelis pinus*

[a] Species marked with asterisks probably are the most effective consumers of tree seed
Common names after Jones and others (1986), except for the forest deer mouse

(see Sullivan, this volume). Similar examples for birds would include sparrows, finches, doves, grosbeaks, juncos, and crossbills. Examples of part-time mammalian granivores would be insectivorous mammals (shrews), ground squirrels, and some voles. Avian species such as jays, some thrushes, and flickers also take seed opportunistically.

Data comparing the percentages of seed consumed among taxa of seed eaters are scarce, and have been acquired with animal exclosures and seed tagged with radionuclides (Black 1969; Gashwiler 1967,1970; Lawrence and Rediske 1962; Radvanyi 1966,1970). These studies, which were done in early stages of forest succession, generally indicate that deer mice are the most effective seed eaters, easily capable of consuming over 50 percent of seed in field situations. Chipmunks also can remove substantial percentages of seed, sometimes to nearly 40 percent, but they usually are less than half as effective as deer mice. Shrews are less effective than rodents, taking less than 10 percent of available seed. Birds appear to take about 25 percent of available seed, or roughly half as much as deer mice. Bearing in mind that such data varies greatly with seed availability or vulnerability to seed eaters and populations of seed eaters (making comparisons across successional stages especially suspect), a crude ranking of effectiveness would place deer mice at the top, followed by birds and chipmunks, shrews, and other animal groups.

Many of these mammals and birds also clip the cotyledons of newly germinated seed, or take entire young seedlings, but these activities are not discussed here. This occasionally may be a major cause of mortality (Gashwiler 1967, Noble and Shepperd 1973, Maguire 1989).

Because of the large number of species involved, this chapter usually will not address particular species unless they illustrate a group characteristic. It will discuss the effects of silvicultural practices on five groups of seed-eating animals (from table 1: shrews, deer mice, chipmunks, ground squirrels, and selected birds) and offer some approaches for minimizing seed losses. These groups do not include all mammals and birds that eat seeds, nor in some cases even species that specialize on seeds, such as the pocket mice. Treatment here is limited to those species known to eat tree seed and inhabit forest lands within primary timber-producing areas.

This chapter is written from a strongly ecological perspective. This was necessary, in part, because the effects of many silvicultural practices on small mammals and birds are poorly known, and I have made several best guesses from a personal knowledge of their natural history. The primary reason for an ecological perspective, however, is that the interactions between silvicultural practices and wildlife populations can only be well understood by knowing the habitat requirements and roles of wildlife species in these forest ecosystems. This report, therefore, will not review traditional methods of control, such as protective seed coatings or direct methods of animal control, but will focus on alternative silvicultural approaches for reducing seed depredation. As discussed by Black and Lawrence (this volume), one of the driving forces in the search for silvicultural alternatives to alleviate animal damage problems has been the increasingly stringent restrictions on the use of chemical methods for animal population control. At present, only zinc phosphide, chlorophacinone, and diphacinone are permitted for use aboveground.

Population Responses to Common Silvicultural Practices

Seed-eating mammals and birds occur in all stages of forest succession. Some species typically are found in the earliest grass/herb stages, others in the later brush/sapling stages, others in stages after canopy closure or in fully developed woodland, and still others in the full range of successional stages. In dense forests that develop complete canopies, there is a tendency to find higher numbers of some species (particularly deer mice) in old forests (>100 years postharvest or disturbance) rather than in young forests (from canopy closure to 60-70 years), but most change in species composition occurs during and just after canopy closure (West, in press). At this point in succession, the animal community shifts in response to the transition from resources associated with the plant and animal communities of open environments to the very different resources present under the forest canopy. This means that most species shifts take place within the first 20 to 30 years after harvest. Species composition, thereafter, changes relatively little, although the abundance of species may vary. In more arid environments, where a complete canopy may not develop, the species turnover between young and late successional stages may not be as pronounced.

The value of understanding such species-replacement patterns lies in predicting the effects that particular management prescriptions might have on local populations of mammals and birds. Species-replacement patterns are fairly well known for some (but not all) areas of the Pacific Northwest.

Shrews

The Pacific Northwest has many shrew species, particularly in the forests west of the Cascade Range crest. As a group they are small bodied (ranging from 1/7 to about 1/3 ounce), short lived (usually less than 1 year), and active in all seasons They consume foods of high energy content, primarily invertebrates, although they are capable of taking very young vertebrates and even other shrews. Forest-dwelling species are known to consume tree seed. The habitat associations of shrews are varied, so their response to habitat modifications associated with timber harvest also are varied. Some species (the vagrant shrew, for example) are found in open environments, often in meadows or early stages of forest succession and occasionally in wetlands. Others, like the Trowbridge's shrew, primarily inhabit closed-canopy forest. A third group of species can be found in several habitats. In Washington and Oregon, the montane shrew would be an example of one such habitat generalist.

Harvesting—Under different plans for even-age management, the amount of original tree canopy and ground-level vegetation left after harvest can vary considerably. Substantial portions of forest canopy as well as ground-level vegetation can remain after shelterwood cuts, particularly near unharvested trees. Much less of the canopy and undisturbed ground is left following most seed-tree operations, and clearcuts, of course, generally leave very little habitat undisturbed. Because populations of different shrew species respond to the resultant habitats according to their particular needs, one expects that the shrew component of the small mammal community on the recently harvested area would differ from that present in the forest before harvest. How much different the postharvest community will be depends on the degree of habitat alteration.

Populations of forest-dwelling species will not persist below a threshold of canopy coverage and associated conditions of the forest floor. Species that require open habitats, similarly, become locally uncommon as the ground-level conditions become unfavorable for plants of low-growth form during canopy development and closure. It is possible that well-stocked shelterwood systems may support shrew populations

that are very similar to those in forests. On the other hand, seed-tree operations typically result in extensive alterations at ground level that are more characteristic of clearcuts than shelterwoods. Accordingly, one would expect to lose forest-dwelling species over the course of a year or two after harvest and acquire a shrew community of habitat generalists and perhaps a species favoring early successional conditions. Whether and how quickly the harvested area is colonized by a species characteristic of early successional stages depends upon the distance to the nearest source population.

Uneven-age management in dense forest may not alter the existing shrew community at all. In operations where individual trees or small groups are harvested and forest-floor vegetation is not greatly altered (a process that mimics natural patterns of tree replacement) forest habitat for shrews basically will be unchanged. Similarly, uneven-age management in open stands would have little effect.

Site preparations—Slash and stump removal have similar effects on shrew populations, although the duration of the effects differs. Shrews require overhead cover, both as protection from their predators and to provide their prey with suitable microsites Many shrews inhabit the interiors of rotting logs, where they seek a variety of arthropods. Shrews are not common on areas characterized by extensive bare ground. Slash removal temporarily decreases habitat quality for shrews, contributing to low abundance and diversity, but subsequent plant growth partially replaces cover lost in this way. Depending upon the course of plant succession, suitable cover may develop quickly if grasses and herbs dominate the ground cover or more slowly if shrubs become the primary ground cover. Stumps are valuable habitat elements for shrews, because they provide suitable cover and foraging sites for many generations. If policies of stump removal are followed in successive harvests, these habitat elements are lost, leading to permanent reductions in the abundance and diversity of shrews.

Burning after harvest may have short- and long-term effects on shrew populations. The persistence of reduced populations of forest-dwelling shrews after a burn is a function of burn intensity, uniformity, and the subsequent rate of plant succession. Population growth occurs earlier on light and typically patchy burns and on sites with growing conditions that promote rapid succession than on heavily burned sites. After short-term population reductions, however, shrew abundance may match or exceed that on forested sites, although shrews of general habitat affinities and those favoring open habitats may have replaced forest-dwelling species. Intense burning may lead to a prolonged grass/herb stage and magnify these effects. Such increases in the abundance of grassland-dwelling shrews are supported by elevated plant productivity at ground level, which supports high populations of invertebrate prey. A long-term effect of burning may be to reduce the value of large, woody debris as a habitat element for shrews by hardening the wood and slowing its rate of decomposition. This results in lowered abundance of invertebrate prey and makes burrowing into the log more difficult for shrews.

Without appropriate studies, the effects of scarification (removal of duff to expose mineral soil) on shrew populations are difficult to assess. Most scarification is done in early successional stages, so it affects shrews adapted for grassland/herb environments. These species create burrows and runways within the layer of dead vegetation that develops at ground level, and they use the burrows and runways created by vole species *(Microtus)* that inhabit these successional stages. Scarification has

relatively little effect on these shrew populations beyond the negative effects of reduced surface cover, as discussed above. Such ground disturbance may have a short-term negative effect on their populations, but scarification often enhances the growth of grasses and herbs, and it may enhance the habitat quality of shrews favoring open habitats. The use of herbicides to control vegetation competing with trees may, temporarily, lower habitat quality for shrews by selectively reducing the cover and productivity of ground-level vegetation.

Thinning—The effects of thinning on shrew populations are not clear a *priori.* Shrew populations may decrease in proportion to the amount of surface disturbance associated with the operation, or increase with heightened ground-level productivity promoted by increased ground insolation. Replicated censuses in thinned and unthinned stands will be required to answer this question. Precommercial thinning may benefit shrews, though no studies document this relation. Felled trees provide increased cover, and the reduced canopy promotes ground-level productivity. Commercial thinning also reduces the canopy, but it is associated with much more ground disturbance that may reduce shrew populations for a few years. If extensive, it may lead to the establishment of shrew species normally found in early successional stages. On balance, however, I suspect that population gains resulting from enhanced ground-level production eventually may outweigh the short-term losses.

Deer mice

Deer mice, collectively, are the most renowned mammalian seed eaters in the Pacific Northwest. There are many deer mouse species in this region, especially if one considers species that use the low-elevation forests of California. In coniferous forests, however, there are two species of particular concern (table 1). As new species are identified from the coastal forests of British Columbia, this number will increase.

Deer mice do not hibernate, although they may become relatively inactive in very cold weather. They are primarily nocturnal. Their potential lifespan is longer than the shrews, but it infrequently exceeds 1 to 1.5 years. Deer mice inhabit all stages of forest succession, and in common with Trowbridge's and montane shrews and red-backed voles, they are the most abundant species in coniferous forests (Aubry and others, in press; West, in press). They have varied diets, which certainly is a key factor in their wide distribution. Deer mice take invertebrates whenever possible, but the bulk of their diet usually consists of fruits, seeds, and other vegetable matter. They are not strict herbivores as are many vole species. Regarding tree seeds, deer mice prefer large and apparently less resinous ones. Captive-feeding trials and fieldwork with deer mice have shown they generally prefer (in decreasing order) the seeds of pines, Douglas-fir, hemlocks, and spruces, but they dislike the seeds of western redcedar, true firs, and larch (Gashwiler 1967; Black 1969). One deer mouse is capable of consuming and caching hundreds of seeds per night.

Harvesting—Deer mice usually are most abundant during the early stages of forest succession. They often are the first species to reach appreciable numbers after harvest or fire. Brush fields are especially good habitat, although deer mice are less common where grasses and herbs form complete ground covers. Deer mice are usually less abundant in closed-canopy forest, but they are still one of the most abundant species in this stage.

Even-age management that removes all or most of the canopy and forest-floor ground cover produces near perfect habitat for deer mice It is likely that deer mouse

populations are at all time highs throughout the Pacific Northwest. They inhabit the late stages of forest succession and easily survive harvest operations by retreating betowground, so rapid population growth within harvested areas is assured.

I am unaware of work on the population response of deer mice in this region to uneven-age management. There would seem to be little to encourage the growth of deer mouse populations to the extent that woodland conditions and ground cover remain relatively undisturbed after harvest. Increased disturbance should increase habitat quality for deer mice.

Site **preparation**—Like shrews, deer mice use woody debris extensively, but because of their larger body size, deer mice do not benefit as much as shrews from small debris (about 4 to 6 inches in diameter or less), instead, they find medium (6 to 20 inches in diameter) and large debris (greater than 20 inches in diameter) valuable for nest sites and protective cover. Stumps are especially valuable habitat elements for deer mice. Radiotelemetry in a second-growth Douglas-fir forest has indicated that many nest sites for deer mice are located in large stumps [personal observation].

Some individuals may survive and persist following severe burning, but populations comparable to prebum levels of abundance may be delayed until vegetation has developed to provide sufficient cover and food. Deer mice forage on burned areas almost as soon as these sites cool down. Individuals from adjacent lightly burned or unburned habitat use burned areas intermittently, as do individuals residing in unburned patches within the larger burned area. Despite the potential for short-term delays in site occupancy, deer mice are one of the first species to inhabit such areas permanently.

Scarification probably has little effect on populations of deer mice. It could be a short-term advantage in improving access to food supplies if soil seed banks are exposed, and the resulting bare ground, conceivably, could improve their efficiency in finding sown tree seed.

Herbicide treatment may affect deer mouse populations differently, depending upon plant-community composition and its response to the herbicide. Different studies of the population response of deer mice following herbicide treatment have shown decreases (Ritchie and others 1987), increases (Borrecco and others 1979), and little change in abundance (Anthony and Morrison 1985). One suspects that the different responses reflect differences in plant-community composition (site and time since disturbance), variations in the effectiveness of herbicide treatment, and differences in sampling design, rather than local differences in deer mouse response to habitat alterations. Herbicide treatments that do not prevent development of shrub cover and moderate cover of grasses and herbs are favorable for deer mice. Those that are successful in greatly reducing these habitat elements lead to temporary decreases in deer mouse abundance. Because of the characteristically rapid growth of plants during early succession and the high aptitude of deer mice for colonization, even successful herbicide treatments are short lived, and reduce populations for two or three years at best.

Thinning—Canopy reductions probably help populations of deer mice by increasing plant productivity at ground level. Development of a dense shrub cover also favors deer mice. Thinning might have one potential disadvantage for deer mouse populations if it removes fruit or seed-producing subcanopy trees and results in the loss of potential food resources.

Chipmunks

With the exception of the Townsend's chipmunk, which is present in closed-canopy forests, chipmunk populations are most abundant in early stages of forest succession or in environments with discontinuous canopies. Within forests, they tend to center activities along forest edges or openings and in talus. Chipmunks are larger than deer mice, have longer potential lifespans, and hibernate intermittently in response to snow cover. They are active during the day and seek a variety of plant and animal material, including seeds, fruits, fungi, and insects. Townsend's chipmunk is semi-arboreal and may take seeds from the tree canopy, but other species are basically ground-dwelling. Chipmunks cache seeds and use them (along with other stored food) during hibernation.

Harvesting—Some chipmunk species may benefit from even-age management, while others may not. For species favoring open environments, a harvest plan that maintains a patchwork of young, precanopy stands within a closed-canopy forest provides acceptable habitat. This is the case for the yellow-pine chipmunk among higher elevation stands west of the Cascade Range crest. The Townsend's chipmunk, on the other hand, would lose habitat under the same circumstances, because it prefers conditions associated with closed-canopy forest. There appears to be a gradient in the degree of dependency that the Townsend's chipmunk shows toward well-developed forest. In drier, southern portions of its range Townsend's chipmunk seems fairly restricted to forest. Father north, however, under moist conditions, it frequently is found in early successional stages and may be more numerous there than in nearby forest (West, in press).

Uneven-age management, as generally practiced on open, mixed-conifer stands, most likely has little effect on chipmunk populations. Such management on dense stands probably would be beneficial by creating the small forest gaps favored by chipmunks.

Site preparations—Chipmunks use large, woody debris extensively for nesting, feeding, lookout posts, and as movement routes. Large rocks and the crevices between them can serve many of these functions, but in their absence, elimination of downed wood and stumps would lower habitat suitability. Chipmunks, because of their larger body size, require larger debris than shrews and deer mice.

Chipmunks respond to burning after harvest much like deer mice. Depending upon the severity of the bum, chipmunk populations either are reduced for a couple of growing seasons, or they increase if the burning is followed quickly by a flush of plant growth. Burns of light and medium intensity may be beneficial if they stimulate herbaceous growth, but a severe burn that consumes most large, woody debris probably is not beneficial.

Chipmunk numbers sampled in studies of herbicide effects on small mammal communities (Black and Hooven 1974) typically were too low to clearly indicate population responses. It is likely that populations are only slightly affected by herbicide, unless the treatment severely reduces vegetation. Even in such cases, the chipmunk population regains its former density after a couple of growing seasons without repeated treatment.

I am unaware of studies that assess the effects of scarification on chipmunk populations. Judging from the natural history of chipmunks, however, I would not expect the effect to be substantial or long lasting.

Thinning—On balance, thinning operations probably are beneficial to chipmunks. Chipmunk populations should respond favorably to an opened canopy and the resulting increase in plant production at ground level. A potentially detrimental effect on chipmunk populations might be the loss of some food resources if fruit-producing trees are removed.

Ground Squirrels

Of the five groups considered in this chapter, ground squirrels probably are the least effective seed eaters; although, with their colonial tendencies, they can be a conspicuous element of the forest fauna. Ground squirrels, collectively, have the largest body size of the five groups, and the golden-mantled squirrels are about half the size of the California ground squirrel (table 1). The two smaller species are most common in dry, open forest, forest edge, and especially in meadows east of the Cascade crest. On forested areas, the California ground squirrel is found in early successional sites, and it occupies low elevation sites as well. All are active in daylight. They enter burrows and hibernate in response to snowfall, but they often may emerge from burrow systems well before snowmelt of the following spring. Rather than creating problems for forest regeneration, California ground squirrels have earned recognition as pests of agricultural fields and orchards.

Diets are broad for the group, but the golden-mantled squirrels tend to rely more upon fungi, fruits, herbs, and grass, while the California ground squirrel seeks fruits and nuts, grains, and green vegetation, including a wide variety of agricultural crops. All these squirrels supplement their diets with animal material. They consume tree seeds opportunistically, but their effectiveness as seed eaters is reduced, because they are inactive for much of the year, do not specialize on tree seed, and have less abundant populations than most smaller species.

Harvesting—The effect of even-aged harvests on species of ground squirrels probably differs in degree rather than in kind. Golden-mantled squirrels are present but less abundant in closed-canopy forests than in meadows. In open environments, they still require some form of cover: either large, woody debris, or rocks and talus. Given sufficient ground cover, golden-mantled squirrels would benefit somewhat from even-age management. Much greater benefit, however, would be realized by the California ground squirrel, which reaches highest abundance in open environments and benefits from the creation of extensive clearcuts. Uneven-age management in dense forest would be beneficial to ground squirrels, but it would have little influence in open forest.

Site preparations—Removal of large woody debris reduces habitat quality for golden-mantled ground squirrels, but the effect is not as critical as for smaller mammals. Optimal conditions for this species are lush meadows with substantial cover in the form of rocks and large, woody debris, but meadows without cover are used to a lesser extent The presence of nonvegetative cover probably is not as important for California ground squirrels as for this species.

We have almost no information on the individual effects of burning, herbicide treatment, and scarification on ground-squirrel populations. This is, in part, because areas where the smaller species were studied were too small to provide a good sample of the ground squirrels Burning probably has only short-term, negative effects on ground-squirrel populations. Depending upon the severity of the burn and the subse-

quent rate of plant growth, populations would increase, most likely in excess of those on unburned sites. The increased abundance and quality of forage on burned areas might be exceptionally favorable to California ground squirrels. As long as herbicide effects were in force, lowered populations of ground squirrels would be likely, but scarification probably would not have much effect on ground squirrel populations unless the prescription called for the removal of large woody debris. As discussed above, this might negatively affect golden-mantled ground squirrels.

Thinning—Reductions in canopy cover in dense stands probably would be beneficial for golden-mantled squirrels. This judgment is based on the observation that population abundance tends to be higher in areas of open canopy (Trombulak 1988). I am unaware of studies that directly address the issue of thinning on the population response of ground squirrels. California ground squirrels are found primarily on open areas, so thinning should have little influence on them, and they might not inhabit the forest even after thinning.

Birds

Literally scores of bird species are known to consume tree seed both before and after the seed reaches the ground (Smith and Aldous 1947). Of the small research effort directed toward seed consumption by birds, most attention has focused on ground-foraging birds. It is not clear what percentage of seeds in wild stands are removed by birds (such as crossbills, grosbeaks, band-tailed pigeons, red-breasted nuthatches, finches, and siskins) while seeds are still held by cones, although reports from seed orchards indicate that the losses can be substantial (Black, personal communication). That these species are reliant upon seed crops is supported by the observation that they may leave regions experiencing major cone-crop failures (Bock and Lepthien 1976). Research simply has not been done in the canopy, because the incidence of seed depredation is viewed as infrequent and largely unpredictable. This is partly because canopy-foraging birds are migratory, forming fall and winter flocks. Flocks may not visit the same sites every year, and the size of fall flocks may vary in response to factors unrelated to seed crops.

Compared to canopy foragers, more ground-foraging birds are resident species, or they adjust to seasonal changes with elevational movements rather than extensive migrations. This means that they are present on an area longer each year, and they may be more evenly dispersed on the landscape. Attempts to measure losses of seeds to ground-foraging birds occasionally have been made, but with varied results. Losses to birds on some areas were considered high (Hagar 1960), but quantification of losses generally are absent, with the exception of Black (1969), who considered seed losses rather variable and minor. Part of the problem in obtaining good data is the difficulty of distinguishing between seeds lost to birds and mammals. Species most frequently cited as responsible for seed losses include juncos, sparrows, finches, thrushes, and doves (Eastman 1960, Gashwiler 1967, Black 1969).

Harvesting—As with seed-eating rodents, most ground-foraging, avian seed-eaters reach greatest abundance in early successional stages. Open environments of grassland and brush are very attractive to sparrows, juncos, finches, and doves. Some species find all needed resources in such environments, while others obtain a mix of resources from fields and adjacent forest edges. Harvest procedures that convert large areas to early successional stages, therefore, favor these species (Wight 1974).

There are no completed studies that have systematically looked at differences in avian communities during the initial decades following even- and uneven-aged harvests. One might guess that the incomplete conversion of forest habitat resulting from uneven-age management would be less favorable to many ground-foraging granivores and might lead to decreased seed losses. Preliminary results from an ongoing study in Oregon are consistent with this hypothesis (McComb, personal communication). If so, and if birds are shown to be effective agents thwarting forest regeneration, then levels of harvest could be adjusted below those promoting large populations of granivorous birds.

Site preparations—The effects of site treatments after harvest on ground-foraging birds have not been examined systematically. No information has been gathered for the effects of wood removal or scarification. There is some data for the effects of fire and herbicide treatment. Wood removal probably is less important for granivorous birds than for mammals. While some perching sites are lost to this treatment, I view it as rather neutral for this avian group. This, clearly, is a serious and negative influence on populations of many other birds that use the wood as a foraging substrate. Scarification might be beneficial to granivorous birds in the short term, as seeds from the duff and soil are exposed. The ground surface is simplified on the scarified zones, and seeds are easily detected, so foraging efficiency might increase. Over a longer term, scarified areas could either improve or decrease habitat quality, depending upon the composition of the invading plant communities.

There are a few studies in this region that have investigated the pattern of avian community development following forest fire (see Huff 1984). These cases differ significantly from a slash-burn treatment in that much more wood is present on unharvested areas after the fire, both on the ground and standing. This undoubtedly influences avian colonization and renders inferences from the available literature suspect. We lack properly replicated comparisons of avian communities on burned and unburned, harvested sites. This having been said, I suspect that more intense burns, which can enhance grass/forb successional stages, might favor those granivores specializing on seeds of herbaceous plants. This could result in larger populations of tree-seed eaters.

Under conditions of moderate herbicide effectiveness in western Oregon, avian density and diversity was similar on sites treated with phenoxy herbicide and on untreated sites (Morrison 1982). Populations of ground-foraging species showed inconsistent differences between treated and untreated sites, with the exception of the white-crowned sparrow, which was more abundant on treated sites. I am unaware of replicated studies that have looked at avian response on areas effectively treated with herbicides. Herbicides simplify habitat structure, so I suspect that the resultant environments temporarily might favor ground-foraging birds

Thinning—Effects of thinning on bird communities are just now being addressed in this region. Preliminary results for second-growth, western hemlock forests show few differences in the composition of avian communities on thinned and unthinned stands (Artman 1990; McComb, personal communiication). There are, however, differences in abundance for some species Repeating a similar pattern in Finnish boreal forest and in ponderosa pine forests in Arizona, thinning tends to enhance populations of ground-foraging birds. In the hemlock forests of western Washington, dark-eyed juncos were more abundant in thinned than in unthinned stands (Artman 1990).

Recognition and Assessment of Animal Damage

As previously recognized (Black 1969), there are many reasons why our understanding of seed depredation is rather poor. Mortality of seed, whether artificially or naturally dispersed, is a complex phenomenon involving weather patterns, plant competition, seed-bed conditions (several factors), and attack by fungi, invertebrates, and vertebrates. These factors may act simultaneously, although the relative importance of any given factor may vary spatially and temporally. These influences must be addressed in studies of seed mortality if we are to understand the process. With some exceptions, this has not been done.

Regeneration bottlenecks must be identified rather than assumed. The capacity for seed consumption by vertebrates (mainly caged, small rodents) too frequently has been substituted for field measurements of consumption. It is clear that caged rodents can consume prodigious quantities of seed, but the relation of this potential to actual field consumption and, most importantly, its consequences for forest regeneration, frequently is not clear. The role of animal-caused mortality in the failure of a given case of regeneration rarely is clear because of the additional sources of mortality after germination. In studies of seed depredation, these usually are not addressed.

The best documented cases of seed depredation and the effect that this has on forest regeneration have been done with exclosures and radio-tagged seeds (Gashwiler 1967,1970; Black 1969; Lawrence and Rediske 1959,1962; Radvanyi 1966,1970, 1971). By constructing barriers that differentially restrict the movement of animal species into seed traps, it is possible to assess seed losses to individual species. These techniques require a good deal of effort, but they are needed to partition seed losses. Marking seeds with radioactive trace elements has allowed estimates of toss through relocation of individual seeds. When seed eaters open the seed coats and leave characteristic signs, it is possible to assign tosses to particular groups of seed eaters. While the technical tools are at hand, they have not been used sufficiently in comprehensive programs addressing the fate of seeds from seed-fall or sowing through germination and establishment. Until this is done in the different environments of the primary tree-growing regions, the relative importance of seed depredation in the process of forest regeneration largely will remain unpredictable.

Suggestions for Minimizing Seed Losses

This chapter treats seed survival and successful regeneration as the balance between viable seed production and losses due to seed eaters. This is admittedly simplistic, because many additional factors influence this interaction and act independently on seed production or seed-eater populations. Any one of these factors could have overriding effects on regeneration in a given case. Long-term field experiments are needed to identify factors that are consistently important

The survival of viable seed is subject to many factors; therefore, regeneration is an inherently variable process. The probability of successful regeneration, minimally, is a function of good seed production and low consumption of seeds by seed eaters. From a silvicultural perspective, and similarly from a rangeland perspective (Everett and Monsen, in press), the trick is to combine these two conditions. Low seed consumption can be obtained by reducing the per capita rate of seed consumption or by avoiding large populations of seed eaters.

Seed production is episodic for many tree species (Fowells 1965); therefore, the effectiveness of predation varies. Seed eaters, typically, are most effective in consuming high proportions of seed in years of low seed production. If forest disturbance (or harvest) happens to precede a year of high seed production, rapid establishment

is likely. Animals are not completely efficient at locating all seed and simply are incapable of destroying all seed in a good seed year. A fairly low proportion of the seed available in a good year are needed to reach adequate stocking levels, and under these conditions, naturally regenerated stands often are overstocked. Even seeds that are located and cached may not be consumed, either because they were not relocated by the animal (rather unlikely) or perhaps because of the animal's death (quite likely). Turnover of individuals in small mammal populations is very high, particularly during their spring and summer breeding seasons, and it seems unlikely that a new territory owner would find every cache left by the previous owner. Cached seeds, in effect, are planted, and they may germinate and grow successfully. If poor seed crops follow a disturbance, it may be many years before seedling density is adequate. On average, except for tree species with consistent yearly seed production and relatively few seed eaters (perhaps western redcedar, Sitka spruce, and western hemlock), one should not expect adequate regeneration from natural sources in a given year. An interesting exception to this observation may be the enhanced seed production that has been noted for trees remaining in shelterwood harvests (Williamson 1973). Broadcast seeding operations with seeding rates similar to rates of average or poor production of natural seed usually are unsuccessful. If seeding cannot be done at rates comparable to seed production in good years, and if rapid establishment is imperative, planting seems in order.

Reducing The Rate of Consumption

In terms of reducing seed consumption by individual seed eaters, a number of approaches have been suggested, although few have been tested systematically. Probably the simplest suggestion is to seed tree species that have low appeal for rodents and birds. This clearly is a suggestion with limited application, but it bears mentioning as a reminder that rates of predation for some species (such as western redcedar, larch, and true fir) are low Minore (1986) has shown that this may not always be the case for true fir. In locations where such tree species are acceptable, seeding operations might be simple and successful.

Seed survival may depend as much upon microsite characteristics (good seed bed conditions, concealment from seed eaters) as on the simple abundance of granivores. Do seeds in soil depressions or covered with a mulch layer, soil, small or large debris, or even snow fare better than exposed seeds? It might be instructive to focus on various physical differences between successful and unsuccessful microsites. If such differences were known, more successful seeding procedures could be developed.

Hall (1967), for example, concealed ponderosa pine seed by simply covering it with soil and found a twofold increase in seedling establishment on plots with covered seed over seedlings established on plots with uncovered seed. What proportion of this difference was due to losses to seed eaters versus increased survival due to improved microclimatic conditions, unfortunately, is not clear. Soil cover would improve seed survival by reducing both these mortality sources; therefore, the procedure might be worth consideration elsewhere. Birds rely more upon sight than smell, so this approach could reduce avian predation rates substantially.

Alternative foods (sunflower seeds) have been investigated for reducing the predation rate on Douglas-fir and lodgepole pine (Sullivan 1979, Sullivan and Sullivan 1982). The technique was successful on some plots but marginally helpful on others. The general approach is worth testing in different forests with attention to the kind of alternative food, to the effect of abundant, alternative foods on seed-eater populations, and to the costs of alternative foods in relation to tree seed sown at higher rates.

Avoiding Large Populations of Seed Eaters

In addition to minimizing the number of seeds taken by individual seed eaters, one also wants to avoid large populations of seed eaters, both in time and place. The typical pattern of animal abundance in the Pacific Northwest is a simple annual cycle, with a population peak in the fall following spring and summer breeding periods and a population low in early spring that precedes reproduction of the current year and reflects the mortality of the previous winter. The magnitude of the population peak varies from year to year, but the annual cycle usually is present.

The timing of seeding clearly is an area requiring further investigation. High predation rates might be avoided by sowing appropriately stratified seeds when seed-eater populations are at annual low points, such as late winter or spring (Janzen 1971). Radvanyi (1970) found that seed loss was more closely related to the timing of seeding than the population abundance of seed eaters. Adjusting the timing of seeding is simple and may prove very cost-effective. A related suggestion for regions with persistent snow cover is to sow in late winter or early spring to combine concealment of seed by snow (Radvanyi 1970,1971) with low population abundance (Sullivan and Sullivan 1982).

Over longer time frames, harvest operations could be scheduled during good seed years when seed production would be sufficient to overcome losses due to seed eaters (Janzen 1971, Shearer and Schmidt 1971). This approach potentially would be effective, but, it would be more costly, because it would require monitoring of seed crops and scheduling of harvests accordingly. On very difficult sites, one might opt for an uneven-age management strategy or forego harvest altogether.

Uneven-age management creates less suitable habitat for many seed eaters than created by even-age management, because species of seed eaters with the highest potential for seed depredation reach highest population densities in early stages of forest succession. Such locally high populations not only cause higher seed mortality within a recently harvested area, but they also serve as source populations that contribute to rapid colonization and population growth in adjacent areas following harvests, because individuals move from areas of high abundance to areas of low abundance. By avoiding the locally high populations of seed eaters that develop on early successional areas, uneven-age management might lower depredation rates over large areas

Removal of woody debris superticially appears to be a good strategy for reducing populations of most mammalian granivores. Removal of cover certainly reduces granivorous small-mammal populations on a short-term basis (measured in months on productive sites). Aside from the question of whether the reduction in population is long enough to be effective, the practice may result in cumulative problems, because pest species (the best granivores) are better at colonizing simplified habitats and recovering from population reductions than are most nonpest species. The cumulative effects of habitat simplification resulting from debris removal, heavy burning, and herbicide application is most effective against nonpest species. Over time, they could lead to a reduced number of species and more communities disproportionately composed of pest species. Before making a blanket recommendation for habitat simplification, a well-designed research program is needed to allay these concerns. Without such work, it may be imprudent to employ such measures widely on public lands where concern for persistence of native wildlife increasingly is an important issue.

Future Research

Virtually all aspects of the relation between granivory and silviculture would benefit from additional research. The suggestions for reducing seed losses (above) reflect this fact, in that most are ideas for experimentation and refinement rather than established procedures. Seed predation is a complex process; therefore, its investigation requires greater effort than expended so far. An extension of the time frame over which research is done is of primary importance. We are interested in circumstances that produce acceptable stocking levels. As discussed above ("Recognition and Assessment of Animal Damage"), studies of seed production or consumption are only a part of the story. Such studies, to be effective, should be appropriately replicated, relatively long term, and cooperative, involving silviculturalists and wildlife biologists (West and others 1980).

We need a better understanding of the replacement patterns of wildlife species during forest succession for most regions. This must include some knowledge of the threshold values for habitat elements critical for particular species. Anticipating the responses of wildlife populations to novel silvicultural prescriptions cannot be done without this information.

A very promising area for research is the timing of seeding. Both annual (late winter or spring) seedings and the timing of harvest relative to multiyear cycles of seed production are worthy of research. The approach holds promise of substantially increasing seed survival at low operational and ecological cost. It would require no modification or simplification of habitat structure and would essentially mimic natural regeneration by allowing seeds either to escape being eaten when seed-eater populations are low or to overwhelm losses from seed eaters when seed crops are good.

Uneven-age management strategies, finally, may be worthy of further consideration from the standpoint of improving forest regeneration by reducing seed loss to birds and mammals and perhaps improving the survival of seedlings, particularly on sites with harsh growing conditions (Williamson 1973; Williamson and Minore 1978). The most effective seed eaters might not find habitats capable of sustaining extremely large populations, and a source of seeds always would be available on site.

Summary

In response to unreliable forest regeneration after early seeding efforts, caused in part by intermittent seed production and losses to seed eaters, planting has become the primary means of reforestation for many tree species. Planting will continue to be the method of choice, but a better understanding of seed production and predation could improve the success rate of seeding operations. Perhaps more importantly, this knowledge could enhance the chances for success of natural regeneration.

Population responses of seed-eating birds and mammals and their effects upon silvicultural practices vary as functions of their natural history. A knowledge of species' responses to changes in habitat structure is helpful in predicting responses to silvicultural treatments. The interactions between silvicultural practices and seed-eating animals, therefore, are complex. Often they must be considered at the species level or at the level of species groups that share response patterns. Our present state of knowledge regarding the consequences of seed consumption on stocking levels is insufficient. Correlations between seed losses and animal abundance are poor, and our ecological knowledge frequently is inadequate to predict population responses of granivores to silvicultural treatments. Long-term, well-replicated work is needed to answer these questions.

Seed losses can be minimized by diverse approaches that reduce the consumption rate of seeds or avoid large populations of seed eaters. Avoidance of seed eaters can be by direct means, such as population control, or by indirect means, such as timing seeding operations at times when populations of seed eaters are low. Research is needed on the topics of seed concealment from seed eaters, on the provision of sacrifice or alternative foods during seeding, and especially on the timing of seeding. By seeding at low points in the annual population cycle, regeneration may be obtained without recourse to habitat modifications or direct measures of animal control. Similar advantages may be gained by monitoring seed production and scheduling harvests during years of high seed production, thereby taking advantage of seed quantities that exceed the consumption capacity of seed eaters.

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO SELECTED WILDLIFE SPECIES

Chapter 9
Voles

LEONARD R.ASKHAM

Abstract

Voles can be a significant forest-management problem in newly established plantations. Thirteen different species of voles have been identified in the Western United States and Canada, but the Oregon, longtail, and mountain voles present the greatest management challenge. Voles cause little damage in their natural habitats. They build extensive burrow systems and feed on grasses and forbs aboveground and belowground throughout the year. With optimal habitat changes, however, they seriously threaten new plantations. Populations rapidly expand. Competition for food intensifies. Soon, the burrow systems are expanded and feeding shifts to newly planted conifer roots as grass and forb roots become less palatable or scarcer. Once these burrow systems are established, feeding on tree roots continues throughout the winter and, particularly, while the upper regions of the soil profile remain frozen. As roots and the remainder of aboveground forage become less available, the animals begin feeding on newly planted trees and, particularly, those surrounded by dense thatch or heavy snow. By spring, the trees are completely girdled and the roots destroyed. The reduction of vole damage

LEONARD R. ASKHAM is vertebrate pest management specialist, Department of Horticulture and Landscape Architecture, Washington State University, Pullman, WA 99164.

requires a basic understanding of habitat management. Once this is understood, planning can begin for a combination of vegetative changes that will make the site less inhabitable for rodents. This chapter also discusses direct control and integrated strategies applicable to four common problems of reforestation.

Keywords: Voles, meadow mice, forest plantations, management, *Microtus, Phenacomys, Clethrionomys,* habitat, behavior.

Introduction

Goals and Objectives

The information presented in this chapter describes the care and feeding of voles. It describes the difference between these animals, where and how they live, what kinds of damage they can do in forests, and how their impact can be managed with direct and indirect cultural practices.

Damage

Voles, much like pocket gophers, damage forest plantations by feeding on young tree roots, and much like rabbits and porcupines, by feeding on stems. The difference is that porcupines generally clip stems at a 45-degree angle, while voles leave more of a pointed tip. Another difference is that rabbits leave large, angular toothmarks and sometimes wood chips at the bottom of the tree when they feed on stems. Voles, on the other hand, leave small whorled or circular marks on the cambium and small chips after feeding. Damage, however, often is not apparent until needles turn brown the following spring. Damage sometimes can only be determined by pulling trees from the ground and inspecting their roots. Gophers generally consume entire roots from larger trees by clipping them off at an angle. Voles, on the other hand, begin by stripping cambium from the roots and leaving pointed root tips. Other damage is only apparent from physical inspections of root collars. Voles often feed up the roots to the soil surface just below the litter, where they are protected from predators and weather while girdling the tree.

Damage can be moderate or extensive. Moderate damage, which is generally limited to a few trees around the border of the plantation, can be detected by poor tree-growth and vigor. Extensive damage, however, covers many acres. Sullivan and Martin (1990), for example, found that 41 percent of forest plantations studied in British Columbia were not restocked satisfactorily because of vole damage. Planted trees were attacked significantly more often than trees originating from natural regeneration. Site preparation on susceptible plantations, they concluded, generally had been either mechanical or nonexistent. Postharvest debris, consequently, was highly complex with limited vegetative cover. Older plantations with serious damage, furthermore, had high levels of vegetative complexity. In another study in China, radial growth was reduced 27.5 percent, and height growth was reduced 30.5 percent in sublethally damaged plantations (Sullivan and others 1990).

Vole Biology

Identification, Distribution and Habitat

Voles, often called meadow mice, are one of the most common rodents encountered in reforestation work. They are easily identified by their small beady eyes, flat ears and short tails that generally are half as long as their bodies. Taxonomists have separated voles into three genera: *Phenacomys, Clethrionomys* and *Microtus.* Each is a distinct group with several species (and possible subspecies) that are described with more detail in standard keys and texts (for example, Bun and Grossenheider 1976). All three genera can be found in the Western United States.

The Pacific, tree, and mountain *Phenacomys* (figs. 1,2, and 3) are generally 2.5 to 3.5 inches long and weigh about 1 ounce. The Pacific vole prefers dense forests near small streams. The tree vole is an arboreal species with a diet almost entirely consisting of spruce, hemlock, and fir needles. The mountain vole, on the other hand, is not as restricted as the former two. It can be found in several different habitat types, such as open grassy areas near mountaintops, some pine and spruce forests on rocky slopes, in dry areas, or near water. In general, none is considered a significant pest.

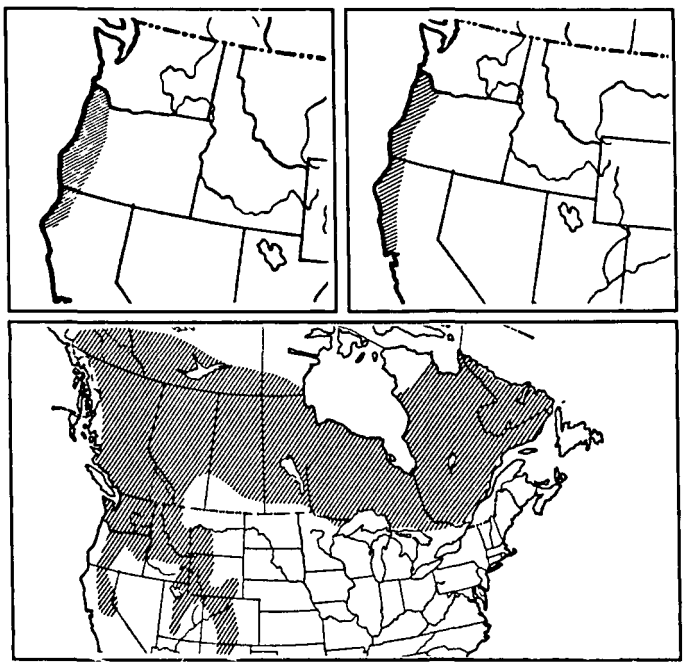

Figure 1—*Upper left.* Padfic phenacomys (range map)

Figure 2—*Upper right.* Tree phenacomys (range map)

Figure 3—*Lower.* Boreal redback vole (range map)

Only two of the three *Clethrionomys,* or redback voles, have been found in the Western United States. The boreal redback vole prefers damp coniferous, deciduous, or mixed forests (fig. 4), while the California redback vole (fig. 5) is found only along the moist, log-strewn forest floors of the California, Oregon, Washington, and British Columbia coasts. Both species are slightly larger than their *Phenacomys* cousins; they range from 5 to 6 inches long and 1 to 1.5 ounces. None, as yet, has been reported as a significant cause of forest-plantation damage.

Fifteen different species of *Microtus* have been identified on the continent (Maser and Storm 1970). Eight can be found in the West: meadow, gray-tailed, California, Townsend, Richardson, longtailed, montane, and Oregon (figs. 6 through 13). These species are the largest of the three genera, and the combined length of their heads and bodies ranges from 2 to 5 inches. It is often difficult to tell them apart. Most are bicolored with light bellies and reddish to grayish-black backs. Their principal habitat is thick, heavy grass cover. The longtailed, Oregon, and montane are the most prolific and destructive of the *Microtus* in western forest ecosystems.

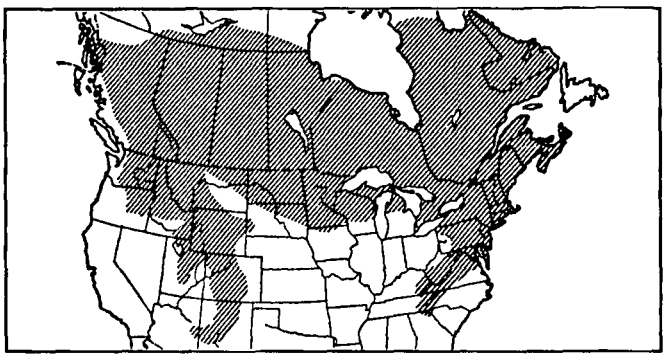

Figure 4—Boreal redback vole (range map)

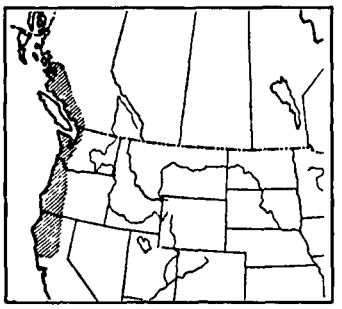

Figure 5—California redback vole (range map)

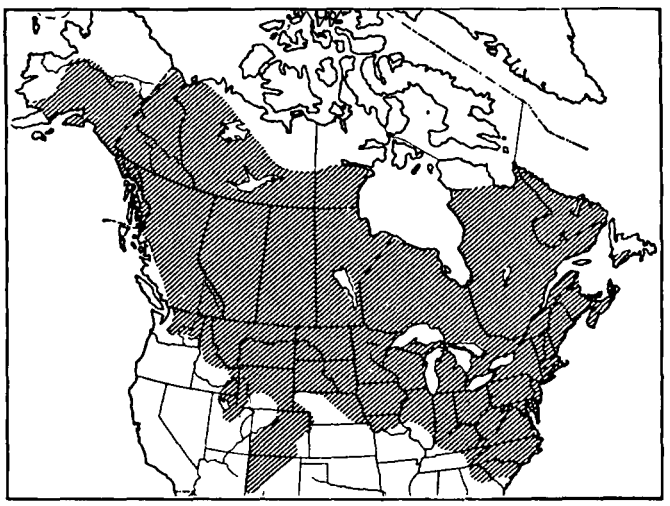

Figure 6—Meadow vole (range map).

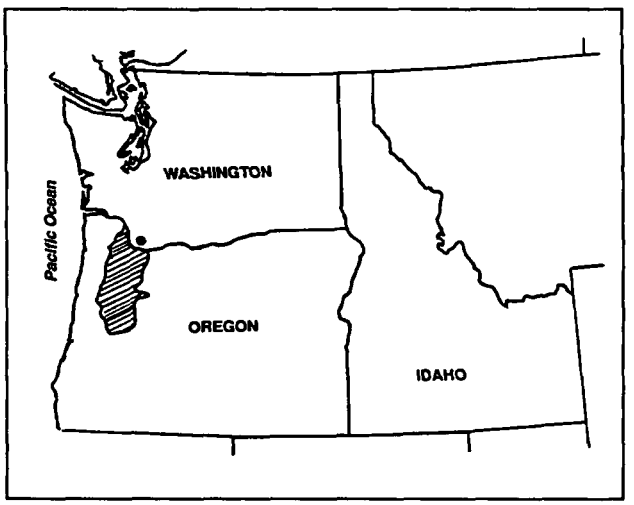

Figure 7—Gray-tailed vole (range map)

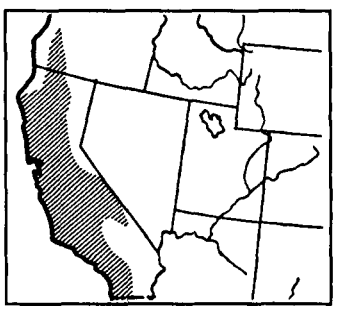

Figure 8—California vole (range map)

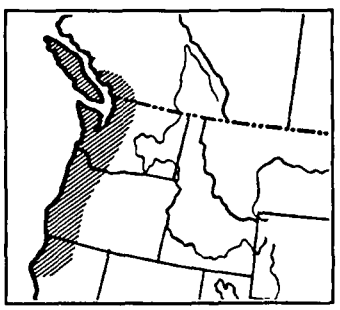

Figure 9—Townsend vole (range map)

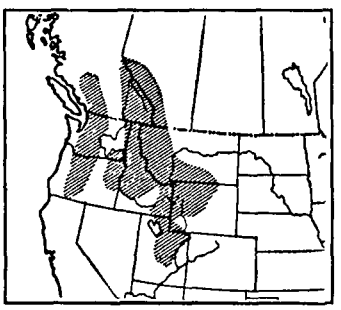

Figure 10—Richardson vole (range map)

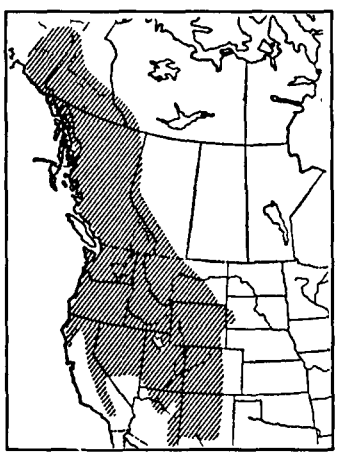

Figure 11—Longtail vole (range map)

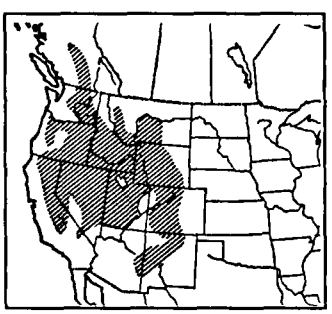

Figure 12—Oregon vole (range map)

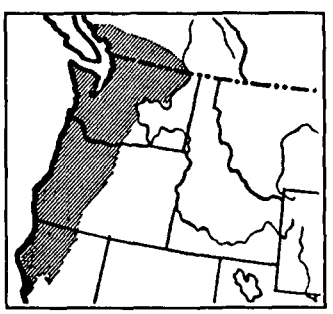

Figure 13—Montane vole (range map)

Longtail vole—This species reportedly occurs from eastern Alaska southward into southern Arizona and New Mexico and from the Pacific eastward into South Dakota (fig. 11). They are primary dwellers of marshes and marshy areas along water courses, but they can also be found among togs, brush piles and talus slopes as long as such cover is near water. In most cases, the proximity of water appears to be the deciding factor in the habitat preference of the species. They may, however, be found far from permanent water. Total length varies from 4 to 5 inches and they may weigh between 1.25 and 2.5 ounces. Color varies from dull gray or brownish gray to dark blackish or reddish brown.

Oregon vole—This species generally is grayish- or yellowish-brown to reddish- or blackish-brown. It weighs about 0.5 to 1 ounce and is about 3 to 4 inches long. It lives in moist coniferous forests of California, Oregon, Washington, and a small part of British Columbia (fig. 12). The animal seems to prefer cutover Douglas-fir areas, but it also is found in woodland, glade, forest, south-slope, and riparian cover types. Few are found in forests with sparse ground cover of mixed grasses and forbs. It generally is most abundant in serai vegetation of recently logged or burned areas and in short or dry fields of grass. Along the eastern part of its range and in the Olympic Mountains in Washington the species inhabits the dryer subalpine forest, meadows, and alpine areas. Densities remain low in forested areas but abruptly increase in clearcuttings (Hooven and Black 1976).

Montane vole—Total length for this species ranges from 4 to 5.5 inches. It weighs between 1 and 3.5 ounces, and its color varies from light grayish, to brown, dark brown, reddish brown, and sometimes blackish brown. The montane vole is found in varied habitat throughout Oregon and Washington east of the Cascade Range (fig. 13). In Idaho, it generally is confined to the southern two-thirds of the State. Montane voles live in sagebrush-juniper woodlands, forests, fields, and sagebrush flats, and they depend on extensive runway systems in lush grass cover.

Food and Cover

Longtail, Oregon, and montane voles eat almost anything. Their preferred diet, however, is lush, green vegetation, and they forage during all hours of the day and night. Caged montane voles eat grasses and forbs equal to half of their body weight within 24 hours (Askham, personal observation). This means that a population of 100 animals may consume up to 325 pounds of fresh vegetation, tree roots, and bark in 1 month. During the winter, when new plantings are the most susceptible, the same number of animals can remove over half a ton of forage, roots, tree bark, and sapwood.

Summer water needs of voles mostly are obtained from food, dew, and precipitation. Most voles spend much of the hot-dry season under heavy cover and belowground to conserve moisture. Unlike mice, voles do not have large home ranges. Their territories are generally limited to an area of about 25 to 50 square feet. Feeding is generally confined to shallow, depressed runways 1 to 2 inches in width that are located between burrow openings and in plant root masses just below ground.

Females raise the first litter of the season in nests that voles build in heavy cover during winter and spring. The nesting sites are shifted belowground when the weather becomes hot and dry. Some nests and food caches are located 6 to 10 inches below the soil surface

Summer feeding is confined to grass and forb roots 1 to 6 inches below the soil surface and along tree and shrub roots as deep as 36 inches. Voles sometimes feed aboveground at night after a rain, or when the temperature drops. In extremely cold climates where the top 2 feet of soil freezes, the animals excavate complete burrow systems with large food caches and nest sites as deep as 3 feet. Food caches are separate from nest and fecal chambers and are filled early in the year with vegetation and seeds.

These nests sometimes contain dry grasses and forbs accumulated over 4 to 5 years as nesting material for previous generations. As many as 12 or 15 animals live in these nests during the winter. Because much of their life is spent underground and their population numbers fluctuate rapidly, voles are not easily monitored or managed.

Habitats

The effects that habitat changes have on animal populations have been clearly demonstrated. Resident and sometimes migrant populations can be encouraged by increasing food, water, and protection or cover (Hooven and Black 1976). This encouragement may be the unintended outcome of management efforts that do not consider the relation between a species and its habitat.

In Scandinavia, where voles are a very serious problem, habitats have been divided into five categories: primary production, temporary production, secondary survival, invasion, and transition (Myllymaki 1976). Each category describes a basic habitat that helps define the conditions of vole management.

Primary production habitats are characterized by high cumulative production and survival of offspring during the entire reproductive season. This category predominantly consists of succession habitats on relatively fertile and fresh but not flooded soil: old fields and abandoned pastures. A further characteristic is their great diversity in plant species and a predominance of grasses and forbs. The continuous production of new plant biomass and appropriate shelter provides relatively undisturbed conditions for both reproduction and winter survival. Many clearcut or burned areas reseeded with grasses fit into this category.

Temporary production habitats are those with seasonal or occasionally high production but proportionally low survival of offspring. Typical examples are clover-grass fields with two peak-production periods during the early summer and fall. Drastic changes in shelter, however, lowers survival for young and adult voles.

Secondary survival habitats are those suitable only for seasonal or periodic reproduction. They are adequate for maintaining existing populations for most of the year. This category includes permanent grassland habitats that differ from the first category in two respects: seasonally unfavorable physical conditions such as floods or droughts, and less diversified flora that provide only temporary cover for effective reproduction. The bulk of clearcut reforestation areas, if they have not been reseeded with grass, are in this category.

Invasion habitats provide very poor conditions or none at all that might allow reproduction or even survival. This category includes the bulk of cultivated fields, but it excludes pastures, orchards, and nurseries. It also occasionally excludes seed orchards where grass has been mechanically removed. Edges, road rights-of-way, and border-grass strips, for example, provide islands of higher category habitats and function as sources of immediate invasion. Invasion habitats are important because they are temporarily populated during winter.

Transition habitats usually provide shelter tor dispersing voles but seldom provide enough food tor permanent colonization. The most typical type of transition habitat is a mature forest. Where these habitats have been extensively studied in Finland and Sweden, primary production habitats are seldom far from forest crops. Nonterritorial, subadult populations are likely to adopt a vagrant mode of life as prevailing conditions become unfavorable. Winter invasion between habitat types has been observed throughout the Northern Hemisphere and is considered the rule rather than the exception.

Population Dynamics

Breeding can occur anytime during the year. Litter sizes range from one to eight offspring but generally there are only three or four young. Females begin producing litters 30 to 40 days after they are born and every 21 days thereafter. Theoretically, if one breeding pair has an average of 6 young per litter with no mortality, then that pair and its descendents can produce up to 1,000 young in 1 year. If each succeeding litter continues to reproduce with the same efficiency, over 1,500 animals could be produced in only 6 months (fig. 14).

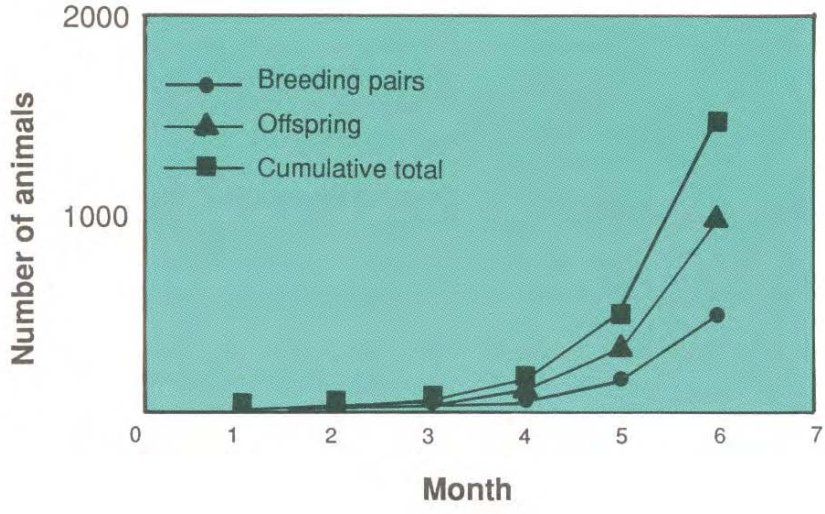

Figure 14—Population growth graph

Under normal wildland conditions, population densities may range from 20 to 35 animals per acre. During peak years, the population may reach 150 to 200 animals per acre. In monoculture environments, such as forest plantations and agricultural settings where ground cover often is heavy, populations may increase to 1,000 or 2,000 per acre (Askham 1988), but these numbers are rarely sustained for more than a year. Nearly all green vegetation is consumed during such periods, and the population collapses with few survivors. If the land is not denuded, ticks, fleas, mites, and lice rapidly spread diseases through the population in the early spring until only the fittest remain to resume the cycle (Bacon and others 1959, Kartman and Hudson 1971, Schwan 1975).

The female's ability to produce healthy young is another limiting factor in vole production. With a sufficient source of nutrition, a healthy female, theoretically, can produce about 12 litters per year. Normally, however, females produce only three or four

litters, and fewer offspring survive from each succeeding litter. If a female begins production with a high content of body fat, then most if not all of the first litter will survive. If she breeds immediately after the first litter, however, fewer of the second litter will survive, because the fetuses and nursing offspring from the first litter will compete for her food reserves. The problem becomes more acute with each succeeding litter until the female dies, fails to breed, or aborts while necessary reserves accumulate in her body. Few voles live more than one year.

Population Assessments

As with any management program, population assessments should be conducted before and after treatment. Assessments before treatment are important, because they provide basic information (such as the type and relative abundance of animals) needed to develop a successful management program. Visual assessments are difficult to quantify because the animals are not easy to find. Assessments are based on the signs voles leave behind, such as cut grass, open holes, and droppings. The animal's activities, furthermore, often are affected by temperature, moisture, and the time of day or year.

Snap traps are the easiest and least expensive method of sampling a population. They can also provide some quantifiable numbers. Any number of traps, preferably 50 or more, can be selectively placed where the animals are most active. Random location, straight-line transects, and predetermined grids may work very well for sampling populations of deer mice, but snap traps must be placed directly in active runs to accurately assess vole activity. Randomly placed traps do not capture a representative sample of the population, because voles confine most of their activity to their runways. The major disadvantage of the snap-trap method is that each trap can capture only one of several animals at any one time. This method, therefore, underestimates the total population of the site.

Live traps (such as those produced by Sherman) and pitfall traps are more expensive to buy or build, but they have several advantages. They can provide better population data (such as species composition and frequency) with either simple or sophisticated sampling procedures (trap and release, toe clipping, and weighted samples) that provide detailed population assessments A second consideration is that no individuals are removed from the population during the assessment period (even though that may not be your ultimate objective). Several individuals may be caught at one site with a pitfall trap during the sampling period of a few hours. This is something that a single-catch trap cannot do. Pitfall traps also must be placed where voles are most active. This provides a better indication of the density of the resident population, because the trap is open to all small mammals during the sampling period

The major advantage to both snap and live traps is that each captured species can be identified. The disadvantages are that larger animals may spring the traps, eat the captured animals, or remove the trap from the site if it has not been secured.

Trapping efficiency improves with the attractiveness of bait. Whole or processed grains or combinations of grains and honey or molasses work very well. Where vegetation is scarce, fresh grasses and forbs have been successful in luring voles into live traps. This author's preference is peanut butter, with its strong odor and salty taste, but different combinations can always be tried to capture more animals.

The efficiency of population monitoring can also be improved by covering each sampling site with some form of protective cover (litter, long grass, building paper, or

cardboard) to encourage vole curiosity. These sampling sites may have to be moved several times, and several kinds of locations may have to be tried for each vegetation type to identify the most efficient or reliable method. Once established, the process must be repeated during the posttreatment assessment.

Numbers obtained from trapping are merely baseline data. Managers rarely are interested in or concerned about the actual number of animals in a given location. The primary concern should be the effectiveness of treatments to reduce the population. A simple assessment can be calculated from the baseline data. If, for example, 48 out of 50 traps per night capture a vole, then the baseline population is 96. If the numbers do not change during the second sample a few days or weeks later, then the management program has not been successful. If only two or three traps capture voles or have had bait taken during the second sampling, then the treatment has removed approximately 90 percent of the population.

Population Management

Research on managing voles in forest plantations is extremely limited. Most information in the remainder of this chapter was compiled from other disciplines, such as agriculture and wildlife biology, and from personal observations. The conditions under which these studies were undertaken, however, were very much like those encountered by practicing foresters It is logical, therefore, that these findings will also apply to forest plantations.

The answer to the question "How does this information help practicing foresters develop a management program?" is quite simple. Knowledge of the relative abundance, habits, behavior, and habitat of a particular species provides a better idea of what to expect from modifications to a given environment It provides a predictive tool, and it enables forest managers to prescribe specific measures of intervention when a given population exceeds some acceptable level of activity. Basic intervention measures may be either indirect or direct Each has strengths and weaknesses that will be described in this chapter, along with their management implications, but that discussion builds on several, general biological principles reviewed below.

General Principles

Animals require three things to survive: food, water, and protection (fig. 15). Remove any one of the three legs of this triangle and the animal will either move or die. This is a basic principle of forest management. In forest ecosystems, habitat modification is the key to long-term success. Control programs should be considered successful if 85 percent or more of the population is removed; at lower levels of removal, residents and emigrants quickly replace the missing animals. Natural mortality, sampling error, or weather conditions can cause reductions of 25 percent or less. If, for example, total activity on a site decreases from 96 to 50 percent, then 21 percent of the decrease may be the result of the control program. The remaining 25 percent may be the result of natural mortality. This uncertainty may be avoided by comparing final results against a control plot

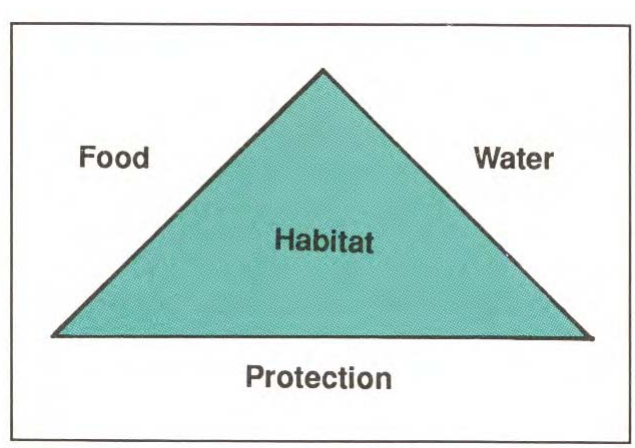

Figure 15—Survival triangle

In natural conditions (those unaltered by humans), the balance between animals and their environments tends to be rather stable. Although fluctuations occur within populations, they generally do not exceed the limits of the habitat carrying capacity. Carrying capacities change, however, with altered environments. Silvicuttural treatments atter a site's carrying capacity for a particular species. In monocultures such as forest plantations, nurseries, seed orchards, or range rehabilitations and improvements, for example, the carrying capacity for rodents can increase many times and improve the potential success of the animal.

Resource managers often must cope with existing conditions and forego optimal planting conditions. The worst condition for planting is on a site with an established cover crop within 3 to 5 years after tagging or fire This is primary vole-production habitat. Competition for water and nutrients is strong on such sites, and the rodent population is well established. This problem can be resolved with several approaches that either modify the voles' environment or remove the animals before replanting.

Indirect Control

Indirect control, for the purpose of this discussion, is any method that introduces natural enemies or physical barriers to restrict an animal or group of animals. The introduction of parasites and diseases into rodent populations has been extensively explored during the last 50 years. Researchers concluded that the process was extremely hazardous to human health. Most of the diseases to which rodents are susceptible, such as the plague, tularemia, salmonella, rabies, and leptospirosis, also infect humans.

Diseases, however, are a prevalent part of every rodent population. During periods of low population densities of rodents, disease is generally confined to a few individuals. When populations increase and the animals are subjected to more stress, they become more susceptible to viruses, bacteria, and parasites. Research in the 1950s on the cause of vole population-crashes pointed toward a cause-and-effect relation between tick infestations and vole mortality. Ticks that emerged from winter hibernation in the spring rapidly infected entire colonies within a short time Once infected, the vole population rapidly disappeared.

Predators are among the most effective agents of biological control. Numerous studies have shown that voles are the principal diet of many predatory animals, particularly during the winter (Phelan and Robertson 1978, Sullivan and Sullivan 1980). Many of these same studies have also shown that the population cycles of predators are dependent on the cycles of their prey (Newton 1976), Several research projects that studied predators and their effect on prey populations found that without modifying prey habitat, prey populations were seldom reduced. Studies at Washington State University research facilities have shown that the modification of rodent habitat and the addition of nest boxes and perches for raptors helps maintain rodent populations at lower levels for longer periods than possible without such modifications. The extensive use of such devices, however, has yet to be proven over large areas and requires more study. It may, however, be an effective tool in the arsenal of rodent management.

Physical barriers are practically useless. Vole tunnels, as noted earlier, have been excavated to depths of 30 inches. Other tunnels have been located at depths exceeding 40 inches in archaeological sites (Askham, unpublished data). Holes found in local road cuts are a good indication of how deep these animals dig. Tree-trunk guards of wire mesh or plastic, paper cartons, and building-paper wraps do not prevent vole damage. Voles burrow under the wraps and climb into them from above.

They even build nests in the wraps when they become loose, and they eat the bark at the root collar where the tree is exposed. Anything extending above the collar under the snow is consumed. During the rest of the year, voles feed on the roots. Trees planted in wire-mesh baskets are protected until the roots outgrow the container if the hole size does not exceed 0.25 inch, and the tree may survive if it is large enough; otherwise, it's replanting time. Wire-mesh fencing also is ineffective. The animals always seem to find a way over or under it.

Direct Control

Direct control, for the purpose of this chapter, is the physical destruction of the animal or its immediate environment, or modifications to that environment that limit the animal's chances of survival. Trapping is not a solution, because it only eliminates part of the population. It does not limit replacement through migration or new offspring, and it is extremely expensive and rarely justifiable. Habitat modification, however, is one of the most effective ways to manage any animal population (Godfrey and Askham 1988).

Habitat modification can significantly limit habitat carrying capacity for voles in older successional stages (Sullivan and others 1990) The physical destruction of vole habitat is fast and extremely effective. Where fire, floods, and volcanic eruptions have spread, or on logged sites, destruction of vole habitat generally is so complete that it often takes several years for the microtines to reestablish their extensive colonies. Plowing or disking (scarification) destroys vole food sources, cover, and burrow systems, and it also destroys the animals themselves. Those that survive are subject to heavy predation and starvation. If the treated area is large (several acres or more), then only those animals that can escape into existing cover along the border will survive. As with any disturbance, however, succession begins anew with the establishment of grasses and forbs—prime habitat for any voles. Treatment, therefore, must be timed appropriately to be effective (Sullivan and others 1990).

Vegetation management with herbicides has an established record of controlling voles. A number of herbicides are available, so additional references should be consulted to select materials appropriate to site conditions Black and Hooven (1974) found that Oregon voles were less abundant on plots treated with herbicides than on nontreated plots. They also found that plots returned to normal within 2 years after treatment, and their relative species composition was similar to untreated plots.

Application strategies can include either area or spot treatments. Area applications are those in which several acres are treated to remove either all vegetation or specific types. Area application might be considered, for example, on a large clearcut with extensive grass and fort) ground cover on a site where scarification is not viable. Spot treatments are those in which vegetation around individual trees is treated to remove unwanted cover Spot treatment may be an alternative, for example, in a seed-tree nursery where some ground cover is desirable to contain erosion and provide vehicle access. Litter often is removed mechanically during the first year, under such conditions, to further reduce vole-habitat quality This technique confines most subterranean activity of voles to the vegetative strips between the plantings and away from the tree's root system. Once snow accumulates, however, resident as well as migrant voles tunnel under the snow to the trees in search of food. Unless the population is controlled before the snow pack is established, herbicide treatments are of little value.

Several herbicides, such as Round-up (isopropylamine salt of glyphosate) and Embark (diethanolamine salt of mefluidide), have been formulated at lower

concentrations that regulate growth. These new formulations have effectively reduced vegetative growth for up to 6 weeks in some trials, and they have effectively removed about 60 percent of the biomass. This method also changed the species composition of the ground cover from a predominance of forbs to a predominance of grasses. The nutnent content of the biomass, furthermore, was also reduced (Askham and Godfrey, unpublished and current research).

Repellents have had mixed results in various trials over the years. Some trials have compared the efficacy of applying different materials to seeds to discourage feeding by mice (Dimock 1957) and voles (Szukiel and Lewandowski 1987) before planting. Others have applied different materials directly to seedlings. None of these methods were consistently effective in reducing or eliminating rodent damage to crops.

Where vegetation and litter cannot be removed, less palatable or luxuriant and slower growing cover crops might be substituted for an existing crop. One alternative is shallow-rooted, slow-growing fescues. In limited trials that substituted these grasses, vole populations were eliminated while the surrounding populations flourished (Askham, unpublished data).

Vole control rarely is successful during winter or summer. Inclement weather conditions during winter often preclude rodenticide applications except in mild climates. In the summer, particularly in areas where voles have taken shelter belowground, habitat reduction and rodenticide have little immediate effect. The animals continue to feed on vegetative root masses, and the rodenticide does not reach the targeted species. Habitat reduction during the summer, however, drastically affects the animals when they resume foraging aboveground in the fall. It also renders rodents more susceptible to predators and rodenticide.

Another form of direct control incorporates rodenticide applications. Rodenticides are toxic-chemical formulations specifically developed for rodents. Rodenticides are only effective, however, if the bait reaches the animal (Hunter and others 1985) and is more attractive than the animal's existing food source. Voles confine their aboveground feeding to their principal runways. If the bait does not reach these runways and burrow openings, then it is not eaten and is not effective. That is one of the principal reasons why grass cover must be removed, reduced, or opened up before baiting (Hunter and others 1987). An alternative is to hand-place the bait at each burrow. Any bait that does not taste good, becomes soft or moldy, or falls apart when it becomes wet, will not be attractive to voles. It is important, therefore, to understand how each bait affects the targeted animal and how the bait holds up in different environmental conditions.

Rodenticides are classified as either acute or chronic. Acute rodenticides are single-dose, fast-acting, highly toxic, and generally nonreversible (barring immediate action by a physician or veterinarian). Chronic rodenticides require multiple doses before their effects are apparent, they are slower acting, and their effects often can be reversed with an antidote.

Acute rodenticides include strychnine, sodium fluoroacetate, (compound 1080), and zinc phosphide. Acute rodenticides either affect the nervous system and cause paralysis, or they destroy vital internal organs. Zinc phosphide is the only acute rodenticide registered, as of 1990, for aboveground rodent control. Current labels and local regulations, however, should be consulted.

Zinc phosphide (commonly known as "zp") baits are formulated on grains or in pellets and provide quick results after six to eight baits have been consumed. Both formulations have about the same efficacy if used during the right weather conditions. They do, however, have two limitations: bait shyness and rapid decomposition in the presence of moisture. Bait shyness occurs when an animal feeds upon a treated material and becomes sick but does not die. The animal then associates the sickness with what they have just eaten and no longer feeds on the bait. This behavior may be passed along to their offspring and compound the problem. During first-year treatments, mortality may exceed 85 percent, but the remaining 15 percent or more of the treated population may develop bait shyness. With annual use, the success rate for the compound generally declines until only 20 to 30 percent of the population is removed with a single baiting. Efficiency rarely improves with multiple applications.

Zinc phosphide also readily decomposes and becomes phosphine gas when exposed to moisture. Phosphine gas causes paralysis and kidney failure in animals. It rapidly dissipates in the open, leaving only zinc—a black, nontoxic element. Zinc, by itself and in small concentrations, is not toxic to wildlife or domestic animals. Zinc phosphide baits, consequently, do not remain as a nontarget hazard in the field for any extended period of time. They may not be effective, however, for more than 24 to 48 hours. Effective baiting with zinc phosphide requires between 24 and 48 hours of continuous exposure to the bait by target animals, so baits must be placed during warm and dry weather. Humidity also affects the formulations in their unopened storage containers. A newly opened container of zinc phosphide should have a strong garlic odor. If it does not, the bait is not toxic enough to perform adequately and should be returned to the vendor.

Only two chronic rodenticide compounds currently are available for forestry: chlorophacinone and diphacinone. Both are anticoagulant agents that cause internal hemorrhaging and death. Formulated under a variety of trade names, such as Ramik and Rozol, both compounds are equally effective on voles.

The advantage of these compounds is that the animals do not become bait shy during the control process. With death occurring several days after ingestion, the result is not associated with feeding. One major disadvantage, on the other hand, is that the compounds must be consumed for 6 to 9 days to provide adequate control. If bait is not placed in the field in amounts sufficient to provide continuous feeding for the entire population, the bait is exhausted and the animals recover from the toxic effects of the rodenticide. Multiple applications often are required during the treatment period. The toxicants also decompose over time when exposed to direct sunlight. With ground-spray applications, decomposition may occur within a few hours, depending on cloud cover and time of applications. Precipitation also makes pelletized rodenticide swell and fall apart. When this happens, the baits are no longer palatable to the targeted species. They also lose their lethal characteristics, because sunlight penetrates the pellet and decomposes the active ingredient.

If all of the bait is consumed from the treatment area, or if precipitation destroys the bait before completion of the control program, then additional applications should be made within the time limits specified on the label. Each area should be checked daily to monitor the progress of the treatment program.

Integrated Management

Nature abhors a vacuum. If rodent populations are not kept under control during reforestation programs, the potential for crop damage increases overtime. Direct or indirect controls rarely are effective by themselves in controlling rodent infestations for any length of time. Long-term results require a combination of direct and indirect management strategies (Marsh 1984). Murua and Rodriguez (1989), for example, report that combinations of silvicultural practices that include rodenticides can decrease rodent damage. The constant replacement of animals into a given habitat prevents that habitat from remaining vacant for long periods. A population of voles may be decimated by the removal of all of the animals' habitat, but within a year or two, regrowth and replacements will restock the site.

Management Strategies

Large, Old Clearcut (Dry Site)

The following hypothetical example of a 4- to 5-year-old clearcut illustrates the most difficult scenario for planning a management strategy. In this case, 35 acres of Douglas-fir were cable logged from a steep hillside, the slash was burned, and the site was then reseeded with grass to prevent erosion. Natural reproduction was scarce. The results of a stocking survey averaged 42 four-year-old trees per acre. An average of 3 feet of snow accumulated over the site between November and March. The area is bordered on three sides by old mature stands and on one side by a 20-year-old plantation.

The site has become a primary production habitat for voles. Grass and forb biomass, the principal vegetation on the site, ranges between 16 and 24 tons per acre. The adjacent, mature forests may be classified as transition habitats with some shelter and food for dispersing voles. The fourth edge of the clearcut block is a temporary production habitat that is adequate for maintaining low populations of animals throughout the year. An initial survey of the site indicates a severe infestation of voles. Open holes and active runways between the holes and under the heavy grass are so numerous that it is difficult to walk without stepping on one or the other. Eighty-five out of 100 snap traps placed in the active runways caught voles during the first 24 hours after placement.

The primary objective is to remove the grass cover from the site. Several direct and indirect alternatives are possible: fire, herbicides, rodenticides, and predators. In this case, with a dry climate on a south-facing slope where the vegetation quickly matures during the summer, fire is the logical option. The major disadvantages of this tool are erosion, the loss of natural reproduction and ground cover, the potential for uncontrolled fire in the adjoining stands, and air pollution.

Immediately after burning (within 2 to 3 days), zinc phosphide baits should be broadcast in and around all the burrow openings if the ground is not wet and if it is not raining. The fire will destroy vole habitat but it will not kill many of the animals that escape the heat and smoke by hiding in their burrows. Placing the rodenticide at a time when the animals are searching for food improves the efficacy of the treatment, and general broadcast treatment to the entire block, therefore, may not be necessary.

Population activity samples should be taken after 48 hours, and a second rodenticide, preferably an anticoagulant should be applied if required. Nest boxes and perching poles can then be located on the block during planting. One box per 10 acres and 1 pole per acre should be sufficient (Askham 1990). Raptors should begin using the perches within 30 days, and they should begin occupying the boxes by the following spring, if they are in the area.

Large, Old Clearcut (Wet Site)

Given the same situation, but in wet climates or north aspects where the vegetation matures in the early fall, herbicides may be the appropriate tool if applied early during the growing season. Growth in the current year will be killed, but no habitat from the previous year will be removed. This method, therefore, removes the food source while protecting the soil from erosion, particularly on steep slopes. It has the disadvantage, however, of providing cover for surviving and invading animals. Fire and rodenticide applications before planting may be necessary to remove the remaining biomass. Planting should begin as soon as the vole population is reduced below some predefined, acceptable level (preferably by 85 percent or more) and as soon as moisture conditions permit. Nest boxes and perching poles may also be added as a predator inducement if a sufficient number of bird-trees or snags have not been left on the site.

Some stocking mortality should be expected as the result of invasion from the temporary-production habitat adjoining the site, particularly if a heavy ground cover persists after the herbicide treatment. Most tree damage is apparent immediately after snow melt. Spot or strip removal of vegetation with herbicides at the interface between the two habitat types limit (but not eliminate) invasion across the border. If vole damage kills or damages 20 percent or more of the new trees, then vegetation should be mechanically removed, or a rodenticide should be applied in the transition zone. Followup surveys and treatments, where warranted, should be made each year for a minimum of five seasons after replanting.

Mixed-Species Shelterwood

The third scenario begins with a mature forest before harvest. In this situation, an 80-acre bbck of mixed spruce, hemlock, and Douglas-fir located along a stream will be tractor logged during the next 2 years. A shelterwood cut leaving 20 percent of the stand as seed trees has been proposed by the district silviculturist. One edge of the block is bordered by a 10-year-old clearcut. Another edge is bordered by a mature stand, and a third is bordered by a meadow. An initial population assessment produced the following numbers: 25 percent of the traps caught voles, 50 percent caught deer mice, and 10 percent caught shrews. Deer mice, being the primary pest, should be dealt with first (see chapter 8).

The primary concern is to plant this block as soon as possible aflei harvest. Planting will convert the block from a transition habitat that provides habitat for dispersed voles to a secondary-survival habitat during the second and third years. Within 5 years after harvest, the planted block may even become a primary-production habitat. The clearcut block, currently in the secondary-survival habitat-stage, and the mountain meadow (temporary-production habitat) present the most serious threats to regeneration efforts. As vole populations expand in these habitats, dispersal will push new individuals into the newly logged block. As the block moves through different successional stages, the tendency will be to support greater numbers of animals per unit area each year until some level of carrying capacity is reached.

Vegetation modifications may not be needed during the first or second year if site preparations are adequate. It is assumed that most of the reforestation will occur through natural seeding (hence the shelterwood cut). The potential for a rapid expansion of the vole population (generally within 3 to 4 years) poses a serious problem for the resource manager. As the stand matures, a close watch on the understory vegetation will be needed. If a transition or invasion habitat with little or no grass cover can be maintained, then little else will be required to protect the plantation from voles. If, however, the site rapidly matures into temporary- or primary-production habitat for voles, then the vegetation will have to be reduced or removed, particularly

along the clearcut, mountain meadow, and stream. This presents some interesting problems, because a stand of small trees will probably be established by that time. One option will be to apply a growth inhibitor to retard vegetative growth and change the species composition of the understory. A more drastic option would be to apply a herbicide. In either case, a wide (100 feet or more) buffer strip between the two areas should be established to protect the new plantation. Adjacent cover crops also may have to be removed and controlled during the same period. In addition, rodenticides periodically may be needed to remove the residual population.

Nest boxes could be added to the site to improve its appeal to raptors. Additional perches would not be necessary, because 20 percent of the stand was maintained with seed trees that provide roosts for the birds. The site should be monitored for 5 years, and adjustments should be made in the management plan as needed.

Small Clearcuts

The fourth scenario involves planning for a series of 2- to 20-acre clearcut blocks in a 60- to 80-year-old stand. During the initial stand-inventory, only 25 deer mice and 15 voles were recorded per acre as part of the resident animal population. Voles, however, may increase rapidly in the clearcuts. Silvicultural treatments for the unit were preplanned, so site preparation before planting is minimal. Given the characteristics of the stand, some debris must be burned after harvest. Spot herbicide treatments of grass and forbs should be done with backpack sprayers where needed. Planting should begin immediately after harvest, preferably during the fall right after the last tog has been hauled off the landing. Rodenticide treatments for voles do not seem to be warranted. Rodenticide treatments for mice, however, may be justified if a large portion of the reforestation plan relies on seed dispersal from adjoining stands. One or two nest boxes might be tacked to the trees around the edge of each block. Site monitoring should continue for 5 years. If the vole population appears to be increasing or tree damage exceeds some predefined level, say 20 to 30 percent, then herbicides, rodenticides, and some mechanical grass removal may be warranted.

Summary

This chapter has described what voles look like, where and how they live, when and what kinds of damage might be expected from voles, and how they might be managed under different circumstances. Voles are interesting but difficult to manage in the forest. Most are much larger than mice, their close cousin, and with their scraggly coats and beady eyes, they look a little like a bottle brush running through the grass. They eat green vegetation each day in amounts that equal about half their body weight, but they cache very little. Their range tends to be limited to a few hundred square feet, but their populations can reach several hundred per acre within a short time. Extremely high or plague populations that often occur in 3- to 5-year cycles can devastate a reseeding or replanting program. Because they are active at night and during the day, voles are easily monitored.

Management strategies fall into two general categories: indirect and direct. Indirect strategies such as introduced diseases, however, are not a reliable option and neither are physical barriers. Predation is a most effective biological-control agent, and predator-habitat enhancement has some potential. Birds-of-prey alone, however, are not sufficient to control extremely high populations of voles in a forest plantation.

Habitat modification by a variety of techniques is the most important direct-management option. Habitats can be divided into five categories: primary production, temporary production, secondary survival, invasion, and transition. Changing these

habitats can be extremely effective, but this is an expensive and time-consuming operation. By changing the voles' environment during logging, mechanical site-preparation, fires, and with herbicides, the animals can be eliminated, reduced to some acceptable level, or discouraged from dispersing into plantations.

This chapter also identified two basic classes of rodenticides, acute and chronic, that may not be a preferred management choice. Often, however, they must be used to clean up or eliminate a population when plantations are endangered.

Voles are difficult to control without a combination of integrated management strategies, and the four different reforestation scenarios provide some guidelines. The first, and worst scenario contends with a large population of voles in heavy grass and the potential for immediate reinvasion from some of the surrounding areas. The second scenario is the same as the first, but the site is wetter and more difficult to work with. The third scenario involves a seed-tree cut where many options are limited by standing timber and other factors. The final scenario demonstrates how a series of small clearcut blocks might be handled if the forest manager had the luxury of preplanning the silvicultural treatments for the unit

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chipter 10
Pocket Gophers

REX E. MARSH AND ROBERT W. STEELE

Abstract

The description and presence of western pocket gophers of the genus *Thomomys* is common knowledge to most practicing foresters. Population densities vary widely and are influenced by weather, altitude, soil characteristics, and, most importantly, by food quality and quantity. Logging practices that improve habitat can result in constant, annual increases of the gopher population in a new plantation until the carrying capacity of the habitat is reached. In preferred forest-habitat, a high-density population of gophers (15 to 25 gophers per acre) can damage a significant percentage of conifer seedlings.

Gopher populations expand into unoccupied but suitable habitats predominantly by the dispersal of young gophers An area that has been depopulated by baiting may be reinvaded by young animals from other areas or by high survival of young born to the few gophers that survived the control operation.

Gophers can tolerate a wide range of environmental situations and are highly adaptable to favorable but changing ecological conditions. Gophers in logged-over areas feed on a wide variety of plants but generally prefer fleshy or succulent roots and stems of herbaceous plants They injure tree seedlings by root pruning, stem girdling, and stem clipping.

REX E. MARSH is specialist in vertebrate ecology, Wildlife and Fisheries Biology, University of California, Davis, CA 95616. ROBERT W. STEELE is research forester, Forestry Sciences Laboratory, Intermountain Research Station, U.S. Department of Agriculture, Forest Service, Boise, ID 83702.

The plant succession predicted for a site after logging, its capacity to support a high population of gophers, and the current abundance and distribution of gophers on the site and adjacent lands, are the major factors predisposing a new plantation to significant gopher problems.

Approaches for preventive management of gophers begin with the selection of silviculture systems. Minimizing disturbance of a site during logging and site preparation decreases the probability of gopher population growth and invasion Natural or near-natural buffers of undisturbed strips of 400 to 600 feet in width between gopher-occupied areas and sites selected for harvest provide protection against rapid invasion by gophers. Planting as soon as possible after harvest is the single most important method of all the preventive silviculture practices available for pocket gopher management. Higher densities of stocking can compensate for seedling losses anticipated from gophers, and the planting of larger seedlings of top quality enhances rapid establishment of plantations. Larger stock also can survive greater injury from gophers.

Aggressive vegetation control with herbicides lowers gopher populations by reducing their food supply. Good results require a lag period of about 1 year, so herbicide treatments should considerably precede planting unless supplemented with gopher poisoning. Caution should be exercised with herbicides applied to release conifer seedlings in areas with moderate-to-high densities of gophers, because feeding pressure on seedlings may increase if alternate food sources diminish.

Where pocket gophers are traditionally a problem, silviculture approaches (including habitat management) often must be supplemented by direct-control measures to protect seedlings with physical barriers (plastic mesh tubes, for example) or with poison baits. Direct control of gophers with poison baits applied by hand or with burrow builders is the most common method of reducing tree damage. Population reduction also can be achieved by trapping gophers or fumigating burrows. The integration of silviculture practices with direct gopher-controls probably is the most effective approach to reducing gopher damage.

Keywords: Pocket gopher, *Thomomys spp.,* vertebrate pest, gopher control, gopher damage, preventive control, gopher invasion, control strategies, seedling mortality, pest control, animal damage control.

Biology / Ecology

Taxonomy and Distribution

The most widely distributed species associated with forest damage is the northern pocket gopher, with the Mazama gopher second in importance. The Botta, mountain, and Townsend gophers also cause serious damage, but their distributions encompass fewer forests.

Pocket gophers, so named because of their external, fur-lined cheek-pouches, are fossorial (living belowground) and herbivorous rodents of the family Geomyidae; three genera are found in North America. Eight species make up the genus *Thomomys,* which is found over most of the Western United States in a range extending from central Alberta in Canada and well into Mexico, and from eastern North Dakota and eastern South Dakota to the Pacific Ocean. *Thomomys.* the predominant genus in the 13 western states and two western provinces of Canada (fig. 1), represents one of the major pests of western forests and is the only genus addressed in this chapter. Pocket gopher genera and species rarely overlap to any major extent in their distribution.

Figure 1—The distribution of the genus *Thomomys* in North America

Description

Pocket gophers are morphologically and physiologically well suited for spending nearly their entire lifetime belowground. The gopher has a rather broad head with a short, thick neck. The shoulders are stout and limbs muscular, and the tail is relatively short and almost naked. The eyes and ears are small and inconspicuous. Gophers have poor vision but their senses of smell and taste are well developed. Their mouths can close with the four front teeth (incisors) protruding outside the lips; this permits digging with the teeth without getting dirt in the mouth (fig. 2). Gophers carry food items in external, fur-lined cheek-pouches located on each side of the head. Gophers vary in body size; the length of the head and body ranges from 5 to 9 inches Adult males are substantially larger than females.

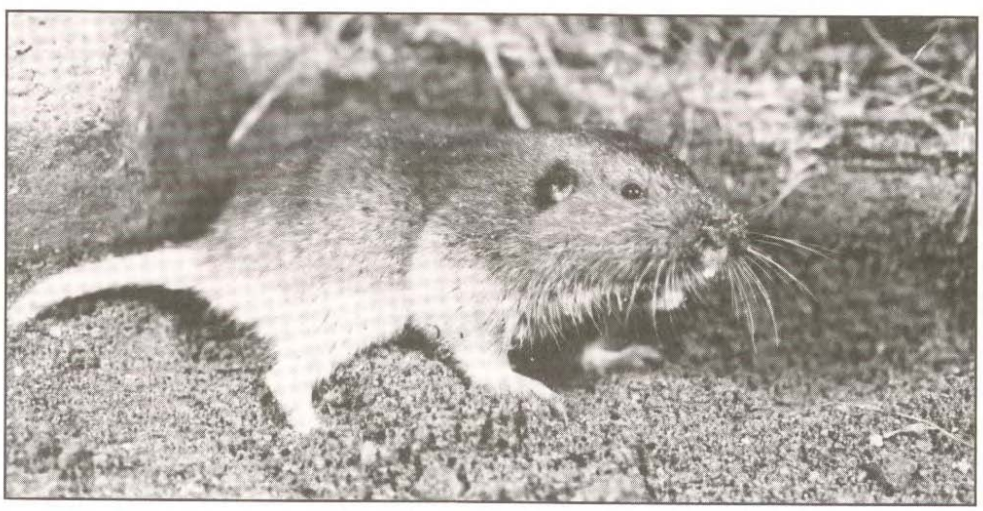

Figure 2—The pocket gopher is well suited for spending nearly its entire lifetime belowground and feeding on a variety of plants They are observed aboveground in this photograph (Photo by Jerry P dark)

Activity Periods and Burrow Characteristics

Gophers may be active below/ground at any time, day or night, and may cause damage year-round, because they do not hiberate. Seasonal changes in burrowing behavior that presumably relate to optimum soil-moisture and weather cause many fresh mounds of soil that appear in early summer and fall. Extensive summer mounding, however, may be delayed at higher elevations During other periods of the year, mounding is less frequent. Gophers routinely move displaced soil into abandoned tunnels. Under a snowpack, they also place excavated soil in vacated snow tunnels. As the snow melts, these soil-filled tunnels collapse, leaving a network of conspicuous soil casts on top of the ground.

Pocket gopher burrow-systems provide shelter, protection from predators, and safe, reliable access to food resources. Each gopher maintains a complex network of tunnels from 2 to 3 inches in diameter These often consist of several hundred linear feet of tunnels, most of which run parallel to the ground surface Feeding or subsurface tunnels are usually 4 to 10 inches belowground and are constantly modified The more permanent and commonly used tunnels are deeper Gophers use short side (or lateral) tunnels to move soil aboveground.

Excavated soil pushed out through a lateral tunnel forms a crescent or fan-shaped mound on the ground. This characteristic distinguishes gopher mounds from mole mounds, which are shaped more like miniature volcanoes. Gophers plug entrances to burrow systems with loose soil to regulate the burrow microenvironment. If an occupied burrow system is deliberately opened with a shovel, the gopher will rapidly close the opening with soil, sometimes within minutes, but occasionally it may take as long as 48 hours for the opening to be discovered and closed. This trait can be measured to provide census data and assess the presence or absence of a gopher in the burrow system

In addition to lateral tunnel entrances where displaced soil is deposited, other openings to the soil surface in forest and rangeland habitats are used as feed holes where the gopher comes aboveground to gather plant food and nest material. Gophers rarely travel more than 12 to 18 inches from the hole, and they immediately retreat when disturbed. Feed holes frequently lack any associated soil mounding and are often numerous and most prevalent in late summer and early fall. When not in use they are kept plugged with soil. These holes with "plugs" are relatively inconspicuous to the untrained eye, but their presence indicates gopher activity.

Burrow chambers constructed for nests and food storage vary widely in size, but they average about 8 to 14 inches across and may be as deep as 5 or 6 feet Several nest chambers in one gopher system are not unusual. Multiple food chambers for caching food are also common; some of these may be very shallow and near the ground surface.

Reproduction

The typical breeding season for pocket gophers is late winter and spring. The major breeding period of about 4 weeks, however, seems to vary from year to year, presumably because of such factors as weather and food availability. In more northerly latitudes, at higher elevations, and in regions with a cold winter, breeding may be delayed by a month or two. The gestation period is 18 to 19 days. One litter per year is the norm for *Thomomys* spp. in forest habitats Litter size is normally four to five offspring, but it also may vary depending on the year and area. The young gophers do not breed until the following breeding season, when they are about a year old.

Home Range and Territory

The home range of a gopher is defined as its current and recently occupied burrow system. Home range is synonymous with territory except possibly duhng breeding periods. The home ranges of male Botta gophers on rangeland average about 2,700 square feet (0.06 acre) with an approximate maximum of 8,000 square feet (0.18 acre) (Howard and Childs 1959). The range of females (1,300 square feet) is about half the range of males. These ranges are comparable with data collected for other *Thomomys* species. Food requirements, the abundance of suitable food year-round, and population density, apparently are paramount factors in determining the size and shape of home range. The shape is highly variable and follows no particular pattern. Home ranges change over time, but any shift normally is not dramatic.

Gophers are highly antisocial and live alone in their burrow systems except during the breeding season and when the mother is rearing young. Both sexes vigorously defend their territories against intruders of either sex

Longevity and Mortality

Maximum longevity for gophers is about 5 years; however, the average lifespan ranges from 1 to 1.5 years. Less than 10 percent of the gopher population is estimated to reach 2 years of age, and females live somewhat longer than males.

Parasites and predation apparently play minor roles in regulating population densities, but information on disease-caused mortality is unavailable. Inclement weather, adverse environmental conditions, and a shortage of quality food, apparently, are the major factors that contribute to mortality. Mortality is highest among juveniles (less than 1 year old), and winter mortality of all age groups takes the greatest toll.

Population Dynamics

Gopher populations are relatively stable compared with many other rodent species, but they can increase annually until the carrying capacity of the habitat is reached. In rare situations, rapid declines occur with no apparent cause.

Population densities vary widely and are influenced by climate, altitude, soil (depth, type, drainage), and, most importantly, by food quality and quantity. Territoriality and social characteristics undoubtedly play a significant role in determining the upper limits of gopher populations. Densities as high as 41 gophers per acre have been reported (Howard and Childs 1959), but a population of 15 to 25 gophers per acre is considered high in forest lands. Mean densities per acre are often much lower than average overall densities, because population distributions are patchy. Local distribution is limited by unsuitable soils, excessive moisture conditions, or nonpreferred plant-community types.

Population patchiness caused by ecological factors (such as excessive moisture, unsuitable soil) seldom changes much, especially if the habitat is not significantly modified for several years. Population patchiness, however, may result from spotty invasions of recently disturbed habitat previously unoccupied by gophers. Spotty infestations of gopher populations in these cases expand until all of the suitable habitat is populated. Patchiness resulting from only a partially successful poisoning program is a similar scenario. Assessments of overall densities and the potential for seedling damage must, therefore, consider wide gradations of gopher densities. Effective management requires a recognition of the propensity for a gopher population to increase

Movements, Dispersal, and Reinvasion

Young gophers disperse at approximately 8 weeks of age. Some remain close to their natal burrows; others may disperse overland or through existing tunnels. Dispersal of these juveniles is most common during late spring, summer, or early fall, depending on the breeding period. The distances traveled vary from a few yards to several hundred feet. Aboveground travel probably occurs mostly at night.

In areas free of winter snow, most movement into new territory by established adults takes place through tunnels dug belowground. In areas of high snowfall, however, substantial tunneling may occur aboveground within the snowpack. Burrowing through snow facilitates dispersal, because it enables gophers to cross terrain unsuitable for underground burrowing.

Feeding Habits and Preferred Foods

Gophers prefer vegetation associated with early successional stages of forest development, and they are capable of utilizing a wide variety of plants (Cox 1989). The pocket gopher's diet consists mainly of the fleshy and succulent roots and stems of herbaceous annual and perennial plants that are commonly abundant in early successional forests. Gophers, however, will feed on most plant parts, including tubers, leaves, bark, sapwood, and (occasionally) seeds and fruits. Smaller plants may be severed from their roots, pulled through the soil into the burrow, and entirely consumed by gophers. In early forest development, grasses are a significant but smaller component of the total diet (Burton and Black 1978), and gophers often are abundant in climax meadow communities.

When preferred food becomes scarce belowground, gophers may venture a few inches from their burrow opening to feed or collect food items aboveground. Root feeding, stem debarking, and clipping of certain shrubs and seedlings of conifer species may occur at any time of year, but injury is most severe in the winter. Burrow food-caches of roots and stems help gophers survive during food shortages.

Preferred Habitats and Environments

Pocket gophers occupy a wide variety of habitats. They can tolerate a wide range of environments and are highly adaptable to favorable, changing conditions that result from activities such as logging and agriculture. This, together with their wide geographic distribution, relatively high densities, and preference for many plant species important to man, makes gophers a serious pest to agriculture and forestry.

Gophers favor habitat with an abundance of annual and perennial forb species; however, they do well in mixtures of forbs and grasses. Dense populations often are found in mountain meadows, foothill rangelands, and low-elevation valleys.

In forest lands, gophers prefer more open habitat with little overstory canopy, and in the Pacific Northwest they are widely distributed in Douglas-fir, pine, true fir, and mixed conifer forests where they occur in natural openings, clearings for roadways or power lines, and in cut-over or harvested areas (including recently burned forests). Gophers generally avoid dense mature forest and dense conifer/shrub communities, but if these areas are set back to early serai stages by logging or fire, then they become suitable for dense populations of gophers

Pocket gophers co-evolved with plants, so it is natural for gophers to favor the same soils and conditions that support their preferred food-species. Some soil factors limit local distribution, but gophers tolerate a wide range of soils. They prefer clay loams and sandy loams, granites, pumice, schist, and other soils that are light in texture and very porous. These soil characteristics facilitate the good drainage and gas ex-

changes necessary for survival in burrows. Gophers may contribute to the increased percolation and penetration of water, but they also may significantly hasten surface and subsurface erosion of soil. In some regions, however, imperfectly drained soils may contribute to increased numbers of gophers, because the condition favors certain preferred forbs (Volland 1974). Gophers avoid very rocky or gravelly soils and soils with small particle sizes, such as heavy or gumbo clays; consequently, these soil types support few gophers. Gophers prefer deep soils that allow them to avoid temperature extremes near the ground surface. Shallow soils limit food resources and space for burrowing; consequently, gophers are more vulnerable to high-moisture conditions and predation.

Excessively wet soils, seasonal ponding and high water-tables from melting snow, and shallow soils unprotected from freezing temperatures by an insulating snowpack, are devastating to gophers A snowpack that lingers into the summer decreases gopher survival, because the quality and quantity of food diminishes as the dietary needs for successful reproduction and nursing of gopher litters increase.

Certain topographic and physical features directly influence habitat suitability. Slopes in excess of about 35 percent generally are less populated with gophers. Slope direction influences such factors as wind, temperature, soil freezing, snow accumulation, and the speed of complete snowmelt. Rock outcroppings and streams inhibit gopher movements.

Tree Injury and Damage Identification

Pruning of seedling roots, stem girdling, and stem clipping are the most common kinds of gopher injury to seedlings. Stems of small seedlings of 0.5 inch or less may be clipped at or near ground level and the roots and stems may be eaten. Small seedlings may be pulled from below into tunnels, leaving little evidence of the tree's existence. Root pruning in plantations may go unnoticed until the tops turn brown from summer drought or until normal-appearing seedlings tip over at odd angles (fig. 3). These trees easily can be pulled from the ground to reveal the absence of roots (fig. 4). Damage to seedlings and saplings occurs year-round but is most frequent and severe in winter.

Larger seedlings or saplings may not be killed outright if gophers remove only a portion of the roots or root bark and if the stem is only partially girdled. Shortened needles, premature needle drop, shortened internodes, poor color, or poor growth are common characteristics of excess root-pruning or injury. Saplings and older trees sometimes die if gophers repeatedly feed on them. When conifers reach about 10 years of age, however, they generally are much less vulnerable to injury.

Extensive aboveground clipping and girdling of seedlings, saplings, and larger trees occurs under the snow, and damage is more frequent and severe if snow remains all winter and well into spring or early summer (fig. 5). Under deep snow, gopher injury (barking) sometimes extends 6 feet or more above the ground on small limbs or stems of saplings and poles, but it is of little consequence. This type of injury is sometimes confused with porcupine damage. Bark girdling of seedlings by gophers, however, may be complete or nearly complete, this leaves considerable wood exposed in the spring as evidence of winter feeding-activity. Gophers may gnaw deeply into the wood of seedlings and leave a sculptured effect (tig. 6). This helps distinguish gopher damage from damage by rabbits, voles, and porcupines, which rarely gnaw into the wood.

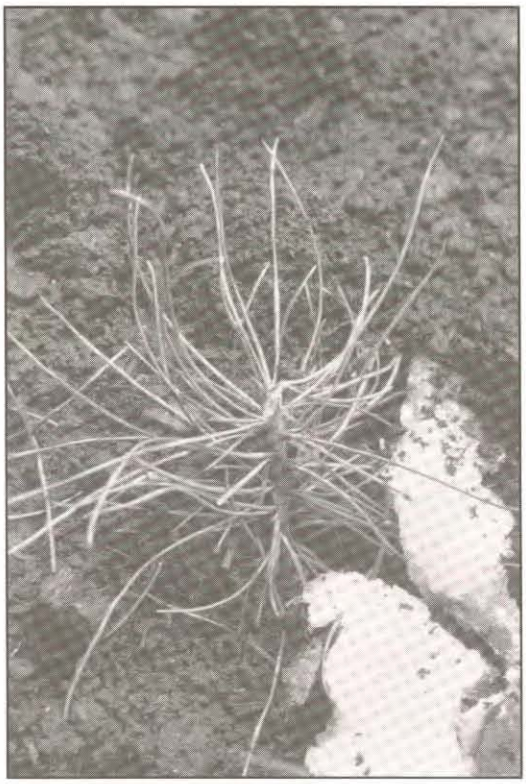

Figure 3—*Top left:* Pine seedling that is loose (unanchored) in the soil, because all major roots have been severed by gophers (Photo by Rex E. Marsh).

Figure 4—*Top right:* All the fine roots and root bark of this seedling have been eaten by a pocket gopher. This type of damage is typical (Photo courtesy Weyerhaeuser Company).

Figure 5—*Right:* Diagonal clean cut of pine stem several inches aboveground occurring while seedling was covered with snow.

Figure 6—*Bottom right:* Aboveground injury to pine seedling caused by pocket gophers burrowing through the snow. Note that gophers gnaw into the wood, giving the stem a sculptured appearance (Photo courtesy Weyerhaeuser Company).

Factors Predisposing a Stand to Gopher Damage

Factors that predispose a site to gopher problems should be evaluated before logging and include:

1. Local gopher-history concerning the severity and ecological distribution of damage relative to forest regeneration
2. Current herbaceous understory in its undisturbed condition
3. Predicted plant succession after tagging and site preparation, and its suitability for sustained populations of pocket gopher
4. Current gopher population (density and distribution) on site and on adjacent lands
5. Percentage of border adjacent to (or within a short distance from) land vegetated with preferred forage species and free of a dense complex of trees/shrubs
6. Suitability of soil and percentage of site suitable for burrowing by gophers
7. Amount of snow accumulation and date when 75 percent of area is normally free of snow
8. Topographical and physical features (such as degree of slope, direction of slope, and drainage of soils

Many of the above factors are included in models that predict gopher damage in conifer plantations. One such model developed for use in conifer plantations in south-central Oregon (Hoi-ton 1987) is a good starting point for computer-oriented managers interested in predictive models. Modifications will be required to accommodate specific local conditions and situations.

The identification of plant communities that are more prone to high densities of gophers is a major step toward predicting current and future gopher problems in regenerating stands of conifers. Volland (1974) and Steele and Geier-Hayes (1987, 1989) have made substantial strides, regionally, in identifying plant communities or serai stages highly preferred by gophers Predisposing factors that favor gophers after natural catastrophes (such as fire, blowdowns, and epidemics of mountain pine beetle) are comparable to factors that accompany logging, and the same considerations, therefore, are needed.

History of Damage and Control

The history of pocket gopher damage to seedlings in the immediate area of a site and the characteristics of sites or stands where the most damage occurred provide the essential clues and background for predicting future injury. Information on the success or failure of past control efforts also provides significant direction for future control.

Assessing and Monitoring Gophers

Reconnaissance surveys of gopher abundance, distribution, and source areas (such as meadows, road banks, etc.) may indicate potential problems. A review of the records for adjacent or similar areas may provide some clues of pending gopher problems, and decisions should be made accordingly. Where the regeneration history indicates that the potential for gopher damage is high, a reconnaissance survey may be warranted before harvest of a particular block is even considered. High potential for gopher damage may influence the type of harvest, the size and shape of the block, and the need for buffer areas or other methods of control, such as preharvest gopher baiting.

If the initial survey suggests a potential gopher problem, then one or more in-depth gopher appraisals should be conducted before site preparation and prior to planting. A series of 0.01-acre plots should be established to measure gopher abundance in terms of the percentage of "active plots" (USDA 1988). At least 1 percent, and preferably 5 percent of the area should be surveyed for the presence or absence of fresh (less than 48-hour-old) gopher mounds. Plots (11,8-foot-radius) should be located systematically throughout the parcel and spaced approximately 209 feet from center to center for a 1 -percent sample or about 93 feet apart for a 5-percent sample (fig. 7). Old gopher mounds first should be knocked down, and the plots should be reread 24 to 48 hours later.

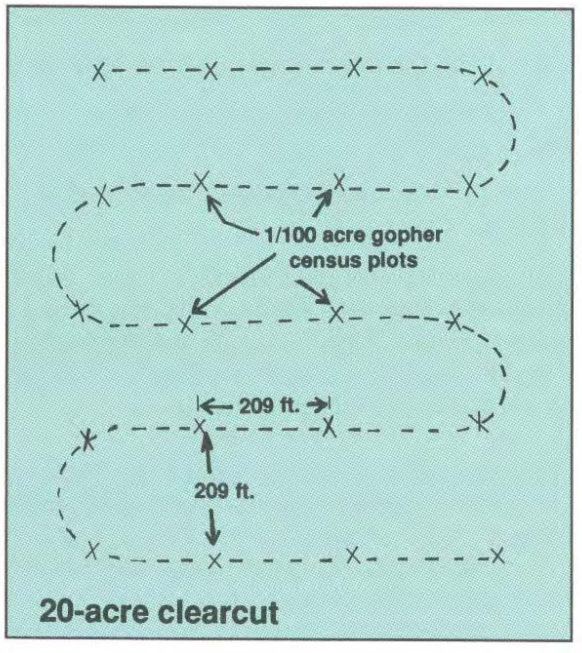

Figure 7—To assess gopher popula-tions, 0 01-acre plots at about 1 plot per acre are placed in a zig-zag fashion across the parcel with the plots spaced approximately 209 feet apart

In parcels to be planted or before the winter-damage period in new plantations (0-2 years old), the Forest Service suggests that a positive reading for the presence of gophers in 25 percent or more of the 0.01-acre plots is a good rule-of-thumb indication that gophers should be controlled. In older plantations, 40 percent or more gopher-infested plots indicates the need for control action. In areas with a history of severe gopher problems, these action-thresholds (percentages) should be reduced by 50 percent or more. Early fall is the ideal time to take a census of gophers, because the mounding prevalent during that period re-fleets the abundance of gophers just before winter (when seedling damage is most likely).

Gopher monitoring must be conducted on at least an annual basis over a period of 3 to 5 years after planting if a potential for gopher problems remains. Seedling stocking-surveys routinely are taken at 1 and 3 years by the Forest Service. These surveys often are used to determine gopher numbers and assess damage, but the frequency of these surveys often is inadequate for effective gopher control. With no intermediate check, extensive seedling damage frequently occurs by year 3. Routine monitoring, therefore, is a must.

The open-hole technique of determining gopher activity is a census method useful for evaluating the effectiveness of a baiting program. An established index of pretreatment activity can be compared with the posttreatment assessment to arrive at the percentage of control achieved (see the open burrow survey, USDA 1988).

Silvicultural Approaches for Preventive Management

Rationale

Foresters long have recognized the potential of certain silvicuttural practices to minimize gopher problems, but they lack information about how, when, and where preventive measures can be effective. Current, published information is scattered and not readily available. Studies that attempt to synthesize the best current information cite many specific examples that describe specific methods for particular situations, but this does not necessarily imply that results from those methods can be extrapolated to different sites. General recommendations rarely suffice; therefore, the forester must appraise each site and manage it accordingly. Pesticide use is becoming more limited; consequently, preventive silviculture practices in animal damage management will, necessarily, play greater roles in the future. Direct control of pocket gophers with poison bait, however, will remain a major forestry practice for the foreseeable future.

Preventive measures of gopher management, ideally, should be considered when the type of silvicultural system is selected and when a stand is being considered for harvest Management options are lost with each step from cutting through planting to final rotation. Once the seedlings are in the ground, the time is past for taking indirect preventive measures. Management options, therefore, become more limited, and direct control methods (such as baiting) become one of the few remaining effective options.

"New perspectives" (also called "new forestry") in forest management currently is receiving much favorable attention and will predictably have a major effect on wildlife habitat and potential problems of animal damage. The emphasis of new forestry is on partial cutting and less-severe disturbances; therefore, it should decrease gopher problems.

Types of Silviculture System

The major factors determining the effect of a harvest system on the potential for pocket gophers are: the amount of overstory removed, the amount of soil disturbance, and the response of the resulting plant community, especially the herbaceous vegetation. Partial cuts (single-tree selections, salvage, sanitation, or thinning) generally create less-favorable conditions than regeneration cuts (shelterwood, seed-tree, or clearcut), and light cuts have less effect on understory vegetation. Selectively cut stands of grand fir in Idaho, for example, have fewer gophers than clearcuts (Steele and Geier-Hayes 1987). In California, Buchner and Rorabaugh (1979) found no difference in gopher numbers between shelterwood and clearcuts; however, others have found that clearcuts support dramatically larger populations of gophers. Clearcutting tends to maximize all factors and contributes to conditions conducive to increases and invasions of pocket gophers. Repeated partial cuts in a stand, however, can result in higher and sustained densities of gophers than might result from clearcutting. Uneven-age management with group selection is more prone to gopher problems than individual-tree selection. The least amount of site disturbance generally decreases the probability of a buildup of the existing gopher population and invasion (Anderson 1976).

In some extreme cases, if direct gopher-control is not an available option or is ineffective, it may be advisable not to log certain parcels at all, because successful reforestation is too uncertain.

Buffer strips—As Volland (1977) suggested, natural or near-natural buffer strips left between gopher-occupied areas (sources of infestations) and sites selected to be logged may reduce invasion or at least slow rapid invasion. Buffer strips probably should be at least 400 feet and preferably 600 feet in width. Any buffer width over 200 feet is helpful, but wider strips offer better protection from invasion.

Partially cut strips are less effective than uncut buffers, but they may be left to separate a clearcut from a gopher-infested meadow or riparian area. Barnes (1974) found that this method effectively inhibits gopher invasion (or about 2.5 years. Barnes (1974) also found no evidence, after 4 years in another situation, of gophers moving across a 600- to 700-foot strip of uncut lodgepole pine that separated gopher-occupied habitat from a clearcut. In both instances, gopher baiting or vegetation control would have slowed the gopher invasion or served as a practical alternative to wide buffers. Buffers can be logged after the trees of the protected block(s) are established and less susceptible to gopher damage; otherwise they may be left indefinitely as wildlife habitat.

Size and shape of logged area—The size and shape of a plot contributes to the speed with which a gopher-free area is invaded from surrounding, infested habitat. This is especially true for gopher-susceptible clearcuts Assuming an area is free of gophers, the time required for gophers to invade the entire area from the outside increases with the size of the block Even if the area is already populated with gophers, larger blocks may facilitate control efforts, because they are less influenced by gopher invasion from outside areas. This is related to the edge effects: as the distance from an infested edge to the center of the block increases, gophers must travel further to occupy the same space. Long narrow plots, therefore, should be avoided in favor of square-shaped blocks when gophers are a potential problem, unless this restriction seriously conflicts with other resource considerations.

Site Preparation

The type of site-preparation ordinarily has a relatively minor impact on direct mortality (Downhower and Hall 1966) among existing pocket gophers, except for a few special situations like deep disking More importantly, however, site preparation strongly influences post-logging plant-communities that, subsequently, have a significant influence on gopher populations. The effects of different site-preparations vary widely, depending on existing plant communities and physical and abiotic site factors.

Mechanical—Hand scarification before planting, although expensive, is the site-preparation method that probably is the least favorable to pocket gophers, because it disturbs the least amount of soil. Mechanical preparation with a bulldozer typically creates continuous 10-foot-wide strips 10 to 12 feet apart This method disturbs about one-third or more of the soil surface and results in an early serai stage of herbaceous plant species. Narrow scrapers attached to bulldozers or scarifying machines drawn by a tracklayer efficiently accomplish the task and minimize soil disturbance.

Plowing and deep disking results in highly disturbed soils, but it may actually kill a substantial number of existing gophers and destroy their burrow systems. Intensive and deep rototilling of the soil over an entire area on a tree farm is an example of this method. Soil disturbance in continuous strips interspersed with undisturbed strips, however, often predisposes seedlings to gopher damage by rapid reinvasion, because the strips of loose soil are virtual freeways for easy burrowing. Gophers can take down a row of seedlings with amazing speed by following the path of least resistance.

Steele and Geier-Hayes (1987,1989) concluded that in certain Douglas-tir and grand fir habitats of Idaho, machine scarification or unintentional soil disturbance by heavy grazing with livestock results in early serai herbaceous-growth that favors gophers. Many of these eariy serai herbs exist on-site in the form of seeds buried in the soil and duff that profusely germinate after significant disturbance. Barnes (1974) suspected that harvesting methods and slash-piling in clearcuts (which resulted in mounds or ridges of loose soil) facilitate easy digging by young, dispersing gophers and provide starting points for new burrow systems.

Burning—In the grand fir/blue huckleberry habitat of central Idaho, gopher activity is apparent in clearcuts scarified without burning, but virtually no activity is apparent on similar sites scarified and broadcast burned or just broadcast burned (Steele and Geier-Hayes 1987). This relationship is also evident in Douglas-fir/pinegrass, Douglas-fir/white spirea, and grand fir/mountain maple habitat-types. The results of prescribed burning or scarification followed by prescribed burning in these habitat-types also are less favorable to gophers than scarification alone. Burning without scarification sometimes results in a dense shrub layer that quickly reduces early serai herbs. Burning can also produce mid-to-late serai herbaceous layers commonly less preferred by gophers. Mechanical scarification alone, in contrast, generates early serai herbaceous layers that favor gophers.

Some areas burned by wildfire, however, regenerate with an herbaceous plant community very favorable to gophers. The reforestation of the Cave Mountain burn in south-central Oregon, for example, was severely impacted by gophers (Barnes 1974) The 1960 Chiloquin burn in Winema National Forest was one of the largest single areas with a gopher problem in the Pacific Northwest. Restocking on some 1,600 acres was virtually destroyed by pocket gophers within 6 years of planting (Canutt 1970). Wildfire and prescribed burns, unless extremely hot and very slow moving, have almost no direct, detrimental effects on gophers, because these burrowing rodents often have nests more than 4 feet belowground.

Chemical—One successful and current strategy controls vegetation during the year before planting or seeding and allows the vegetation to recover and develop with the seedlings. The objective of this strategy is to give seedlings an advantage by first reducing the vegetation and gophers and then letting the vegetation develop as an alternative food-resource for any remaining gophers. Potential conifer damage, thus, is minimized (K. Wearstler, Jr., personal communication). This strategy strives for initial success of reforestation and avoidance of multiple treatments for vegetation-control, but it requires continuous monitoring and rapid action if gophers begin to increase.

Competitive vegetation—In some locations east of the Cascade Range, fine-rooted grasses seeded on clearcuts prevent invasion of bull thistle, which is a major food source for pocket gophers (Hall 1974). This approach also controls other gopher foods, but seed mixes must not include the thick-stemmed grasses (such as bromes) that support gopher populations. Gophers reportedly prefer orchard grass, timothy, and smooth brome over chewings, hard fescues, and some wheatgrasses.

Overstory removal by logging or wildfire sometimes results in a rapid increase of shrubs that significantly impede herbaceous growth favored by gophers. Moderate-to-dense shrub cover usually supports few pocket gophers. This is particularly true where snowbrush and greenleaf manzanita thrive, as in central Oregon. Bitterbrush

cover also supports few gophers. The value of shrub cover in limiting gopher populations under some circumstances may be counterproductive, because it has detrimental effects on conifer establishment and growth (Barnes 1974). Shrub establishment, nevertheless, may be a practical silvicultural approach to maintaining low gopher populations or to confining gopher populations to certain areas (for example, by buffering a larger area). In central Idaho, for example, snowbrush not only reduces gophers but also provides microsites for natural establishment of Douglas-fir. It is also a recommended cover on severe sites where Douglas-fir seedlings need protection (Steele and Geier-Hayes 1987). Brtterbush cover also helps regenerate Douglas-fir in the Rocky Mountains, but it is somewhat less effective than snowbrush.

Seeding and Planting

Foresters agree that speed in reseeding or replanting a logged area is critical (especially in the absence of vegetation control) to reduce gopher damage by getting ahead of gopher population-buildup. Planting should be as soon as possible after harvest and preferably within 8 months. Seedlings should have time to become established before a new stand of gopher-preferred forbs proliferates. Early serai herbaceous-vegetation generally requires 2 to 3 years to reach its maximum after logging, and gophers may increase during that time. Early planting is the single most important of all the preventive silvicultural practices available for pocket gopher management.

Stocking density—The type, amount, and time of planting of seedling stock may influence injury by gophers. Where serious gopher problems are predicted, planting more seedlings per acre increases the probability that a desired number of trees will escape damage. This is not as simple and straightforward as it may seem, however, because depending on the level and distribution of gopher populations, doubling the number of trees planted may not double tree survival. An increase in planted trees, usually, is disproportionate to tree survival, and the cost-benefit ratio may be unacceptable or marginal at best. Gopher damage often is patchy, and the distribution of the surviving trees, therefore, may not be desirable, even if numbers are adequate.

Size of stock—Trees larger than 2-0 with a good root-to-shoot ratio would have a better chance of survival against gophers, assuming they can survive on a site. Larger planting stock should be capable of rapidly reaching a growth stage where it is less susceptible to gopher damage (Capp 1976). With larger diameters, more bark can be removed from the stem before it is completely girdled. Seedlings with larger-diameter stems, moreover, seldom are bent or pinned by gopher movements in the snow or by the formation of casts, this avoids misshapen trees.

Quality of stock—High-quality seedlings with inherent vigor are extremely important, because they become established and grow more rapidly. Improved methods of handling tree seedlings from the nursery to the field have significantly decreased losses from a variety of causes (including gophers). Healthy trees can tolerate more damage (stress) than trees with poor vigor can tolerate.

Tree-feeding preference of gophers—Crouch (1971) found no difference among ponderosa, Jeffrey, and lodgepole pines in their susceptibility to gophers. Black and Hooven (1977) also found no significant difference in gopher-damage occurrence among five tree species planted in southwest Oregon. This evidence supports the general conclusion that all major, commercial conifer-species planted in the West are subject to serious damage in areas with high populations of gophers.

Radwan and others (1982) found that the source of tree seeds affected gopher-feeding preferences and associated damage by as much as 31 percent. They speculated that trees from some areas might contain greater proportions of chemicals that naturally deter gopher damage. Genetic manipulation to increase resistance to gopher damage is of interest, but it has not been developed; therefore, it is not a management alternative for practicing foresters.

Stand Tending

Chemical vegetation management—Herbicide application as a silvicultural practice to modify habitat and reduce or eliminate food resources is an important gopher-management option. Some foresters practice aggressive vegetation control early in the establishment phase of regeneration, and they consider this method critical to the reduction of gopher problems. Reduction in gopher food, however, often is the secondary result of herbicide applications intended to release valued species of trees from competition with other plants.

Early experiments to control pocket gophers by altering their food source with herbicides were conducted on a mixed forb-grass rangeland in Colorado The concept was first mentioned by Cummings (1948). Spraying with 2,4-D resulted in an 83-percent reduction of perennial forbs and an 87-percent decrease in pocket gophers (Keith and others 1959). The diet of pocket gophers switched from 82 percent forbs and 18 percent grass species to about equal amounts of each. Gophers feed extensively on grasses when more preferred forbs are scarce, but their populations usually decline under such circumstances.

In a mixed conifer region of southwestern Oregon, Black and Hooven (1977) studied the effects of herbicide-induced habitat on the abundance and feeding activities of pocket gophers. Grasses were controlled with atrazine and simazine, and forbs and shrubs were controlled with 2,4-D. All three chemicals were applied in combination for complete control of vegetation, and the number of gophers decreased to about one-tenth the population found on untreated plots.

Applications of atrazine increased the survival of ponderosa pine by decreasing the number of gophers (Crouch and Hafenstein 1977). In south-central Oregon, one or two fall applications of atrazine on plots of ponderosa pine seedlings resulted in fewer gophers and significantly higher rates of survival and growth as measured 10 years later (Crouch 1979).

The application of herbicide after planting reduces the gophers' natural food and may temporarily increase gopher-feeding pressure on conifer seedlings by limiting alternate food sources. Two such instances have been documented. In one case, herbicides killed bracken fern and increased the mortality from gopher damage of five tree species. In another case, the grass/forb community was controlled with herbicides, and the mortality of lodgepole pine seedlings increased threefold (Boyd 1987). In both cases, the seedlings were planted before the gopher population diminished. This suggests that caution should be exercised when herbicides are applied to release tree seedlings in areas with moderate-to-high densities of gophers. Vegetation with manipulation by herbicides generally is short-lived, especially in areas of high rainfall. The most efficient and effective methods of vegetation management with current herbicides are discussed in detail in chapter 4.

Biological Control of Gophers

Concept and Potential

Biological control is the use of diseases, parasites, or predators for the control of a pest species. In practice, this generally involves the deliberate introduction of fatal or debilitating pathogens or exotic predators. Although biological control is effective for the control of certain introduced insect and weed pests, it generally is less effective with native species of pests. With vertebrate pests, most biological controls that introduce exotic diseases or predators are ineffective, and many have a deleterious effect on other wildlife species. A good example of a significant negative impact is the introduction of the mongoose into the Hawaiian Islands to control rats. Many similar examples can be cited. One of the few examples of effective biological control of a vertebrate pest is the introduction of myxoma virus (an often fatal pathogen) to control the (introduced) European rabbit in Australia. Pocket gopher diseases and their regulatory effect on populations are mostly unknown. The introduction of a fatal disease, even if biologically sound, therefore, is not a current option.

Encouraging Natural Predators of Gophers

Few studies have been conducted on avian, mammalian, or reptilian predators and their effect on pocket gopher populations. Most studies conclude that predation does not significantly reduce gopher populations. Hansen and Ward (1966) argued, for example, that weasel predation slows pocket gopher increases but does not prevent substantial populations from developing. Gophers are fossorial, and they are inaccessible, therefore, to all but a few predators except when they are aboveground. A few predators (such as badgers) effectively dig gophers out of their burrows.

Avian predators, such as long-eared and great horned owls, red-tailed hawks, ferruginous hawks, and northern goshawks, may be more efficient than mammalian predators in capturing gophers. Kimbal and others (1970) observed a reduction of gopher populations in the vicinity of an artificial roosting site for raptors. Similar studies of hunting perches and raptor predation on pocket gopher populations, however, were inconclusive (Christensen 1972). Hall and others (1981) also demonstrated that artificial perches increased raptor hunting in nearby areas, although no reductions in gopher populations could be measured.

The control of pest species with predators is a concept fraught with misconceptions about predator-prey relations. These species evolved together, the number of prey available generally controls the number of predators in the area rather than the predators controlling the prey. A study relating numbers of coyotes to numbers of pocket gophers found no correlation between the two (Robinson and Harris 1960)

Predators may regulate the population of a prey species in local situations but rarely to levels below economic damage thresholds. Unlike many insect predators and herbivorous insects that are host-specific, many vertebrate predators are generalists that feed on a wide range of prey that includes pest and nonpest mammals or birds. Strong evidence indicates, moreover, that limited predation is beneficial to the prey species, because it removes the less fit individuals from a population and actually may stimulate reproduction (compensatory replacement).

The best that might be expected from natural predation is that in combination with other methods (such as vegetation control or population reduction with poison) the decrease in gopher abundance will be greater than by any single method alone. Artificial perches or some unmerchantable "whip" trees left in clearcuts as natural perches, therefore, may be useful silvicultural practices (Hall 1974). Certain snags also might be saved to provide suitable nesting sites for predators. Predation is more likely to limit dispersal aboveground and slow population-growth than to reduce overall populations.

The New Forestry movement emphasizes the retention of fallen logs, piled and unburned slash, and greater protection for riparian vegetation. These components of new forestry enhance wildlife habitat and encourage small mammalian predators such as the long-tailed weasel, ermine, martin, skunk, wolverine and red fox. Other resource considerations, such as the impact of predators on endangered wildlife species and livestock, therefore, also must be considered.

Direct Control Measures

Traditional Methods

Silvicultural approaches that heavily rely on habitat management for gopher control often must be supplemented with direct-control measures. Direct control of animal damage or measures of vertebrate pest-management can be divided functionally into two categones; one aimed at reducing the population of the offending species, and the other directed at protecting the trees from damage with physical barriers, such as plastic-mesh tubing or chemical repellents. Biological and ecological factors and cost-benefit considerations determine whether to focus on the resource, the pest, or both.

The two approaches can complement one another or provide important alternatives. Where rodenticides may not be an option, for example, physical protection of trees may be the only available solution. Tubing is a preventive measure, because it must be installed at the time of planting and before damage occurs. The need for tubing, therefore, must be anticipated.

The reduction of gopher populations with traps, poison baits, or burrow fumigants is direct and immediate, and it is often termed "traditional control." Poison baits are most common, because they are the most cost-effective method, and they provide predictable control.

Direct methods of animal damage control should, when possible, be part of an integrated management plan that includes appropriate Silvicultural practices. The USDA Forest Service Animal Damage Control Handbook for Region 6 (1988) provides more specific information on direct methods of control.

Seedling Protectors

Vexar or similar photodegradable polypropylene mesh has long been used to protect conifer seedlings from damage by snowshoe hares, rabbits, mountain beaver, deer, and elk. In the 1960s, Anthony and others (1978) evaluated Vexar tubes and their protection of conifer seedlings from gopher damage. Before planting, seedling roots and aboveground parts are slipped into Vexar tubing 2 inches in diameter and some soil is added to hold the roots in place until planting. Vexar tubes have also been tested with plug seedlings. The tubes provide substantial protection from gopher damage aboveground and belowground. Small-scale trials in which only the aboveground portions were protected were less successful Gophers can gnaw through the tubing, but they generally tend not to do so. In one significant exception, however, . thousands of seedlings were damaged aboveground by gophers that gnawed through the tubing beneath the snow

Protective barriers substantially increase the cost of planting, and despite some impressive results, long-term effects on trees have not been adequately evaluated. The concept is sound, but the reduction of gopher damage with tube-type protectors presently is limited.

Repellents

Repellents suitable for protecting seedlings from gophers do not, at present, exist. Various commercial, chemical rodent repellents, such as R-55 (tert-butyl dimethyltrithioperoxy-carbamate) and bioMeT-12 (tn-n-butyltin chloride) have been

tested, but their limitations include cost, lack of persistence, phytotoxicity, and poor efficacy in the protection of conifer seedlings. Thiram and BGR (putrescent whole egg solids) are effective at controlling several other forest mammalian pests, but they show no promise tor controlling pocket gophers.

Trapping

Trapping, although labor intensive, effectively controls gophers where numbers are low and acreage is small. The Macabee trap is the most popular of several types of kill traps (Barnes 1973), principally because it is very effective and requires less digging to set (fig. 8). The Cinch trap, which has been around for a long time, is attracting renewed interest, but it is not marketed extensively. Trapping is reasonably cost-effective on large acreages only if it begins before gopher populations exceed about five animals per acre. Manpower must be adequate to ensure decisive results that avoid the cropping effect characteristic of long-term, minimal trapping. Trained and experienced gopher trappers significantly improve results from this method Bounty systems have always proven ineffective and are not recommended.

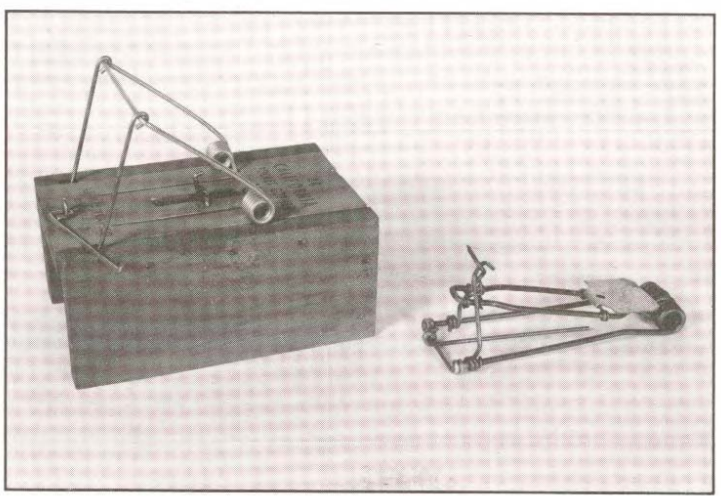

Figure 8—Trapping can be an effective method of control where gophers are not too numerous Box-type trap is on the left and a Macabee is on the right (Photo by Rex E Marsh).

Poison Baits

Baiting with rodenticides can be highly effective in reducing pocket gopher populations over large areas. Grains, such as oat groats, wheat, milo, and hulled barley, are the bait to which rodenticide is applied. Strychnine is the acute toxicant used most extensively, and several different bait formulations are commercially available. Zinc phosphide currently is registered for gopher control as loose grain and grain-based pelletized baits, but its effectiveness usually is considerably lower than results obtained with strychnine. Strychnine and zinc phosphide both are restricted-use pesticides, and applicators must be certified in the safe and proper use of these chemicals.

The chronic anticoagulant rodenticides, diphacinone and chlorophacinone, are marketed for gopher control as loose grains, grain-based pellets, and in paraffinized grain blocks (Marsh 1987). Anticoagulant baits act slower and require repeated feedings to cause death; therefore, control is more expensive. Anticoagulants recently have been scrutinized more closely as potential methods of gopher control in forest situations. Cholecalciferol (vitamin *Dy}* currently is under investigation and shows considerable promise. The potential for primary and secondary toxicity to nontarget species is minimal for all rodenticides in current use, because baits are placed belowground and the great majority of gophers die in their burrows.

Methods of Bait Application

Hand baiting—Hand application of gopher bait involves locating underground tunnels with a metal probe after noting the presence and location of fresh mounds. When the tunnel (preferably a main one) is located, the probe is rotated to enlarge the opening and then removed. The recommended amount of bait is then spooned or poured into the tunnel, and the hole is closed with a clod or with a piece of bark. At least two locations should be baited in each gopher system. Where gophers are very dense, baits may be placed about every 100 to 200 square feet.

Hand-operated probes have been designed with a bait reservoir to make hand-baiting operations more efficient. Burrow tunnels can be probed and located with this tool and a measured amount of bait is then released into the tunnel with a dispensing mechanism. This mechanization simplifies and speeds the baiting operation. Several designs and makes of these probes are on the market, and some are better than others. Models that deliver a precise amount of bait, do not dribble bait in the "off" position, and are least prone to plugging up with soil are most desirable.

Burrow builder—The burrow builder is a tractor-drawn device that constructs an artificial burrow 8 to 10 inches beneath the soil surface and deposits poisoned grain bait within the burrow in preset amounts and at preset intervals. The tractor operator runs the machine back and forth across the control area at regularly spaced intervals (about every 15 to 20 ft) to make a series of parallel burrows (fig. 9). Artificial burrows formed in this manner intercept most natural gopher-burrow systems in the area. Gophers, by nature, readily explore these artificial tunnels and consume the bait.

Figure 9—Gopher baiting with a mechanical burrow builder

The burrow builder is recommended for use whenever and wherever possible, because it greatly speeds gopher control. Most importantly, however, it does not rely on visual identification of individual gopher systems as in the case of hand baiting. The burrow builder, therefore, often controls gophers more effectively than hand baiting. Machine baiting is especially useful in the spring, when the density and locations of gophers may not be evident, because few fresh gopher mounds may be produced at that time. New forestry methods, however, leave more obstructions in the habitat and limit the acreage that can be serviced by this method. Modified use patterns, however, can overcome some of these problems.

Burrow builders were designed for agricultural use, and commercially available models are not rugged enough for the more severe terrain and conditions in forests. Reinforced models, however, have been constructed specifically for use on forest land (Canutt 1970) (fig. 10). The site cannot be too steep or contain much slash or rocky or gravelly soil. Flat or gentle, sloping, and open-type sites with deep soil and few obstructions are most suitable for this method. The soil must contain enough moisture to produce good, firm burrows with few collapses.

Figure 10—Loading bait into a heavy-duty burrow builder modified for forest use (Photo by Warren Sauer)

Baiting with a burrow builder, however, may provide underground avenues for gopher dispersal if a high degree of gopher control is not achieved. This potential problem can be minimized by running the rows parallel with the edge of the plot with the greatest likelihood of supplying invading gophers. Artificial burrows should not extend across the block so that easy movements throughout a clearcut are minimized. Lifting the baiter from the ground momentarily every few hundred feet breaks up continuous tunnels and helps avoid this problem. Tree planting machines that produce avenues of disturbed soil cause a similar problem by making it easier for gophers to tunnel from tree to tree.

Efficient and effective gopher control, regardless of the method of bait application, requires well-trained personnel. Poor control often can be attributed to poor timing and improper techniques of application or a lack of attentiveness by control personnel.

Baiting Strategies

When the predicted potential for increases in the gopher population after logging is high, one of the most effective preventive-measures is to control gophers on the block to be logged and on adjacent sites with traditional methods (poison bait or trapping, for example) before logging begins. Very little effort may be needed to reduce the population to very low levels at this early stage. Gophers usually are controlled with poison bait placed after harvest and before planting. Waiting until gophers start to damage seedlings is the least advisable strategy of control

Hand baiting achieves the best results with follow-up baiting after the initial treatment A residual 20 percent of the original population may be reduced by another 80 percent with a second baiting. This reduces the gopher population to a level that greatly prolongs the time to recovery. Controls that reduce the gopher population by 75 percent or less, in practice, generally result in the recovery of the population within 1 year.

The percentage of population killed is a misleading measure of control, because it does not take into account the propensity of the remaining population to return to damaging levels. This relates to a sigmoid-shaped population growth curve: the population must build momentum before it rises sharply (fig 11). Ninety-percent control of a dense population leaves from 2 to 10 times as many survivors as 90-percent control of a medium or low population. The ability of the survivors to repopulate makes it highly desirable to control gophers when population densities are very tow. Early control of a growing population prevents a later, more serious problem.

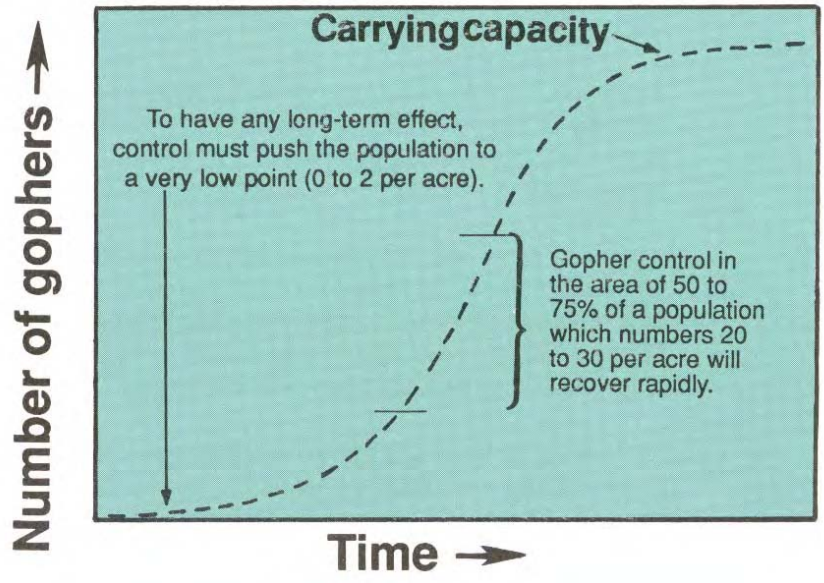

Figure 11—Gopher populations plotted over time result in a classic, sigmoid-shaped population-growth curve Effective control must push the population to a level well below the steepest portion of the curve, otherwise, the population will recover rapidly

A major problem with hand-baiting to control gophers in forest situations is the lack of a fresh gopher sign that indicates the location of burrow systems. This is especially true at higher elevations in spring or early summer, when mound building is infrequent or absent. If hand-baiting is carried out in early spring before mounding is extensive, old mounding and winter casts also should be used as baiting cues. Spring baiting is highly desirable from a biological point of view, because it controls gophers before breeding, during gestation and before the young can fend for themselves. Effective spring baiting with a burrow builder significantly reduces population recruitment; therefore, from a timing point of view, it is superior to baiting in the late summer or fall after the annual population increase.

Hand-baiting in summer and early fall, when visual evidence of gophers is at its highest and before the snow season begins, is a common practice. Increased gopher activity at this time partly results from dispersing young that start new burrow systems. Highly effective late summer or fall control pushes the population to low levels and reduces seedling losses, which are severest in winter.

Gophers also should be baited in a buffer zone of at least 200 feet but preferably about 400 feet in width and surrounding the primary block to prevent reinvasion. This substantially increases the control area; however, it results in more lasting control of gophers and greater savings from reduced seedling loss and less need for repeated treatments. Failure to treat gopher-infested buffer areas has doomed many control efforts.

Residual gophers that were missed or survived previous treatments are also a serious problem. Gophers repopulate poisoned areas more rapidly than they disperse into new areas, because unoccupied burrow systems provide instantly available harborage that assures high survival. Early treatments when populations are still low, therefore, are extremely important.

In suitable habitat, unless the gopher population is reduced to very low levels, baiting annually or biennially may be required until the herbaceous layer reaches a serai stage that supports few gophers or until the trees reach a size where gophers cause little damage.

Control of small, incipient populations of gophers in and around sites before logging is an excellent baiting strategy that, unfortunately, is rarely practiced. The trend towards new forestry probably will increase the emphasis on preharvest baiting of gophers. Sources of potential gopher infestation on adjacent meadows, along roads, etc., definitely should be controlled before planting.

Fumigants

Fumigants, such as gas or smoke cartridges, have been used for controlling various burrowing rodents. They are relatively ineffective, however, for controlling pocket gophers. Past failures to control gophers with fumigants were attributed to the extensiveness of burrow systems, the ability of gophers to detect toxic gas and rapidly block off tunnels, and the preference of gophers for porous soils that leak gases. Aluminum phosphide, a restricted-use pesticide registered for the control of burrowing rodent pests, apparently is an exception that is quite effective for controlling pocket gophers. It works best when the soil moisture is relatively high It is used in landscaped areas and some agricultural situations, but because of its relative newness for gopher control, it has not been used in forest plantations.

Fumigants usually are more expensive than baits. They most often are used to control small numbers of pocket gophers in high-value crops or on sites where the costs can be justified. This method holds great promise as a followup application in cases where treatment results from baiting are unsatisfactory.

Assessing Control Results

The effectiveness of traps or poison baits as methods of control can be assessed by measuring tree survival and effects on the gopher population. Protective control with plastic-mesh tubing generally can be assessed only by measuring seedling survival. Assessments must be periodic, because the duration of the effects of control is an essential component of regeneration success. The USDA Forest Service Damage Control Handbook (1988) is a good guide to these methods.

Research Needs

Considering the monetary losses to forestry caused by gophers and the amount spent on their control, the magnitude and severity of the problem certainly justifies additional management attention and research expenditures.

The following are some of the most important research needs from a forester's point of view, with the emphasis on silvicultural approaches and habitat management:

1. More comprehensive data are needed concerning habitat types and their suitability for supporting gophers for each principal plant community within forest habitat. Computer models for predicting gopher problems should be developed, ultimately, including gopher-population models and expert-systems models to direct managers to the best combinations of indirect and direct control measures on the basis of costs and benefits.
2. Information is needed about the influence of specific silvicultural practices on gophers and their population response to habitat manipulation in each principal forest type.
3. Better correlation of surface activity (evidence) with actual gopher damage levels is critically needed.

Other research areas of somewhat lower priority include better analyses of costs and benefits and predator-prey relations, the relation of nursery fertilization schedules to the susceptibility of seedlings to gopher damage, and the breeding of trees resistant to gopher damage.

Summary

Pocket gopher management with a major emphasis on silvicultural practices and a secondary focus on an integrated approach to damage control can be summarized briefly with the following points-

1. Some basic knowledge of pocket gophers and their biology and ecology is essential to making the best management decisions. Knowledge of the history of gopher problems relative to harvesting methods, site preparation practices, and reforestation in the general area also are essential components of integrated management planning.
2. Assess and predict before harvest the potential for gopher problems after harvest.
3. Decide on a silvicultural harvest system that favors pocket gophers as little as possible in areas where the potential for gopher damage is high.
4. Apply silvicultural practices (size and shape of plot, buffer areas, site preparations, etc.) that minimize potential gopher problems during regeneration.
5. If gopher damage is a potential problem, it is most critical to plant as soon as feasible after harvest.
6. Monitor gopher populations on a regular basis and be especially alert to increases in the density or range of populations.
7. When appropriate, restrict food by managing vegetation to reduce gopher numbers or reduce population growth.
8. Continue to monitor for gophers at least once and preferably twice annually.
9. Bait when a gopher problem is imminent and do not wait until damage already is excessive. Rapid and thorough action is essential, especially in young plantations (0 to 3 years old).
10. Keep good records on gopher damage and management activities. Lessons from past successes and failures can lead to improved silvicultural practices.

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 11
Mountain Beaver

STEPHEN L. CAFFERATA

Abstract

More serious damage to Douglas-fir plantations is caused by mountain beaver than by any other animal species in the Pacific Northwest. Mountain beaver cause patchy damage within stands by clipping seedlings, climbing young trees and clipping lateral branches and tops, barking the bases of saplings, and by undermining and barking roots. Significant mortality and growth loss are associated with this damage.

The mountain beaver is a rodent weighing 2 to 4 pounds with a number of unique characteristics. Among these are a low birth rate (single litter per year averages 2.5 young, with females generally not becoming pregnant until the second year after birth), relatively long life (5 to 6 years), and generally healthy condition. They are sensitive to high and low temperature extremes and need large quantities of water or succulent vegetation. They eat a broad variety of vegetation and are unique in their ability to live on sword fern and bracken fern. They range from sea level to 7,000 feet. In dryer climates, mountain beaver are most common in cool, wet draws and north slopes. They are frequently found on south slopes and near ridge tops in moister situations.

STEPHEN L. CAFFERATA is forestry manager, Willamette Area, Weyerhaeuser Company, Springfield, Oregon 97477.

The key strategy for controlling mountain beaver damage is to manage stands to maintain mountain beaver populations at low levels. This prevents the occurrence of devastating damage and allows steps to be taken that reduce increases in damage when it occurs. Silvicultural approaches can help maintain populations at low levels, but these approaches probably will not be sufficient and direct methods also will be needed where mountain beaver pressure is intense.

Silvicultural approaches to damage control are those methods that maintain sites and stands in conditions that do not encourage the expansion of mountain beaver populations. Such methods include a consideration of harvest unit size and shape, site-preparation techniques, encouragement of predator populations, rapid postharvest regeneration with large transplant stock, stocking density, the timing of precommercial thinning, the level and timing of commercial thinning, and the method of logging.

Direct approaches to the control of mountain beaver damage are needed when populations are high, damage levels are unacceptable, or populations are increasing in spite of existing Silvicultural techniques. Two basic approaches are possible: tree protection and direct population control. Tree protection is done with physical barriers that most commonly are plastic-mesh tubes placed around seedlings either after planting or at the nursery. The nursery-installed barriers are then planted with the tree. Populations are controlled either by trapping or with poison bait. Trapping is the most common method of direct control.

Most land managers use a combination of approaches. The most environmentally sound and cost-effective method of managing damage at acceptable levels during the life of the stand most commonly is an integrated approach. Stand monitoring must be continued to ensure that populations of mountain beaver never are allowed to build up to levels where they can do significant damage to stands at advanced ages.

A decision methodology is needed for selecting the best methods Neither preventive nor corrective strategies are ideal. The former may require the expenditure of unneeded resources and the latter may be too late. More predictive ability is needed to refine management decisions.

Keywords: Mountain beaver, animal damage, vertebrate pest, mountain beaver control, animal damage control, pest control.

Biological Characteristics

The mountain beaver is a small mammal occupying a unique ecological niche in the Pacific Northwest (fig. 1). This burrowing species also is active aboveground. As the only surviving member of a primitive family of rodents, *Aplodontidae,* it frequently has been studied. It is restricted to the west side of the Cascades and the northern Sierra Nevada Mountains to the coast. It is commonly called mountain beaver, but it is not closely related to the beaver *(Castor canadensis).* Other common names include mountain boomer, boomer, whistler, mountain rat and (the Indian name) sewellel (Borrecco and Anderson 1980). Few people have ever seen a mountain beaver, and the name causes much confusion among the general public.

The mountain beaver is a barrel-shaped rodent. The adults are about 1 foot long and weigh from 2 to 4 pounds. The body is muscular with short legs. The front legs are well adapted for digging, with clawed toes. The snout has long vibrissae or tactile hairs, and the ears and eyes are small The tail is short and furred and the fur generally is reddish brown. Color variation is one difference among the seven recognized

Figure 1—Photo of mountain beaver (Weyerhaeuser Company photo)

races, but it also occurs within populations (Godin 1964). All mountain beaver have a small white spot at the base o1 the ear The feet are bare soled with five strong digits. Mountain beaver can hold and grasp objects with their front feet, and they sometimes feed while sitting on their haunches holding food in their front feet. This grasping ability also makes them agile climbers, and their tree climbing ability is well known. They have poor eyesight and have difficulty detecting stationary objects, but they can detect gross movements. The high eye position gives them poor depth perception Hearing is confirmed, but its importance remains undetermined. Smell appears to be the most used sense of the mountain beaver, and it is used to find and select food as well as to detect danger and recognize other members of the species. The long vibrissae or tactile hairs also sense and guide the mountain beaver's movements and are very important for movement within burrows (Goslow 1964).

Life Cycle

Mountain beaver are solitary creatures, and they avoid contact with one another even when their home ranges overlap. Males are in breeding condition from mid-December to mid-April Estrus occurs in females within a period of 5 to 7 weeks in February and March. All females in a population ovulate about the same time each year. Females generally do not become pregnant until the second breeding season after their birth. The gestation period is about 30 days. Birth occurs in late March to early April. Litter sizes usually are two to four offspring, and two to three young per litter is most common. The sex ratio is even. Nursing lasts about 2 months, and the young emerge from the burrow about 2 weeks later (in June). One litter is born per year By 4 months, mountain beaver weigh 70 percent of their adult body weight. Yearling animals weigh about 90 percent of their adult weight. Research suggests that mountain beaver commonly live 5 to 6 years (Feldhamer and Rochelle 1982).

Population Dynamics

The time it takes for mountain beaver to reach breeding age, their single litter per year, and their small litter size means that populations of this species are more stable and less explosive than populations of many other rodent species. The comparatively long life span also contributes to population stability

The solitary lifestyle and clean habits of mountain beaver, apparently, keep them disease free. They are hosts for parasites, including tape worms, fleas, mites, and ticks. Nests generally harbor various parasites, including the largest known flea (Feldhamer and Rochelle 1982).

Predators of mountain beaver are numerous and include most carnivores. Coyotes, bobcats, and great horned owls are principal predators. Golden eagles and many other small predators also prey on the rodent. Limited information exists on the effect of predators on mountain beaver population densities. DeCalesta and Witmer (1983) estimated that mountain beaver supplied 90 percent of the daily intake required of bobcats and coyotes on the Elliot State Forest in southwestern Oregon. This extrapolates to 200 mountain beaver per bobcat and 223 mountain beaver per coyote per year.

Specific data on population replacement rates for mountain beaver is not available. Rough estimates, however, indicate that significant replacement is possible. If 25 percent of the population is composed of mature females, then the population-increase potential without mortality would be 60 percent the first year. Mortality of adults and higher mortality of young prevents this from occurring. Replacement rates under different conditions are not known.

Key Requirements

Mountain beaver are vulnerable to hot and cold temperature extremes. They can maintain their normal body temperature under conditions that range from 25 to 86 degrees F. (Johnson 1971). This inability to effectively thermoregulate restricts them to specific climates and necessitates a burrow system that moderates temperature extremes. Their nest chamber is well insulated and allows them to maintain body temperature when resting.

Another unique characteristic of this species is a primitive kidney that limits the animal's ability to concentrate urine. It is one of the least efficient of mammals in terms of conserving water, and it must consume approximately one-third of its body weight in water daily. Mountain beaver, therefore, require available water or large quantities of succulent vegetation, and their burrow systems must be high in humidity (Johnson 1971).

Mountain beaver eat foliage and bark from a wide range of plant species. Sword fern and bracken fern (when available) comprise a large portion of the animal's diet (the former in winter). The mountain beaver's ability to digest and utilize these plants is unique in that the animal obtains more nutritional value from these species than do most other mammals, and mountain beaver are the only mammals that can subsist on these ferns. Pregnant and lactating females require high intakes of protein, and they switch to plants such as conifers and grasses that are richer in protein than the ferns (Voth1968).

Mountain beaver utilize a wide variety of other plant species, including vine maple, red huckleberry, salal, Oregon grape, thimbleberry, salmonberry, elderberry, and miners lettuce. It is estimated that two and one-half times as much vegetation is cut and gathered as is eaten (Voth 1968). Some is used for nest material. Much is wasted. The typical foods of mountain beaver are low in nutritive value; therefore, the animal must spend three-quarters of its active periods gathering and eating food (Voth 1969). Table 1 shows the general categories of food in the mountain beaver diet. Mountain beaver, like other rodents and hares, eat their soft feces to recover the essential vitamins produced during the digestive process.

Table 1—General categories of food items in the diet of mountain beaver as determined from counts of epidermal fragments from fecal pellets

	Age and sex group[a]		
Vegetation category	Males and nonpregnant females[3] (N=12)	Lactating females[3] (N = 3)	Juveniles[3] (N=4)
Pteridophytes (ferns)	84.0	37,7	90.7
Conifers	3.4	33.9	0.0
Grasses	2.5	18.4	4.6
Forbs	1.9	4.8	2.6
Hardwoods	5.4	1.3	1.3
Mosses	1.0	3.5	0.9
Shrubs	1.1	00	0.0

[3] Numbers given are percentages of total tor each age and sex group
Source Feldhamer and Rochelle 1982, adapted from Voth 1966

Distribution

The present range of the mountain beaver extends south from southern British Columbia to central California. It extends from the Pacific coast east to the Cascade Range and the Sierra Nevada. The animal ranges from sea level to about 7,000 feet in elevation. It is most abundant in Oregon and Washington, where it is found in humid, densely vegetated areas, primarily at low elevations (Walker and others 1975). Mountain beaver require conditions where succulent vegetation is abundant and where relatively high humidity can be maintained in burrows (Voth 1968).

Populations generally are arranged in a clumpy distribution in draws and moist areas. North and east slopes are the most common locations in southerly, drier climates. In many instances, however, populations may be found living away from draws, on south slopes, and at high elevations in moister situations.

Mountain beaver populations are very low in dense conifer stands (Hooven 1973). Brushy openings in stands provide suitable habitat that often supports populations of the animal (Hooven 1977). After timber harvest, mountain beaver populations may increase rapidly, especially in preferred habitat types of fern, shrubs, and young hardwoods. Under these conditions, populations of three to six animals per acre are common. Populations of the animal in young stands are highly variable, but as many as nine animals per acre have been found in such stands.

Home Range and Activity

Mountain beaver spend their lives in home ranges that average less than 0.7 acre in size. They live in burrow systems that radiate from a central nest chamber (see fig. 2). Martin (1971) found that these chambers "were most frequently located at sites with good drainage, usually under small mounds, logs, uprooted stumps, logging slash, or thick vegetative growth." In addition to a nest chamber, mountain beaver build feeding, refuse, fecal-pellet, and earth-ball chambers. Nests are roughly circular, 20 to 24 inches in diameter, and 14 inches high. They are filled with up to a bushel of vegetation that provides insulation. The feeding chamber may be as large or larger than the nest chamber, and it also is used to store both wilted and fresh vegetation.

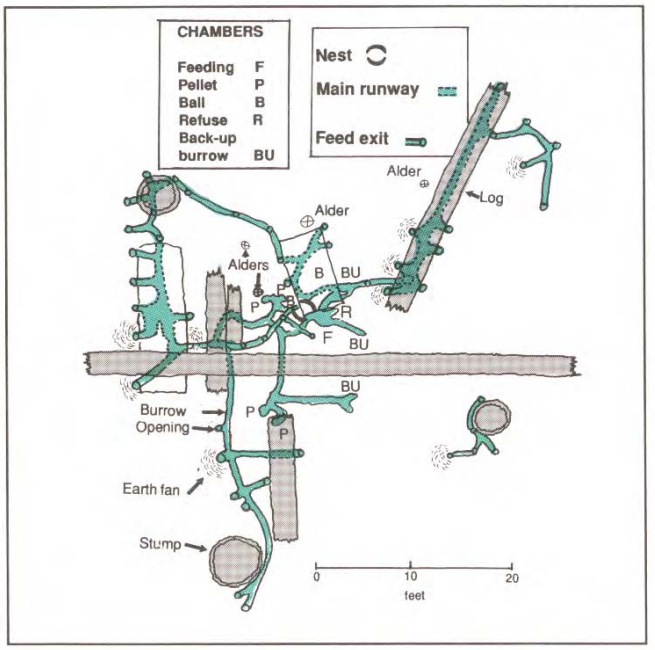


Figure 2—Underground tunnel system of a mountain beaver (Voth 1968)

Decayed plant material may be placed in a refuse chamber. Mountain beaver use the earth-ball chambers to store stones and compacted dirt that they use to block entrances to the nest and feeding chambers The animal may trim its teeth on these items (Voth 1968).

Mountain beaver seldom range more than 80 feet from their nest chamber (Martin 1971). They primarily move through their shallow burrow system, which has numerous openings, for food-gathering purposes. The animals move short distances aboveground They may consume vegetation aboveground, but they generally clip vegetation and move it to burrow openings or other caches where they either consume the vegetation or store it before moving it again to a more secure location. The feeding chamber is the most secure destination (Voth 1968)

Each animal has an individual nest and defends its territory. Their home ranges overlap, however, and they share some runways. Once established in nest sites, mountain beaver use them tor extended periods (periods of more than 3 years have been recorded) (Martin 1971). They readily occupy the existing nest systems of other mountain beaver if the resident dies or departs (Goslow 1964)

Juveniles travel relatively long distances once expelled from the nest Distances of one-third of a mile have been measured, and the animals may swim streams as they search for suitable nest sites. Males travel longer distances outside their home ranges during the breeding season Martin (1971) tracked one animal that roamed 350 feet from its nest.

Mountain beaver are active during seven periods per day that are interspersed with resting periods. They are mostly active aboveground at night, but some foraging also occurs at dusk. Mountain beaver move about the burrows at all times (Ingles 1959,

Voth 1968). Activity aboveground is curtailed during winter weather (Kinney 1971), and apparently little movement occurs during freezing weather. The animals tunnel under snow in winter and may tunnel to the surface and walk on the snow crust (Scheffer1929).

Damage Identification and Presence

Evidence of feeding on conifer and hardwood plants is one of the key indicators of the presence of mountain beaver. Feeding occurs both aboveground and belowground. Aboveground, the animals clip plants measuring as much as 1 inch in diameter, and the diagonal clip is characteristic of rodents (see fig. 3). Mountain beaver also climb young trees and shrubs and clip lateral branches as well as terminal shoots as high as 20 or more feet. Basal barking of conifers occurs in trees of a wide range of diameters (3 to 16 inches at ground level), but this is most common in trees with diameters of 4 to 6 inches at ground level (fig. 4).

Figure 3—Clipped seedling–3/4 inch in diameter clipping (photo by Bob Anderson).

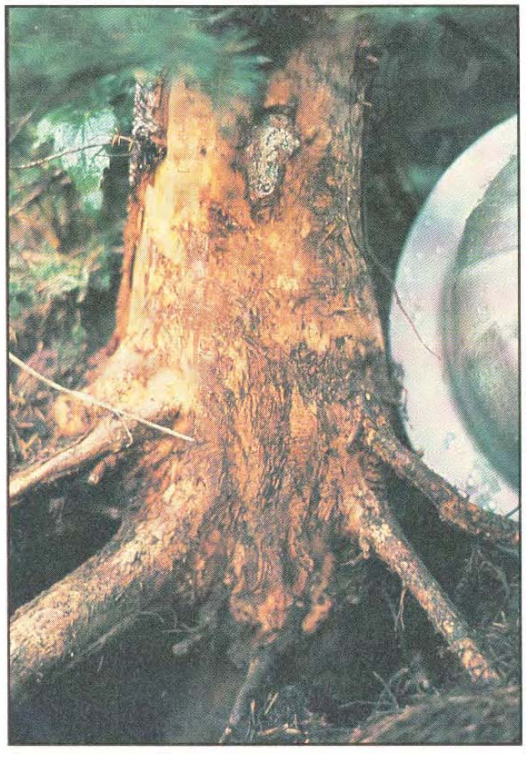


Figure 4—Basal barking and undermining of pole-size Douglas-fir (photo by Bob Anderson)

Mountain beaver cause belowground injury to conifers by uprooting or burying seedlings. They undermine and bark the roots of saplings. The latter two types of injury cause extensive damage in conifer stands of 10 to 20 years of age. Damage mainly occurs in and around burrow systems.

The existence of mountain beaver in an area can also be determined from the presence of shallow burrow systems of about 4 to 8 inches in diameter (Voth 1968). Fresh mounds of earth (kick outs) often may be found at burrow entrances. These may contain up to a cubic yard of earth and stones (Dalquist 1948). There may also be mounds of cut vegetation stacked at the entrances

In freshly logged units with concentrations of heavy slash, mountain beaver have been reported moving under slash and brush. Burrow systems may be hidden under the slash in these situations, increasing the difficulty of detecting their presence (Doug Soules, personal communication).

Clipping of seedlings by mountain beaver can be confused with clipping by rabbits and hares. Rabbits and hares, however, seldom clip stems of more than 0.25 inch in diameter, and they frequently leave portions of their clippings at the base of the damaged tree. Round, flattened, ovoid droppings often are left in the area (Lawrence and others 1961). Mountain beaver, conversely, may clip stems of up to 1 inch in diameter, and their larger, cylindrical droppings (0.5 x 1 inch) never are left on the surface but are deposited in fecal chambers (Voth 1968).

Damage from mountain beaver and black bear occurs in sapling-size stands. Bear damage to the lower stems, characteristically, is indicated by bark strips left at the base of the tree and by long, vertical grooves caused by canine teeth scraping on exposed sapwood. Barking extends further up the stem, and bear remove large patches of bark. Mountain beaver pull the bark from the tree in strips and leave scattered horizontal tooth marks and irregular claw marks. Bark strips are not left at the base of the tree (Lawrence and others 1961).

Most mountain beaver damage of commercial importance occurs in stands of Douglas-fir. Severe damage to western hemlock, however, also occurs (Hoyer and others 1979), and damage has been observed on most conifer species growing in mountain beaver habitat.

Population density is difficult to determine and usually is estimated on the basis of field sign, which consists of burrow density, fresh "kick out" mounds of earth, clipped vegetation, and damaged trees and habitat. The prediction of population levels on the basis of counts of burrow entrances or other sign components so far has not been possible. Greater sign frequency usually correlates with more animals present. It also is important to consider home range size when making population estimates and to remember overlapping home ranges are common

Severity of damage is easier to determine and normally is recorded in routine stand exams of young plantations. In a survey of forest managers in Washington, Oregon, and northern California in 1979, the Mountain Beaver Subcommittee, Northwest Forest-Animal Damage Committee found about 70 percent of the total problem was in new plantations.

Damage to sapling stands is not nearly as well understood as damage to young plantations, because these stands less frequently are visited and systematic information on mountain beaver damage or activity seldom is routinely recorded. In the same 1979 survey, forest managers reported 23 percent of their mountain beaver problem in stands of this age. Damage by mountain beaver is progressive unless damage-reduction measures are instituted. From a distance, dead trees may be confused with root-rot mortality or bear kills, and mountain beaver damage may not be identified for several years. Basal stem and root barking and the undermining of saplings may continue over several years, and levels of damage may differ by year. The reasons why damage in some years is greater than in other years is unknown.

Damage from mountain beaver is clumped in distribution. This creates nonstocked areas in stands rather than random mortality. These openings will continue to enlarge if mountain beaver activity continues as trees around the edges repeatedly are damaged or killed (Neal and Borrecco 1981)

Mountain beaver do more serious damage to Douglas-fir plantations than do any other animal species that cause damage in the Pacific Northwest. Of the types of damage, seedling clipping is the most serious. The survey by the Mountain Beaver Subcommittee, Northwest Forest-Animal Damage Committee (1979) reported damage by mountain beaver on more than a 0.25 million acres in Washington, Oregon, and northern California. It is probable that damage is greater than reported, as much damage goes undetected in older stands Snow damage where trees fall over, for example, in some cases may be related to undermining and root girdling by mountain beaver.

Response to Habitat Change

Harvesting has the greatest influence on mountain beaver habitat. Low preharvest populations of mountain beaver in closed-canopy conifer stands frequently increase several fold as sparse-understory plant-communities develop into dense, herbaceous, vegetative cover of shrub and hardwood after clearcutting. Mountain beaver populations frequently are fairly high even before harvesting in more open stands of conifers with well-established understory plant communities and in hardwood and shrub-dominated stands. Motobu (1978) found 3.8 animals per acre in a recently harvested hardwood unit. These mountain beaver populations rapidly expand to high levels after harvesting. Heavy damage to plantations usually results from these high populations. Preharvest inspections of stands are used to determine both the presence and density of mountain beaver and the need for control.

Partial cuts, including commercial thinning and shelterwoods, also affect mountain beaver populations. As stands are reduced in density, more light reaches the forest floor and more understory vegetation develops. Many of these plant species are utilized by mountain beaver, and populations can expand in both area and density. This expansion may lead to more difficult damage control in new plantations established after final harvest. Commercial thinning is an example of a management regime that can increase mountain beaver populations. It is unlikely that the resulting increase in population would have an adverse impact on the residual stand. Regeneration after the final clearcut harvest could face a well-established population of mountain beaver with a network of burrow systems unless the stand has regained sufficient density to shade-out understory species

Site Preparation

Site preparation after harvest consists of four general types and combinations. These are mechanical (hand and machine), chemical, burning, and logging only. Each preparation has unique impacts on the mountain beaver.

Logging generally has the effect of increasing populations (Hooven 1977). The type of logging system and the stand harvested determines specific effects. Ground skidding and high-lead logging may disrupt burrow systems more than full-suspension systems. Concentrations of slash can provide additional cover and potential nest sites. Destruction of existing vegetation from skidding generally causes vigorous resprouting and provides germination spots for early successional species. Most of these effects result in improved habitat, and populations respond with rapid increases. Damage to plantations usually follows.

Mechanical site preparation with tractors and brush blades has the most lasting impact on mountain beaver habitat. This method collapses burrow systems and uproots brushy species. Preferred brush species may be slow to re-establish as grass and forbs may densely establish. The method destroys suitable nest sites and greatly reduces populations. Reinvasion is slow, as mountain beaver seem to prefer to move through existing burrows in their search for new nest sites. They are highly vulnerable to predators in open scarified areas. Well-scarified areas frequently stay free of mountain beaver through plantation establishment, although they may become a problem in the sapling stand that follows When slash piles are created during scarification and not burned or incompletely burned, mountain beaver frequently occupy these sites and damage trees near the piles. Some success has been achieved in alleviating this problem by creating numerous small piles no more than 10 to 15 feet wide and 4.5 feet tall (Tim Kosderka, personal communication). These piles, if kept small enough, apparently do not provide adequate nesting or cover habitat in scarified ground, and they break down quickly Mechanical site preparation with spot scarifiers or backhoes is unlikely to significantly affect mountain beaver. Burrow system destruction is spotty and desirable plant species remain in adequate quantity. Minor impact on the mountain beaver population can be anticipated.

Broadcast burning on two brown-and-burn hardwood conversion units, and its effect on a population of mountain beaver, was studied by Motobu (1975). In a complete burn, where nearly all the slash was consumed, about half of the population was . killed by the fire. Predators had good access to the site and were attracted by the burned carcasses Coyote activity increased and caused further mortality in the population. There was no evidence of the mountain beaver leaving their home ranges within the burn for adjacent unburned areas, but they did move to unburned areas within their home range. The population re-established and later caused damage to the 15-year-old stand. In the less complete burn, where 20 percent of the area remained unburned, 80 percent of the population survived. The surviving individuals largely were found in unburned portions of the unit but still within their home ranges. The intensity of a burn, therefore, significantly affects a population and its ability to rebuild after a fire. Activity is reduced after a burn, and fresh evidence of the animals (such as burrowing and earth mounds) can be seen only after several weeks elapse A population can exist on stored food with little or no signs of activity until the unit "greens up." After a burn, populations will rebuild rapidly to preburn or higher levels.

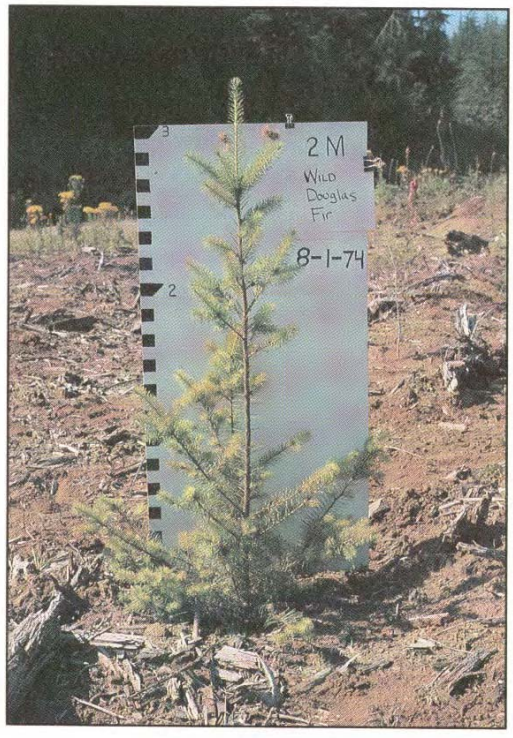
Brown-and-burn techniques increase fire intensity, especially where conifer slash is insufficient or where much green vegetation is present. Units are treated with herbicides, the vegetation is allowed to brown and dry, and then the unit is burned under

warm, dry conditions. This technique also reduces postburn resprouting of brush species, and it results in more complete bums that would tend to increase population mortality. Hand slashing in heavy brush and burning after also increases the completeness of burns. Most broadcast burning after harvesting occurs under cool, moist conditions in the spring and without fire-enhancing treatments. This likely results in lower impacts on mountain beaver populations. Fifty-percent mortality probably is the upper limit in all but the most extreme cases.

Chemical site-preparation reduces competition to seedlings by suppressing existing species before planting. These chemicals selectively control forbs. grass, or various brush species. They may be used in combination for multiple species control. The duration of effectiveness varies with the chemical and the species. The objective of the treatment is to give the new seedlings a competitive advantage. Most treatments last one or two seasons. Normally, however, several species of plants that are resistant to the chemicals remain after treatment. New germinants and sprouts also form parts of the plant community. This technique, apparently, does not significantly affect mountain beaver populations. Some shifting among plant species in the animal's diet undoubtedly occurs.

Artificial Regeneration

Artificial regeneration either by planting or seeding after harvest can profoundly influence mountain beaver populations. Where dense stands can be established and brought to complete crown closure, mountain beaver populations can be virtually eliminated, providing damage to trees can be controlled until stand development is accomplished. Under such conditions, densities of understory plants are limited. This situation occurs in coastal areas where large numbers of natural hemlock become established and form dense stands. Stands, typically, are planted at a density that does not result in early, complete crown closure. Mountain beaver populations, consequently, remain in such stands for many years The number of trees per acre necessary to achieve early crown closure depends on many factors, but it can be computed with stand-density diagrams described by Drew and Flewelling (1979).



Selection of planting stock also affects time to crown closure and the time when young trees are most susceptible to damage. Large transplant stock (20 to 40 inches tall) reduces these time periods. Large stock also is resistant to other problems (including vegetation competition and damage by other animal species, such as deer, elk, or hares) that can extend or increase the period when trees are susceptible to mountain beaver (fig. 5).

Figure 5—Large Douglas-fir seedling

Release Treatments

Release treatments of various types (chemical and manual) suppress vegetation that competes with desirable conifer species. Most treatments are selective and, apparently, have little impact on mountain beaver populations. Some reports suggest that release treatments may encourage additional feeding on conifers as more desirable species are suppressed.

Grass has been seeded on the Alsea Ranger District to control brush, and sheep have been introduced to browse on brush and grass. This browsing keeps the grass at a palatable stage for elk. Mountain beaver do not extend their runways into the grass-seeded areas. Grazing sheep collapse the runways, and effective predators of mountain beaver (coyote and avian) focus their hunting activities in these areas, thus heightening mortality among mountain beaver (Virgil Morris, 1989. personal communication).

Stocking Control

Stocking control in sapling-size stands maintains growth rates of the most desirable trees Mountain beaver in sapling-size stands usually are associated with openings. Damage primarily occurs around the edges of these openings, where the trees are growing within the mountain beaver home range The openings may be caused by seedling clipping at a much earlier age. It is theorized that as the stand canopy begins to close, the understory vegetation thins out and becomes less abundant and desirable. Mountain beaver associated with these openings begin barking the stems and roots of saplings This damage is progressive, and it maintains the openings as trees are killed. Trees that are not adjacent to active burrows seldom are damaged (Neal and Borrecco 1981, Hoyer and others 1979)

Stocking control in these stands changes stand composition and allows understory vegetation to redevelop. In theory, damage should decline as more food becomes available until the stand begins to close and again reduces the understory vegetation. Sapling trees, apparently, also become less susceptible to damage as they increase in size. Trees above 8 inches d.b.h. are unlikely to be damaged (John Todd, 1989, personal communication). Trees larger than this are damaged, but the frequency and impact of such damage are much less.

In practice, stand damage in sapling-size trees seems to be a recurring loss, and damage is higher in some years than in others. The difference from year to year is difficult to explain (Hoyer and others 1979). Damage to 40 percent or more of the stand has been documented (John Todd, 1989, personal communication) in clumpy distributions that have a very significant impact on timber yield. Delay of precommercial thinning until mountain beaver populations are reduced after stand closure or after trees reach less vulnerable sizes is a potential strategy to reduce damage.

Commercial Thinning

Commercial thinning effects should be similar to precommercial thinning. The degree of stand closure before thinning will determine the status of the mountain beaver population. If the stand is dense and closed with little or no understory vegetation, it is unlikely to harbor mountain beaver. More open stands may have a population of mountain beaver that could increase as the stand is thinned. It is unlikely that these animals will cause significant damage to the leave trees. Their major impact will come after final harvest and regeneration

Damage Management Strategies

No single management technique works in all cases to reduce mountain beaver damage to acceptable levels. In many situations, a specific unit may require more than one management technique. The overall strategy must be to manage forest stands to maintain mountain beaver populations at reasonably low levels to avoid devastating damage. Specific techniques then can be employed to reduce damage and meet management goals within economic limits.

After mountain beaver populations grow to high levels (three or more animals per acre) great effort is required to reduce the populations. Rapid regeneration is critical to gain control of the site as quickly as possible. Techniques that work to reduce minor damage often are ineffective after populations reach high levels. Individual tree barriers, for example, may protect young seedlings, but large populations of mountain beaver clip the tops above the tube, undermine the plant, and bark the root. Where populations are maintained at moderate-to-low levels, this damage seldom becomes a problem. As stands with reduced mountain beaver populations achieve free-to-grow status (trees above brush—usually 4 5 feet high or higher), management directed at mountain beaver populations often is abandoned. This may lead to severe problems at age 10 to 20 years, when control not only is very difficult, but when the need for control is often discovered only after extensive damage already has occurred.

Management strategies must be designed and implemented to maintain populations at low levels throughout the life of the stand. This can be done best through habitat manipulation In many instances, additional direct methods (including individual-tree barriers and population control techniques) also are required.

Root-rot pockets often form openings in stands with shrub and herbaceous vegetation. These often contain potential epicenters for expansion of mountain beaver populations Specific plans must be made to establish stands of alternate species in root-rot pockets to create crown closure and prevent continuing mountain beaver problems.

Habitat Manipulation

Habitat manipulation to control damage from mountain beaver consists of maintaining the site and stand in a condition that does not encourage the expansion of populations. In even-age management, the size, shape, and location of the harvest unit can have a lasting impact on mountain beaver damage. Small and narrow units are highly susceptible to invasion from adjoining areas with populations of mountain beaver. A narrow unit adjoining a hardwood riparian area with a large population, for example, would be under constant pressure. Larger and more symmetrical units with less perimeter area aids in population control.

Habitat manipulation is a continuous process that requires the establishment of uniform stands free of openings or pockets of brush. Such openings can be important, even in stands 20 or more years old. Extra expenditures can be justified to eliminate these open areas in order to protect the surrounding stand.

Early canopy closure to reduce preferred food species helps ensure that populations do not rebuild and cause problems at later stages of stand development. Stand density control is an important part of this process. Precommercial thinning must be timed to discourage population buildup and damage. If populations are kept low, it is unlikely that commercial thinning will be followed by significant increases in mountain beaver populations If animals are present at the time of commercial thinning,

consideration must be given to the effect of thinning on the creation of mountain beaver problems for the next rotation. Prescriptions and timing should be adjusted if necessary.

Site preparation before regeneration is another opportunity to manipulate habitat. It may destroy nests and burrows, reduce cover, and control prime food species. If nests are located under stumps (as they often are), stump uprooting is necessary to destroy the nests. Mechanical scarification is very effective because it destroys burrow systems. Site preparation that exposes mountain beaver to increased predation by destroying runways and other cover can help to prevent population buildups.

Predator encouragement can help prevent population buildups and should be included in an overall strategy to maintain mountain beaver populations at low levels. Restricting the trapping of bobcats and coyotes and providing raptor roosts may encourage predation. Predators are not likely to control large populations of mountain beaver, but they may aid in reducing the abundance of the rodent.

Selecting the planting stock, the planting density, and the timing of planting relative to harvest are key decisions. Large transplant stock are less susceptible to mountain beaver damage and more resistant to mortality. Borrecco and Anderson (1980) examined 6,000 trees after 2 years in the field on 24 randomly selected plantations in western Washington. Mortality of clipped seedlings averaged 53 percent (±14 percent) for 2-0 nursery stock and 36 percent (±7 percent) for 2-1 seedlings In addition, larger stock gains control of the site and reaches crown closure sooner, thus shortening the susceptible period and limiting the population buildup of mountain beaver. Larger stock that survive clipping also suffer less height reduction, as shown in fig. 6 Increased planting density also helps the stand attain crown closure sooner. Reducing the time interval between harvesting and planting similarly helps.

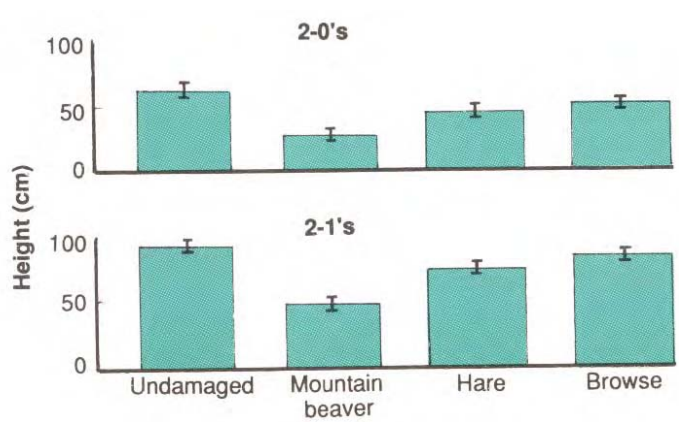


Figure 6—Mountain beaver damage and impact on the height of 2-0 and 2-1 nursery stock after 2 years in the field Heights of undamaged seedlings are compared against the heights of seedlings damaged by mountain beaver, snowshoe hares, and deer (Borrecco and Anderson 1980)

Direct Damage Control

In most cases where mountain beaver populations are established, direct control of damage is necessary. Failure to do so results in tree mortality, thus creating openings and uneven stocking that not only adversely affects timber yield but also sustains mountain beaver populations that may cause significant damage later in the life of the stand

Two approaches are possible: tree protection and control of the mountain beaver population. Trees can be protected either with repellents or with barriers that keep animals away from trees. To date, repellents have not been operationally effective against mountain beaver. Campbell and Evans (1988) have tested aversive conditioning by treating cull Douglas-fir seedlings with big-game repellent-powder (BGR-P) and placing them in mountain beaver systems. Subsequent planting of seedlings treated with BGR-P significantly reduced damage. More trials are needed before this approach can be recommended for operational applications, but it suggests that opportunities exist for creative new approaches. Campbell and Evans (1988) includes an excellent discussion of a variety of tests.

Fencing—Fencing to exclude mountain beaver from plantations primarily has been done for genetic-evaluation plantations and research areas. The fence must have 1-inch mesh at the bottom and must be buried to a depth of 2 to 3 feet. All animals within the fence must be eliminated, and careful fence maintenance is required, as well as monitoring for underground intrusion by mountain beavers. Mountain beaver, apparently, seldom climb over fences tall enough to exclude big game. This method of control, however, is not practical on an operational scale

Individual tree protection—Individual tree protection with plastic-mesh tubes is a technique that protects seedlings from clipping by mountain beaver. This expensive technique can be cost effective in a variety of circumstances (fig. 7). Its primary use is in areas where direct population control is nearly impossible or prohibitively expensive. Tubes can be used effectively on edges of clearcuts and in draws and brushy pockets where problems are likely or where reinvasion is probable after direct population control. Tubes frequently are used in unburned units with heavy slash where trapping is ineffective. Replanting of areas where mountain beaver caused mortality to previously planted trees is another case where tubes potentially may be effective. Small units (under 30 acres) or narrow units often are most effectively protected by this means.

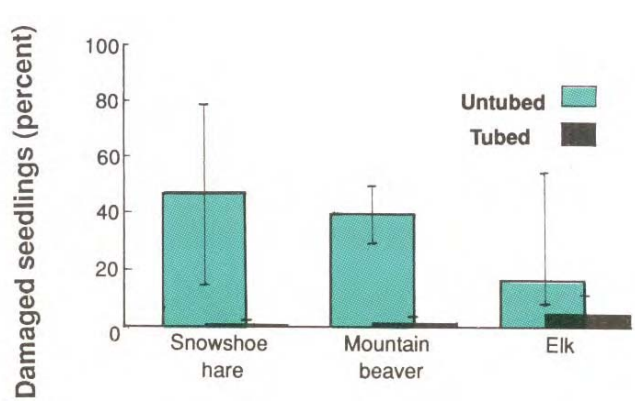


Figure 7—Mean percentage (and ranges) of damage by snowshoe hares, mountain beaver, and elk to young Douglas-fir seedlings protected by Vexar tubing compared with those left unprotected (untubed) (Borrecco and Anderson 1980).

Tree tubing, as it frequently is called, is not always effective. Tubes are clipped through and pushed under by mountain beaver that then clip seedlings inside the tubes. Mountain beaver climb the tubes and clip seedlings off at the top of the tubes. In one instance, 14 years of repeated top clipping of an individual tubed seedling was observed. Specific individuals, apparently, learn to chew through or climb tubes, because this type of damage often is localized around a specific mountain beaver's home range, and neighboring systems often do not show any evidence of either type of direct interaction with the tubes. Damage of this type usually is not extensive and normally can be expected to be less than 5 percent after 1 year.

Burying of tubed trees by mountain beaver also may occur where trees are planted in active burrow entrances, but undermining and root barking of tubed trees are the most serious damage. Where populations are unchecked, this damage can occur after stands are well established and thought to be out of danger. Populations of mountain beaver must be limited to low levels to avoid this type of damage, whether or not the trees are protected with tubes.

Significant resources have been expended to develop a tube that will degrade quickly enough to avoid constricting the growth in diameter of seedlings. Tube color affects degradation rate and can be prescribed and ordered for specific life spans. In practice, dense herbaceous vegetation and seedling crowns on high sites prevent light from reaching the tubing, thus greatly extending degradation times. Some foresters have gone to the expense of removing tubes from seedlings to avoid anticipated constriction problems. The expanding bole of the seedling, however, actually stretches the tube, making the plastic filaments thinner and thinner until they ultimately break, and the tube does no harm to the young trees. This generally occurs when the trunk is 5 to 7 inches in diameter. Trees that grow out of the side of the tube incorporate the tube in the wood, and it is unlikely that this will result in later problems.

Protective tubes can be installed on seedlings either before or after planting The most common method is installation of rigid tubes on seedlings with a second crew after planting. Single crews also may plant the tree and then install the tube. Specific diameter, mesh size and angle, and length must be prescribed to fit the tree species and stock size to be protected. Tubes normally are ordered in nested groups for ease of handling and shipping. When installed, the individual tubes must be anchored to the ground and supported. Various anchoring techniques are used, but the most common technique involves weaving a bamboo staff or dowel through the tube into soil. Laths attached to tubes with twist ties also have been used, but they are subject to breaking at ground level, and this pulls the seedling over. Large stock, such as transplants, can provide much of the support for the tube. Length of tube, mesh diameter, and shape are critical to reducing tube leader interaction if tubes significantly longer than seedlings are installed (Campbell and Evans 1975). Tubes significantly taller than the seedlings must be installed vertically to prevent seedlings from growing through the sides of the tubes. Tubes taller than 18 to 24 inches are not necessary for operational reduction of mountain beaver damage. Rigid tubes, typically, are nested in groups of 10 tubes made of polypropylene. Each tube measures 3.25 inches in diameter (±0.5 inch), has 14 to 17 strands of 50-mil thickness, is 18 inches long, and has a life span of 24 to 30 months.

A second approach to the installation of tubing is to install the tubes on the seedlings at a centralized location, frequently the nursery. With this approach, a softer plastic-twill material closely matched to seedling height is placed over the seedling. The softer material takes up much less space than a rigid tube. Tubed seedlings then are placed in standard seedling bags for shipment to the field. Planters bag up the tubed seedlings and plant them normally but with 1 to 2 inches of the tube in the soil to anchor them. This technique is only suitable for sturdy transplant stock, because the seedling must provide support for the tube. Typical twill-tube specifications are 1.75 inches inside diameter, 14 strands of 50-mil thickness arranged in a diamond pattern, 18 inches long, and a life span of 24 to 30 months. These tubes also are made of polypropylene and polyethylene.

Tubing installed at the nursery has the advantage of much lower cost, and it ensures that all planted seedlings receive protection. The main disadvantage of pretubing is

the added difficulty of planting seedlings vertically upright and at the proper depth. Ensuring that soil is compacted properly around the seedling's roots and around the tube in the planting hole also is very critical. Some additional mortality can be expected. Proper spacing of seedlings often is improved because the tubed seedlings are more visible to the planters.

Proper timing for the installation of pretubing is important. Tubing should be delayed until just before planting to reduce storage. Handling during tubing must be controlled to minimize the impact of root drying and exposure. Additional mortality of approximately 10 percent can be expected with this approach because of the extra handling and planting errors.

Direct population control—Direct population control is done either by trapping or poison baiting. Trapping is the most common and widespread technique for controlling mountain beaver damage (Mountain Beaver Subcommittee, Northwest Forest Animal Damage Committee 1979). Crews normally place Victor 110 Conibear kill traps (two to three traps per mountain beaver system) in main runways (figs. 8 and 9).

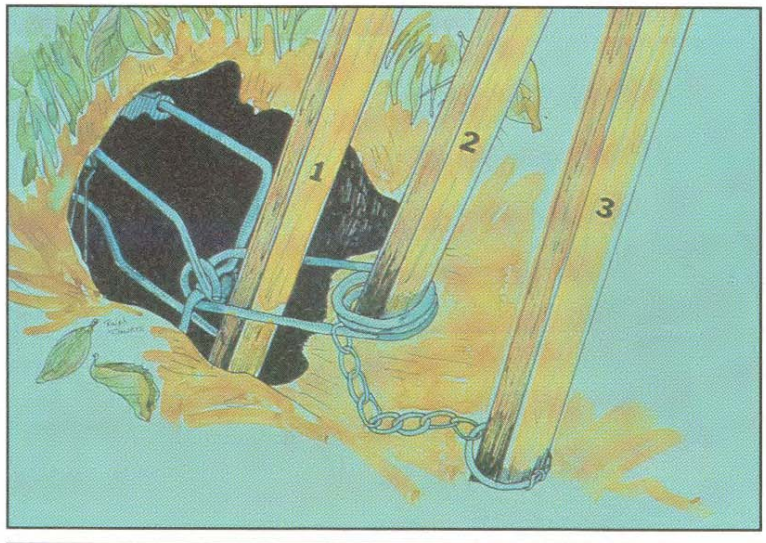


Figure 8—Conibear trap set showing placement of the third stake in the ring at the end of the trap chain

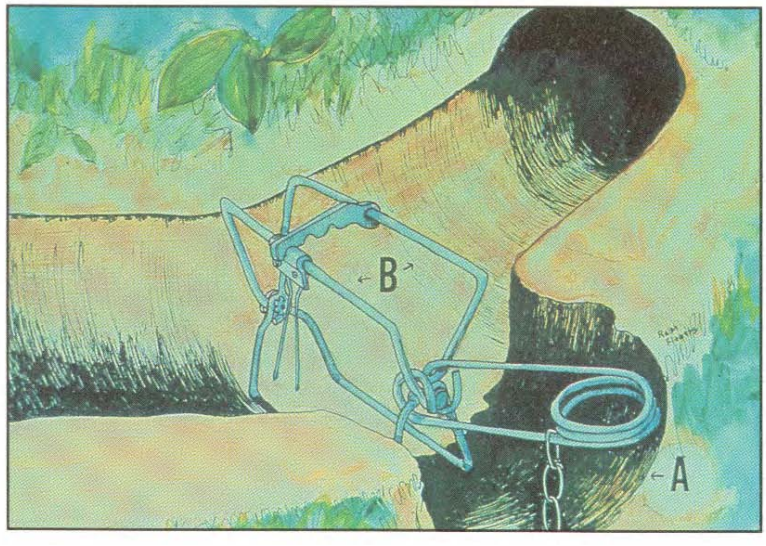


Figure 9—Conibear trap in typical burrow with a cutaway view showing the trap introduced through the feed exit (A) and placed across the main runway (B)

As many as 20 to 25 traps may be set per acre; however, 8 to 10 traps usually are sufficient. Traps generally are checked once or twice during a 5-day period before they are moved. Daily checking is not required with kill traps. Trapping on new units should be done as close to the time of planting as possible to minimize reinvasion time (Motobu and Jones 1977). Trapping, optimally, is done in the winter when vegetative cover is minimized. Trapping during cold, dry periods is ineffective because animal movement is minimal. Buffer areas of 300 feet may be trapped around plantation units to reduce reinvasion; however, this frequently is not done, and it is of questionable operational value.

Units need to be reasonably free of slash for effective trapping so that animals are forced to live in burrow systems that can be found consistently and set with traps. Broadcast burning is a technique that greatly enhances trapping effectiveness and reduces labor. At least a 6-week interval after burning is needed to locate active systems before trapping (Motobu and Jones 1977). Units must be monitored for reinvasion and retreated by trapping or baiting before significant damage occurs. Rapid reinvasion has been observed in some cases. Larger units with less border per planted acres are the units that can be trapped most effectively. Small units and long narrow units, or units adjacent to heavy population areas, require a continuous trapping effort. A small proportion of nontarget animals may be taken by trapping, including rabbits, hares, woodrats, skunks, mice, weasels, mink, and, occasionally, others (Motobu and Jones, 1977). Proper trap placement, trigger positioning, moving traps after five nights, and the timing of trapping can minimize impacts on nontarget species. Spring trapping also should be avoided.

Mountain beaver have been poisoned in a variety of ways over the years. One registered, restricted, and prepared strychnine bait presently is available for use in Oregon by licensed applicators (Orco Boomer-Rid Mountain Beaver Bait SLN Reg. No. OR-840029). Operational use of this material has been limited, but tests show it can be effective (Schaap 1986). Recent tests conducted by Campbell and Evans (1989) and Campbell and Engeman (1990) have shown very little effect on nontarget animals. The most recent test showed poor results but was done in March with spring plant flushing. Additional testing is planned to continue registration.

Baiting must strictly follow label instructions and state law. It consists of identifying the main runways of a mountain beaver system and placing from three to five pellets of bait deep within the system (preferably 2 or more feet deep) and well below ground level in several locations in main runways. Feeder tunnels, excavation openings, and deadend runways must be avoided. Where systems are extensive and overlapping, three to four bait stations per system are adequate. Isolated systems may require five to eight stations. All stations must be underground where they are neither visible nor easily accessible from outside the burrow. Baiting should be done at least 2 weeks before planting and during the winter when available food is low. Baiting should not be done during freezing weather, heavy rain, or after new growth in the spring.

Units must be carefully monitored for resurgence of activity, and methods of direct control should be implemented before population buildup or significant damage occurs. Other direct methods of population control, such as slash burning and predator encouragement, are not adequate to sufficiently control populations or alleviate damage if used alone.

Combination approaches—Most land managers use a combination of approaches among and within units. The objective is to manage damage at acceptable levels during the life of the stand. The most cost-effective and environmentally sound method of doing this, in most cases, requires a mix of approaches, including habitat manipulation and either individual tree protectors or direct population control (or both), The control strategy should start with preharvest assessments that lead to site specific silvicultural prescriptions, including unit design, site preparation, choice of planting stock, vegetation management, and direct strategies of damage control. Stand monitoring must continue to ensure that populations do not build up and cause significant damage as the stands mature.

Decision Methodology

Decision methodology is needed to develop the most environmentally sound and cost-effective methods of achieving and maintaining target stocking levels. Two approaches, generally, can be taken The first approach is an anticipatory or preventative strategy. The second approach is a corrective or postdamage strategy. Managers employ both methods, although the second approach may be either planned or unplanned. Decisions must be based on the projected costs and benefits of alternative courses of action. Costs of alternative approaches are relatively easy to forecast. Benefits are much more difficult to forecast, and the margin of error is great. The most reliable source of information on the consequences of alternative treatment strategies is the experience gained from similar situations in nearby locations. Such results can be factored in and compared against new approaches.

Monitoring is mandatory to determine damage and population levels. Annual checks often are needed during the first few years, but monitoring intervals may lengthen at older ages. More frequent monitoring also is needed at precommercial thinning time. Mountain beaver behavior is unpredictable, and midcourse corrections in the damage-control strategy may be required. No forester wants to invest dollars for mountain beaver control after sustaining significant damage and would rather prevent damage. Damage must be managed throughout the life of the stand, and this must be done by maintaining populations at acceptable levels.

Research Needs

Listed below are some examples of research needed to improve methods for controlling damage from mountain beaver.

- Most research work on mountain beaver has been concentrated in the coastal areas, and research in the Cascades is needed to confirm basic biology and habits. Mountain beaver frequently are found in the Cascades in unexpected places, and damage is less predictable than in coastal areas.
- More understanding of mountain beaver damage in sapling-sized stands is needed to predict when and where damage will occur, why it occurs in some stands and not in others, and how it is affected by practices such as precommercial thinning.
- More information on the influence of predators on mountain beaver populations would be valuable.
- Additional knowledge is needed of the response of mountain beaver to silvicultural treatments and other habitat manipulation.
- More data are needed on the response of mountain beaver to methods of direct control. Areas of concern include birth rate, survival impacts, and sources and timing of reinvasion.

- Information is needed on how the amount of slash present on a site affects burrow and nesting patterns.
- Research on toxicants presently and potentially available is needed.
- Alternate strategies are needed to control damage with lower costs and in an environmentally sound manner.
- Predictive ability on the consequences of alternative control strategies over time is needed.

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 12
Porcupines

WENDELL E. DODGE AND JOHN E. BORRECCO

Abstract

The porcupine is a large rodent easily identified by the stiff quills that cover most of the upper body. Porcupines commonly feed on the phloem (inner bark) and foliage of many species of trees and have been recognized as a serious, forest problem-species since the early 1900s.

A combination of control methods, frequently, are required to provide effective control Effective management of an ongoing porcupine-control program requires evaluation of current levels of porcupine damage to determine if control methods are needed and to monitor how effectively control efforts reduce damage to trees in various control units.

Porcupines may cause injuries to trees of all ages, but young trees in plantations and large saplings up to pole size are most susceptible. Injuries in older trees usually are confined to the thin, unplated bark of the upper crown. Where barking injuries cause girdling, the results are obvious: death of trees, dead tops, and misshapen crowns. Repeated injuries to a tree increase the probability of girdling and serious deformities that reduce the tree's value as lumber These types of injuries are less important where trees are grown for firewood or other fuel and fiber products.

WENDELL E. DODGE is wildlife research biologist (retired), U.S. Department of the Interior, Fish and Wildlife Service, Pittsfield, NH 03263. JOHN E. BORRECCO is regional pesticide-use specialist, U.S. Department of Agriculture, Forest Service, San Francisco, CA 94111.

The availability of lush herbaceous vegetation during the spring and summer and the presence of vigorous stands of young trees in or near stands of large trees during the fall and winter are influential factors that affect porcupine habitat Porcupines utilize large-sized trees for resting, and they find excellent den sites in rock outcroppings, talus slopes, and other protected sites such as slash piles or logs.

Removal of large overstory trees and control of understory and ground vegetation within plantations may reduce the attractiveness of sites to porcupines. Removal of large piles of slash, wind-rowed material, and jumbled accumulations of nonmerchantable logs prevents their use as den sites. Silvicultural practices that may help reduce porcupine problems include managing for greater species diversity and delaying thinning to maintain higher stand densities. Shelterwood and seed-tree harvest systems may encourage porcupines by leaving potential roost trees, and group-selection or small clearcuts create ideal combinations of young and large trees that provide winter habitat for porcupines

Newly planted seedlings can be protected with individual plastic-mesh tubes. Fencing to exclude porcupines is possible but generally limited by cost to small areas of high value, such as research or progeny test sites Trapping can be effective in removing problem animals where dens can be located or where animals can be attracted to traps Hunting is the most species-specific and effective method available for controlling porcupine damage. Knowledge of porcupine movements and habits is vital to ensure proper timing of hunting. Daytime hunting is most effective when animals can be tracked on snow. Night hunting with a spotlight is recommended during the summer and fall in moist meadows and along stream margins, old logging roads, or wherever succulent, herbaceous vegetation can be found

Keywords: Animal damage, Pacific Northwest, porcupines, direct and indirect control methods.

Introduction

Taxonomy and Distribution

The North American porcupine is the only member of the rodent family Erethizontidae, and it is classified as *Erethizon dorsatum* with seven described subspecies (Anderson and Rand 1943). This monotypic family is found only on the North American continent from Mexico to Alaska, east to New Brunswick, and south to Tennessee (fig. 1). It is absent from the southeastern and south-central United States. The western yellow-haired porcupine is found in all the Western States from the high plains of Colorado to the Pacific States, and populations are now present west of the Cascade Range in California, Oregon, Washington, and British Columbia. The number of porcupines in the Douglas-fir region built up over the past two decades

Description

The porcupine is the second-largest rodent native to North America (the stream beaver is larger). Adult males may weigh 30 pounds or more (fig. 2), but average weights range from 10 to 15 pounds and length varies from 25 to 40 inches.

The porcupine is the only rodent that possesses a dorsal pelage of modified hairs better known as quills. These range in length from newly generating to longer than 4 inches on the shoulders. Quills on the lateral surfaces of the tail on an adult animal are short and thick, and they are formidable weapons when driven into an attacking predator by the porcupine's flailing tail. Overlapping barbules on the dark tips of quills expand when moistened in tissue fluid and are "pulled" inward by the muscle-fiber contractions of the porcupine's foe. Only the face and ventral areas of the porcupine's

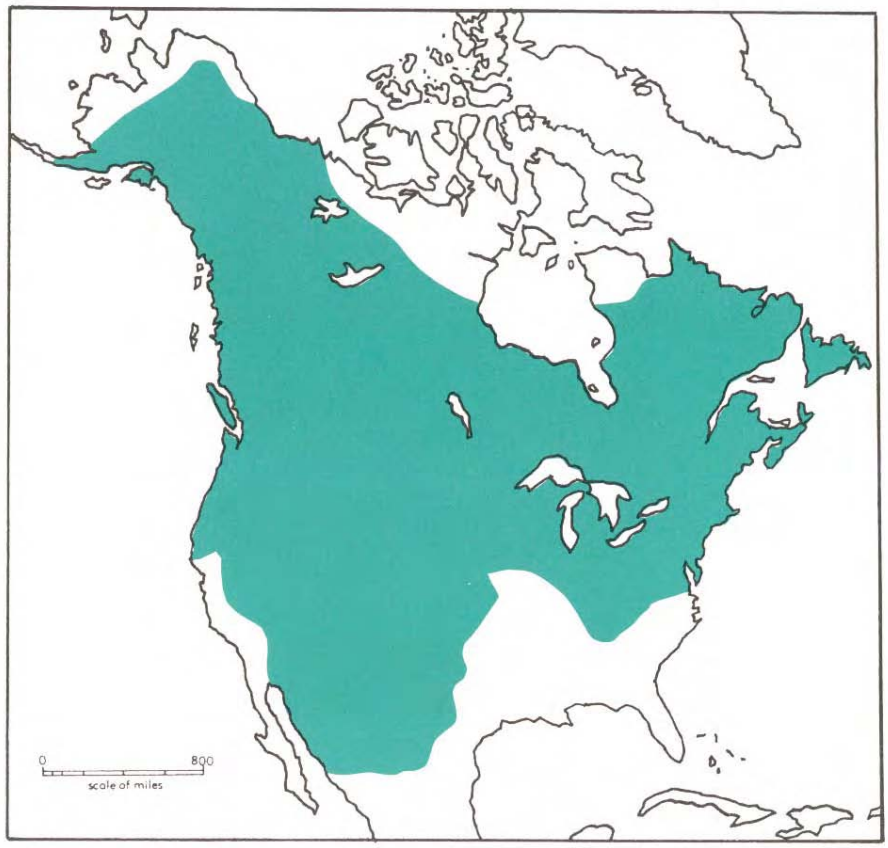

Figure 1—Range of the porcupine, *Erethizon dorsatum.* Adapted from Hall and Kelson (1959).

body and tail lack quills. Porcupines do not "throw" quills, but the quills are loosely attached and easily dislodged when the tail is flailed at an attacker Guard hairs, especially on adult animals, may be 10 to 12 inches in length over the shoulders. Guard hairs on the western subspecies are yellow-gold in color — hence the common name "yellow-haired." In winter, quills and guard hairs are supplemented by a dense woolly undenur. Young-of-the-year are dark-pelaged until the following spring (at 1 year of age) when immature hair is shed.

The porcupine is well adapted to climbing, and its long claws and stout, muscular tail with stiff ventral bristles are useful when ascending or descending trees. The animal's legs are short and pigeon-toed, and its feet are flat with dimpled pads and strong, curved claws (four front, five rear). The opposition of the long toes, claws, and foot-pads enable porcupines to grasp with their forefeet, and they often sit on their haunches and tail while eating foods grasped in their forepaws.

The animal's nose is blunt with large nostrils and a number of sensory vibrissae. Its eyes are small and dark, and its ears also are small and not readily visible in the pelage. The porcupine's eyesight is extremely poor; however, its sense of smell and hearing are well developed. Low-frequency sounds, such as footsteps and leaf

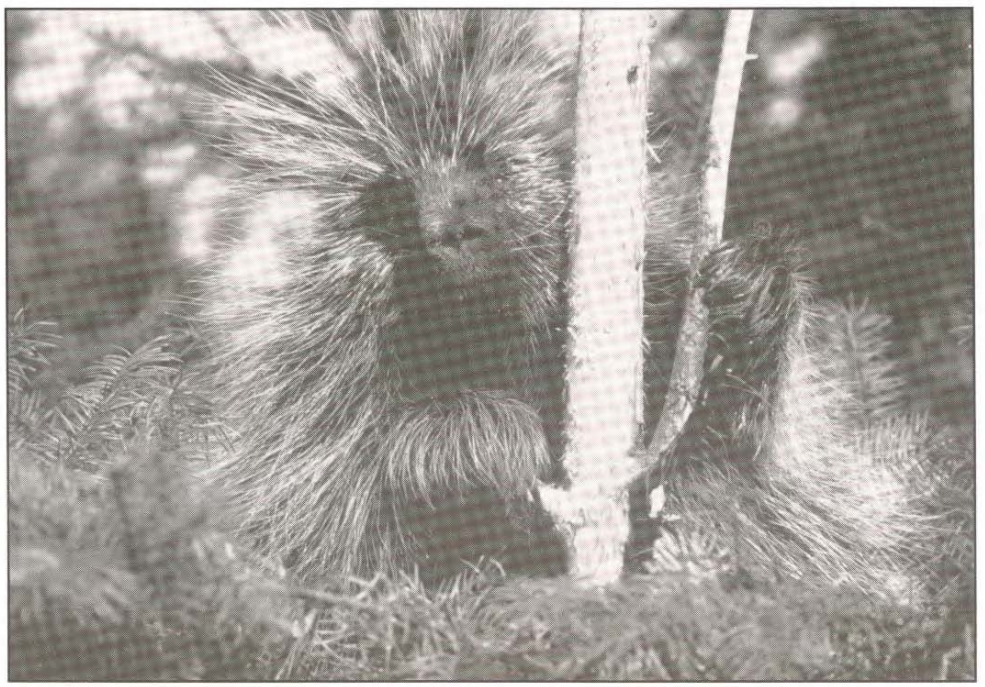

Figure 2—Adult porcupine and typical winter feeding injury (Photo courtesy of Weyerhaeuser Company)

rustling, quickly alert porcupines. These cautious animals frequently stop, sit on their hind legs and "test the wind."

Porcupines possess a total of 20 teeth (upper and lower): 4 incisors, 4 premolars and 12 molars. The orange-enameled incisors are long and exposed, but inner lips occlude the mouth behind them. Premolars are replaced at about 22 months of age and this provides a reliable method of determining the age of porcupines (Dodge 1967) The animal's molars are flat crowned and suited for grinding foods

Economic and Ecological Significance

Porcupines have been recognized as serious forest pests since the early 1900s, and dendrochronological studies in pinyon pine have shown porcupine feeding injuries dating from the early 1690s (Spencer 1964). The earliest published record found for this study is an article by Babbitt (1913) that claimed porcupines were ".. . doing an astonishing amount of damage to reproduction and young timber..." on what is now the Tahoe National Forest in California. Babbit indicated that 90 percent of the trees had been ruined by porcupines. Taft (1916) reported observations and experiences over a period of at least 20 years (dating from about 1886) of trying to control porcupines causing damage in spruce and pine forests in the Rocky Mountains:

> An acquaintance with and study of the habits of the porcupine, extending over a generation of time, has convinced the writer that this rodent has not one redeeming trait, nor can a good reason be given why he should be permitted to exist. Like his brethen, the pocket gopher, the rat, and the mouse, he should be billed for extermination. In furtherance of this belief I began a warfare upon the species with gun, pistol and trap and found at the end of a dozen years that no inroads had been made upon the number in my vacinity [sic].

Taft went on to report one instance where he measured 42 of 57 trees (74 percent) "destroyed by porcupines" in a plot of about 0.1 acre. He also described his 1910 effort to control porcupines with boards soaked in salt brine and sprinkled with strychnine (the precursor to the strychnine salt block),

This early attitude toward porcupines seems rather harsh in light of modem environmental consciousness, but it does emphasize some interesting points. Porcupines have been recognized as a major forest pest for a century, but there has been no significant change in the nature of the damage problem or its solution,

Lawrence (1957) reviewed and documented several reports of the seriousness of porcupine damage in the Pacific Northwest He reported, for example, that the USDA Forest Service estimates that porcupines annually killed or seriously damaged about 200 million board feet of public and private timber in the ponderosa pine forests of eastern Washington, northern Idaho, and western Montana Lawrence (1957) also noted that the Northwest Forest Pest Action Council estimated that 10 percent of the pine stands in many areas of eastern Oregon had been destroyed, and he documented an appraisal of 100,000 acres owned by the J. Neils Lumber Company in Klickitat County, Washington, where porcupines caused severe damage to trees on 5,000 acres and moderate damage on 10,000 acres

In a 1988 survey of animal damage on National Forest lands (Borrecco and Black, 1990), 35 percent of all National Forests reported porcupines causing damage to trees. Porcupine damage was reported from all regions of the country except in the south-central and southeastern regions without porcupines. Several National Forests with histories of porcupine damage to ponderosa pine and other conifer plantations maintain ongoing control programs. In an effort to control porcupine damage to pine plantations on the Deschutes National Forest in Oregon, for example, 1,050 porcupines were shot in 1988 at a cost of $14 per animal. The Umatilla National Forest in Oregon developed a unique cooperative agreement with the owners of an adjacent industrial timberland (Kinzua Corporation) for joint porcupine control on the Forest and adjoining commercial timberland The plan called for killing up to 1,500 porcupines during the first year (1989) of the 5-year agreement at an estimated cost of about $10 per animal.

Porcupines may have some positive economic value One common claim is that a lost person could survive by eating porcupines that are easily killed. Some people have speculated that foliage clippings left by porcupines could promote survival for winter-stressed deer and hare (Ferguson and Merriam 1978). Some Indian craftpersons, moreover, still use dyed quills in their craftwork, and porcupine quills and hair are used in tying fishing flies.

Porcupine Biology

Longevity

Porcupines are relatively short-lived animals with maximum lifespans of 5 to 7 years. An occasional animal may reach 10 or more years (Brander 1971, Dodge 1982), but tooth wear from abrasives in food generally leads to shorter lifespans.'This is more typical of animals in arid-sandy or lava-pumice habitats

Reproduction

Porcupines become sexually mature in their second fall (18 months). Unlike more prolific rodents, the porcupine gestation period is relatively long (7 months) and produces only a single newborn. The breeding season occurs from September through December and peaks from mid-September to mid-October. A! female in breeding condition may be attended by a number of males, and this often leads to

surprisingly violent battles. These battles often involve frontal attacks by porcupines standing on hind legs and viciously biting around the face and shoulders of their opponent. It is not uncommon for the combatants to be recipients of each others' quills. These short-lived encounters are followed by rest periods and quill pulling with incisors and forepaws (Dodge 1967).

Contrary to early speculation, porcupines normally copulate on the ground by rear mounting, similar to most other quadrupedal mammals. Males "walk" on their hind legs and shower females with copious bursts of urine. The receptive female porcupine arches her tail over her back, thus providing a platform for the male's forepaws or chest. These breeding encounters are often accompanied by unforgettable, screeching vocalizations that have been attributed to mountain lions and other large predators.

Young are born from April through August, weigh 12 to 14 ounces, and are precocial with eyes open and incisor and premolar teeth present. Their quills are functional upon drying, and the defensive, head-down attitude and tail-flailing behavior are innate. Newborns almost immediately feed on vegetation; however, they remain with the lactating female into early fall.

Behavior

This species is essentially nocturnal with occasional feeding forays at dusk and dawn. Porcupines generally are solitary except during breeding season and occasional multiple-occupancy of winter den sites. Daytime resting sites during summer may be merely protective shrubs, gullies, or other secretive locations, but winter dens or "rest" sites can be in selected trees, tree cavities, uprooted tree stumps, or human-made structures such as rock fills, culverts, abandoned buildings, and logging debris. Porcupines spend considerable time feeding and resting in trees during the winter months, but almost all spring and summer activities are on the ground (Dodge 1982).

Porcupines generally are not vocal animals, with the exception of breeding "screeches" and the soft "cooing" of females and offspring. Unreceptive females "squawk" at investigating males, and hostile males usually are the source of the more audible breeding vocalizations.

Home Range and Movements

Seasonal home ranges of porcupines differ depending upon habitat and, more importantly, climate. In milder climates, such as that found in the coastal plains and western Cascades, porcupines exhibit a nearly identical winter and summer home range with shifts of activity centers based on food availability Daily movements, resting locations, and habitat use are strongly influenced by food availability and food habits (Dodge and Barnes 1975, Smith 1982). Dodge and Barnes (1975) reported average home ranges in western Washington of about 200 to 260 acres. Daily linear movements averaged about 800 feet (range 300 to 2,300 feet), but Dodge and Barnes found no seasonal differences in mobility.

Smith (1975,1979) reported similar home range sizes (173-200 acres) in northeastern Oregon, but daily movements during the winter were one-third of spring and summer movements. Areas of severe cold and deep snows restrict winter movements and home range to a few acres, and some animals remain in one or more closely grouped trees or "pockets" throughout the winter Winter movements generally cover only small distances from den or "roost" sites to nearby feeding areas. Summer range consists of movements related to food availability. Females (especially those with dependent young) have smaller home ranges than do males. Winter and summer home ranges generally do not overlap (Dodge and Barnes 1975).

Habitat

Porcupines are found in a great variety of serai stages and forest types over an extensive geographic range. Stocking and age of stands, type of ground vegetation, availability of water, and presence of den sites or roost trees are important habitat factors (Lawrence 1957). Describing the general characteristics of porcupine habitat requires a consideration of both geographic location and season.

In the drier, colder climates typical of the areas east of the crests of the Cascade Range and Sierra Nevada Range and sometimes referred to as the east-side pine region of the Pacific Northwest, porcupines commonly use different habitats seasonally. Porcupines are found from April through August in meadows, riparian areas, or wherever succulent herbaceous vegetation can be found. Agricultural fields with crops such as alfalfa also attract porcupines during this season, because they provide abundant supplies of the lush, herbaceous vegetation porcupines prefer. As ground vegetation becomes less available during the fall and winter, porcupines move into forested areas and start feeding almost exclusively on phloem and needles in trees. Porcupines prefer to rest in large trees and to feed in dense stands of young plantations. Dens located in talus slopes, rock outcroppings, uprooted stumps, or logging debris also are used as resting sites during the winter and for giving birth.

In the warmer or milder climates typical of the coastal mountains and western slopes of the Cascades (Douglas-fir/western hemlock region), porcupines use nearly identical summer and winter habitats, primarily because of the prevalence of green food throughout the year. Porcupines prefer sheltered plantations in basins, ravines, and on slopes with south exposures (Dodge and Canutt 1969). They also use den sites in caverns in road-ballast rock, culverts, old log landings, lava flows, stumps, or hollow logs.

Availability of lush, herbaceous vegetation during spring and summer and of vigorous, young trees in or near stands of large trees during the fall and winter, apparently, has the greatest influence on the use of porcupine habitat.

Food Habits

Porcupines, essentially, are vegetarians, but they occasionally may gnaw on shed antlers and bones (probably for minerals and other nutrients). Almost all winter feeding is in trees, and ground-feeding begins along wet seeps and stream courses as soon as the snow melts in spring Summer feeding is almost entirely'on the ground, and food consists of selected grasses, forbs, aquatic succulents, cultivated legumes, fruits, and other agricultural crops (Dodge 1967).

Winter food, predominately, is phloem and foliage of woody shrubs and,trees. Principal winter foods are conifers, and porcupines generally select the dominant conifer species over other species in conifer habitat. West of the Cascade crest, porcupines select Douglas-fir first and western hemlock second, They select ponderosa pine in the transition zone and where it occurs in the porcupine's range They also feed on many species of pines, firs, and larches throughout the Western States., Many woody shrubs also are winter foods of the porcupine. Elderberry is a selected food during late winter and early spring in the western Cascades. Porcupines, where present, also consume large amounts of dwarf mistletoe, and Taylor (1935) expressed concern that porcupines may be vectors of dwarf mistletoe infestations.

Spring foods include buds and catkins of aspen and willows and pollen buds of conifers. Virtually all other spring, summer, and early fall foods are ground vegetation

such as forbs, grasses, and succulent wetland or riparian plants. Some more commonly consumed aquatics include sedges, water lilies, arrowhead, pondweeds, and aquatic liverworts West of the Cascade crest, porcupines actively seek wet areas for skunk cabbage sprouts exposed after snow melt. Aquatic plants (floating and emergent) are selected foods during summer and early fall, and porcupines wade to the point of buoyancy while feeding on aquatic plants.

Porcupines seek out mast-producing oaks to feed on fallen acorns, and they clip acorn-bearing branches. They often litter the ground with clipped branches and shredded hulls, and they "rake" large areas of leaf litter in search of fallen mast, even in the spring when acorns may be germinating. These "scratchings" often are confused with those of wild turkey or deer, but they can be distinguished by the lack of turkey scratches or hoof marks,

Porcupine Damage

Identification and Types of Damage

Porcupines commonly feed on the inner bark (phloem) and foliage of conifers, especially ponderosa pine (dark 1986, Lawrence and others 1961). Feeding injuries are characterized by prominent horizontal or oblique tooth marks (1/8 inch wide) in the sapwood Supplemental field signs include bark chips, clipped needles, quills, and oblong, fibrous fecal droppings found at the base of barked trees (fig 3). Most of these activities occur during winter, when porcupines spend much of the time feeding in trees because of the lack of ground vegetation Feeding trails from dens to trees or between trees also may be evident in deep snow. Winter-feeding damage to tree stems and crowns is readily discernible, especially in the midmorning or midafternoon on bright days when the white, shiny, fresh damage stands out distinctly. Clumps of damaged trees generally are in areas of deep snow and extreme cold near trees where porcupines often remain throughout the winter. These same stands also are highly visible during summer when the tops die and become brownish-red "flags." This browning, however, also is typical of disease, insect, tree squirrel, bear, and other types of tree damage. Seedling girdling by porcupines can be distinguished from girdling by pocket gophers by comparing the size of incisor marks and other signs, such as pocket gopher burrow-casts. Stem girdling by tree squirrels also can be distinguished from porcupine damage by incisor marks and the shredded or strip appearance of bark "peelings" under the damaged tree (fig. 4).

Porcupines injure trees of all ages, but young trees of up to pole size are most susceptible. They prefer the thin, smooth bark of younger trees, and basal barking of ponderosa pine seedlings is common. Injuries in older trees usually are confined to the thin, unplated bark of the middle and upper crown. Lawrence (1957) described three types of damage: top barking that frequently kills the terminal shoot and several whorls of branches, basal barking that can girdle and kill the whole tree, and clipping of small branches or seedlings.

Results of barking injuries and girdling are obvious: death of trees, dead tops, and misshapen crowns. In young saplings, a single occurrence of extensive barking without girdling (and even some top-girdling) may cause no serious defects unless the trees are weakened and become more susceptible to attacks by insects or diseases. Repeated injuries to a tree increase the probability of girdling and serious deformities that reduce the tree's value as lumber. These types of injuries are less important where trees are grown for firewood or other fuel and fiber products. Injuries, however, reduce the amount of annual growth and affect long-term fiber production (Krefting and others 1962, Storm and Halvorson 1967)

Figure 3—Supplemental field signs Fecal droppings and quills found at base of an injured tree (Photo courtesy of Weyerhaeuser Company)

Figure 4—Supplemental field signs Comparison of bark strips peeled by tree squirrels and bark chips caused by porcupines (Photo courtesy of Walter E Howard)

The loss of young seedlings can be mitigated by replanting Losses of saplings and older trees are hard to overcome, and this fact emphasizes the need for vigilance in young, susceptible stands and the need for corrective measures that prevent significant levels of damage. The Animal Damage Control Handbook (USDA Forest Service 1988), indicates that control of porcupines should be considered in managed stands where 3 percent or more of the crop trees are damaged annually. Where levels of damaged trees already are significant, control of porcupines helps to reduce the probability of repeated injuries and helps prevent long-term impacts on timber production.

Damage Surveys

Porcupine damage severe enough to require control can be observed and accurately plotted by low-level flights in fixed-wing aircraft or helicopters. Fresh winter damage is white, shiny, and easily located from aircraft, especially in early morning'and late afternoon when the sun is at a low angle. Feeding trails in deep snow often are evident from aircraft Higher observation points also can be utilized to "glass" or "scope" large areas for evidence of damage Summer evidence of porcupine injuries from the previous winter includes yellow (more recent) or red-colored foliage in the tops of trees (sometimes called "flags"). Color infrared aerial photographs, if available, can be used to help interpret evidence of damage. Bear damage, insects, or disease, however, also cause "flags." Summer and photo-detected evidence of porcupine damage must be verified with ground checks

The more humid, snow-free areas (western Cascades) require even more rigorous reporting by the foresters, harvest crews, and other personnel who detect evidence of porcupine damage. These reports also should be verified and plotted, and control efforts should be implemented. Damaged elderberry stems also are roadside indicators of porcupine presence. Summer evidence of porcupines is more difficult to detect, but early evening or predawn spotlight searches of meadows, lake shores, and agricultural areas (especially alfalfa) usually reveal their presence. Another more time-consuming method of surveillance is to cruise dusty or muddy dirt roads to

detect the typical pigeon-toed, dimpled paw prints of the porcupine. A tail drag also is often evident, and wallows or trails in alfalfa crops are readily identified. Roost or rest trees can be identified easily by the abundant collections of fecal pellets and the characteristic odor of porcupine urine at their base.

Control Methods

Physical Barriers

Individual seedling protectors such as plastic-mesh tubing or wire cages can protect newly planted seedlings. Once a seedling grows above the top of the tube or cage, however, porcupines can climb the tree and cause damage. Aluminum flashing (minimum 24 inches wide) placed around the trunk of larger trees and above the expected snowline can protect special trees (such as selected seed trees). This technique also can be adapted to protect other objects, such as signs and buildings. Fences and individual tree guards are expensive and labor-intensive methods with only limited use in protecting forest stands.

Fencing porcupines out of an area is possible, but high cost generally limits this method to small areas of high value, such as research or progeny test sites and unusual ornamental vegetation and man-made structures. Electric fences are effective when the wire is placed about 2 inches above 18-inch-high woven wire (or poultry) fencing (Schemnitz 1983). Fence climbing also can be discouraged with an overhanging wire strip placed around the top of the fence at a 65-degree angle to vertical The most practical use of fencing, probably, is to intercept porcupine movements and to direct the animals toward traps. A wire-mesh drift fence or metal flashing as low as 24 inches can direct porcupines to traps set in openings or at the ends of the fence (fig. 5).

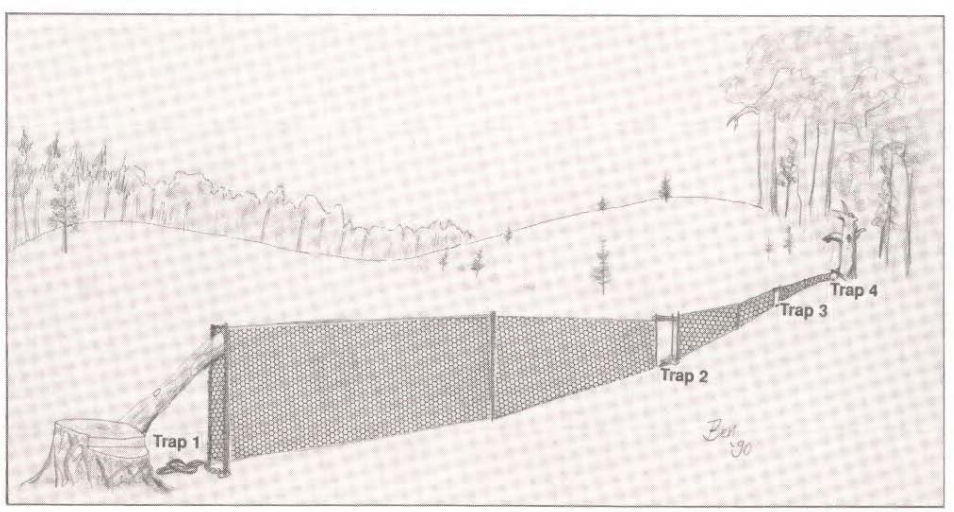

Figure 5—Porcupine drift fence used on the Sisters Ranger District, Deschutes National Forest Fence is constructed of 2-foot-tall chicken wire and is about 150 feet long with openings located every 50 to 75 feet Drawing courtesy of Denis Benhower

Trapping

Trapping (with a No. 2 leg-hold, 330 Conibear, or live traps) can be an effective method of control in areas where porcupine dens or trails can be identified or where movements can be intercepted and directed to the traps. These tools are' labor intensive and require daily inspection to release non-target animals. We recommend offset and padded jaws for No. 2 and larger leg-hold traps. The advantage of leg-hold and live traps is that nontarget animals can be released, but one disadvantage is the need to dispose of the porcupines. The leg-hold trap, even with offset or padded jaws, also may injure nontarget wildlife. Judicious placement of traps, however, can be quite selective, because other wildlife rarely inhabit an occupied porcupine den

Installation of drift or guide fences of poultry-mesh wire or nylon netting can enhance trapping. Heacox and Lawrence (1962) used this drift fence approach with a large cage-type trap with one-way gates to capture porcupines. These cage traps contained strychnine-salt blocks to poison the captured animals, and the decaying carcasses, apparently, also were attractive to other porcupines. '.

Personnel in the Silviculture Department' on the Sisters Ranger District, Deschutes National Forest, Oregon, have successfully controlled porcupine with a drift fence technique. They stretched a 2-foot-tall fence of chicken wire (>150 feet long) across a plantation with fresh porcupine damage, and they left breaks or openings every 50 to 75 feet (fig. 6). Porcupines that encounter the fence follow it until they find a place to

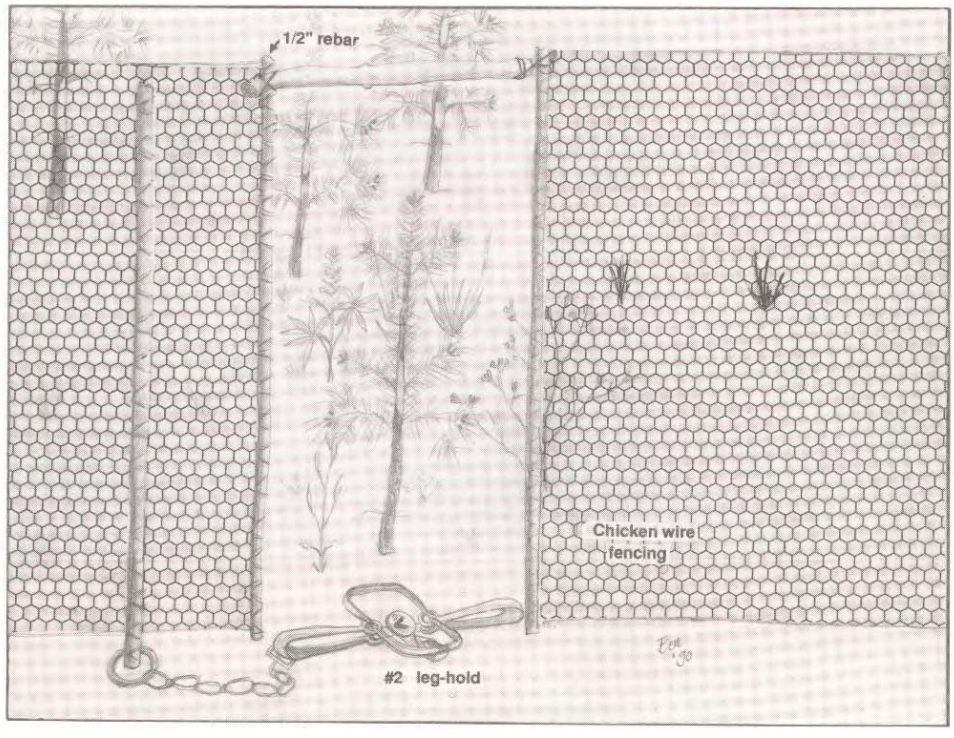

Figure 6—Closeup view of trap placement in opening in the porcupine drift fence Drawing courtesy of Denis Benhower

' Information provided by Dave Moyer, Don Rowe, Dave Priest, and Dennis Benhower, Sisters Ranger District, Deschutes National Forest

go around or through. A No. 2 leg-hold trap is placed in each opening and at each end of the fence. Fences can be placed in any configuration, but most often they are set in a straight line across primary routes of travel, such as draws and gullies or near water sources. Fences located in the middle of areas with fresh, heavy damage generally are effective. A fence located in a draw between an area of rock outcroppings or roost trees and a water source almost invariably produces positive results. Traplines are checked every 24 hours, preferably in the morning so that animals are not left in the sun for very long. Most other animals that encounter the fence can climb or jump over it, thereby reducing the potential for capturing nontarget animals Golden-mantled ground squirrels, however, occasionally have been caught. One person can set up this fence in about 30 minutes, and one individual can take it down and set it up in a new location in less than an hour. District personnel report that the annual take of porcupines has decreased 67 percent each year from 1987 to 1990 with this method, and areas with fresh damage are difficult to find.

Another technique is to place a No 2 leg-hold trap or a conibear 330 trap in the entrance to a trap ring (USDA Forest Service 1988). Trap rings (fig. 7) are most effective if placed on the perimeter of new plantations in areas with a history of porcupine problems. Animals are drawn to the ring by the strong odors of apples, rancid bacon fat, or cat food

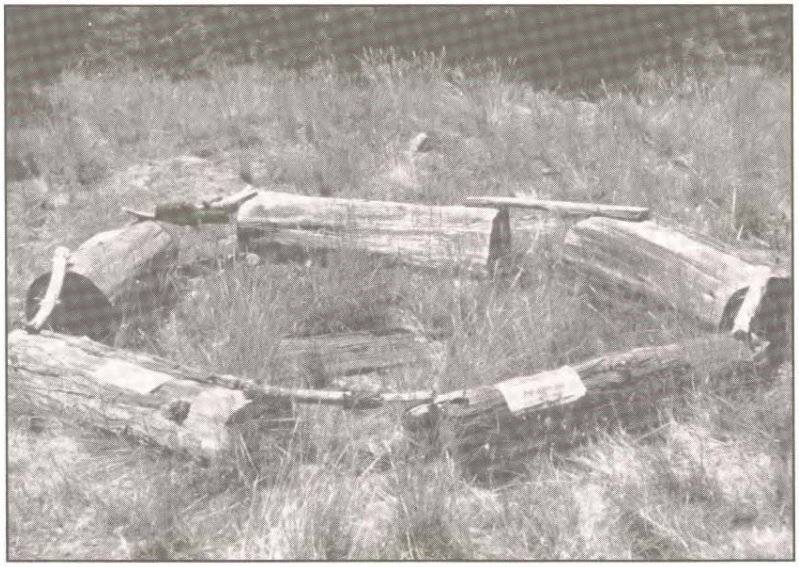

Figure 7—Trap ring located on the perimeter of a new plantation on the Goosenest Ranger District, Klamath National Forest

Baiting of trap sites often enhances capture success. Apples (porcupines prefer red delicious) are best (Dodge 1958), but they deteriorate rapidly and frequent rebaiting is necessary. Fetid scents, such as those used by coyote trappers, also attract porcupines The local state fish and game agency should be consulted about trapping regulations and laws before a trapping program is begun

No toxicants currently are registered for control of porcupines. Strychnine-salt blocks have had variable success, but their use has raised considerable concern} regarding hazards to nontarget wildlife and secondary poisoning of predators and scavengers. The efficacy of the strychnine-salt block was evaluated by Anthony and others (1986) in northeastern California and southeastern Oregon. They optimized poison-block placement by tracking the locations of radio-tagged porcupines; nevertheless, bait acceptance was extremely poor. The authors not only concluded that sodium chloride is an ineffective bait, but they also concluded on the basis of subsequent strychnine-salt block bioassays with caged porcupines that strychnine is not a suitable toxicant for control of porcupines. Other researchers Lawrence (1957) and Dodge, (1958) observed similar results with western and eastern porcupines, respectively, and speculated that the high tannin content of the porcupines' diet likely precipitated the strychnine. Anthony and others (1986), however, noted that the test animals' acclimation period before the bioassay tests should have eliminated previously consumed tannins. This suggested that porcupines may have some "built in" resistance to high levels of strychnine

Anthony and others (1986) found the "cubby" set (a small plywood lean-to nailed to heavy logs with salt blocks nailed to the interior available to porcupines but not cattle or big game animals) more effective than installation on trees to control porcupines. They also confirmed that these methods are a hazard to other wildlife, and they recommended against the use of strychnine-alkaloid salt blocks-

Most available animal repellents do not deter porcupines, although Schemnitz (1983) indicated that thiram might be effective. While not specifically registered for control of damage by porcupines, thiram may be applied to seedlings, foliage, or stems of plants that need protection (Section 2(e) of the Federal Insecticide, Fungicide, and Rodenticide Act [FIFRA])

Copper napthanate-based wood preservatives have shown some effectiveness as repellents that discourage porcupines from gnawing on plywood signs and plywood-sheathed buildings, but none of these compounds are registered or recommended for such uses The Missoula Equipment Development Center (MEDC) tested various sign materials and found that porcupines were attracted to the glue in plywood (USDA Forest Service 1975). After testing different plywood samples, the MEDC found that plywood made with melamine/urea glue was most resistant to porcupine damage

Hunting

Hunting is the most species-specific and efficient method presently available for controlling porcupines. Knowledge of porcupine movements and habits is vital to ensure proper timing of hunting. Winter is the best time for systematic hunting in areas known to have damage Daytime hunting is most effective when animals can be tracked on snow. This usually is possible during late fall, winter, or early spring. Porcupines tend to be quite active after snowstorms, and their tracks and droppings are easily found at such times. Porcupines feed in trees and their movements tend to be restricted during winter; therefore, the animals are more likely to be found near fresh damage at that time.

Night-hunting with a spotlight is the recommended method for the summer season around wetland areas and in nearby agricultural areas such as alfalfa fields During the summer, porcupines are likely to be found far from damaged trees. Night hunting along roads also is useful during the breeding season in late summer or early fall

Nighttime hunting must be coordinated with local fish and game authorities before initiating a program. Early morning and late evening hunting in moist meadows, along stream margins, or wherever succulent, herbaceous vegetation can be found also is useful during spring and early summer.

Porcupine hunting in the more humid, snow-free areas (such as the western Cascades) is far more difficult and labor intensive because of the porcupine's irregular movement patterns (not restricted because of cold and deep snow). Hunting with a trained dog can greatly improve success and extend effective hunting periods in these and most other areas. Many breeds of hunting dogs can be trained to track and hold porcupines at bay without attacking.

Random or recreational shooting of porcupines is not likely to provide the intensity of effort needed for effective control. Successful hunting must be persistent and well-organized. In areas of heavy damage, it may be economical to employ or contract skilled porcupine hunters. They must be reliable and concentrate their efforts on known areas of damage. This probably is easier to accomplish by contracting with either USDA-APHIS-ADC personnel or with experienced, professional, private contractors.

The Goosenest Ranger District of the Klamath National Forest in northern California contracted with USDA-APHIS-ADC for porcupine control in areas where damage losses of $70,000 or more had been documented. At a cost of $10,000 per year, over 600 porcupines were removed over a 2-year period with spotlight hunting at night Concentration of effort in alfalfa fields adjacent to the forest reduced forest damage at a cost of about $33 per porcupine; meanwhile, the program helped farmers reduce the amount of their crop lost to porcupines.

Biological Control

Quills usually provide excellent protection from predators, nevertheless, mountain lions, bobcats, coyotes, fishers, bear, and other predators prey on porcupines (Hooven 1971). The fisher, a furbearer of the mustelid family and a natural predator of porcupines, has been credited with significantly reducing porcupine populations in the Northeast and Lake States in areas where it was reintroduced or where fisher numbers increased naturally (Cook and Hamilton 1957, Earle and Kramn 1982). Many Western States have successfully reintroduced the fisher, but few data are available regarding the influence of fishers on porcupine populations It is unlikely that fishers alone will prevent or control porcupine damage, but predators certainly might help keep porcupine populations at low levels after a successful program of direct control.

Silvicultural Treatments

Several authors have suggested various treatments on the basis of their knowledge of porcupine biology and ecology, but documented evidence of the effects of Silvicultural treatments on porcupine populations or habitat use are lacking in the literature. The extensive distribution of porcupines across North America, the diversity of forest or vegetation types where this animal is found, the variety of the habitats they use and vegetation they eat at different seasons, and the relatively large home ranges and mobility of the animal suggest that this species is highly adaptable. Simple habitat treatments are unlikely to alleviate porcupine occupancy or invasion of forest stands or plantations. Porcupine use of habitat, however, suggests some actions that may help reduce the potential for serious problems.

Silvicultural Systems

In the lodgepole pine, interior ponderosa pine, and true fir forest-types, large clearcuts can result in abundant summer food supplies, but they initially fulfill few nabitat needs for the porcupine during the winter, especially in areas with snow. Shelterwood and seed-tree harvest systems may encourage porcupines by leaving potential roost trees in close association with a newly developing stand of young trees. Group selection or small clearcuts also may create an ideal combination of young and large^trees for winter habitat. Removal of the large overstory trees and control of understory and ground vegetation within plantations would reduce the attractiveness of these sites to porcupines. Rock outcroppings, slash piles, and downed logs, however, reduce the effectiveness of these treatments. The effect of uneven-age management on porcupine populations and the incidence of damage with such methods is unknown. Conditions after harvest determine the impact. If uneven-age management results in a more open canopy that allows the development of diverse ground vegetation and provides a diverse mixture of tree age-classes, then porcupine damage on younger trees could become a more serious problem. Efforts to provide more slash piles, downed logs, and snags for other wildlife also should benefit porcupines.

Old-growth stands of coastal Douglas-fir, western hemlock, Sitka spruce', and coastal redwood provide little food for porcupines. The dense canopies of these stands result in little ground vegetation, while the large diameters and great heights ofithe trees make them unsuitable as winter habitat. Clearcutting creates an abundance of food during the early stages of plant succession and some authors have attributed the increased prevalence of porcupines in western Washington and Oregon and northwestern California to logging activities (Dodge 1966, Dodge and Canutt 1969, Hooven 1971, Yocom 1971). Seed-tree and shelterwood systems enhance food production, but the extremely large size of mature trees left on site in these areas should not attract or provide roosts for porcupines as they would in other areas. If future management of these forests emphasizes maintaining the character of old-growth stands (tall, large diameter, closed canopies), then porcupine abundance probably will decrease. Single-tree and group-selection regeneration cuttings probably have little positive effect on porcupines. Intermediate cuttings such as thinnings (Van Deusen and Myers 1962), improvement cuttings, salvage, and sanitation cuttings generally should benefit porcupines by opening stands.

Other Silvicultural Practices

Some other Silvicultural practices that may help reduce porcupine problems include managing for greater species diversity, delaying thinning, and maintaining higher stand-densities. Porcupines may cause injuries to a wide variety of timber species, but differences in susceptibility often are observed. Sullivan and others (1986), for example, found no injuries to amabilis fir and western redcedar in a western hemlock-Sitka spruce forest type with a total incidence of damage of about 53 percent of the trees.

Other research evidence suggests that porcupines feed on more trees in pure stands than in stands of mixed species (Harder 1980) This finding supports the view that porcupines prefer more open-grown stands with faster growing, more vigorous, dominant, and codominant trees,

There are no documented, cost-effective methods of habitat manipulation currently known to alleviate porcupine occupancy or invasion of forest stands or plantations. Sullivan and others (1986) suggested evaluation of experimental sanitation-spacing in second-growth western hemlock-Sitka spruce stands in north-coastal British Columbia where the less frequently injured Sitka spruce, amabilis fir, and western redcedar

would be favored as future crop trees over the more susceptible western hemlock. They also suggested leaving additional hemlock stems as buffers or alternative food for porcupines. It is doubtful that this would be cost-effective unless sanitation cuttings were a management practice carried out to enhance stand production or shorten rotation regardless of porcupine damage. Natural stand succession resulting in a closed-canopy forest with little understory vegetation essentially eliminates porcupines. This, however, occurs some time after the trees reach the sapling and pole stages that porcupines prefer.

Forest management practices should include policies to remove natural and man-made den sites with potential for use by porcupines. Porcupines, for example, generally select smaller road culverts as opposed to large-diameter, open pipes that are not secretive enough (and also easier to control). Large-size rocks should be avoided in road fills, if possible, because they provide a maze of open spaces that are readily used by porcupines for dens. Log and debris dumps, such as those often found at abandoned landing sites, should be removed when the harvest operation is completed Slash or brush piles and windrowed materials from site-preparation activities also provide excellent cover for future porcupine occupancy and either should be removed by burning or compressed with heavy machinery. Burning and herbicide control of understory vegetation also may help reduce porcupine damage.

A combination of methods may be required to provide effective control. It is extremely important to obtain data on current levels of porcupine damage and to monitor how effectively control efforts reduce damage to trees

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO,
SELECTED WILDLIFE SPECIES

Chapter 13
Tree Squirrels, Woodrats, and Beaver

THOMAS P. SULLIVAN

Abstract

This chapter discusses the interaction of tree squirrels and other rodent species with the silvicultural management of forests in the Pacific Northwest. The major emphasis is on red squirrels, followed by Douglas squirrels, western grey squirrels, dusky-footed woodrats, bushy-tailed woodrats, and beaver. Tree squirrels damage coniferous trees by various feeding activities. Their barking of the boles of saplings and pole-size trees causes the most serious problem. Incidence of red squirrel damage to lodgepole pine crop-trees in susceptible thinned stands in the interior of British Columbia ranges from 36 percent to 96 percent. Squirrels prefer to feed on vigorous stems, and the resulting lost growth of these trees may be substantial Squirrels generally are abundant in large (>4 square miles) areas of unmanaged juvenile pine 2 to 3 years after a heavy cone crop. Thinning significantly! reduces squirrel populations, particularly thinning to low tree-densities (200 stems per acre, for example). Maximizing the area thinned (>250 acres) and maintaining patches of mature forest within the overall habitat mosaic further minimizes damage. Mature forest provides preferred habitat for squirrels, and a mosaic of different-aged stands enhances wildlife diversity and, presumably, predator species. Reduction of cover via vegetation management and thinning should make Douglas-fir stands less attractive to woodrats and reduce damage. Except for elimination of food sources and the aquatic habitat, cultural practices have little effect on beaver. Because

THOMAS P. SULLIVAN is assistant professor, Department of Forest Sciences, University of British Columbia, Vancouver, BC V6T 1W5.

beaver damage is relatively predictable in riparian areas, forest management activities should be planned around potential damage problems.

Keywords. Beaver, debarking, Douglas-fir, feeding damage, habitat manipulation, lodgepole pine, thinning, tree squirrels, woodrats.

Introduction

This chapter discusses the interaction of tree squirrels and the damage they cause with silvicultural practices in forests of the Pacific Northwest The major emphasis is on the red squirrel, followed by the chickaree or Douglas squirrel, and the western grey squirrel. Silvicultural management of the dusky-footed woodrat, bushy-tailed woodrat, and beaver are also discussed.

Tree Squirrels

Distribution, Abundance, and Habitat Preferences

In the Pacific Northwest, red squirrels (fig. 1) occur throughout the boreal forest from northern Alaska and Canada southward into the coniferous forest of the Rocky Mountains to southern Arizona and New Mexico. Douglas squirrels are found from southwestern British Columbia southward through western Washington, western Oregon, northern California, and the Sierra Madre The western grey squirrel is found along both sides of the Cascade Range in western Washington, western Oregon, and northern California.

Figure 1—The red squirrel (Photo by L Andrusiak)

Tree squirrels of the genus *Tamiasciurus* prefer mature stands of conifers, particularly white spruce, Douglas-fir, pines, and true firs. Seeds from cone crops are the principal food source (Smith 1968). Cone crops appear to be the driving force in population fluctuations of red and Douglas squirrels. When this hypothesis was tested in long-term experiments, the provision of supplemental food (sunflower seeds) dramatically increased populations of both species (Sullivan and Sullivan 1982a, Sullivan 1990). Densities of *Tamiasciurus* range from 0 05 to 1.7 squirrels per acre (table 1). Grey squirrels, presumably, exhibit similar relations with mast crops in mixed coniferous-deciduous forests but little information is available regarding populations of this species (Flyger and Gates 1982). Densities range from 1.0 to 1.3 squirrels per acre in different types of conifer forest (Hall 1980, as referenced by Baldwin and others 1986). Lawrence and others (1961) described this species as commonly inhabiting oak groves of the interior valleys.

Table 1—Densities of red and Douglas squirrels in various types of forest habitat in western North America

Squirrel species and habitat	Region	Home •range size	Projected density
		Acres/squirrel	*Number/mi²*
Red squirrel:			
Spruce	Alaska	1.25	512'
	Saskatchewan	1.00	640
	Alberta	0.6-0.9	1067-7;11
	British Columbia	1 58	405,
Mixed spruce and aspen	Northern Alberta	2.5	256;
	Central Alberta	1.0-2.0	640-320
Douglas fir-ponderosa pine	Montana	1.25-3.0	512-213
Western hemlock	British Columbia	1.25	512i
White spruce-lodgepole pine	British Columbia	5.0	128
Lodgepole pine	British Columbia	2.25	284
Jackpine	Alberta	2 5	256
Lodgepole pine	British Columbia	2.2	291'
Hardwoods	Alberta	100-20.3	64-32
Douglas squirrel:			
W hemlock-red cedar-Douglas-fir	British Columbia	3.75	171

The principal habitat requirement of the red squirrel is an adequate food supply, but other important features include suitable nest sites, protective cover, and' moisture and shade for cone storage. In coniferous forests, red squirrels cache the annual cone crop for a winter food supply, and they also feed on terminal buds. \ i

Where spruce trees are available, they are used as nest trees, otherwise, conifers with the greatest density of branches are selected, and the nests are often in contact with the trunk (Rothwell 1979). Nests rarely are located in isolated trees or small groups of trees; rather, they are located in trees with crowns in close proximity to surrounding trees The close proximity of nearby trees provides protection from weather and a variety of escape routes, and it reduces foraging time. Dense stands also provide damp, shaded spots for cone caches, which ensures that cones will remain closed and retain their seeds for the squirrels' winter food supply.

A detailed analysis of the cover requirements of red squirrels in mixed coniferous forests in Arizona (Vahle and Patton 1983) indicated that the best habitat consists of multistoried stands with trees of 12 to 14 inches d.b.h. in dense groups s.0.10 acres. This grouping contains at least one dominant, cone-bearing tree, generally a Douglas-fir measuring at least 18 inches d.b.h. Large, standing snags and fallen trees s.20 inches d b.h. are important components of the habitat, because they provide sites for

feeding and caching Tree groups shade the cone cache from overhead and from the sides, and mature, dominant trees are the primary food source for squirrels. Red squirrels, generally, prefer groups of coniferous trees that are the most dense and that contain large conifers, snags, and logs.

Feeding Damage

Tree squirrels damage coniferous trees by feeding activities that cut cones and twigs and bark saplings and mature trees Squirrels eat coniferous seeds, conifer bark, fungi, berries, and buds. Heavy cone-cutting begins with the ripening of seed in late summer. Field signs that indicate squirrel activity include green, unopened cones scattered on the ground under mature trees and accumulations of cone scales that mark feeding stations (Lawrence and others 1961). Cone cutting may have an adverse effect on the amount of seed available for dispersal and natural regeneration (Shearerand Schmidt 1971).

During winter, red squirrels feed on the bark of branch tips cut from ponderosa pine (Lawrence and others 1961). Cut and peeled twigs littering the ground under pines are characteristic signs of red squirrel activity. The Douglas squirrel, by contrast, cuts terminal and lateral shoots from Douglas-fir and true firs.

All three species of squirrels strip bark from the boles of conifers to feed on the exposed sapwood (table 2). Trees in the 20- to 60-year age-classes, generally, sustain the greatest injury Squirrels remove small strips of bark and then lick the surface of the exposed sapwood (Stillinger 1944, Sullivan and Sullivan 1982b). The sapwood and short strips of discarded bark (1 by 3 inches) that accumulate on the ground under the injured tree, characteristically, lack toothmarks (fig. 2, A and B). These bark strips readily distinguish squirrel work from similar crown-girdling injuries by the porcupine and woodrat Most barking damage by squirrels occurs in spring and early summer during the early part of the growing season.

Table 2—Identification of barking damage with respect to squirrel species and tree species (in order of importance) in the Pacific Northwest

Squirrel species	Tree species
Red squirrel	Lodgepole pine Western larch Ponderosa pine Western white pine Douglas-fir Grand fir Paper birch
Douglas squirrel	Douglas-fir
Western gray squirrel	Douglas-fir Ponderosa pine Jeffrey pine

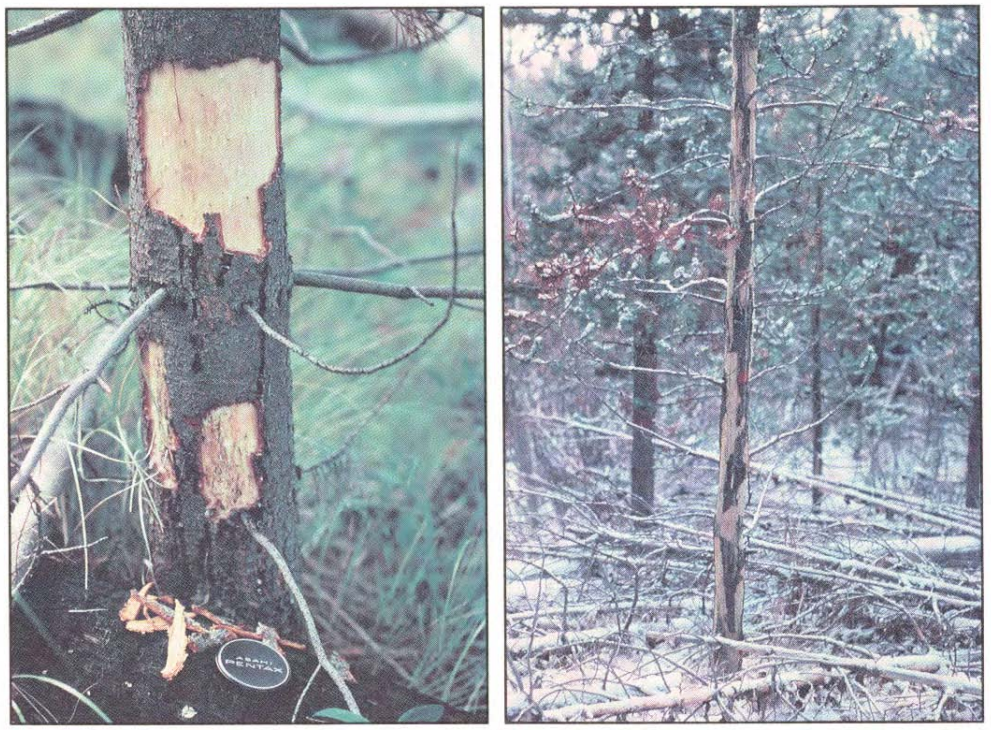


Figure 2—(A) Barking damage to lodgepole pine sapling by red squirrel Note accumulation of bark strips on ground under tree (B) A particularly severe degree of feeding

Damage Assessment

Squirrel damage in plantations and managed stands can be assessed with a simple sampling design of either circular plots (0.01-0.02 acre, depending on stand density) with a constant radius, or by locating variable plots with 10 crop-trees (or leave trees) closest to the plot center. Variable plot sizes in the latter technique would accommodate the sampling of 10 crop trees. In unmanaged, second-growth stands, variable-plot cruise-sampling could be used with a minimum d.b.h. class-limit. The 10 crop-trees nearest to a plot center also could be chosen to represent trees that would be left as the future crop after thinning. Plots should be located along predetermined compass lines that systematically cover each stand. If permanent plots are desired, all sample trees within each plot should be permanently tagged to indicate species, d.b.h. (at reference point of tag), and height. Tree-class, crown-class, and incidence of pathological factors also may be included. This information will provide the basis for analysis of damage and its effect on tree survival, growth, and yield. This sampling scheme could also be used for assessments of woodrat and porcupine damage

Annual assessments of damage should be recorded after the spring-summer feeding period for each tree in a given plot. Records for each tree should include] the number of new (current year) and old (before current year) wounds, their relative position (in thirds) on the stem (lower, middle, upper), the relative stem-location of the most severe wound, and the degree of girdling around the circumference of the stem (classes of 1-24 percent, 25-49 percent, 50-75 percent, 76-99 percent, and 100 percent) by the most severe wound. Feeding may be at any position (such as above 6 ft) on the tree stem; therefore, precise measurements of the actual amount of bark and vascular tissues removed may not be possible.

The degree of stem-circumference girdled and, secondarily, the number of wounds and their distribution on the stem provide the data necessary for assessing the impact of damage on growth. One or more wounds with a damage circumference >50 percent (semigirdled) are likely to reduce tree growth and yield, and the tree may even die at some time in the near future (Sullivan and Sullivan 1986). Completely girdled trees will die Trees with girdling in the upper third of the stem develop spike-tops, and the lower portion of the tree usually remains alive It is unlikely, however, that spike-top trees will ever be of commercial value.

Impact of Damage on

Most work on this subject concerns the red squirrel and management of juvenile stands of lodgepole pine in the interior of British Columbia. Thinning of overstocked stands of lodgepole pine concentrates growth on a prescribed number of stems selected for superior growth and form at an early age in the life of the stand. Squirrels prefer feeding on stems >2 inches in diameter; therefore, crop trees in managed stands remain at risk for several years.

Eleven of 40 thinned stands (27 5 percent) in south-central British Columbia showed evidence of squirrel attacks (Brockley and Elmes 1987). Within damaged stands, an average of 51 percent (range of 6 to 90 percent) of lodgepole pine crop trees had barking injuries. Another survey of 47 thinned stands in north-central and southern British Columbia indicated that the percentage of crop trees attacked in damaged stands (stands where >15 percent of trees in the stand were attacked) ranged from 36 percent to 96 percent (Sullivan, in prep.). These seriously damaged stands, generally, were associated with very large stands originating after a fire or harvest. Direct mortality (complete stem-girdling) and presumed mortality (>50 percent stem-girdling) ranged from 3 to 21 percent in these stands. Tree damage tended to be clumped, which may result in large openings or pockets of reduced growth.

In terms of the debarking of trees, a 10-year assessment of the influence of feeding damage by squirrels on the growth rates of juvenile lodgepole pine indicated that semigirdling (>50 percent of the stem-circumference girdled) clearly suppressed the growth of small trees (diameter <2 inches at start of study) but had little effect on larger stems (fig. 3) (Sullivan, in prep.).' The height increment was significantly reduced by partial girdling in small-diameter trees but not for those >2 inches d.b h (diameter at start of study).

The frequency of squirrel attack is significantly greater among large-diameter stems than among small-diameter stems, so the incidence of complete girdling usually is low (<10 percent). Analysis of barking and its effect on the diameter increment over a 10-year interval at another study area indicated that, paradoxically, damaged trees grow significantly faster than undamaged trees in some diameter classes (fig. 4).

Analysis of the radial increment of thinned trees at the second study area, indeed, indicated that before attack by 10 squirrels, stems that were later damaged grew significantly faster than stems that later escaped damage (fig 5A). This significant difference also was sustained throughout the postattack period. It is not surprising, therefore, that some damaged trees grew faster than undamaged trees (fig. 4), because squirrels apparently prefer to feed on vigorous stems. The lost growth of these trees may be substantial (Brockley and Sullivan 1987, Sullivan and Vyse 1987)

' Sullivan, T P , in prep Influence of stand and site factors on incidence of squirrel damage in young lodgepole pine

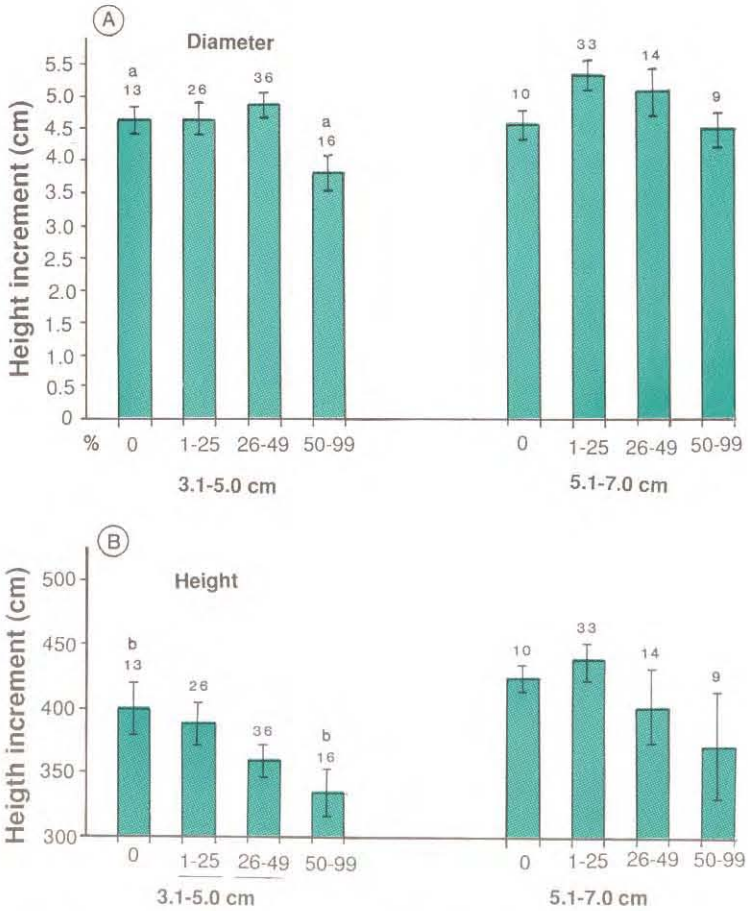
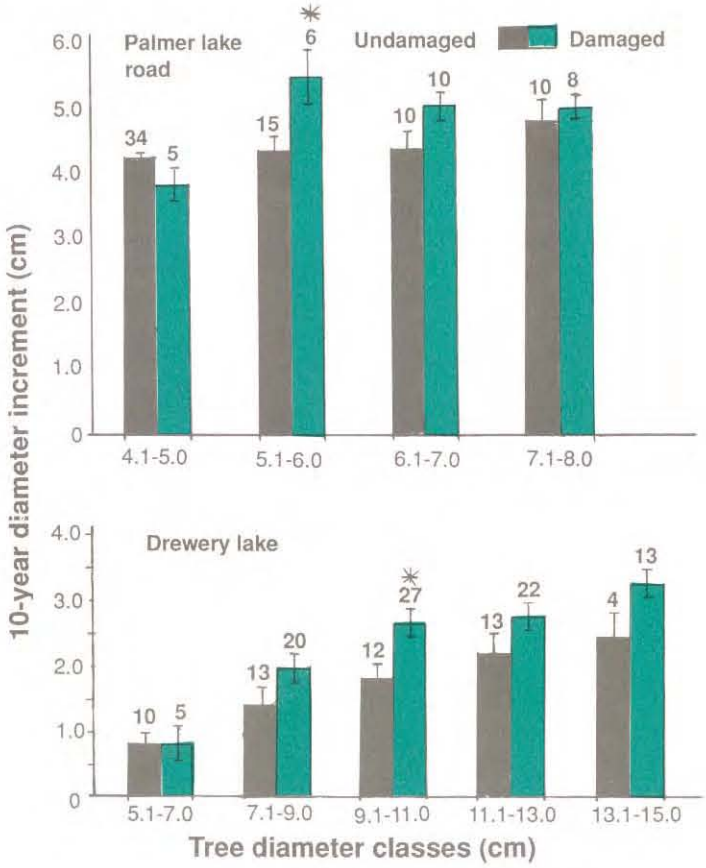


Figure 3—*Left.* Impact of semigirdling damage on **(A)** diameter and **(B)** height increments in the spaced stand at Prince George. Sample sizes are shown above each bar, with range indicator of ±1 SE, a-a b-b, $p < 0.05$.

Figure 4—*Right.* Impact of squirrel damage on diameter increment for undamaged and damaged trees at **(A)** Palmer Lake Road and **(B)** Drewry Lake. Sample sizes are shown above each bar, with range indicator of ±SE. "*" indicates $p < 0.05$.



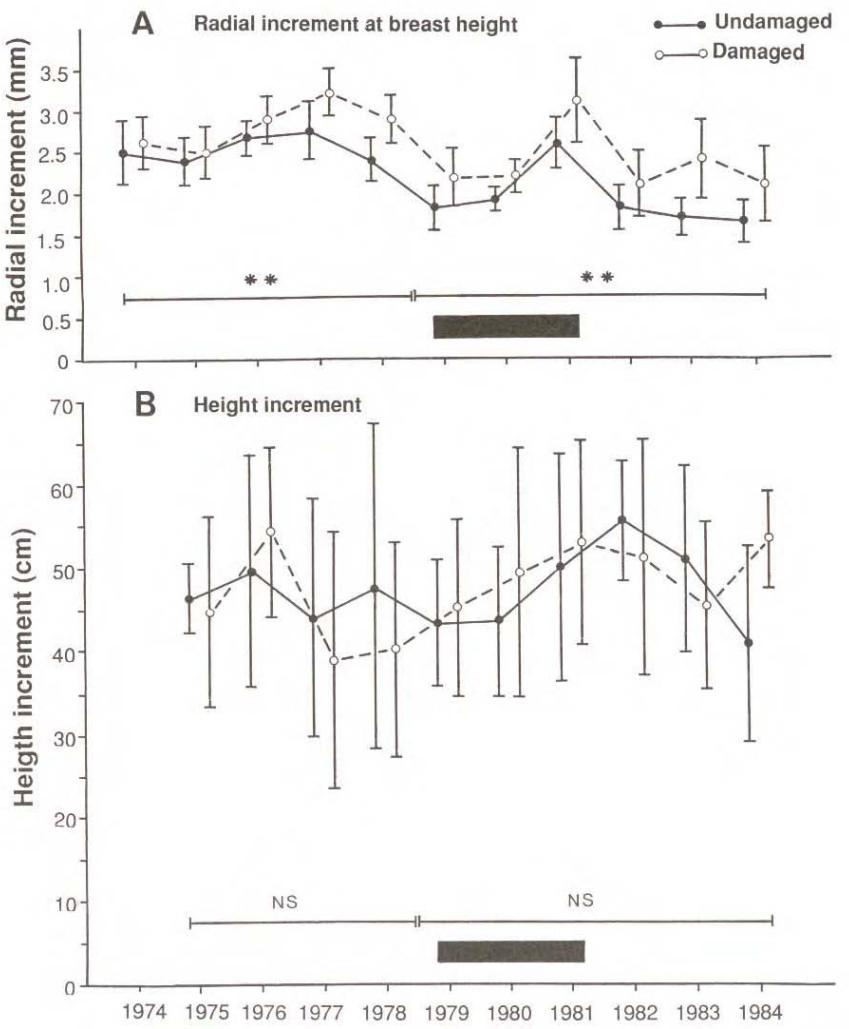


Figure 5—Radial increment **(A)** and height increment **(B)** of spaced lodgepole pine for damaged and undamaged trees before and after squirrel damage at Drewry Lake Vertical bars represent 95-percent confidence intervals Means of undamaged trees are joined by solid lines, means of damaged trees are joined by broken lines Horizontal bars represent ANOVA comparison of damaged and undamaged stems within a given period "*" indicates p <0 01, "NS" indicates p > 0 05 Horizontal shaded bar indicates outbreak of squirrel damage (1979-81) (from Sullivan and Vyse 1987)

Population Fluctuations and Damage

Lodgepole pine responds favorably to nitrogen fertilization when other nutritional, soil, and moisture factors are not limiting It appears, however, that the improved palatability and nutritive quality may significantly increase the susceptibility of pine crop trees to attack by red squirrels, at least with respect to small stands (Brockley and Sullivan 1987, Sullivan and Sullivan 1982c) Assessment of squirrel damage in operationally fertilized stands, to date, has recorded severe attack (range of 43 to 74 percent of crop trees damaged) in only 4 of 23 stands (Sullivan, in prep.). These severely damaged stands were on good sites for tree growth, particularly with respect to moisture. Operational fertilization, therefore, apparently does not increase squirrel damage in stands that are not already susceptible to attack because of other factors (such as tree vigor, extensive area of juvenile stands, or high population of squirrels).

Information about the population fluctuations of squirrels is important for predicting the incidence of damage to crop trees in thinned stands. Figure 6 illustrates the

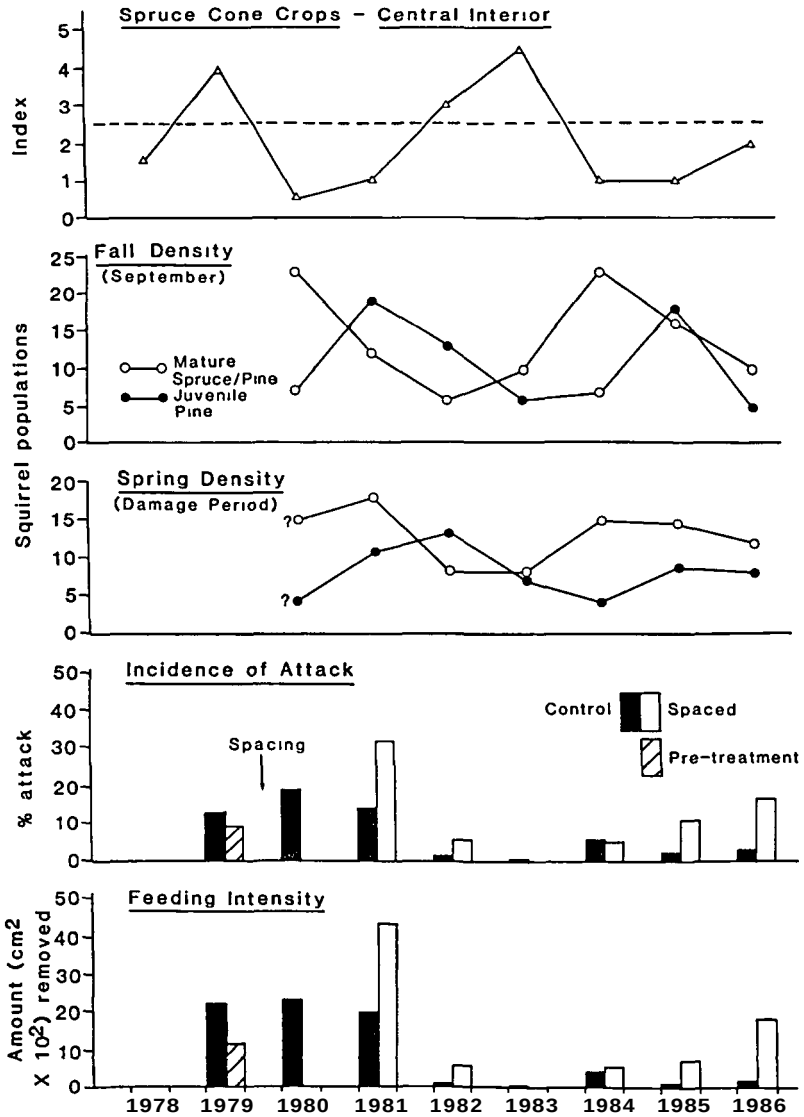


Figure 6—Interrelation of spruce cone-crops, squirrel population density, incidence of attack, and feeding intensity at the Prince George study area (from Sullivan 1987)

relation of interior spruce cone crops to populations of the red squirrel at F^rince George. Heavy spruce cone crops were recorded in 1979 and 1983 in the central interior (Sullivan 1987). Squirrel populations in mature forest with a significant component of spruce peak in abundance during the year after a substantial cone-crop, because reproduction, recruitment, and survival are increased. The highest annual density occurs when recruitment of juveniles reaches a maximum in the fall (usually in September). This high density may persist for an additional year, depending on the size of cone crop, the incidence of spruce trees, and several other factors. Surplus squirrels from the increased population in the mature forest eventually "spill over" into stands of juvenile lodgepole pine that, presumably, are suboptimal habitat. At 2-3 years after a heavy cone crop, therefore, squirrels are abundant in juvenile pine stands, and their density may rival that of mature stands (Sullivan and Moses 1986; Sullivan, in prep.).

This general pattern suggests a predictable population cycle for red squirrels in juvenile stands, at least in areas where cone crops in nearby mature stands can be accurately monitored The historical trend in spruce cone crops in the central interior indicates an average interval of 3 to 4 years between medium-heavy to heavy crops. This trend suggests that high squirrel populations and damage could be expected in susceptible stands of juvenile pine approximately every 3 to 4 years, at least in areas influenced by spruce cone crops. There could certainly be local and geographic variation in the magnitude of the overall cone crop in a given year. This should be considered in predictions of increased squirrel abundance.

Habitat Manipulation—Thinned vs. Unthinned

The response of squirrel populations to thinning of lodgepole pine was measured at intensive study areas in the central interior of British Columbia (Sullivan and Moses 1986) Densities of red squirrels were lower in thinned than unthinned stands of juvenile lodgepole pine. Densities in the thinned stands (0.09/acre at Prince George and 0.20/acre at Cariboo) were comparable to the lowest estimates of density reported for any of the major habitat types in North America (Rusch and Reeder 1978). Densities in the unthinned juvenile stands (0.5/acre at Prince George and 0.4/acre at Cariboo) were comparable to those reported for mature pine and mixed coniferous forests (Rusch and Reeder 1978). Eleven of 14 squirrel captures (6 individuals), significantly, were at perimeter trap stations on the thinned grid at Prince George. The squirrels that damaged pine stems in this stand, therefore, presumably lived in the adjacent, unthinned stand or were transients

Several researchers have suggested that marginal habitat acts as a dispersal sink for squirrels, especially juveniles, from surrounding favorable habitat. The generally high proportion of juveniles in young stands suggests that this process was functioning in these study areas It is possible that stand thinning over a large area (>250 acres, for example) may reduce immigration from surrounding areas and help alleviate damage from the red squirrel. Even low numbers of squirrels, however, evidently can cause high levels of damage to juvenile trees. A population-reduction program to reduce squirrel damage, therefore, probably would be ineffective because of the difficulty in achieving complete removal of all animals. The resiliency of squirrels during periods of depopulation, furthermore, would result in the rapid filling of available habitat

Thinning of juvenile pine stands, in summary, reduces red squirrel densities, although it may not reduce tree damage to an acceptable level Increasing the area of thinning, however, may help reduce damage. The study area of unthinned)uvenile pine exhibited several characteristics of suboptimal habitat (low proportion of breeding females, low survival rates, and high fall recruitment), and yet it was able to support spring-to-spring densities similar to the densities of so-called optimal mature forest habitat. Juvenile pine stands may provide a dispersal sink for yearling and juvenile squirrels from surrounding mature forest areas

Habitat Manipulation-Stand Density

An operational stand-density experiment was initiated in the fall of 1988 to test the influence of variable tree-density on squirrel populations and damage. Three densities (200, 400, and 800 stems per acre) of lodgepole pine in operationally thinned areas were established at two study areas in the interior of British Columbia (fig. 7). The incidence of attack on potential crop trees before thinning ranged from 37.0 percent to 49 0 percent at Prince George and from 37.5 percent to 49 0 percent at Penticton Creek Stands at both study areas, therefore, had a history of chronic attack by squirrels and provided excellent test areas for manipulating stand density.

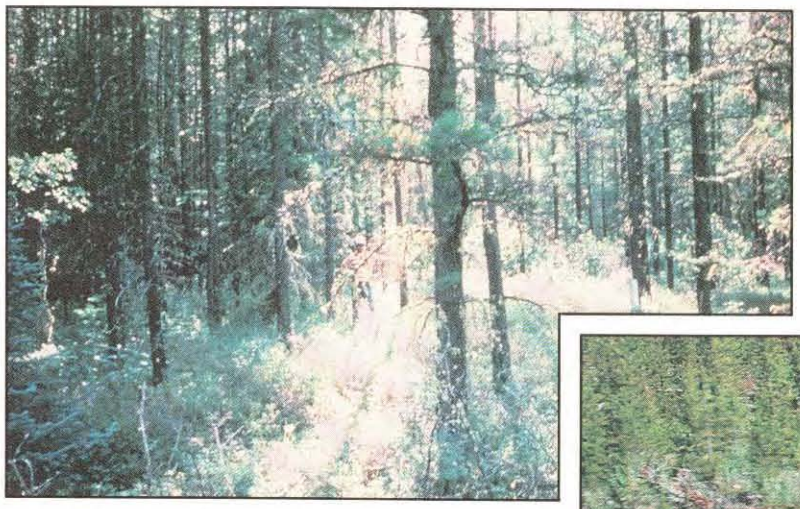
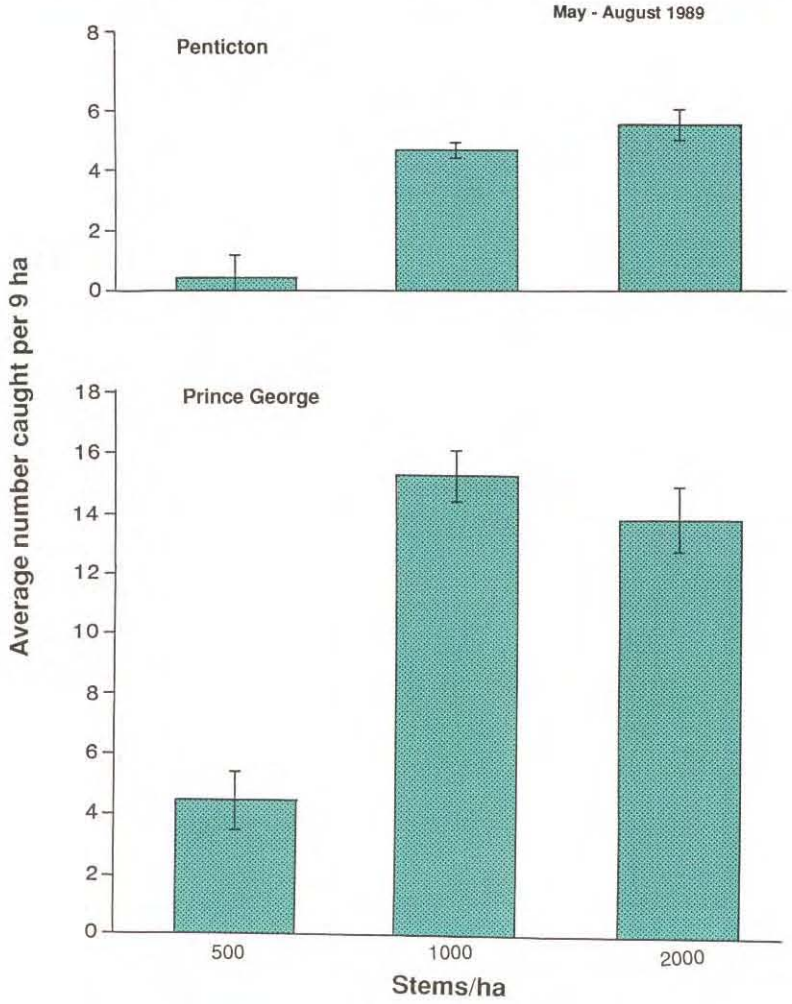


Figure 7—*Above and Right:* Unthinned and thinned stands of lodgepole pine.

Figure 8—*Below.* Response of red squirrel populations to manipulation of density of lodgepole pine stands during the first year after treatment. Vertical bars represent 95-percent confidence limits.



Squirrel populations were live-trapped at 2-week intervals during May to .August 1989 in each of the stands. Squirrel populations were significantly reduced in the low-density thinning at each study area (fig. 8). This preliminary result clearly demonstrates that the "open" habitat produced by "heavy thinning" (200 stems per acre) dramatically reduced the number of squirrels residing in this managed stand. The incidence of damage to lodgepole pine crop trees in 1989 was relatively low (range of 2.0 to 13.5 percent) in all stands. Statistical comparisons, however, were not possible.

Forecast Model

Figure 9 illustrates a forecast model that predicts when and where outbreaks of squirrel damage will occur (Sullivan, in prep.). The two major factors are (1) an extensive (>2,500 acres) stand or mosaic of stands of fire or postharvest origin with limited areas of mature forest, and (2) the frequency of interior spruce and fir cone-crops leading to increases in the squirrel population in stands of juvenile pine. Fire-origin stands tend to have high densities of stems that leave a great accumulation of slash after spacing. This slash load, presumably, provides good cover for squirrels. Susceptible stands have average diameters >2 inches.

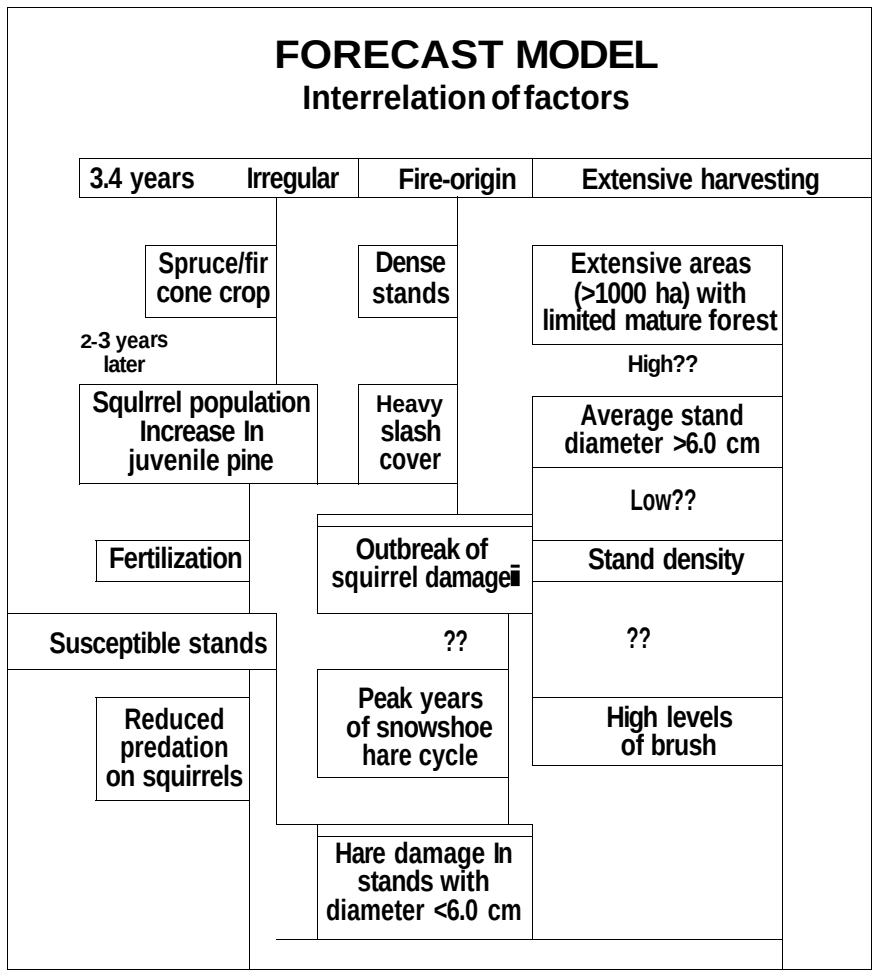


Figure 9—Forecast model to predict when and where outbreaks of squirrel damage will occur in managed stands of lodgepole pine (from Sullivan, in prep)

Additional factors that may contribute to an outbreak of damage include predators that switch from squirrels to snowshoe hares during peak years of the hareicycle, and high levels of competing vegetation that provide cover and perhaps food for squirrels in juvenile stands. High-density (>800 stems per acre) managed stands may be more susceptible to attack, although this requires experimental verification on an'operational scale. Fertilization may potentially increase squirrel attack but only in'those stands that are already susceptible to attack, i

Decisionmaking Profile

A decisionmaking profile (fig. 10) can aid in the assessment of the risk of squirrel damage when a prethinning survey is conducted. The profile lists three levels of risk that are based on the nine factors describing conditions that make juvenile! stands susceptible to squirrel attack. Stand-tending should be avoided in stands with a high-risk rating. The investment, instead, should be allocated to other stands that have a low risk of future squirrel attack. Stands with a moderate risk of attack may still be managed, and the risk may be minimized by brush reduction, slash removal, or witholding fertilization. The recommended treatment is to leave more stems per acre in the thinning prescription to compensate for future losses to squirrels and other pests (Sullivan 1987). A lower density of stems (<400 stems per acre, for example), however, might reduce squirrel activity and damage, particularly in light of the results discussed in the section of this chapter covering habitat manipulation. "

Decision making profile—pre-spacing

Risk assessment checklist — to avoid susceptible stands

When

- 0 Is there a regular cone crop in nearby mature forest (Spruce Fir)
- 0 Peak years (± 2 years from expected peak) of snowshoe hare cycle (reduced predation on squirrels)
- 0 Average stand diameter >6.0 cm dbh
- 0 Age classes 1 & 2 (10-40 years)

Where

- 0 Extensive stands (>100 ha)
- 0 Incidence of attack >15% in unspaced stands
- 0 High slash load after spacing
- 0 High levels of brush
- 0 Fertilization planned

Checklist score (maximum of 9)	Degree of risk
1-2	Low
3-5	Moderate
6-9	High

Figure 10—Decisionmaking profile to **assess** the risk that a given juvenile stand of lodgepole pine, when operationally spaced or thinned, will be attacked by squirrels (from Sullivan, in prep)

Silvicultural Methods to Minimize Damage

Damage from squirrels, in summary, may be minimized with the following silvicultural methods:

1. Maximize area (>250 acres) of thinning within overall juvenile stand (in other words, avoid leaving small blocks of thinned stands within an extensive, unthinned juvenile stand or group of contiguous stands).
2. Optimize stand density (200 stems per acre) and fertilization options to maximize tree growth while making habitat unfavorable for squirrels.
3. Remove brush mechanically or chemically
4. Maintain patches (>125 acres) of mature forest adjacent or nearby managed stands to provide squirrels with preferred habitat.
5. Choose mixed-species composition (such as Douglas-fir and lodgepole pine) wherever possible
6. Provide alternative foods (sunflower seeds) during the feeding period from late spring to early summer.
7. Band trees with 20-inch-wide metal strips to protect cone crops.

Information Needs

The following information is needed to provide the basis for a management plan to minimize squirrel damage:

1. Response of squirrel populations and damage to various stand densities and tree pruning on an operational scale.
2. Response of squirrel populations and damage to reduction in vegetation (various shrub species).
3. Predator (raptors and marten) enhancement via management of snags and diversity of habitats

Woodrats

Distribution, Abundance, and Habitat Preferences

The distribution of the dusky-footed woodrat ranges from the Columbia River in western Oregon south to northern Baja California along the Pacific Coast. It mainly occupies the low slopes or foothills of the transitional zone, particularly in young, dense forests of Douglas-fir, various pines, oaks, and other deciduous trees. This species is also found east of the Cascade divide over much of the Great Basin sector of northeastern California, particulariy in juniper woodland (Murray and Barnes 1969). The distribution of the bushy-tailed woodrat ranges throughout forest types of the Pacific Northwest wherever dense thickets of trees or other vegetation provide food and cover. Densities of dusky-footed woodrats range from 0.6 to 1.6 per acre (Hooven 1959) with home ranges of 0.6 acre for males and 0.5 acre for females (Cranford 1977) Woodrat activity is significantly higher in areas of 75 to 100 percent cover than in areas of less cover. Woodrats, therefore, use many different habitats, including cliffs, gullies, talus slopes, forest floor, and thickets from coastal rain forest to interior dry grasslands.

Woodrats characteristically build bulky stick-nests or houses in the crowns of trees and in sheltered sites at ground level. These nests may be 3 to 6 feet in height and diameter and are composed of bark and other material that is all finely shredded. The dusky-footed woodrat is a semiarboreal species, whereas the bushy-tailed woodrat is less arboreal and is usually found near abandoned buildings and rocky outcroppings (Lawrence and others 1961) The bushy-tailed species, therefore, does not cause as much forest damage as the dusky-footed woodrat.

Feeding Damage

Woodrats eat a wide variety of vegetative material, including fruit, seeds,, and green and dry foliage of both herbaceous and woody plants. They may also consume some animal matter, such as insects and, occasionally, carrion. Dusky-footed woodrats girdle the boles and branches of young Douglas-fir and grand fir. They remove patches of bark from the upper bole and limbs of 10- to 30-year-old sapling and pole-size conifers. Woodrats line their nest chambers with this bark and it does not appear to be a food source. Small lateral branches and terminal leaders, however, may be clipped from tree crowns for food and nest-construction materials (Lawrence and others 1961). The incidence of recorded damage to Douglas-fir ranges from 25 percent (Hooven 1959) to 43 percent (Nettleton 1957) in western Oregon.

Barking of the upper bole by woodrats leaves a relatively smooth surface with a few scattered toothmarks. Feeding by porcupines, in contrast, leaves a heavily gnawed appearance on the exposed sapwood. The characteristic sign of damage by tree squirrels, as discussed earlier, is short strips of discarded bark that accumulate on the ground under trees that have been attacked. This sign is lacking under trees barked by woodrats (Lawrence and others 1961). I

Silvicultural Methods to Minimize Damage

Scattered thickets of sapling Douglas-fir that regenerated in association with hardwood brush-species are the stands likely to suffer the most damage from woodrats. Incidence of attack may be particularly severe where trees are sufficiently close together to allow woodrats to jump from one tree crown to another. Low-density stands and large stands with little brush cover have little damage from wpodrats (Nettleton 1957, Hooven 1959). As discussed in the tree-squirrel section, thinning and pruning young stands, and reducing logging debris and vegetative cover should make the habitat less attractive to woodrats and, consequently, minimize damage.

Beaver

Distribution, Abundance, and Habitat Preferences

The beaver is abundant throughout the Pacific Northwest and is well known as a forest-dwelling animal because of its tree-cutting and dam-building activities. According to Lawrence and others (1961), tree-cutting damage generally is less serious than damage caused by plugged culverts that result in flooding and road washouts. Active beaver colonies are likely to be found in mixed coniferous-deciduous forest-habitat. Watershed size, stream width, and the percentage of hardwood vegetation have significant positive effects on the density of active colonies (Howard and^Larson 1985). |

Beaver usually are associated with deciduous tree and shrub communities that may be either edaphic-climax communities or transient (subclimax) communities (Slough and Sadleir 1977). Edaphic-climax deciduous communities typically are found on alluvial soils and in riparian zones. Beaver habitat usually develops after^ a disturbance by fire, but it may also be initiated by windthrow, insect outbreaks, and logging (Lawrence 1964). i

Feeding Damage

Beaver feed on the foliage of herbaceous plants in summer, and they primarily eat tree bark (particularly aspen, poplars, and willows) during winter. In the Coast Range, they eat salmonberry, red alder, and vine maple, mostly within 100 feet of a stream Douglas-fir and ponderosa pine also may be cut for food. Beaver tend to cut down mature trees and leave cone-shaped stumps approximately 12 to 24 inches in height. Teeth marks are distinctively broad and chisel-like (Lawrence and others 1961). Beaver leave large wood chips around stumps and peeled sticks in or near water.

Silvicultural Methods to Minimize Damage

Beaver damage is relatively predictable in certain riparian areas, so forest-management activities should be planned around potential damage problems. Beaver usually extensively alter or modify their aquatic habitat over time, so most cultural practices have little impact on them with the exception of eliminating food sources and aquatic habitat where possible. Tearing out dams on a daily basis and removing dam construction materials sometimes causes individual beaver or colonies to move to another site (depending on the availability of construction matehals). Beaver might, however, be even more troublesome at the new location. Once beaver become commonly abundant in a watershed or large contiguous area such as a stream system, swamp, or other wetlands area, periodic replacements or reinvasions of suitable habitat can be expected. Physical removal of beavers, however, can provide temporary control.

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 14
The Lagomorphs: rabbits, hares, and pika

GREGORY A. GlUSTI ROBERT H. SCHMIDT, ROBERT M. TIMM,
JOHN E. BORRECCO, AND THOMAS P. SULLIVAN

Abstract

Rabbits, hares, and pika have all been implicated in causing damage to trees in the Pacific Northwest Damage is generally to seedlings, limbs, and saplings smaller than 2 5 inches in diameter, with damage involving either clipping of the stem or bark removal as the lagomorphs are feeding Damage prevention methods include synthetic or biological repellents, exclusion (individual seedling protectors or fencing), or lethal control methods such as poisoning or shooting Silvicultural methods useful in reducing lagomorph damage include vegetation management, thinning, fertilization, and selection of browsing-resistant seedling sizes

Keywords Lagomorpha, *Sylvilagus, Lepus, Ocotona, Brachylagus,* rabbits, hares, pikas, snowshoe hares, silviculture, forestry, animal damage control, vertebrate pest control

GREGORY A GIUSTI is wildlands ecology advisor, University of California, Cooperative Extension, Agricultural Center, Ukiah, CA 95482 ROBERT H SCHMIDT was wildlife and natural resource specialist, Department of Forestry and Resource Management, University of California, Berkeley, CA 94720 and currently is assistant professor, Department of Fisheries and Wildlite, Utah State University, Logan, UT 84322-5210 ROBERT M TIMM is superintendent and wildlife specialist, University of California, Hopland Field Station, 4070 University Road, Hopland, CA 95449 JOHN E BORRECCO is regional pesticide-use specialist, U S Department of Agriculture, Forest Service, 630 Sansome Street, San Francisco, CA 94111 THOMAS P SULLIVAN is assistant professor, Department of Forest Sciences, Faculty of Forestry, University of British Columbia, Vancouver, British Columbia, Canada V6T 1W5

Introduction

Lagomorphs (rabbits, hares, and pikas) occur throughout the world. They are an integral part of the biotic landscape on many continents both as major consumers of vegetation and as food for carnivorous mammals, birds, and reptiles. In the Pacific Northwest, lagomorphs, especially snowshoe hares, cause damage to both managed and unmanaged forest stands (Lawrence and others 1961). This chapter outlines basic differences between rabbits and hares, their behaviors, habitat needs, breeding biology, and damage factors. The chapter also reviews methods of animal damage management that reduce lagomorph damage, and it describes silvicultural alternatives to help forest managers decide which option would most effectively prevent or reduce damage in a given situation.

The discussion concentrates on rabbits, hares, and pikas distributed in northern California, Oregon, Washington, southern British Columbia, Idaho, and western Montana, and it focuses on the timber-producing areas of each state. Some lagomorph species included in this chapter occur both in forested and nonforested habitats Timber species may vary greatly over such a large geographic region, but feeding damage and management strategies for rabbits may be similar to those for hares.

Taxonomy and Description

The taxonomic order Lagomorpha includes all rabbits, hares, and pika The genus *Sylvilagus* includes the true rabbits, *Lepus* includes hares, and *Ocotona* includes the pika. In all lagomorphs, a small "pegged" tooth is located directly behind each top incisor tooth. This characteristic separates members of the lagomorph order from the order *Rodentia.* As in rodents, the incisors of lagomorphs grow constantly. Lagomorphs lack canine teeth, and a long gap or diastema occurs between the incisors and the molars

Rabbits, technically, can be distinguished from hares by the presence of a distinct and unfused interpanetal bone in the skull (Hall 1981). Maxillary bones, both for rabbits and hares, are highly fenestrated (containing a lattice network of porous bony tissue).

True rabbits, or cottontails, are separated into eight species (Chapman and others 1982, Chapman and Flux 1990). They include the eastern, desert, brush, Nuttall's, swamp , marsh, New England, and pygmy rabbits. Cottontails are widely distributed throughout the United States and Canada. Within the Pacific Northwest, there are four major species: the eastern, Nuttall's, brush, and pygmy rabbits (fig. 1). In addition, the range of the desert cottontail extends into northern California, where it may occasionally cause problems

There are eight species of hares within the United States and Canada (Dunn and others 1982, Bittner and Rongstad 1982). They are the black-tailed jackrabbit, the white-tailed jackrabbit, the antelope jackrabbit, the white-sided jackrabbit, the Alaskan hare, the arctic hare, the snowshoe hare and the (introduced) European hare. Within the Pacific Northwest, there are only three hares the black-tailed jackrabbit, the white-tailed jackrabbit, and the snowshoe hare Some geographic overlap occurs (fig. 2), but each species of hare usually is found within its own ecological niche, thus simplifying species identification.

Figure 1—Distribution of brush rabbits, pygmy rabbits, eastern cottontails, and Nuttall's cottontails within the Pacific Northwest region. Maps adapted from Chapman and Flux (1990) and Thomas P. Sullivan (pers. comm.).

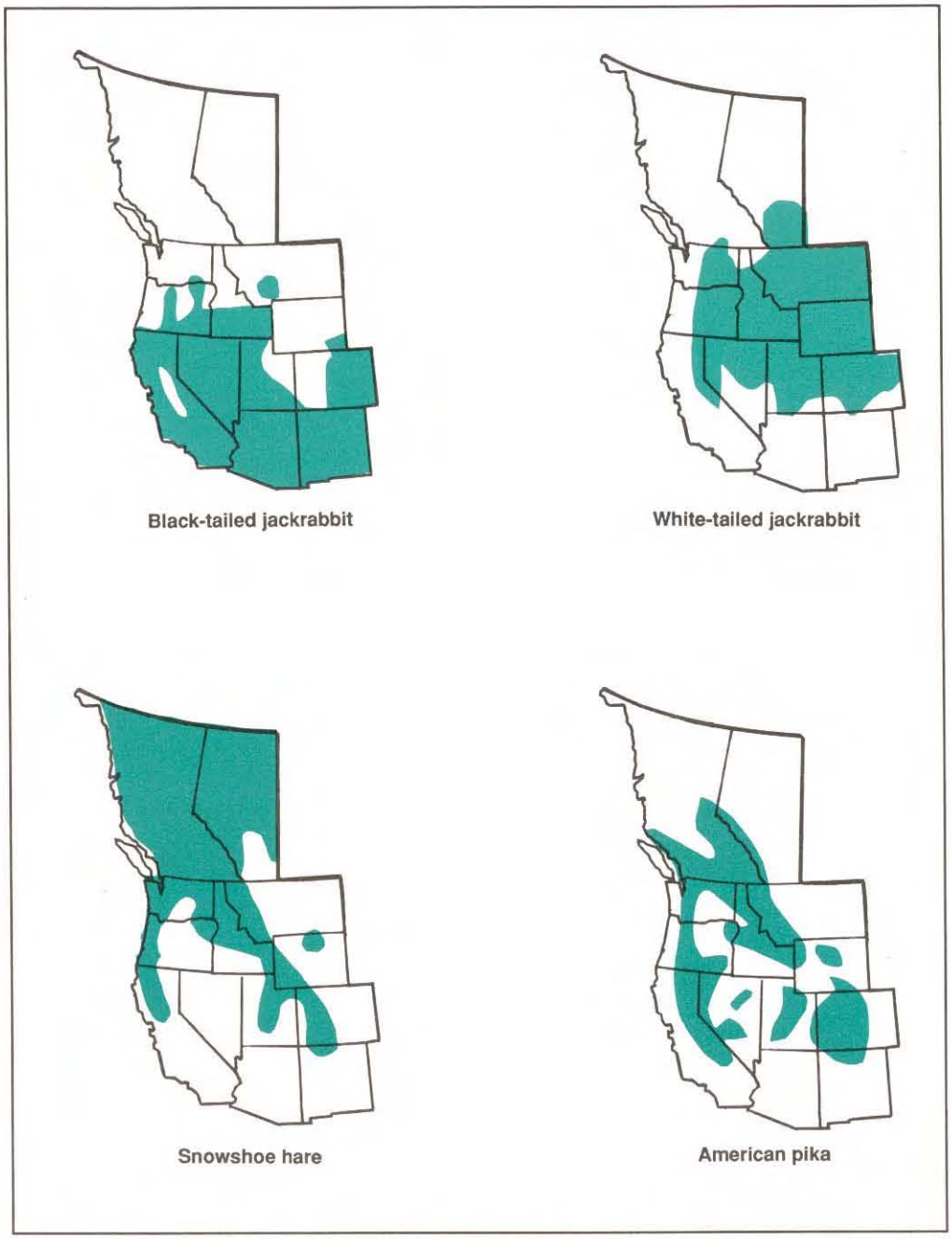

Figure 2—Distribution of black-tailed jackrabbits, white-tailed jackrabbits, snowshoe hares, and pikas within the Pacific Northwest region. Maps adapted from Chapman and Flux (1990).

The third member of this order is the pika. There is only one species of concern in the Pacific Northwest (Hall 1981). Pikas are widely distributed (fig. 2), but stringent habitat requirements keep their presence rather localized. This species therefore receives only a cursory examination in this chapter.

Rabbits all share some basic biological traits. They are relatively small animals, ranging from about 10 inches in length (pygmy rabbit) to about 18 inches (eastern cottontail; Hall 1981). All are drab in color, varying from shades of black to rusty brown. They all have relatively large ears and large rear feet. Female rabbits and hares tend to be larger than males.

Hares share some characteristics with rabbits. They have large ears and large feet (the hind foot is usually larger than 4.2 inches long for adult hares; Hall 1981). Hares, however, generally are much larger than rabbits and range in size from 5J5 to 7.5 pounds and from 14.5 to 25 inches in length.

Color patterns differ greatly among this group The black-tailed jackrabbitjis gray to blackish in color with black-tipped ears and a black streak on the top of the tail. The white-tailed jackrabbit and the snowshoe hare both can change from a br'own or gray summer pelage to a winter coat of white. It is during the winter when confusion can occur with species identification. The white-tailed jackrabbit has a tail that is nearly always white above and below, and the white winter pelage is made up of completely white hairs. The white winter pelage of the snowshoe hare is made up ofjdarker hairs with white tips. In the southern parts of its range, the snowshoe hare does not lose its summer coloring during the winter molt (Flux and Angermann 1990)

Pikas, sometimes known as conys, are small, rat-sized lagomorphs, generally between 4 to 6 ounces in weight and 6 to 8 5 inches in length (Burt and Grossenheider 1964). They are grayish to brownish with no visible tail, and have been described as "round-eared rabbits" Small piles of fresh grass or forbs in rockslides is a good indicator of the presence of these animals (Smith and others 1990).

Reference guides should be consulted for specific identification of any of these species. The mammal identification guide authored by Burt and Grossenheider (1964) should prove sufficient, although regional guides also exist

Reproduction

The reproductive season for rabbits is influenced by day length, geographic latitude, ambient temperatures, and other environmental variables As day length increases, a reproductive hormone, (follicle-stimulating hormone) is released (Chapman and others 1982). Female rabbits then come into estrus (heat) and maintain this state until copulation. Ovulation follows copulation, usually within 10 hours. This physiological process is termed induced ovulation, because copulation is required before ovulation occurs. Without copulation, a female may remain in a preestrus condition for long periods of time. There is considerable latitude, therefore, in the timing of the breeding period.

Cottontails breed in a synchronous fashion. If a sexually active male is present, the copulation immediately follows parturition (birth). Female rabbits often are pregnant while nursing a litter in the nest. Breeding can occur the first spring after birth, and juvenile rabbits, therefore,are usually sexually mature between 6 and 9 months of age (Chapman and others 1982)

Gestation periods are consistent among all rabbit species in the Pacific Northwest and average about 27 to 28 days in length. The breeding season can begin as early as December (California) or February (Oregon) and last until August, depending upon the species, location, and food supply (Mossman 1955, Chapman and Harman 1972, Chapman and others 1982).

Litter size differs among rabbit species and generally exhibits an inverse relation with latitude. Mean litter sizes generally range between 3 to 5 young per litter (Chapman and others 1982). Because of the rabbits' ability to breed in a synchronous manner, however, 1 female can produce several young over the course of one breeding season Eastern cottontails reportedly produce as many as 39 young in 8 litters in a single breeding season (Trethewey and Verts 1971). Total productivity for all species, however, probably averages 10 to 20 young per breeding season (Mossman 1955, Chapman and Harman 1972, Chapman and others 1982)

Rabbits differ from hares in the amount of parental care given to the young. Rabbits are born in a completely helpless and immature state (altricial young) and require significant parental care. They are born naked with their eyes closed and with very limited mobility, similar to newly born dogs and cats Leverets, as young rabbits sometimes are called, are dependent on the mother for food and warmth. The nest is constructed belowground and the young remain in or very near the nest until they are weaned (in about 15 days). Juvenile rabbits are completely dependent upon the mother for nourishment from the first week of life until they begin to eat some green vegetation on about the eighth day (Chapman and others 1982).

Hares, like rabbits, respond to change in vegetational growth and begin to show reproductive activity as new vegetation begins to emerge. The exact time of new vegetational growth varies at different latitudes and locations. Reproduction is somewhat similar to rabbits, but a number of differences do exist. It generally begins in late December or January and lasts until July or August. In California, Lechleitner (1959) found some pregnant black-tailed jackrabbits during all months of the year, but the majority of females did not become pregnant until February, and the breeding period then ended in August. French and others (1965) believed black-tailed jackrabbits demonstrated a strong density-dependent relation between population size and breeding season. Population increases precede decreases in the length of breeding season, and decreases in the population precede increases in the length of breeding season.

The black-tailed jackrabbit begins breeding at 5 to 7 months of age (Dunn and others 1982). White-tailed jackrabbits and snowshoe hares first breed in the spring following the one in which they were born (Dunn and others 1982, Bittner and Rongstad 1982). Gestation periods for the three species range from 34 to 40 days for snowshoe hares and 40 to 45 days for black-tailed and white-tailed Jackrabbits (Dunn and others 1982, Bittner and Rongstad 1982) Litter size among all three species is similar and usually ranges between 2 to 5 young per litter. Reproductive potential generally is less for hares than for rabbits One female hare, potentially, can produce between 7 and 18 young per year, depending on the species. Induced ovulation and synchronous breeding in hares is similar to that for rabbits.

Snowshoe hares, because of their northerly range, are more affected by weather and snowpack than the other species (Bittner and Rongstad 1982); therefore, they begin breeding later in northern latitudes and stop breeding sooner. Litter size also seems

to depend on snowpack depth. Greater snow depths allow snowshoe hares access to vegetation normally out of their reach (Bittner and Rongstad 1982). This provides green food of higher nutritional value and enables females to produce larger litters.

Hares, unlike rabbits, are born fully furred and quite mobile with their eye&open (precocial young). This condition enables them to leave the nest (sometimes called a "form"), usually within 24 hours of birth. The female hare's nest is a small depression in the soil or leaf litter. After leaving the nest, siblings stay together for about one week before dispersing (Dunn and others 1982, Bittner and Rongstad 1982).

Pikas produce 1 or 2 litters per year, each with 2 to 4 young, and often they are born in June or July. The young do not breed until the year following their birth (Millar 1972, Nowak and Paradise 1983:476, Smith and others 1990).

Food and Nutrition

Rabbits and hares throughout the Pacific Northwest share similar food habits and nutritional requirements, although food preferences vary by species and possibly from forest to forest. They are all herbivores and opportunistic feeders, and they all choose foods, when available, that are highly digestible and high in protein. Rabbits, hares and pikas do not hibernate. Basal metabolic rate requirements, therefore,'must be met throughout the year. During spring and summer months, succulent forbs and grasses are the preferred food, and vegetation such as clovers, grasses, sedges, thistles, composites, and ferns are selected During winter months, when these plant species are no longer available, rabbits and hares alter their diets to include woody plants. In some cases, their entire diet during this time may consist of woody plant species, especially twigs, buds, and bark (Chapman and others 1982, Dunn and others 1982, Bittner and Rongstad 1982). Plant species of importance during winter include willows, aspen, alder, sage, and conifers. Mozejko (1972) found that snowshoe hares in western Oregon fed extensively on bracken ferns and willows, but Douglas-fir and western hemlock received the greatest amount of use during winter. It is during this time that new forest plantations are most susceptible to damage.

All lagomorphs practice coprophagy, or reingestion of expelled feces. Two types of pellets are excreted, a hard, spherical pellet and a soft, mucous-covered pellet. Soft pellets are eaten before they reach the ground, the hard pellets are the true waste feces. Lagomorphs probably receive a vitamin supplementation from reingestion of the soft pellets.

Neither rabbits nor hares are considered arboreal, so most feeding occurs near ground level. As snow levels increase, however, lagomorphs gain access to food items that normally would be out of their reach. When this happens, rabbit and hare damage may be contused with that of some other species, because after snows melt, the damage is several inches and perhaps several feet above the ground. If rabbit or hare feeding is suspected, care should be taken to identify the incisor marks and type of cut, the presence or absence of claw marks, and the type of damage inflicted (for example, clipping, barking, and girdling). Fecal pellets or droppings at the site also may assist in identification. One exception to the arboreal rule is the Nuttall's cottontail. Verts and others (1984) have recorded evidence that this species climbs up to 9 feet off the ground in trees

Both rabbits and hares generally feed on plants of relatively small size. They prefer branches, twigs, and small stems of up to 0.25 inch in diameter. During winter months, however, larger trees may be fed upon if the animals are removing bark.

Pease and others (1979) found that captive snowshoe hares require a mean daily intake of 10.5 ounces of woody browse, and Sinclair and Smith (1984) indicated that snowshoe hares prefer mature twigs over earlier growth stages. Snowshoe hares probably need a minimum of 11 percent crude protein from their browse in order to maintain their weight (Sinclair and others 1982).

Lagomorph species generally are nocturnal (active at night) or crepuscular (active at dawn or dusk) in their habits, although resting individuals often are observed during the day. Most feeding damage occurs at night. Feeding also may occur relatively far from where rabbits and hares rest. It is important to remember that the apparent lack of animals resident in the immediate vicinity of feeding damage does not necessarily mean that lagomorphs did not cause the damage.

Pikas, in contrast to other lagomorphs, tend to be active during all hours of the day. They construct "haypiles" of a variety of vegetation that serve as a source of winter food (Smith and others 1990). They store these haypiles in dry, sheltered locations within talus or logging debris around high-elevation landings.

Habitat

An animal's habitat must provide not only food and water, but also cover or shelter that affords protection from predators and the elements for both young and adults. Current forest practices may substantially affect the quality of rabbit and hare habitat, and it often benefits these species. Rabbits and hares, because of genetic, physiological, and behavioral traits, have some specific habitat needs that separate the two groups.

Rabbits generally bear their young in underground nests, so one of their specific habitat needs includes a soil type that allows burrows to be constructed. Excessively rocky or sandy soils may not be suitable for excavation and nest construction. Dense vegetation also is a necessary component for both adults and juveniles. Examples of this type of protective cover include brambles, willows, aspens, alder, and salal. Eastern cottontails, however, sometimes nest on the surface of the ground.

Hares do not require excavated nest sites, so they are not as restricted to specific soil types. Escape cover, however, and thermal cover can be equally important. Hares rely on their speed and quickness for protection and only occasionally seek dense cover to escape danger. Hares, therefore, generally prefer sparsely vegetated areas where visibility is not impaired and escape routes are abundant. Forest plantations between 1 and 20 years old are ideal locations to find hares except for snowshoe hares which, like rabbits, utilize hiding cover as a predator avoidance strategy. Snowshoes tend to prefer dense, second-growth, forest habitats (Wolff 1980).

Home Ranges and Density

The number of animals in a given area and the size of their home ranges are directly dependent on the quality of the habitat Habitat, with its influence on mortality and reproduction, is an important factor in determining how many rabbits or hares are in any given area at any one time and how far those individuals roam within that area. Within the home range, a variety of habitats can directly affect the movements and distances traveled by individuals.

Cottontails have smaller home ranges than do hares. In very general terms, home range size for cottontails usually is less than 10 acres and often is closer to 5 acres (Chapman and others 1982) Rabbits are much more closely associated with dense

cover than are hares. They rely on vegetation for escape cover; therefore, they are less apt to be far removed from their primary source of protection. Size of home range for rabbits is dependent upon a number of factors, including species of rabbit, food and water availability, availability of dispersal corridors (such as roads), rabbit density, season of the year, climate, vegetation patterns, and the age, sex, and Breeding status of individual rabbits. Most activity occurs at night; however, rabbits often can be seen in the early morning and early evening hours.

Hares are much more mobile than rabbits, and similar abiotic and biotic factors affect their home range size. Hares range over several acres in one night as they move between feeding areas and daytime resting sites. Home ranges can vary considerably among hare species. Snowshoe hares have the smallest home range size (about 25 acres), compared to 50 acres for black-tailed jackrabbits and up to 200 acres for white-tailed jackrabbits (Adams 1959, French and others 1965, Dunn and others 1982, Bittner and Rongstad 1982).

Densities of rabbits and hares, like home ranges, are closely tied to habitat quality. An area with good habitat quality (ample food and cover, all in the right proportions), for example, can support relatively higher number of animals than an area with poor habitat characteristics, assuming other environmental variables are similar. Cottontails seldom reach densities greater than 50 animals per acre (Chapman'and others 1982), and density usually is much less. McKay and Verts (1978) reported densities of 1.6 to 6.3 rabbits per acre for Nuttall's cottontail in central Oregon. Black-tailed jackrabbits usually fluctuate between 25 to 250 hares per 100 acres, while densities of white-tailed jackrabbits are less, and one report from Colorado estimated density at 2.5 hares per 100 acres (Dunn and others 1982) Much higher densities may occur in localized areas with abundant food supplies Densities as high as 84 hares per acre have been reported for black-tailed jackrabbits (Dunn and others 1982).

The most variable species, in terms of population density, is the snowshoe hare. Snowshoe hare populations seem to fluctuate about every 10 years. On their "square-mile" study site in central Alberta, Keith and Windberg (1978:18) recorded a low population density of 42 to 74 snowshoe hares per 100 acres in April 1965 and a high density of 2,830 to 5,660 snowshoe hares per 100 acres in November 1970, representing an increase of about 70-fold

Snowshoe hares will exceed the carrying capacity of the habitat during population highs, and they cause severe habitat degradation The population of hares, consequently, crashes and remains low for several years until the habitat recovers and numbers once again begin to increase. The decline results from a decrease in the rate of adult survival, a low juvenile survival rate, and a reduction of the reproductive rate (Meslow and Keith 1968). Numbers of snowshoe hares vary significantly over time, but severe feeding damage can occur, even during periods of relatively low abundance. Sullivan and Moses (1986) demonstrated how habitat alteration can dramatically reduce the population size of snowshoe hares, but reduced populations of hares can still cause damage (80 percent) in plantations because of their ability to travel great distances to preferred feeding sites from adjacent sites. Sullivan and Sullivan (1986), moreover, found that removal of snowshoe hares during a period of peak abundance in British Columbia did not result in a lower hare density, because neighboring or dispersing hares rapidly reinvaded the site.

Cottontail densities, on the other hand, are more closely tied to the availability of dense cover. As with hares, however, surrounding areas of suitable habitat may provide adequate cover for individuals to move into an area from an adjacent parcel.

Pikas occur at variable densities (2-10 per acre), depending on the size of the rocky habitat. Low densities occur on large rockslides and higher densities occur on islands of rock piles (Broadbooks 1965) In California, distances between habitat islands of greater than 1,000 feet apparently were difficult barriers for dispersing juveniles to overcome (Smith 1974).

Mortality Factors

Naturally occurring factors can severely affect lagomorph populations. Disease, climate, food limitations, parasites, and predators all remove individuals from the population. As with most wild populations, species numbers often are highest during the fall months after the recruitment of young into the population. Overtime, biotic and abiotic factors reduce populations to their lowest point just before the breeding season. After breeding and parturition, population numbers once again, are high. The following section focuses on factors that induce mortality in rabbits and hares.

Diseases and Parasites

Rabbits and hares are susceptible to the tularemia bacterium, which always is fatal to rabbits and hares in this region. The disease can be diagnosed if internal examination reveals a multitude of tiny white spots on the liver and spleen (Chapman and others 1982). This disease occurs sporadically and is more common in rabbits than in hares. Rabbits and hares are susceptible to a whole host of ectoparasites and endoparasites and bacterial and viral diseases. These diseases and parasites certainly impact individual animals, and some directly or indirectly lead to mortality and affect the population. Parasites and diseases themselves, however, generally are not responsible for major declines in rabbit or hare populations, although they probably predispose individuals to predation or starvation

Snowshoe hares are susceptible to "shock disease." Shock disease is characterized by the sudden onset of convulsions, leading to rapid death resulting from a hypoglycemic condition due to abnormally low blood sugar levels (Bittner and Rongstad 1982). Hares with liver glycogen levels between 0.02 and 0.18 percent die of shock disease. The normal liver glycogen level for snowshoe hares is 5.5 percent (Bittner and Rongstad 1982).

Myxomatosis, a viral disease, has been introduced successfully in Australia and elsewhere as a biological control agent to reduce European rabbit populations. It is one of the few successful attempts at controlling vertebrate species through biological means (Waithman 1981). The disease was accidentally introduced into Great Britain and Europe (Ross and Tittensor 1981) with devastating effects on rabbit populations. In the Pacific Northwest, rabbits are resistant to any severe effects of this virus, which simply causes warts (J.A. Chapman, pers. comm.).

Predation

It should come as no surprise to any forester that many species of carnivores prey upon rabbits and hares. The most common predators of rabbits, hares, and pikas throughout the Pacific Northwest include lynx, bobcat, coyote, weasels, mountain lions, hawks, owls, con/ids, and even feral dogs and cats. Humans heavily prey upon wild cottontails and hares. Predator impacts on lagomorph populations may be more important as a factor in keeping populations reduced by other extrinsic factors (such as disease, starvation, and weather) from recovering as rapidly as they could in the absence of predation. Predators probably do not greatly affect rabbit or hare

populations at specific sites with high numbers of lagomorphs. Keith and Windberg (1978), after analyzing snowshoe hare populations over a 15-year period in Alberta, concluded that winter food shortages, precipitated by a peak density of hares and reflected in spring weight loss and lowered reproduction, provoked an initial population decline and led to increased predation rates that extended the decline. When food supplies recover (at a much lower hare density), spring weight loss is reduced and reproduction and growth rates increase. The population does not rebound, however, until the predator population declines as a function of a decreased prey base. When this happens, the hare population is set to increase, because the habitat has largely recovered from the original degradation.

The pattern described for snowshoe hares is not necessarily how predators impact other hare and rabbit species, but it is important to remember the high intrinsic rate of increase, or reproductive potential, for all lagomorph species. Rabbits and hares can withstand high losses from predators, including harvest or control activities.

Identification of Damage

The species responsible for causing damage to seedlings must be determined to identify possible controls and management strategies. Clipping, the type of damage attributed to lagomorphs, produces a smooth, oblique cut on woody shoots (Lawrence and others 1961). Rabbits and hares tilt their head to the side when clipping with their incisors, and they leave a clean cut as compared with deer and elk, which leave a ragged edge as they tear a shoot or twig, because they lack upper incisors. This smooth, oblique cut is characteristic of all species of lagomorphs, and in combination with the presence of tracks, pellets (often left at feeding sites), and visual sightings, it confirms the occurrence of lagomorph damage (Lawrence and others 1961). Small twigs or seedlings generally are damaged most frequently. Preferred sizes of seedlings selected often for feeding usually are 0.25 inch in diameter or less. In addition to clipping, snowshoe hares also feed on the bark of small trees during winter months. This behavior of barking or girdling trees often may fatally injure the sapling, or it may simply delay growth. Lawrence and others (1961) caution that snowshoe hares in coastal areas frequently use the burrows of mountain beaver for shelter and that clipping injuries to small seedlings by these two species are indistinguishable

Damage generally is localized and often is clumped within a very specific area. The percentage of all damaged trees or seedlings, although localized, can be as high as 100 percent in some situations. The best indicator of the potential threat of rabbit or hare damage to a site is the history of surrounding sites or plantations relative to silvicultural treatment Any sites adjacent or near those with previous feeding damage should be expected to have similar damage. This underscores the need to maintain good records of past problems. A point that cannot be overemphasized'.

Damage Management

Managers confronted with the problem of feeding damage caused by rabbits and hares may adopt a strategy that focuses on controlling the animals to reduce the damage in some way. An alternative strategy is to re-evaluate silvicultural practices that may enhance the habitat that causes the species to become a pest. The strategy that focuses on control offers two well-recognized options, a lethal and a nonlethal approach.

Lethal Methods

Lethal methods of control are limited and subject to local and state regulations and restrictions. Options include shooting, trapping, and baiting with toxic chemicals.

Shooting requires a great deal of personnel, time, and effort. It is most effective during periods when lagomorphs are active (factors include time of day, phase of the moon, weather, and season). Special equipment may be necessary, such as night scopes or spotlights. Local and state wildlife officials should be consulted regarding restrictions, laws, and permits; and the fact that lagomorphs in general and snowshoe hares in particular are resilient (recover quickly) to population reduction efforts (Sullivan 1987), should be remembered.

Trapping generally is not recommended. Lagomorphs can be live-trapped and then destroyed; however, the equipment is costly and personnel need to gain experience over an extended period of time in order to be efficient.

Toxic baits (such as anticoagulants) are registered for use on some but not all species of lagomorphs and in some but not all states and provinces. Marsh and Salmon (1981) and Johnston (1978) provide a thorough overview of jackrabbit control. Local agricultural or wildlife regulatory and resource agencies should be consulted before toxic baits are used.

Nonlethal Methods

Nonlethal methods can be very effective in reducing lagomorph damage Cost analysis before implementation and personnel commitment are two important factors that can determine the failure or success of a damage-reduction program. Options include repellents and exclusion.

In some situations, repellents can be effective if applied before or at the onset of feeding damage. Nearly all repellents are susceptible to weather conditions, and repeated applications may be necessary to maintain their effectiveness. Contact repellents are effective only on the foliage that is treated, so growth after application is susceptible to damage.

Investigators have long searched for a repellent that would provide more or less permanent protection, at least through the most vulnerable period for seedlings. Products as diverse as selenium (Rediske and Lawrence 1962), chemicals resembling skunk and mink odors (Thompson 1953, Pepper 1976), and compounds like predator scents (Sullivan and others 1985) all have been tested, and some are still being evaluated. The repellents most widely used today contain active ingredients with properties of smell or taste that reduce palatability Thiram (tetramethylthiuram disulfide or TMTD) is a fungicide effectively used as a taste repellent (Hooven 1966, Radwan 1969). Jones (1977) indicated that thiram was not an effective repellent for pikas in Washington. Repellents can be extremely useful after seedlings are planted

Exclusion is a successful means of nonlethal control that involves either protection of individual trees or protection of an area. This technique also has high costs for material and labor, but it can be very effective in protecting seedlings when they are small and vulnerable.

A variety of tube-type protectors are available. Plastic-mesh tubes (commonly referred to as Vexar) are most common and are widely used to protect individual seedlings (Campbell and Evans 1975). The appropriate height of these plastic-mesh

tubes depends on the species of rabbit or hare causing damage. Brush rabbits or snowshoe hares may require a tube of 20 inches in height or less, while a jackrabbit may be able to cause extensive damage unless the tube height is over 30 inches. These tubes also protect seedlings from other animals, such as deer and mountain beaver, so actual height specifications should be based on the entire set of potentially damaging animals. Other seedling protectors exist, but most have not been evaluated for effectiveness or economics in Pacific Northwest forests. Exclusion a so should be an effective method of protecting seedlings from pikas (Jones 1977).

Rabbit and hare fencing, although expensive, may provide long-term protection to large areas or highly desirable plantations, such as progeny sites (McKillop and others 1988). Fences should be constructed of mesh or net wire with a weave of 2 inches across or less. A fence of 3 feet in height should exclude all rabbits and most hares, except in areas with deep snow. Fences also protect seedlings from other animals, such as deer, so actual specifications should be based on the entire set of potential sources of mortality. Fences must be secured to the ground to prevent rabbits and hares from digging under them, and most importantly, fences must be maintained. The fence must be checked periodically (at least weekly) to ensure that it is intact and not damaged by weather or larger animals, particularly black bears. All animals within fences must be removed Construction, maintenance, and labor costs associated with fencing, obviously, are very high

Silvicultural Practices and Damage Reduction

With the emergence of "New Forestry" practices that focus on a holistic approach to silviculture, it is more critical than ever to take a "systems approach" to animal damage In the past, silviculturists often opted for short-term solutions and heavily relied on controls when damage was detected. It is crucial that forest managers evaluate the potential of animal damage even before implementation of silvicultural practices under consideration. Within the context of New Forestry, lagomorph damage may turn out to be a natural, even desirable event in the context of forest management! The remainder of this discussion, however, deals with approaches that minimize or prevent lagomorph damage

Lagomorphs respond to stand condition and quality. Silvicultural practices and natural successional changes foster stand conditions that favor certain species but not others. As a stand evolves from one serai stage to another, habitat quality and conditions also change. If one understands the habitat parameters important and necessary for rabbits and hares, then a prescription can be developed that should minimize the potential for producing a situation that either produces atypical (higher) populations of these species or increases the risk of damage to trees.

Rabbits and hares, as noted above, often are associated with disturbed or subclimax communities. Rabbits prefer areas of heavy brush associated with trails, ppen areas, and roads. Jackrabbits often are associated with diverse plant communities of grasses and forbs where the cover is disjunct and less than 3 feet in height. Taylor and others (1935) evaluated how cattle grazing in Arizona affected jackrabbit populations and found that jackrabbit populations responded positively during drought years to the removal of cover that resulted from grazing.

Snowshoe hares often are associated with subclimax forests and transition zones adjacent to heavy cover. Second-growth stands with a dense, brushy understory and a high density of saplings are considered optimum habitat for snowstloe hares (Wolff 1980).

In many instances, routine forest practices may, in some way, enhance habitat quality for cottontails. The construction of roads and skid trails, and the removal of canopy cover in a patchy fashion, increases the amount of edge and thereby increases the amount of suitable habitat. Roads and trails with adjacent covers, such as blackberries, willows, or alder thickets, provide rabbits with newly opened areas for travel that provide greater visibility of predators. It is a common sight to see cottontails sitting at the edge of the road or trail at dawn or dusk. They use the roads extensively for easy access between night-feeding areas and day-rest sites.

Hares, particularly snowshoes, favor clearcut blocks adjacent to areas of pole-size timber. The areas of "edge" (the zone of transition from clearcut to timber stand) often are areas with the greatest activity and highest concentration of hares. Individual hares that transverse the two areas feed in the opened area at night and seek protection and cover on the timbered parcel during the day

Coordinating animal damage management and silviculture certainly is not a new concept. It has long been a common practice to apply silvicultural methods in order to meet wildlife-management objectives, particularly if a featured-species approach (for example, managing stands to provide habitat for deer and elk) is being considered. A similar approach can be considered if the primary objective is to minimize optimum habitat for a particular species.

Habitat Manipulation

Hare and rabbit damage may be reduced via the elimination of appropriate habitat ("no cover-no rabbits"). Radvanyi (1987) and Sullivan and Moses (1986) proposed complete scarification of the site in order to remove alt available habitat. This, obviously, may not be feasible in all cases or in all environments. Altering the habitat, through mechanical, chemical, and manual means, may have to be done on a limited scale. This may include complete removal of slash and manipulation of hiding cover near roads. This approach has produced favorable demographic responses, although damage levels were considered unacceptable (Sullivan and Moses 1986). Borrecco (1976) demonstrated that snowshoe hares (and the resulting damage) respond to herbicide-induced reduction of cover. This effect should be similar regardless of how vegetation is removed It must be noted, however, that habitat manipulation affects not only lagomorphs but also other plants and animals inhabiting a site. Significant habitat manipulation for the reduction of lagomorph damage may conflict with New Forestry objectives.

Seedling Selection

In sites where rabbit or hare damage is anticipated, a sound alternative is the selection of larger seedling stock. The key to this approach is understanding that rabbits and hares tend to select stems of small diameters. Hartwell and Johnson (1983) evaluated Douglas-fir seedlings for snowshoe hare damage. They found that 2-0 seedlings (averaging 1 foot in height) and 3-0 seedlings (averaging 3 feet in height) differed in their susceptibility to hare browsing. The 3-0 seedlings demonstrated greater resistance to hare browsing and showed a reduced impact from browsing-induced delays in growth. This relation between seedling-stock size and degree of damage probably is consistent for many tree species. Economics also may be a significant barrier to this prescription. Some managers, nevertheless, believe stock selection is the most effective protection against herbivory by lagomorphs.

Fertilization

Fertilization is a silvicultural technique that induces lagomorphs to feed on seedlings (Radvanyi 1987). Trees fertilized with nitrogen (N) at rates of 45 , 90, and 135 pounds per acre, with phosporous (P) at 45 pounds per acre, and with potassium (K)

at 45 pounds per acre all had higher levels of feeding damage than did nonfertilized trees (Sullivan and Sullivan 1982). Silviculturists should use their records of fertilization to try to determine if a correlation exists between rates of fertilization, site locations, tree species affected, and feeding damage. Evaluation of past records and experimentation at the local level may yield prescriptions of optimum fertilization rates that do not increase the amount of damage. Fertilization applied to sapling i stands probably has no effect, since the trees should be beyond susceptible size. !lt may be best, however, not to fertilize sites where the potential for lagomorph damage is high.

Stand Spacing

Lagomorph species respond to stand thinning in a fashion similar to that of other inner bark feeders, such as black bears (Giusti and Schmidt 1988). Thinning often creates an environment with habitat quality beneficial to populations of lagomorphs.

Sullivan (1984) evaluated the effects of spacing as a method to minimize feeding damage. He concluded that it was actually stem diameter that influenced hare feeding. He stressed flexibility in planting and spacing regimes that coincide with peaks in the cycle of hare populations, and he suggested a two-tiered thinning approach. This approach would allow for assessment of initial damage in a closely spaced stand, and the level of treatment in the second thinning stage would compensate for tree mortality without serious crop-tree loss. The second-stage thinning is based on the assumption that the trees will have grown beyond the critical-diameter size before thinning. Sullivan and Sullivan (1988) monitored snowshoe hares in thinned and unthinned stands of lodgepole pine in British Columbia. They found that hares responded to increased food availability during the first year after thinning (population density in thinned stands increased), but the effect was short-lived, and the thinned stand was less attractive 2 years after thinning. Trees in both stands averaged about 2 inches in diameter. Areas can be managed, therefore, to reduce long-term attractiveness to hares. In the forest environment, protection is needed for years rather than months (Borrecco 1976)

Selection of Tree Species

More research should focus on the selection of tree species as an approach to minimizing damage. Some species (for example, lodgepole pine and Douglas-fir) are more prone to feeding injuries, while other species, such as the true firs *(Abies)* and spruce *(Picea),* are less attractive to snowshoe hares (T. Sullivan, unpublished data). Attention should focus on how this approach may be applied to other species of trees and their susceptibility or resistance to lagomorph feeding. Selection of tree species either is based on an objective to maintain species diversity similar to what was present before harvest or it is based on market economics. Managing for species diversity is more common on public lands. Selection of tree species, obviously, often is not possible or desirable. S

Summary

Rabbits and hares respond to a variety of silvicultural practices. They selectively feed, usually on seedlings measuring 0.25 inch in diameter or less Both hares and rabbits respond to habitat changes that affect cover, food, and visibility. Silvicultural approaches should be incorporated into current management strategies so as to minimize damage from rabbit and hare feeding. Silvicultural options include habitat manipulation, seedling-size selection, fertilization, tree-species selection, thinning, and spacing. These should be included with more conventional options, such as exclusion, repellents, and population reduction.

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 15
Black Bear

WYMAN C. SCHMIDT AND MARK GOURLEY

Abstract

Black bears can be a significant forest management problem in young to intermediate-age forests of the Pacific Northwest and the northern Rocky Mountains. Bears peel bark from the lower bole of trees and feed on the inner bark and cambium layers. This peeling totally or partially girdles trees, kills some, and provides an entrance point for disease in trees that survive. Bears' favorite trees are Douglas-fir in the forests west of the Cascade Range and western larch in the northern Rockies, but they also feed, to a lesser extent, on associated tree species Most damage occurs in 15- to 25-year-old coastal forests and 15- to 50-year-old forests of the northern Rockies. Rapidly growing, vigorous trees are favorite targets for bears—usually in moderately to lightly stocked stands. Bear damage mostly occurs in May and June when the wood-sugar content of itrees is high. Damage is sporadic and apparently results from learned behavior passed from sow to cub. Silvicultural practices that may help reduce the problem include management for greater species diversity, delayed thinning and fertilizinglwhere bear damage is severe, stands maintained at higher densities, and management objectives and practices adjusted to compensate for losses caused by bears.

WYMAN C. SCHMIDT is research silviculturist, U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Montana State University, Bozeman, MT 59717, MARK GOURLEY is forester, Starker Forests, Inc., Corvallis, OR 97339.

Direct control of problem bears is the most common method of reducing tree damage. Direct control includes hunting, snaring, relocation, and supplementary feeding. Snaring is the most successful of these methods of control, because it targets specific bears that cause the problem, not the entire bear population. Many questions remain to be answered before a totally satisfactory solution to the bear-damage problem is reached. That solution probably will involve some combination of reasonable adjustments in silvicultural practices to reduce favorable feeding conditions for bears and some selective control of bears. This chapter includes a list of questions concerning this subject that remained unanswered.

Keywords: Black bear, *Ursus americanus,* silviculture, bear damage, Douglas-fir, western larch.

Introduction

Black bears are widely distributed in forested areas of North America. They historically ranged over all 48 conterminous states, all Canadian provinces, Alaska, and much of Mexico (fig. 1). Black bears are valued as a big-game species and as an esthetic component of the forest environment. Bears can be dangerous, particularly sows with cubs, but as a general rule they are secretive and gentle animals that avoid people. This chapter describes bear biology, damage caused by bears, and some methods of reducing that damage (fig. 2). Bear damage is most significant in the Pacific Northwest and the northern Rocky Mountains, but it also has been observed in California and Alaska Bear damage in some stands in the Pacific Northwest, for example, affects as much as 90 percent of the stand; however, damage is usually much less severe. Bear damage largely is confined to spring, when some bear feed on the inner bark, cambium layers, and wood sugars of desired conifers. This chapter examines that damage in later sections, but it begins with a review of black bear biology

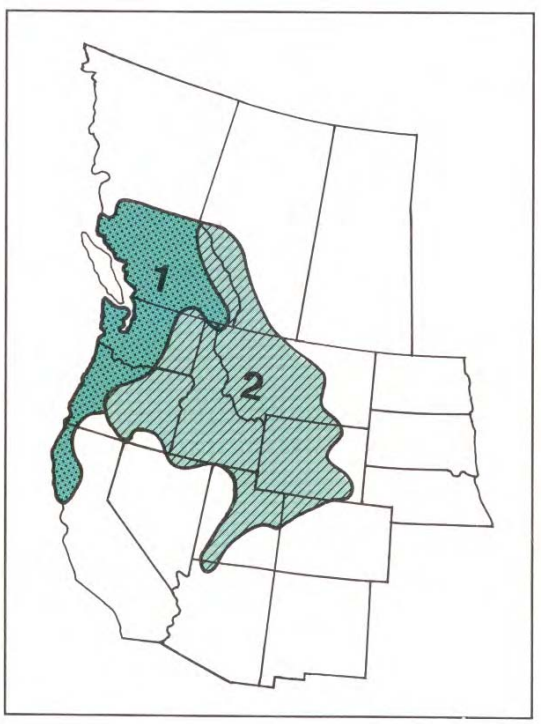

Figure 1—Black bears are distributed throughout North America The two subspecies addressed in this paper are (1) *Ursus americanus altifrontalis* in northern California, western Oregon, western Washington, and British Columbia, and (2) *Ursus americanus, cinnamomum* in eastern Oregon and eastern Washington, Idaho, Montana, Wyoming, and parts of Colorado and Utah (adapted from Hall and Kelson 1959)

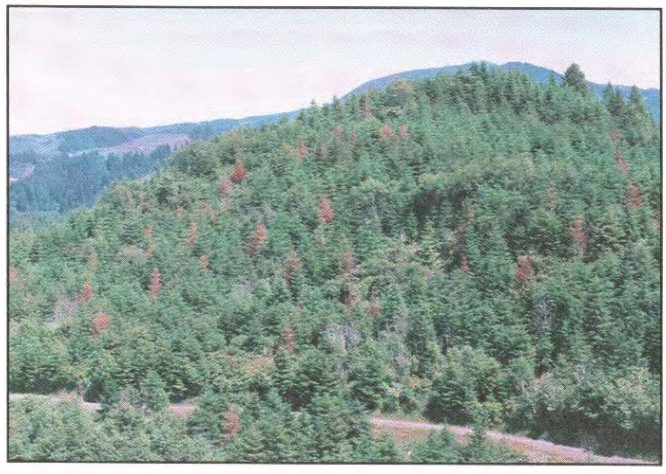

Figure 2—Black bear often leave a dispersed and random pattern of dead and dying trees as illustrated by this photo of a Douglas-fir forest in western Oregon

Black Bear Biology

Two subspecies of black bears are found in the Western United States; the Idaho bear or cinnamon bear is found east of the Cascades and the Olympic bear ranges west of the Cascades. The pelage color of black bears differs greatly, however, and it includes many shadings of black and brown.

Population Structure and Dynamics

Bears generally are sexually mature at 3 to 5 years of age. Bears are classified by age into the following categories: cubs (0-12 months), yearlings (13-24 months), subadults (2 to 3.5 years), and adults (3.5 years and older). Most investigators report that the ratio of subadults to adults approaches one-to-one. Sex ratios for adult bears range from even to skewed in favor of males (Beecham 1980a). Subadult and adult males travel more extensively than other age and sex classes of bears. This behavioral trait increases their vulnerability to trapping and hunting and may inflate estimates of their numbers Mean litter size of bears in several studies ranged from 1.6 to 2.9 cubs, and the size of litters may range from 1 to 6 cubs

Bear cubs may be self-sufficient when as young as 5.5 months and as small as 18 pounds. Average annual survival for bears, including the effects of sport hunting, control operations, and natural mortality, ranges from about 70 to 90 percent. Survival rates are lowest for young cubs and highest for bears older than 3 years. Adult male bears are believed to significantly regulate population densities, primarily by impeding the establishment and survival of subadult males, and possibly by killing cubs. This results in an average age of about 4 years for males and about 7 years for females. The maximum recorded age documented in one study was 14 years for males and 27 years for females (Poekler and Hartwell 1973).

Populations of bears are difficult to quantify. Different populations probably reflect natural variation in bear populations from one area to another that result from variation in suitable habitat or differences in sampling methods. The following tabulation lists bear densities from studies in four regions of the Pacific Northwest (Beecham 1980b, LIndzey and Meslow l977b, Piekieiek 1975):

Region	Density
	Bears per square mile
Idaho	2
Washington	4
California	2
Alberta	1

External parasites found on bears include ticks, fleas, and lice. In isolated cases, internal nematodes and tapeworms are found. Bears that ingest raw salmon and trout carrying rickettsia may contract salmon poisoning that can cause severe illness and, in some instances, death. Parasite-induced lesions from muscleworms may cause unpredictable behavior and death among bears.

Key Requirements

Spatial arrangement and diversity of food and cover are the primary habitat factors that affect bear populations. Most natural forest disturbances, such as wildfire, windthrow, insect and disease epidemics, and forest manipulations (such as fertilizing, thinning, and harvest cutting), therefore, influence the quality and quantity of bear habitat.

Food—Bears are omnivores. Vegetation comprises at least 75 percent of the diet of bears The balance of the diet consists of insects, especially ants, deer, fish, and birds. Herbage, cambium, and inner bark from conifers are principal foods for bear during spring and early summer, and the sugar content of cambium and inner bark in the spring is comparable to that of fleshy fruits. Nuts and berries are predominant components of the diet in the late summer and fall. Insects and their larvae that live in large woody debris are part of the late summer and fall diet and are an important source of protein.

Consumption of vegetation varies by region. In western Oregon and western Washington, the most important food items are false dandelion, salmonberry, grass, salal, devil's club, skunk cabbage, cascara, huckleberry, fungus, cambium, inner bark, and sapwood (Poelker and Hartwell 1973). In northern California, however, bears prefer grasses, sedges, herbaceous dicots that grow near wet meadows and riparian areas, manzanita berries, creek dogwood berries, and oak acorns. Studies of feeding activity in Montana found diets similar to those of northern California, western Oregon, and western Washington, in areas with comparable species. Manzanita, of course, does not grow in Montana, and bears in the northern Rockies eat whitebark pine nuts instead of acorns.

Annual weather patterns vary and influence the proportions of major food categories available to bear Garbage dumps, campsites, and rural residences provide food for opportunistic, foraging bears. In a Minnesota study, bears that supplemented their diets with garbage reproduced nearly twice as fast as bears feeding on native foods (Rogers 1987).

Supplemental diets that provide sugar, protein, calcium, fiber, trace elements and vitamins have been developed to distract bears from feeding on trees (Flowers 1987). There are indications that this may be somewhat effective for a short time, but it is not a long-term solution.

Cover—Bears select habitat that varies in slope, topography, vegetative cover, and food availability. Forested sites are important bedding areas. These sites, ideally, adjoin riparian and wet-meadow sites with abundant herbs. Bears also forage in burned or clearcut areas, especially where berry and grass-forb production is high. Female bears select habitat primarily on the basis of structural cover components rather than specific vegetation types. Thicker cover with steep-slope topography provides greater security for females with cubs than more open, gentle topography. Male bears use forest roads where available, but female bears tend to avoid roads. This reflects the tendency of males to range much greater distances than the females.

Home Range

The home range of a bear is the area a given bear occupies throughout the year. Home range varies by region, depending on habitat and food availability! sex, season, and other factors. Bears tend to move to higher elevations as the season progresses because of the strong correlation between elevation and the phenological development of key food plants.

Adult males occupy significantly larger home ranges than adult females, but home ranges extensively overlap within and between sexes The average size of home ranges, as shown by region in the table below, varies substantially and reflects differences in food and cover: i

Region	Sex	Size
		Square miles
Idaho	Adult male	41
	Adult female	7
Alberta	Adult male	46
	Adult female	6
Washington	Adult male	2
	Adult female	1

Adult male bears travel mostly during the June-July breeding season. The seasonal use of home ranges also varies more for males than females. Seasonalifood-availability and breeding behavior influence the mobility of male bears, and mobility gradually decreases from spring through fall. Home ranges for adult female bears are relatively stable and habitual from year to year. Adult male bears shift home ranges from year to year due to behavioral factors

Subadults usually leave their mother and disperse at ages between 1.5 and 3.0 years. After this family breakup, there are occasional reassociations between the mother and her offspring and also among the offspring. Establishment of home ranges by dispersing offspring apparently is influenced by food distribution and abundance, cover, bear density, and the structure of the bear population.

Individual ranges are established after family breakup. Most females begin to establish traditional ranges when they settle in their mothers' ranges. Some often change their traditional ranges to accommodate young females. Most males disperse greater distances than females and establish home ranges by 4 years of age. '

Identification of Bear Presence

There are several ways to detect the presence of bears in an area. Before and during the mating season, and to a lesser extent in other seasons, bears rub, bite, and claw certain trees known as bear trees (fig. 3). This is done by resident bears and not by transient bears. The reason for marking is unclear, but it probably defines territories. Marking usually is not a management problem, because it is not extensive.

Figure 3—Resident black bears mark trees within their territory by rubbing or biting and clawing trees

Bear scats, which mainly consist of grasses and the inner bark of trees during spring and berry seeds during late summer and fall, can be found on roads, skid trails, and elsewhere (fig. 4). Rolled logs and shredded stumps indicate the presence of a bear looking for insects. Bear footprints near poorly drained areas, stream banks, and road-cut banks may show travel patterns (fig. 5)

Figure 4—Bear scats provide a method for monitoring the presence of black bears and what they are eating

Figure 5—Black bear footprints are distinctive and indicate presence and travel patterns

Bear Damage to Trees

Yellowing and red conifers usually indicate that bears have been peeling trees (tig. 6). Bears peel bark from trees in the spring to feed on the cambium and inner bark, which are high in sugars and other nutrients at that time (Stauth 1989) (figs. 7 and 8). Large strips of bark at the base of the tree, exposed wood (usually on the lower 4 to 6 feet of the tree bole), and teeth marks on the bole are easily identified on freshly peeled trees (fig. 9). Travel patterns across ridge saddles show up when trees along the travel route have been peeled and turn red. In some areas of the Pacific Northwest and northern Rockies, grizzly bear behave in a similar manner, but they are not a significant problem with respect to tree damage in the Pacific Northwest or northern Rockies.

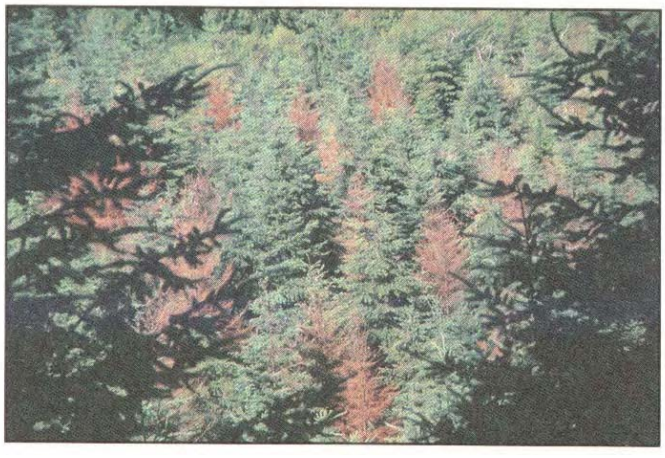

Figure 6—Yellowing and red conifers usually indicate areas of black bear damage, as shown in this western Oregon forest

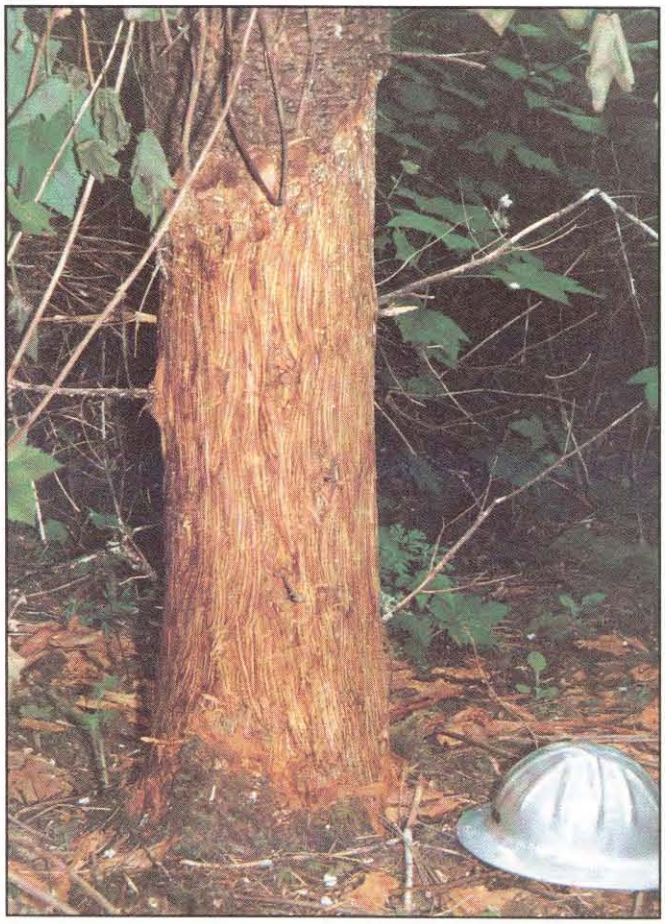

Figure 7—Bears feed on the cambium and inner bark of the lower portion of tree boles as shown on this young Douglas-fir, which is the favored tree species of bears feeding in western Oregon.

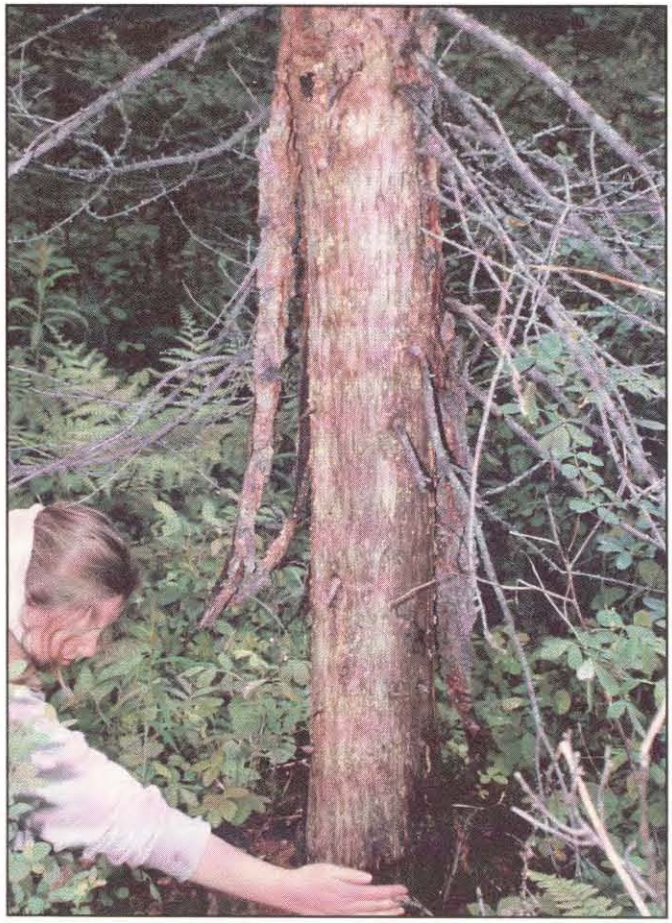

Figure 8—Bears feed on the cambium and inner bark of the lower portion of tree boles as shown on this young western larch, which is the favored tree species of bears feeding in western Montana.

Figure 9—Black bear teeth marks on the bole of a partially girdled Douglas-fir in Oregon.

Complete girdling kills trees, but partial peeling does not necessarily kill trees; instead it leaves trees susceptible to various fungi. Bears peel mostly the lower 4 to 6 feet of the bole, where they easily can reach from the ground (fig. 10). Some bears, however, climb larger trees and feed at upper levels of the bole (fig. 11).

Figure 10—*Above* Black bears seek out vigorous young trees and feed on the nutritious inner bark and cambium, usually on the lower 4 to 6 feet of the tree

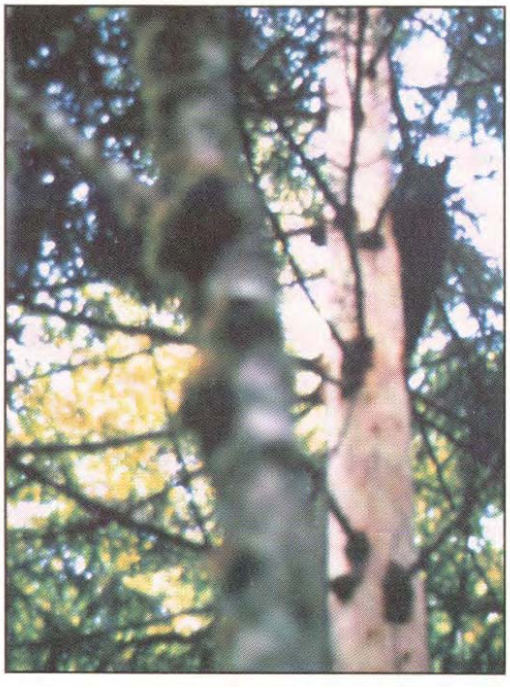

Figure 11—*Lett* Occasionally, black bears climb trees to feed on the inner bark far up the bole of the tree Note the black bear in this Douglas-firi in the coastal range of Oregon

Bears most frequently damage immature trees, and they damage fast-growing, vigorous trees more frequently than they damage slow-growing trees. Bear damage is most common in 10- to 40-year-old trees that are 5 to 10 inches in diameter.

Bears usually peel bark in vertical strips and leave large shredded strips hanging from limbs or laying at the base of the tree. The lower incisors of bears also leave vertical grooves in the sapwood. Wider grooves indicate an older bear, because teeth wear with increasing age.

If trees are girdled with no strips of bark in evidence, then the damage may be the work of porcupines. In coastal forests, girdling of trees near creeks or other water drainages also may indicate beaver damage. Beaver teeth marks usually are at ground level. Beaver and bears occasionally peel bark on the same tree.

Large trees are susceptible to girdling of the upper bole by bears. Bears occasionally climb trees as large as 18 to 30 inches in diameter and feed on the upper boles. Bears, in this case, girdle the upper third of the tree; consequently, the top of the tree often dies. Bark is thinner in the upper third of the tree, so peeling is easier for younger bears. Bark strips may be found hanging from limbs, and damage has been observed on trees as large as 5 feet in diameter, but that is very unusual. This type of damage, apparently, is far more common in coastal forests of Douglas-fir than in interior forests where bears prefer western larch.

Pathogen Infection and Decay

Bear damage affects conifers in the same manner as injuries from logging. Incidence of infection, types of fungi, and amounts of decay vary with tree species and geographical location Some species of fungi cause more decay than others. Larger wounds are more likely to become infected Even minor decay in the lower bole is significant, because that is where most of the tree's wood volume is concentrated. Incipient decay may extend upward a few inches or many feet beyond actual decay, but it usually extends laterally only 1 to 2 inches

Decay in younger trees probably is a more significant problem than in older trees. Trees girdled by bears can deteriorate rapidly and die because of the decay that results from tree injury. A 16-year-old stand with an average d.b.h. of 5 inches, for example, was damaged by bear in western Oregon and lost about 10 percent of its standing trees within 2 years. Complete girdling of the trees, subsequent decay at the groundline, and windthrow during winter storms accounted for most of the mortality.

Damage Differences by Species

A review of the literature indicates that the following conifer trees are susceptible to tree peeling by black bears: Douglas-fir, silver fir, Sitka spruce, white spruce, western hemlock, subalpine fir, western redcedar, western white pine, coastal redwood, western larch, whitebark pine, lodgepole pine, and grand fir. Black bear damage to red alder, aspen, and bigleaf maple also has been documented. Alaska yellow-cedar is damaged by brown bear but apparently not by black bear. Bears damage a wide variety of species, but they demonstrate a decided preference for certain species at different locations. Douglas-fir, for example, generally is the preferred and most abundant species for bears feeding in the western forests of Oregon and Washington, but bears in the northern Rockies prefer western larch. In the redwood area of northern California, bear prefer redwoods over Douglas-fir in their feeding. A recent study of bear-damaged stands in Oregon showed that a wide variety of species suffer bear damage, but it also showed that bears prefer some species over others.

These species and the corresponding degree of damage are shown in the following tabulation (Kanaskie and others 1990):

Species found in bear-damaged stands	Amount of species damaged
	Percent
Douglas-fir	13
Grand fir	8
Noble fir	8
Sitka spruce	7
Incense-cedar	5
Western hemlock	2
Western redcedar	0
Red alder	1
Bigleaf maple	0
Chinquapin	0
White oak	0

In the northern Rockies, bears select western larch, Engelmann spruce, and todgepole pine over Douglas-fir, and larch is the most preferred species. This may partially reflect which conifer species are abundant in favorable bear habitat. In a given region, therefore, serai species of trees, which nearly always are the fastest growing species, apparently are damaged more frequently than their climax counterparts.

Stand Damage

Bear damage is unpredictable, even where combinations of species, size, and age seem susceptible to attack. Some stands with a certain combination of stand and site conditions are hard-hit by bears, while other stands with the same combination are not damaged. Bears prefer to peel the bark of trees in thrifty, rapidly growing stands. Trees of some age-classes and geographic locations are more prone to damage than others. Studies of bear habitat, food availability, tree minerals, stand densities, age, and sex ratios in damaged and undamaged stands have found no valid explanation of why bears select some stands over others. Basal girdling, apparently, is a learned behavior passed from sow to cub. This may explain the expanding, concentric increase in bear damage in some locations, while stands in other locations are not damaged at all.

Frequency and Distribution Over Time

Bears generally return to a stand over several subsequent springs and peel trees in search of food after emerging from hibernation. Damage in the first year generally is light, with less than 5 percent of the trees peeled. Damage in subsequent (but not always consecutive) years may increase to 30 percent. In extreme cases, as much as 60 percent of the stand may be damaged or killed.

A study of a 3-acre stand of 110-year-old Douglas-fir in Skamania County, Washington, showed that 107 of the 132 trees examined had suffered bear damage in the past. More than two-thirds of this damage occurred when the stand was 25 to' 45 years old. Some of the trees were damaged two to five times over a 2- to 46-year period.

Bears can peel between 50 and 70 trees a day during the damage season. Male bears peel trees over larger areas than do female bears, because the home range of male bears is larger. During mating season in the spring, male bears visit several female bears. Male bears peel trees during visits with female bears and in travel corridors between female-bear ranges

Female bears with smaller home ranges concentrate tree damage at a given location. Female bears, especially those with cubs, frequent canyon bottoms and areas of poor access. Female bears often are accompanied by yearlings that also feed on trees

Bears begin peeling trees after they emerge from hibernation Timing varies with the weather from year to year. When sap flow commences, bears start peeling bark from trees—generally from early May to early July. With increasing elevation, there is a corresponding delay in the phenological development of trees, and tree peeling also is delayed. Bear damage at higher elevations is about the same as at lower elevations, but it occurs later in the year.

Damage to Thinned, Fertilized, Diseased, and Partially Stocked Stands

Young stands that are lightly stocked or that have been thinned or fertilized, or both, usually receive more bear damage than heavily stocked stands. Bears select the thriftiest, fastest growing trees. Lightly stocked stands of Douglas-fir along the West Coast, such as those with fewer than 150 trees per acre, grow rapidly for 20 to 30 years. Trees in these stands can be very susceptible to bear damage. Mortality in some of these stands may be so extreme that the standing trees that remain must be felled and the area replanted.

A recent survey of Douglas-fir stands with an average age of 26 years in western Oregon showed that thinned stands in the Cascades had twice as much bear damage as comparable, unthinned stands In coastal stands of the same age, however, thinning prompted no additional bear damage All these stands were thrifty and normally stocked, mostly with Douglas-fir—the tree and stand condition most preferred by bears.

Age of trees also is an apparent factor affecting bear damage in western Oregon forests. An evaluation of the occurrence of bear damage in stands averaging 26 years showed that trees in the 16- to 25-year age class suffered the most damage on a percentage basis (fig. 12). This also may have been a function of tree growth and vigor.

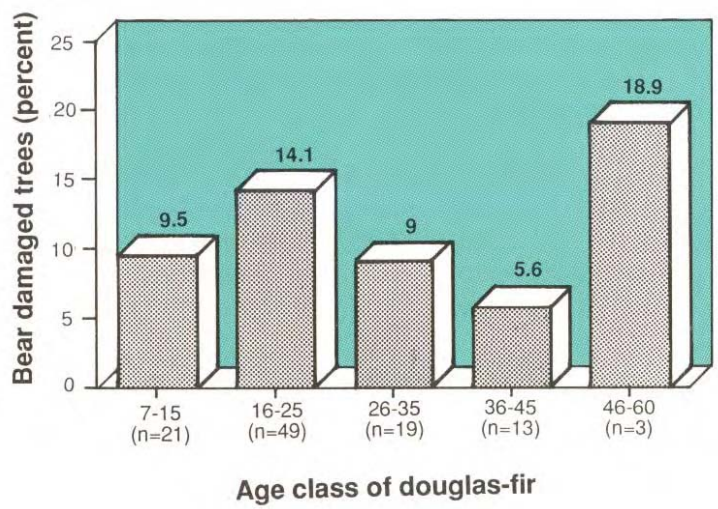

Figure 12—Bear damage found in a survey of western Oregon forests as related to stand age (adapted from Kanaskie and others 1990)

The same survey in western Oregon also identified the extent of damage on individual trees in these young stands of, primarily, Douglas-fir (fig 13). One-third of the trees were completely girdled and destined to die. Some of those in the (76- to 99-percent-girdled class were also likely to die. About one-fourth of the trees were girdled less than 25 percent of their circumference

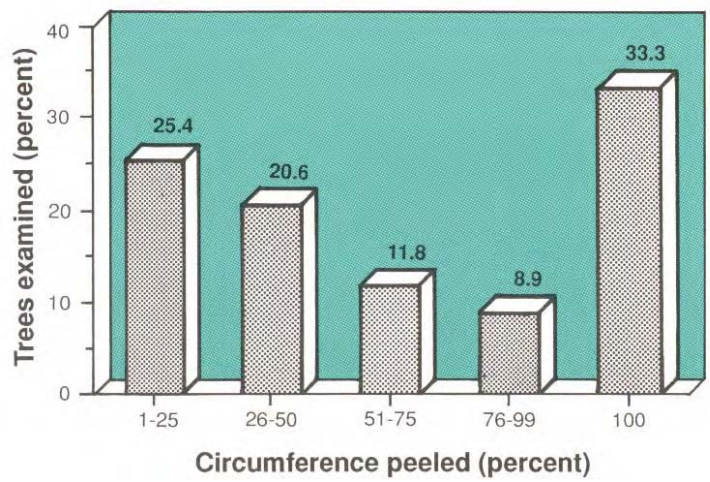

Figure 13—Extent of girdling of individual trees in a survey in western Oregon (adapted from Kanaskie and others 1990)

Similar results were noted at two locations in a study of the spacing of western larch at Coram Experimental Forest in western Montana (Schmidl 1989) Damage was most apparent when trees were 24 to 34 years old, and damage was always heaviest where stand densities were lowest (fig 14) (Schmidt 1987) The trees that bears most preferred were always the largest trees in the area. Where bears had a choice of trees growing in different densities, they much preferred feeding in stands with fewer

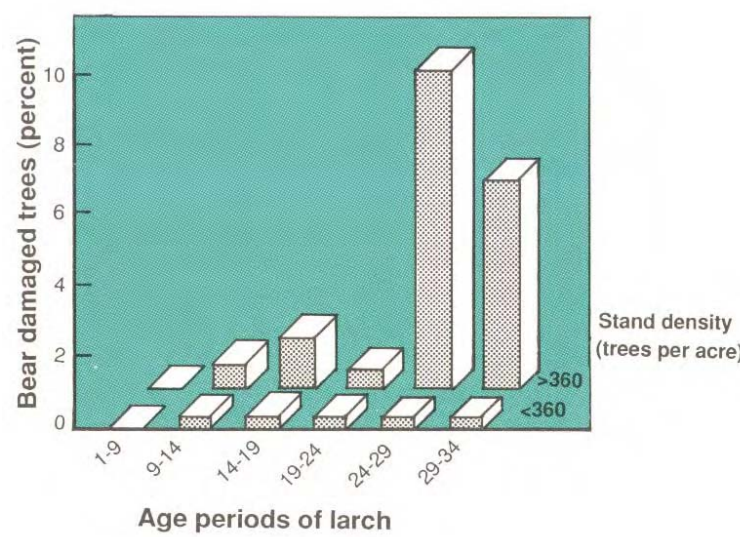

Figure 14—Black bear damage in western larch forests of Montana as related to stand density and stand age (adapted from Schmidt 1989)

than 360 trees per acre (fig. 14). Given an option within a given stand density, bears chose the largest trees (fig. 15). Bears fed heavily on trees in stands with 110 trees per acre and damaged over 70 percent of the trees. Mortality averaged 27 percent in these lightly stocked stands. Interestingly, no bear damage was observed in heavily stocked, unthinned stands of the same age and species composition and in the same area. Tree size, apparently, was a factor; dominant trees in the unthinned stands were about half the diameter of their counterparts in the thinned areas. Two highly interrelated factors—large vigorous trees and low stand densities—apparently provide conditions favored by bears feeding in western larch forests.

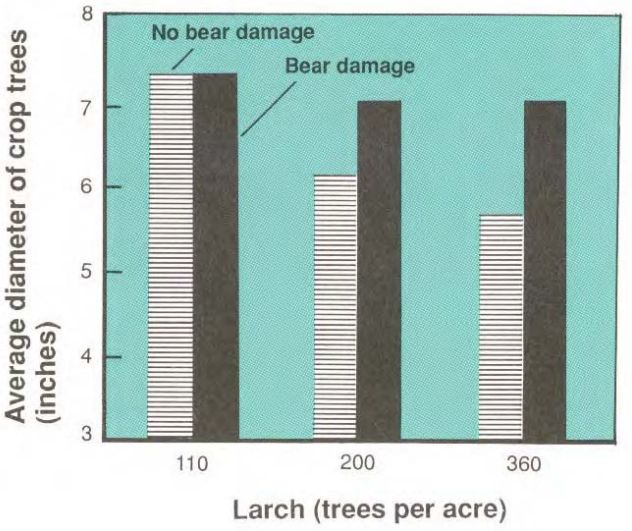

Figure 15—Bear damage within different densities of larch stands on trees of different sizes Bears chose the largest trees when they had a choice of size within a given stand density (adapted fromSchrmdt 1989)

Nearly identical stand age, density, and size conditions at two other study locations 100 miles in opposite directions, however, prompted no bear damage, even though bears were observed at both of those areas. This lends to corroborate some of the theories that bear damage is a learned behavior passed from sow to cub

In another western Montana study (Mason and Adams 1989), bears damaged at least five to seven times more trees in thinned stands than in adjacent, unthinned stands. Damage was again related to tree size. The trees with diameters of 4 to 8 inches accounted for about 85 percent of the total stand damage. Within given diameter classes, however, the highest percentages of bear damage were in the 7- to 10-inch trees, and 41 percent of the damaged trees eventually died. Eight species, including Douglas-fir, occurred in the study area but only western larch, lodgepole pine, and Engelmann spruce were damaged (fig. 16). Larch accounted for 63 percent of the damaged trees, lodgepole pine 25 percent, and spruce 12 percent. Adding to this imbalance was the fact that larch accounted for 93 percent of the total mortality, thus indicating the greater susceptibility of larch to bears.

Fertilization of stands with urea apparently attracts bears (Nelson 1989). A 25-year-old Douglas-fir stand in Oregon fertilized with about 200 to 400 pounds of urea per acre suffered four times as much mortality from bear damage as did comparable

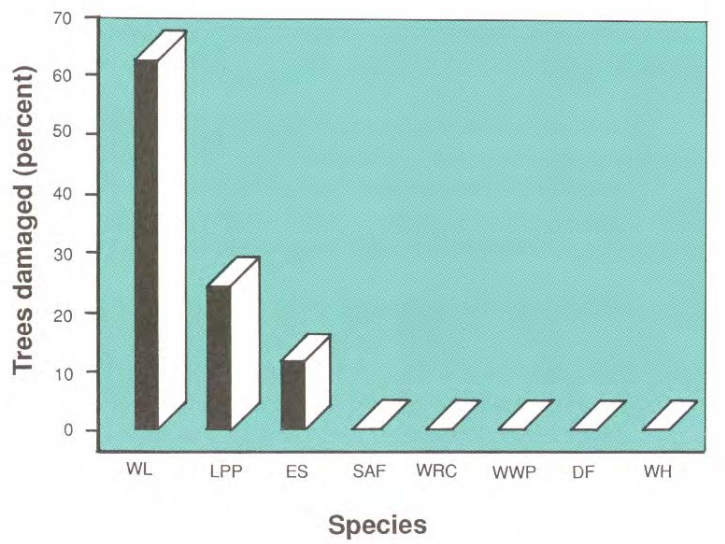

Figure 16—Bear damage to trees of different species in a mixed species stand in northwestern Montana (adapted from Mason 1989)

trees in adjacent unfertilized stands. Western hemlock and western redcedar were present in the area, but only Douglas-fir was attacked by bear

Stands infected with root rot frequently are susceptible to bear damage. Root rot kills trees in pockets, and may temporarily enhance growth in adjacent trees. The growth response of these trees is similar to release by thinning, and it attracts bears.

Damage Surveys

Frequent assessment of black bear damage is necessary to plan strategies for implementation of bear damage management, evaluate past practices, assess economic consequences, and obtain records overtime to support management strategies.

Ground Plot Survey

Bear tree damage is best sampled by stand type. Bears damage trees in pockets randomly distributed throughout a stand. Field sampling should follow predetermined transect lines plotted perpendicular to contours on a map or photo. Frequency of plot intervals along transect lines depends on available resources and the desired degree of confidence. A minimum of one 0.02-acre plot per acre that includes the following data usually provides an adequate sample:

1. Tree species
2. D.bh. class
3. Percentage of circumference peeled (25 percent, 50 percent, 75 percent, 100 percent)
4. Age of damage (present year or previous)
5. Crown description (red, yellow, silver)
6. Total number of trees
7. Total number of trees damaged
8 Total number of trees dead

Other recorded data may include the silviculture history, stand age, site class, and aspect.

Aerial Surveys

Ground-survey plots produce good quantitative data for individual stands, and they show damage trends if sampled over time. Aerial surveys reveal new areas of damage not readily identified by ground surveys, and when done at the appropriate season of the year provide an extensive overview of bear damage. Trends over time can be mapped with data from annual aerial surveys.

Strip flying and mapping—The Oregon State Department of Forestry began annual aerial surveys in northwestern Oregon in 1988 to estimate the extent and distribution of recent bear damage. The aerial surveys are flown along north-south strips with 3-mile intervals between the strips. Pockets of red or silver trees are mapped and delineated as polygons. Trees with red crowns are the result of complete girdling during the previous year. Dead trees lose their needles and appear silver. Late May or early June is the optimum season for aerial surveying, because red trees show up well during this period. Aerial surveys later in the summer are less satisfactory, because needle loss and daytime shadows make detection of damaged or dead trees difficult.

Some of the polygons that delineate damage are identified by the aerial survey and are subsequently examined with ground surveys to confirm bear damage. A correlation is then made between red and silver trees observed from the air and trees actually having bear damage. A recent ground survey in Oregon showed that aerial detection of bear damage was correct in about 75 percent of the cases; the remainder of the damage was caused by other factors.

Other aerial surveys—Mapping bear damage with recent 1 -.12,000 aerial photographs is a successful method of stratifying and quantifying damage. Video cameras have been used but problems with scale, recording picture location, and expense have limited the use of this technique. Satellite imagery shows promise for locating bear damage, but it needs further refinement.

Preventive Strategies

Two major options are currently available to reduce bear damage: apply Silvicultural practices that minimize the attractiveness and vulnerability of trees and stands to bears, and control the bear population.

Silvicultural Practices

Land managers must learn to recognize conditions that lead to bear problems and implement preventive strategies. Enlightened management, where resource management objectives permit, can avoid the creation of extremely favorable habitats for bears. Land managers, as yet, do not have all the information they need to do that, but some common threads of information from the Pacific Northwest and northern Rockies are beginning to help. Tree age, size, growth and vigor, species composition, and stand density can be manipulated. Not much can likely be done about bear habits. There are certainly some exceptions to the following generalizations, but they appear to be true:

1 Most bear damage occurs in 15- to 25-year-old stands in coastal forests and in 15- to 50-year-old stands in interior forests.

2. Bear damage to trees is confined, almost entirely, to bark peeling.

3. In coastal forests, nearly all damage is at or near the base of the tree up to about age 25. After age 40 most peeling is in the upper third of the tree.

4. In the northern Rockies, nearly all damage is at the base of the tree.
5. Lightly stocked stands of vigorous trees are most attractive to bears.
6. Bears prefer the largest, most vigorous trees within lightly stocked stands.
7. Bears seldom damage trees in heavily stocked stands of the same age and species composition.
8. Stocking levels of less than 400 trees per acre in the Northern Rockies and probably less than 300 trees per acre in the more rapidly growing stands west of the Cascades apparently increases the vulnerability of individual trees to bear damage.
9. Bears prefer the more serai species and the fastest growing trees in a stand.
10. In the interior forests, bears highly prefer western larch, but they also feed on lodgepole pine and Engelmann spruce. Bears seldom feed on the shade-tolerant and climax associates, including interior Douglas-fir.
11. Douglas-fir is serai, and it is the feeding host that bears favor in forests west of the Cascades. Most forests on those sites are vigorous, so species pre erence, apparently, is not as pronounced as it is in the northern Rockies.
12. Bear damage is confined mostly to May and June shortly after bears emerge from hibernation.
13. Perturbations, such as fertilization with urea, can prompt significant feeding on inner bark by bears.
14. Bear damage is apparently an early successional stage phenomenon that is enhanced by management practices such as thinning that reduces stand density and increases individual tree growth and vigor. Plantations that are lightly stocked and quite homogeneous in species composition and tree size are particularly vulnerable to bear damage during early stages of stand development.
15. Bear behavior is unpredictable. Some tree, stand, and site conditions that appear to be highly susceptible to bear damage may show little evidence of damage, even if bears are present in the area.

Silvicultural strategies specifically aimed at reducing bear damage have not been explored. Researchers must explore in far greater depth the relation between bears and tree damage. Studies have identified, however, several factors with Silvicultural implications. Silvicultural systems used in mature forests do not appear to be related to bear damage except in how they affect the establishment of young forests of different species composition and density.

Silvicultural practices in young forests can, in some cases, decrease the vulnerability of trees and stands to bear damage. In other cases, however, those practices may increase vulnerability to bear damage. In any event, the facts listed in the previous section certainly limit Silvicultural options with respect to bear. They also, unfortunately, limit the options for stands with the greatest growth potential. Some Silvicultural adjustments that may be made are listed below.

1. Adjust species composition to include a larger proportion of species less attractive to the bears; for example, in the northern Rockies reduce the proportion of species such as larch that are so attractive to bears. In the coastal forests where serai Douglas-fir predominates, however, this option may not be feasible.

2 Delay thinning stands that are in susceptible age-classes if bear damage is frequent in the general area.

3. In the northern Rockies, maintain higher stand densities than normally prescribed for maximum diameter growth. This should reduce the stand's attractiveness to bears and retain a viable amount of growing stock if bears did cause substantial mortality. In forests west of the Cascades, this may not be a viable option.

4. Avoid perturbations, such as fertilization with urea, in forests where bear populations are known to be high and where stand conditions are favorable for feeding by bears.

5 Proceed with intensive management, recognizing that objectives may have to be adjusted to compensate for losses due to bears.

Strategies of Bear Damage Control

Preventive strategies largely are untested and it may be necessary, in some cases, to implement damage-control strategies to meet forest management objectives. Like all damaging influences on a forest, some bear damage may have to be tolerated before it is economically feasible to implement control or preventive treatments. Bear damage crosses property boundaries, so cooperation of all affected landowners often is essential to effectively mitigate damage caused by a highly mobile population of bears. Each forest manager has different objectives and management constraints. What may alarm a small woodland owner may seem inconsequential to a company or public agency with thousands of acres to manage. In some cases, damage-control strategies may be incompatible with the overall objectives of resource management.

Control of bear damage is best accomplished after the damage is surveyed. Control strategies should be implemented during the active period of tree damage (usually May to July). Bear damage often occurs in the same area over a period of years. This should be considered when assessing the cost-benefit ratios of damage control.

Hunting—Licensed hunting is a method of control that may accomplish bear-management objectives, if it is permitted by State regulations. Forest managers can recommend hunting regulations and assist State or Federal agencies in developing special hunting regulations needed to accomplish bear-management objectives. Hunting areas must be large enough so that bears can be tracked over long distances. Hunting seasons should start after bears emerge from hibernation and after the snow has melted, because bears frequent damaged stands in the spring. Areas with moderate terrain and adequate roads are best suited for hunting. Maps of specific bear-damage areas are a real asset for hunters. Records of bears harvested and their locations show trends over time. Listed below are some of the advantages and disadvantages of hunting as a method for controlling bear damage:

Advantages	Disadvantages
1. Allows recreational taking of bears	1. May not target specific damaging bears
2. Reduces bear population	2. Inaccessible or unroaded areas are not
3 Hunters can be directed to specific damage areas	3. The locations where bears are killed are seldom reported
4. Landowner with tree damage has few costs	4 Some people do not like to see bears killed
	5. May not reduce tree damage

Snaring—Snaring is a common method of capturing bears, and it is closely regulated by laws in most states. Bait is hung from a tree in a bear-damaged stand to attract bears, and the snare-spring and cable are set near peeled trees. The Aldrich spring-activated animal snare often is used for this procedure. The advantages and disadvantages of snaring as a method of controlling bears are listed below:

Advantages	Disadvantages
1. Targets specific areas of tree damage and bears that cause damage, and minimizes impacts on the overall bear population	1. Management costs
2. The most selective of all known lethal methods of control	2. May not be acceptable to some people
3. Very cost effective when compared to tree loss resulting from bear damage	
4. Provides valuable information about the biology of bears to appropriate game-management agencies	
5. Provides an opportunity to concentrate control efforts in areas that are inaccessible to hunting	

Relocation—Relocation is often advocated, but extensive experience has shown that it is costly and ineffective. The advantages and disadvantages of relocation as a method for controlling bear damage are listed below:

Advantages	Disadvantages
1. Relocation is more acceptable to some people than killing	1. High management costs
	2. Capturing and handling often injures bears
	3. Most bears return to areas of capture in a short time
	4 May not reduce tree damage
	5. There is no place to take captured bears, because most suitable habitat is already occupied

Feeding—Efforts to reduce bear damage to trees by establishing feeding programs appear effective in some locations but not in others. Feed must be kept dry and protected from rain, so feed buckets should be covered and attached to tree's. The buckets should be checked every 5 to 10 days. Recordkeeping is important to show feeding trends over time. Pellets of bear food can be obtained by contacting the Washington Forest Protection Association. The advantages and disadvantages of feeding as a method for controlling bear damage are listed below:

Advantages	Disadvantages
1. Feeding bears is more acceptable to some people than killing	1. Has management costs
2. Feeding may reduce tree damage	2. Long-term impacts on reproductive rates, tree damage, and bear behavior are uncertain
	3. Incompatible with hunting

The four direct-control methods just described have advantages and disadvantages. As a result, broad-based prescriptions are seldom appropriate. Instead, selection of any of these methods should be site-specific and compatible with overall management objectives, not just bear management. Some methods, such as snaring, can be very effective at immediately reducing damage levels, particularly when specific damage-causing bears are targeted for removal. It must be recognized, however, that even if targeted bears are removed, the mobility and reserve populations of bears in outlying areas will likely refill the ecological void in a relatively short time. All four methods discussed above deal directly with bears; they do not alter the stand and site conditions that provide suitable habitat for bears. Some combination of reasonable adjustments in silvicultural practices and direct methods of bear control may well offer the best alternative currently available.

Control Assessment

Sex, weight, location, date, and approximate age of black bears killed during the hunting and trapping season should be documented to help determine population dynamics and health. This information is useful when reviewing damage control options. Where feeding stations are installed to distract bears from feeding on the trees, the dates of feeding, amounts of feed consumed, weather, and bear sign observed near the feeding station should be recorded. Feeding trends and examination of stands will determine the success of feeding as a damage-control option.

After damage control is completed, an evaluation of damage reduction is necessary. Aerial or ground surveys of stands with a history of bear damage may be accomplished most efficiently in the summer and early fall before rains and snow limit access into the control areas. Assessments of the effectiveness of control efforts to reduce bear damage are helpful for planning programs for subsequent seasons.

Social Acceptance of Bear Damage Control

Hunting, snaring, relocating, and feeding bears draws an emotional response from some people, even if those activities are on private lands (Gourley and Vomocil 1987). Bear damage control takes time and money. A proportional amount of time and money should be spent to inform the general public, wildlife biologists and commissioners, legislators, sportsmen's groups, adjacent landowners, and other interested parties about bear damage to ensure that all control strategies remain available in the future. A successful damage control program must be biologically and economically sound, socially acceptable, and physically possible.

Models

Growth and yield analyses of bear damage and its economic consequences are important. Managers should exercise caution when they use computer models to assess the impact of bear damage on tree growth and yield. Bear damage usually is not evenly distributed throughout the forest; instead, it is widely scattered in clusters throughout a stand. Brush often invades and occupies sites where clusters of trees were killed by bears, and this prevents tree regeneration on those sites

Most models treat bear damage as uniform thinning throughout the stand. Growth, in these models, is transferred to adjacent trees, or the model assumes that seedlings will occupy and grow in sites vacated by bear-killed trees. This does not usually happen. Growth and yield models, furthermore, do not always account for the continuing loss of growth that results from repeated damage over time by bear. Decay and rot by pathogens originating from bear damage also must be accounted for, and few models do this

Damage-control strategies should be implemented only after completion of cost-benefit analyses that consider losses from mortality, decay, reduced growth! and bear control costs. Managers must assume that some diameter classes of trees are not susceptible to bear damage, and they must account for other diameter classes of trees that are presently susceptible but may not be susceptible in future years.

Public land-management agencies must consider all resources in developing land and resource-management plans. In some instances, therefore, maintenance of productive bear habitat and large populations of bears may require acceptance of substantial bear damage and significant reductions in timber yield. Tree mortality caused by bears can create small openings in the forest that are ecological niches favorable to various animals and plants.

Summary

This chapter summarizes information pertinent to bear damage and forest management practices in western conifer forests. It is a synthesis of the most appropriate published and unpublished data available on this subject. The basic ecological requirements of forests and bears provided, in many cases, the basis for conclusions about various preventive forest management practices and bear-control strategies. Considerable information was available, but important segments of knowledge are still missing that are sorely needed to develop comprehensive recommendations. Some of the questions that remain to be answered, therefore, are listed below:

1. What is the extent of bear damage in forests of the northern Rockies?
2. What are the volume-yield reductions in stands that are repeatedly damaged by bears as compared to undamaged stands?
3. Are there positive effects of bear damage on forest resources, such as water and wildlife habitat, that may compensate for losses in timber volume?
4. Are bear activities related to ecological habitat types or other vegetative classes?
5. If moderate to lightly stocked stands are not readily available, will bears concentrate in the slower growing, heavily stocked stands?
6. Are bear attracted to silviculturally treated stands *perse,* or are they just attracted to rapidly growing trees of the right species and size?
7. What, specifically, do bears seek when they feed on trees?
8. Is tree age, in itself, a factor that affects susceptibility to bear damage, or do trees of certain ages and stand conditions simply attain the right size and vigor to attract bears?
9. Is bear damage an early indicator of some stand or tree abnormality, such as root disease?
10. Is there a spill-over effect of bear damage in managed forests that are near bear-safe areas such as National Parks?
11. What effect will the forest-management practices espoused as New Perspectives have on the bear damage problem?
12. Is tree damage definitely a learned behavior passed from sow to cub?
13. If so, what measures could be taken to break that cycle?

14. What other population-control measures might be undertaken?

15. Are some forms of birth control available, such as a "morning after" pill that could be placed in feed stations to reduce the number of successful matings or induce abortions in areas with high populations of bear?

16. What vegetation could be established in damage areas that would be more attractive than trees during the May to June feeding season?

17. What are the long-term effects of supplemental feeding on bear populations and behavior?

18. Does supplemental feeding in one area of bear damage affect damage in other areas of bear damage?

Answers to some of these questions are partially available, and other answers can be deduced from observations and knowledge of the basic ecology and behavior of forests and bears. These are certainly some of the questions, however, that would need to be addressed in a comprehensive research program to solve the problem of bear damage.

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 16
Deer and Elk

JAMES A. ROCHELLE

Abstract

This chapter discusses the biology and habitat relations of deer and elk and how they are impacted by forest management practices in relation to browsing damage and forest regeneration. Silvicultural techniques currently used to reduce the amount of impact of deer and elk browsing are discussed and modification of Silvicultural approaches commonly used to reduce damage are suggested. Prompt establishment of large, vigorous planting stock and thorough site preparation immediately after completion of timber harvest is proven strategy for reducing deer and elk damage and impacts on seedling growth. This chapter identifies research needed to support the development of improved management tools and to evaluate the influences of new Silvicultural approaches currently being applied in relation to the occurrence and control of deer and elk damage.

Keywords: Deer, elk, animal damage control, Pacific Northwest, silviculture.

Introduction

Most reforestation surveys in the Pacific Northwest indicate deer and elk are the most widespread causes of damage. The primary reasons for this are the extensive occurrence of deer and elk on forest land and the fact that woody vegetation, including conifer foliage, is a frequent component in the diet of these species. Essentially all forest land in the Pacific Northwest is occupied by deer, elk, or both.

JAMES A. ROCHELLE is manager, Environmental Forestry Research, Weyerhaeuser Company, WTC 2H2, Tacoma WA 98477.

Natural or management-caused changes in forest ecosystems have important implications for deer and elk because of strong historical, ecological, and nutritional linkages. The responses of deer and elk to these changes have similar implications for the forest manager attempting to produce a new forest stand. An understanding of deer and elk responses to the habitat changes brought about by forest management is a prerequisite to the development of silvicultural approaches to addressing the problem of damage to forests.

This chapter deals with two species of deer: white-tailed and mule, including the black-tailed subspecies. It also deals with two subspecies of elk: Roosevelt and Rocky Mountain. Discussion throughout this paper deals with deer and elk generically, except in cases where specific or subspecitic characteristics are sufficiently different to require a distinction.

Biology of Deer and Elk

Distribution and Populations

Black-tailed deer occur throughout the area west of the Cascade Range from northern California to central British Columbia. East of the Cascades and throughout the Intermountain region, mule deer occur widely, and their ranges overlap with those of white-tailed deer in many areas. White-tailed deer are the most common and widely distributed deer in North America, occurring in 45 of the 49 states and most of tl-.y Canadian provinces. The range of Roosevelt elk extends from California to southern British Columbia and is confined primarily to the coastal areas, except where transplanting has extended their range. Rocky Mountain elk, originally found in the Great Plains and Intermountain West, now also occur widely on the western slope of the Cascades, largely as a result of transplanting efforts.

On a regional scale, populations of deer and elk have been fairly stable in recent years. The number of black-tailed deer observed in the 1940s and 1950s fluctuated widely in association with the conversion of old-growth forests to managed stands over extensive areas, but those fluctuations have leveled off in response to the more subtle and dispersed habitat changes associated with second-growth management. After a period of widespread extirpation in the early part of the century, populations of white-tailed deer have expanded to an estimated level of 15 million in North America, and they appear to have leveled off in recent years (Hesselton and others 1982). General declines in populations of mule deer occurred across the west in the late 1960s and early 1970s. Causes for those declines were not clearly defined, but additional emphasis on habitat relations in recent years has resulted in expanded management efforts and some rebuilding of populations (Mackie and others 1982). In the absence of large wildfires, such as those that occurred widely in the early part of this century, elk populations also have stabilized regionally at levels that most biologists consider fairly high. Extensive transplanting of elk by state agencies has contributed to increasing populations in some areas.

Movement Patterns and Home Range

Migratory and resident behaviors are demonstrated by each of the deer and elk species and subspecies considered in this paper. Depending on the particular subpopulation and the habitat and climatic conditions where they occur, extensive migrations between summer and winter ranges are fairly common in Rocky Mountain elk and mule deer. Roosevelt elk and white-tailed and black-tailed deer more commonly display resident behaviors in which the same area is occupied throughout the year. Local elevational shifts or lateral shifts from one part of the home range to another are further variations observed in both deer and elk The primary factor influencing movement patterns appears to be the seasonal availability of suitable habitats.

Size of home ranges differs between and within species and subspecies of deer and elk. Movements and home-range size differ, in general, among individual animals with the same general habitat; males use larger areas and move more widely than females, particularly when rutting movements are included. Movements and home-range size increase as distances between food, cover, and water sources increase. They also increase with decreasing complexity or diversity of habitats. Nonmigratory species like white- and black-tailed deer typically have small home ranges on the order of 320 acres for females and 640 acres for males. Home-range sizes vary seasonally, particularly for males during the breeding season. Home ranges of Roosevelt elk typically are on the order of 1,000 to 6,000 acres. Rocky Mountain elk occupy similar-sized seasonal ranges often separated by some distance of transitory range. Seasonal home ranges of mule deer range from 100 to 800 acres, and distances of several miles between summer and winter ranges have been measured in some locations.

Factors Influencing Population Levels

Population levels of deer and elk vary on a local scale in response to a number of factors, of which the most important include habitat conditions and intensity of legal and illegal hunting. Predation also can have significant effects in localized situations. In most cases, these factors operate in concert to determine the level of the individual population,

Hunting, historically, is the variable that best lends itself to management control. Political opposition to the taking of female deer and elk often has limited the effectiveness of hunting to control populations. General opposition to hunting of all kinds, furthermore, is increasing nationally. An increased emphasis is being placed on "quality" hunting in many areas of the Pacific Northwest. This usually entails limited-entry hunts, often in walk-in areas, with some type of antler-point restrictions or regulations requiring the use of archery or other special equipment. The result of these programs is that fewer animals are taken, and lower levels of population reduction are achieved.

Habitat changes can take the form of permanent loss to factors like urban or highway development or conversion to noncompatible use, such as some types of agriculture. Other modifications can either improve or degrade the value of the habitat. Forest management's role is one of habitat modification, and it can result in changes that are beneficial, detrimental, or neutral to the big game species of interest. It is through this vehicle of habitat change that forest management can influence population levels and use of local areas. The following discussion examines in detail the mechanisms through which specific silvicultural practices influence deer and elk populations, use of habitat, and damage to forest regeneration.

Characteristics of Deer and Elk Damage to Forest Regeneration

Broad-scale surveys in the Pacific Northwest have consistently listed damage by deer and elk as the most widespread form of animal damage (Black and others 1'979). The similarity of deer and elk damage often prevents specific assignment of cause of damage; however, the wider distribution of deer suggests they are the most prevalent cause.

Several types of damage are caused by deer and elk; however, the most widespread and economically important type is browsing of planted seedlings during the first several years after planting. Other less common and less important types of damage include trampling of newly planted seedlings by elk, and bark removal from saplings through feeding or antler rubbing by both deer and elk.

The growth and survival impacts of deer and elk browsing on seedlings vary with a number of factors. The most important of these are timing, intensity and frequency of browsing, the site conditions under which the seedling is growing, and the size and physiological vigor of the browsed seedling itself

An infrequent, but particularly serious type of damage is caused by elk pulling newly planted seedlings out of the ground. This activity results in mortality of the pulled seedlings, and it often is severe enough to necessitate replanting. A much more common form of damage is browsing, which removes the terminal shoot of the seedling. This type of feeding seldom results in direct mortality, and a single occurrence of browsing on a healthy tree often has negligible effects on subsequent growth. The severity of growth-loss increases with browsing that removes most of the foliage from the seedling, with repeated browsing in consecutive years or seasons, with browsing in addition to damage by other wildlife species, and with browsing on seedlings of small size and low vigor or when the seedling is subject to severe competition from other vegetation. Under these circumstances, seedling growth may be suppressed to the point that the tree is unable to develop as a normal component of the stand and either drops out or contributes less than the expected volume at harvest.

The proportion of the stand with severe damage is a critical determinant of the economic impact of the damage. Heavy browsing on 25 percent of the trees in a plantation of 600 trees per acre scheduled for precommercial thinning, for example, is not likely to justify costs to control the damage, especially if browsing is evenly distributed across the plantation. The level of damage necessary to justify a damage-control treatment is a function of a number of factors specific to the landowner or manager, and it largely is based on expected economic return. The difficulty in predicting long-term growth effects of browsing damage that occurs early in the life of the stand obviously complicates the decision-making process.

Habitat Relations

Foraging Patterns and Diets of Deer and Elk

The literature of food habits and feeding patterns of deer and elk is voluminous, indicating the amount of research and the variation observed among different populations. The diets of deer and elk overlap to a wide degree, and the diets of both groups largely are determined by forage availability. Being ruminants, both deer and elk rely on microbial populations in their stomachs to digest the complex carbohydrates making up the plant tissues in their diets. The amount of vegetation that can be ingested is determined by the size of the rumen and the digestibility of the forage consumed (which controls the rate at which plant material is passed through the rumen). The smaller rumen of deer (as compared to elk) dictates a high rate of forage turnover, which in turn requires the utilization of easily digestible forage. Deer, consequently, exhibit very selective feeding behavior compared to larger herbivores.

Availability is the primary determinant of food habits; therefore, geographic and seasonal differences in deer and elk diets are common. General forage types consumed by both deer and elk in western Washington and Oregon, for example, and examples of species within those types are listed below:

Spring—Forbs, grasses, and new growth on shrubs and trees. Examples are velvet grass, false dandelion, sedges, trailing blackberry, Douglas-fir. Diet reflects a transition from winter to summer foods

Summer—Forbs, grasses and shrubs (leaves, twigs and fruit). Examples are fireweed, dandelion, trailing blackberry, vine maple, thimbleberry, red huckleberry, sedges, and legumes.

Fall—Shrubs, forbs and grasses. Examples are trailing blackberry, red huckleberry, thimbleberry, red alder, tireweed, dandelion, sedges and legumes. Shrubs increase in importance, and fruits commonly are utilized at this time.

Winter—Winter-active grasses and forbs, shrubs, and conifers. Examples are trailing blackberry, sedges, false dandelion, salal, red huckleberry, Oregon grape, Douglas-fir, western redcedar and western hemlock.

A general distinction between deer and elk is that deer primarily are browsers and feed largely on woody vegetation, while elk are grazers that mainly utilize grasses and other herbaceous plants. Availability, however, remains the key determinant, and the above generalization frequently does not hold.

Deer and elk utilize conifers differently both seasonally and in different geographic areas. During spring and early summer, Douglas-fir is preferred by black-tailed deer in some parts of western Washington and Oregon In other areas, it is consumed only in winter when its availability is high relative to other forages. East of the Cascade Range, browsing on conifers more typically is a winter occurrence in response to reduced availability of other forage. Snowfall greatly affects forage availability. Conifers often protrude above the snow, for example, and heavy damage can occur under these circumstances. Where deer and elk are migratory, damage often is most pronounced on migration routes between summer and winter ranges.

Key Factors Affecting Habitat Use

Deer and elk, like other animals, require space, water, food, and cover. The degree to which these components are represented and distributed throughout the forested area largely determines the productivity of the habitat and has a major influence on the occurrence of deer and elk damage in the regenerating forest.

Deer and elk require an area of adequate size to carry out their daily activities of feeding, resting, traveling, breeding and raising young. As discussed earlier, home ranges are the on-the-ground manifestation of this requirement for space, and the variations observed in migratory behavior and size of home range reflect the' way these needs are met

Deer and elk obtain from forage the energy they need to maintain a constant body temperature, carry out daily activities, grow, accumulate energy reserves and reproduce. Forage areas recently have been defined (Wrtmer and others 1985) as vegetated areas with less than 60-percent canopy-closure of trees and tall shrubs combined. These conditions most commonly occur in recent cutovers and young plantations up to the open pole-sapling stage; in some cases, thinned stands and shelterwood areas also qualify.

Water is obtained to varying degrees from the forage consumed, but most animals require free water on a regular basis. Availability of water is an important factor influencing home-range characteristics, particularly in the drier eastern parts of the region and in late summer when elk and deer activity in riparian areas and wetlands increases.

Deer and elk use cover for hiding, shelter, and to conserve energy. Hiding cover and thermal or sheltering cover are two types widely recognized by biologists. Hiding cover is defined as any vegetation capable of hiding 90 percent of a standing adult deer or elk at 200 feet or less. This includes some shrub stands and all forested stand conditions with stem density adequate to hide animals. Topographic features provide hiding cover in some instances. Thermal cover is defined as a forest stand that is at least 40 feet in height with tree-canopy cover of at least 70 percent. These stand conditions are achieved in closed sapling-pole stands and by all older stands, unless canopy cover is reduced below 70 percent. A third type, optimal cover, is of particular importance where heavy snowpacks may make cutover areas inaccessible to deer (Witmer and others 1985). Optimal cover provides snow interception as a result of overstory branch structure and an intermediate canopy, and it contains small openings and a shrub and herbaceous layer. These features result in reduced snow depths compared with cutover areas, and litterfall and rooted vegetation provide a source of forage (Rochelle 1980). Optimal cover usually occurs in stand conditions of mature sawtimber or old-growth.

Forest Management Influences on Deer and Elk Habitat

Road construction and use—Direct influences on deer and elk habitat from road construction include the removal of a portion of the habitat base, either permanently in the case of primary roads or temporarily in the case of secondary roads. Road use can have direct effects through mortality resulting from vehicular collisions with deer or elk. Indirect effects of roads, particularly road use, are of more significance to the use of habitat by deer and elk. There are examples of deer and elk adapting to regular flows of traffic like those associated with logging, but public access for hunting or other recreational pursuits tends to have a disruptive effect on the use of habitat by deer and elk. The disturbance associated with road use can result in higher metabolic rates and greater energy needs of deer and elk, and otherwise acceptable feeding and resting areas, consequently, may not be used. Roads also can facilitate legal and illegal hunting that directly affects harvest levels of deer and elk.

The degree to which roads and their associated traffic affect deer and elk and their use of habitat is determined by a number of factors. One of the most important factors is the cover condition adjacent to the road: the level of disturbance is inversely related to the amount of cover present. The type of road and its level of use also are key influences. The majority of forest roads are secondary roads, and in the absence of log-hauling activity, they are used only intermittently. The disturbance associated with use of this type of road is substantially different than that associated with primary roads (Witmer and others 1985). Use of roads in steep topography creates larger areas of disturbance than on more level ground because of the greater visual distances involved. Roads that are closed to vehicular traffic do not disturb deer and elk and often are used by the animals for foraging, travel lanes, and bedding sites.

Timber harvest, site preparation, and regeneration—Most forest harvesting in the Pacific Northwest is by clearcutting, with significant exceptions in the pine and mixed conifer forest in the eastern part of the region, where several forms of selective harvest often are employed Removal of all or a portion of the forest stand has both immediate and lasting effects on habitat. Clearcutting, much like natural disturbances, such as wildfire or windthrow, reinitiates the process of plant succession. Invasion of forage plants and resprouting of existing species results in dramatic improvements in both the quantity and quality of forage. This condition persists for a period of 10 to 20 years, depending on the productivity of the site and the regeneration practices employed. It is during this period of high use that deer and elk damage regenerating stands.

The utilization of this enhanced forage supply is influenced by the type and extent of site preparation. Where large amounts of slash remain and broadcast burning and scarification are not practiced, access by deer and elk to portions of the harvest unit may be impeded temporarily. The soil disturbance caused by site preparation also may prolong the productive forage period by removing residual vegetation and allowing invasion of desirable herbaceous species.

The timing and density of conifer planting significantly affects the period of high forage production in a cutover area. Planting within one or two years of harvest with high stocking densities (>500 trees per acre) will shorten the productive period compared with delayed regeneration at lower densities. Site productivity and quality of the planting stock also influence forage-production patterns.

Competition control—Herbicide applications sometimes are used to reduce competition between plantation trees and other vegetation on the site. Red alder, vine maple, bigleat maple, salmonberry, ceanothus, and grasses are among the most common competitors. The effects of the treatment can be either positive or negative with regard to forage. The initial decline in forage quantity often is followed by sprouting of woody plants and expansion of species not affected by the treatment. Removal of dense shrub cover also may improve deer and elk access to the site Release of the conifers from competition also has the effect of shortening the period of high forage production.

Precommercial thinning, or stocking control, in which a portion of the plantation is removed to promote growth of the remaining trees, also affects the deer- and elk-habitat characteristics of the stand. The temporary reduction in canopy density allows some forage plants to persist by extending the time the stand remains in an open condition. Heavy accumulations of thinning slash can interfere with animal movement, reducing access to the site for several years.

Fertilization—Application of nitrogen fertilizer at the time of stocking control and at selected intervals during the life of the stand is a practice commonly applied on some forest ownerships. All the vegetation on the site receives fertilizer; therefore, significant improvements in forage production, quality, and palatability are possible (Rochelle, 1979). Fertilization also enhances the growth of the forest stand; therefore, the length of the period of improved forage conditions may be reduced, depending on t"ee density, degree of crown closure at time of fertilization, and timing of subsequent thinning.

Commercial thinning—Removal of a portion of the stand to extract commercial value and control levels of in-stand competition is practiced to varying degrees in the Pacific Northwest. Forage quantity and quality usually are improved by this treatment. The degree of thinning depends on previous treatment history, density, and number of trees removed. Commercial thinning, depending on thinning intervals, can help maintain forage production throughout the managed stand rotation.

Population Responses of Deer and Elk to Forest Management

The preceding discussion indicates that deer and elk interact with forest management in multiple and complex ways This section summarizes the basic relations that determine the status of deer and elk on a particular area of forest land.

Hunting, predation, and other direct influences play a role in regulating the numbers of deer and elk on forest land; however, they operate on the populations that result

from the inherent productivity of the habitat. The number of animals that potentially can be produced from an area, therefore, largely is determined by the interaction of this basic productivity with factors like forest management that modify habitat.

Forest management activities have a major influence on deer and elk populations at the local and regional scale as the result of the patterns of forest succession that accompany the harvest and subsequent development of the forest (fig.1). As with wildfire, volcanic eruptions, or other disturbances, forest harvests are followed by a period characterized by an abundance of high-quality forage for deer and elk. Historic, as well as current population trends, largely are a result of this process. The influence of subsequent management practices largely depends on how they increase or decrease the actual forage base, its nutritional quality, or the degree to which it is available to deer and elk. The availability and use of this forage base is a function of the distribution of harvest units in time, space, and in relation to each other and to cover. To the degree that energy conservation by deer and elk is affected, the " relative balance of forage and cover also affects population productivity. Overall levels of use of habitat are affected by the amount of human disturbance, which largely is a function of road use as modified by the presence or absence of suitable cover.

Alternative management approaches, such as the New Forestry advocated by Franklin (1989), affect deer and elk habitat to the degree they affect the basic relations described above. Many of the anticipated benefits of new forestry are yet to be demonstrated and are not specifically targeted to deer and elk habitat, however,

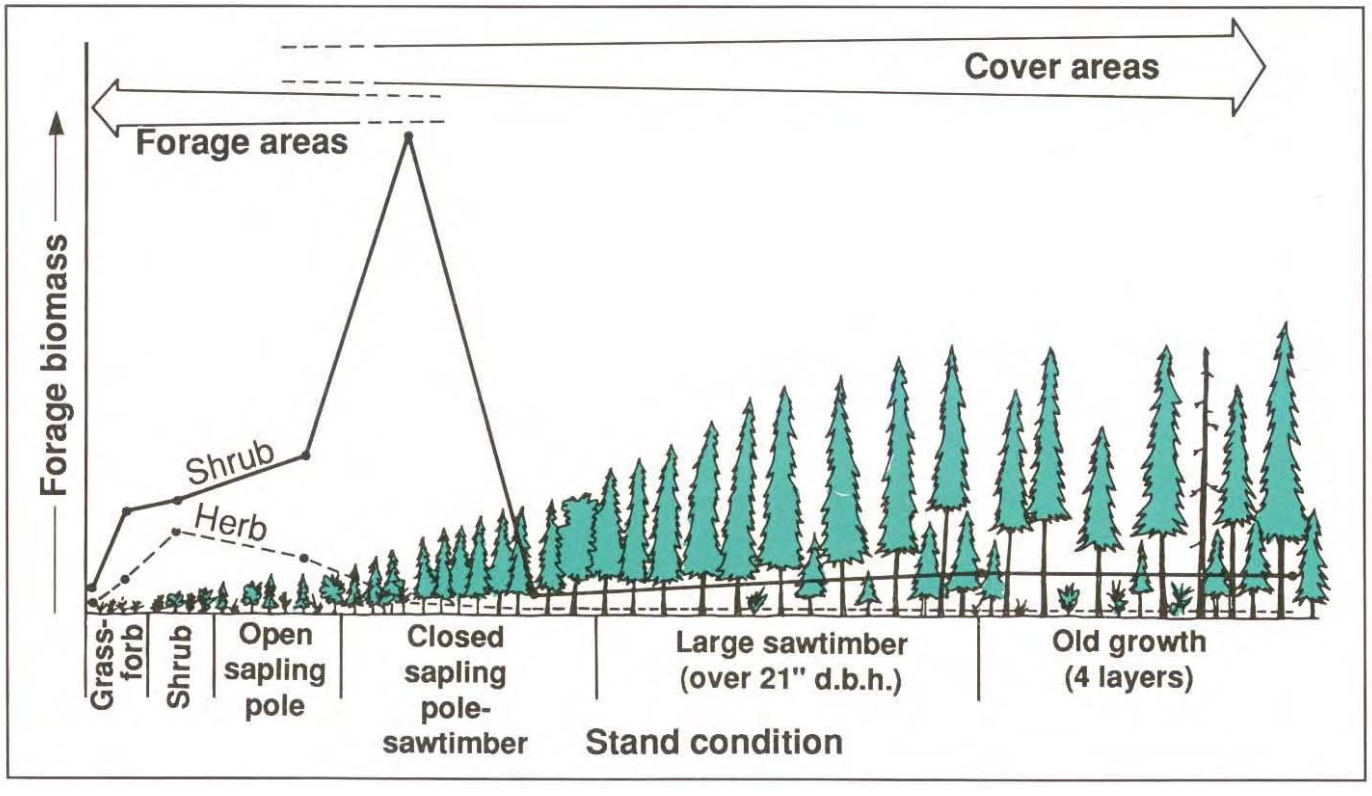

Figure 1—Relation of forest stand condition (or serai stage) to deer and elk forage and cover areas (biomass curves adapted from Long 1976, Witmerand others 1985).

some likely results of the implementation of this approach can be advanced. Partial cutting, as recommended for some situations, slightly reduces forage production while retaining cover in the form o< residual trees. The effect of this practice on the productivity of deer and elk habitat is not likely to be significant, either positively or negatively, and it largely depends on the proportion of trees removed (or retained). Harvest units created with 'feathered' or otherwise irregular margins result in additional habitat edge and may increase utilization of forage in clearcuts by augmenting cover in proximity to food. Partial cutting provides additional edge that potentially may increase the frequency and intensity of browsing on seedlings because of more complete foraging activity in harvest units. This practice was not conceived with deer and elk habitat in mind; however, the largest influence of new forestry on deer and elk probably results from the concentration of timber harvests in larger blocks as opposed to the extensive dispersal of staggered clearcut blocks recommended previously. After natural or human-caused, large-scale disturbances, historically, deer and elk populations have displayed both rapid increases and decreases in response to the changed forage availability. This sometimes is referred to as the "boom and bust" phenomenon. Increased levels of browsing damage have accompanied the increased populations. The scale on which concentration of harvest units is implemented in New Forestry largely will determine the degree to which increased damage results.

Managing Deer and Elk Damage

The number of deer or elk present per unit area of regenerating forest in relation to the amount of available, nutritionally adequate, and palatable forage normally is directly related to the amount of browsing damage. In recognition of this relation, prevention and control of damage have focused on approaches that directly or indirectly influence the number of animals in the area, affect the palatability or availability of forage, or reduce the deleterious survival or growth impacts to the seedling if browsing does occur. Management of deer and elk damage is likely to be most successful with a combination of two or more of these approaches.

Direct Control Methods

This section briefly notes some of the possible methods of direct control. A number of publications detailing these techniques are available through university extension offices and other sources.

Population reduction—The positive relation between density of animals and tree damage has been clearly demonstrated for black-tailed deer (Hines 1973) as has the role of hunting in reducing deer numbers and damage (Crouch 1980). In many areas, more animals could be removed and hunting pressure often is available to do so, but political considerations often prevent implementation of this approach. Reliable and defensible data on the levels and trends of damage is a critical piece of info'rmation needed to support more liberal harvests of animals, including antlerless deer.

Mechanical and chemical barriers—Area fencing or physical barriers on individual trees have been shown to be effective in preventing or reducing deer and e'lk damage. Many different materials, designs, and applications of physical barriers have provided varying levels of effectiveness. Cost is a major deterrent to the widespread use of this approach. A variety of chemical repellents, likewise, have been developed and used with varying levels of success. Cost and the need for repeated treatments are major obstacles to extensive use of repellents.

Silvicultural Approaches to Managing Deer and Elk

As opposition to hunting as a means of damage control increases and as the number of chemical tools available declines, habitat manipulation with silvicultural methods is becoming a more important option for addressing animal damage. This section discusses ways of applying the range of existing silvicultural tools with the goal of preventing or reducing browsing damage by deer and elk and suggests that combinations of these methods, frequently, are the most effective strategies. The approaches outlined in this section may conflict with other deer- and elk-management goals, such as optimizing populations or habitat use; however, those tradeoffs are not addressed here. These goals must be balanced elsewhere, in the context of the biological, legal, political, and economic objectives and constraints associated with the management of particular areas of land.

Timber harvest— As distance from cover increases, the utilization of forage areas by deer and elk declines (fig. 2). Circular or square configurations of the harvest unit create the minimum amount of edge in relation to harvest area. Maximizing the area of the harvest unit also should reduce the intensity of browsing across the unit. In some instances, deer and elk populations may increase after several years in response to the improved forage conditions. Planting as soon after harvest as possible, therefore, is a critical step to enable seedlings to become established and develop the height growth that will reduce the growth impacts of browsing. Building on this approach, blocking-up harvest units to further reduce the amount of edge in relation to plantation area should further disperse browsing pressure, at least temporarily. This again points up the need for immediate regeneration

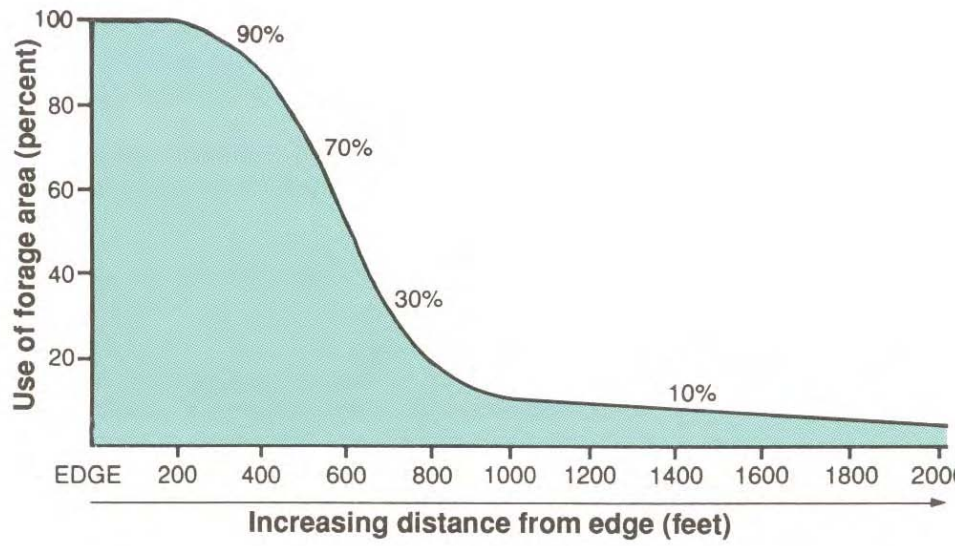

Figure 2—The generalized influence of distance to edge on deer and elk use of forage areas (derived from Hanley 1983, Harper and Swanson 1970, Willms 1971, Witmer 1981, Witmerand others 1985)

Location of harvest units relative to surrounding conditions also can help reduce damage. Populations of deer and elk normally are low in mature sawtimberor old-growth stands relative to younger areas; therefore, clearcuts placed in larger areas of older forest should sustain less feeding pressure and seedling damage than those placed in areas of mixed-age classes, including younger forests. The ability to exercise this option, clearly, declines as harvesting in an area proceeds and as the ratio of forage to cover areas becomes more favorable to deer and elk.

Other factors that interact with open areas include the overall level of forage available and the occurrence of human activity. Where forage abundance is low, the distances animals travel from cover is larger. Merrill and others (1983) documented the extremely large forage areas that elk used in the absence of human disturbance in the Mount St. Helens blast zone.

Road construction and use—Placement of roads normally is a function of engineering considerations, and little flexibility in road location is possible. Engineering and economic considerations also largely dictate road densities. Where flexibility exists for an equivalent amount of road use, however, placement of roads to maximize the area visible from the road results in maximum reduction in damage by deer or elk. Enhanced traffic levels on roads passing through areas that sustain deer and elk damage also may reduce damage, particularly if road use increases during the period when damage occurs Increased road densities also may reduce levels of deer and elk damage (fig 3), but this probably is not practical solely for the purpos'e of damage control. Road closures in damage areas, conversely, may result in increased levels of damage. These observations probably apply only to primary roads that constitute a fairly small portion of the total mileage of forest roads (Witmer and others 1985).

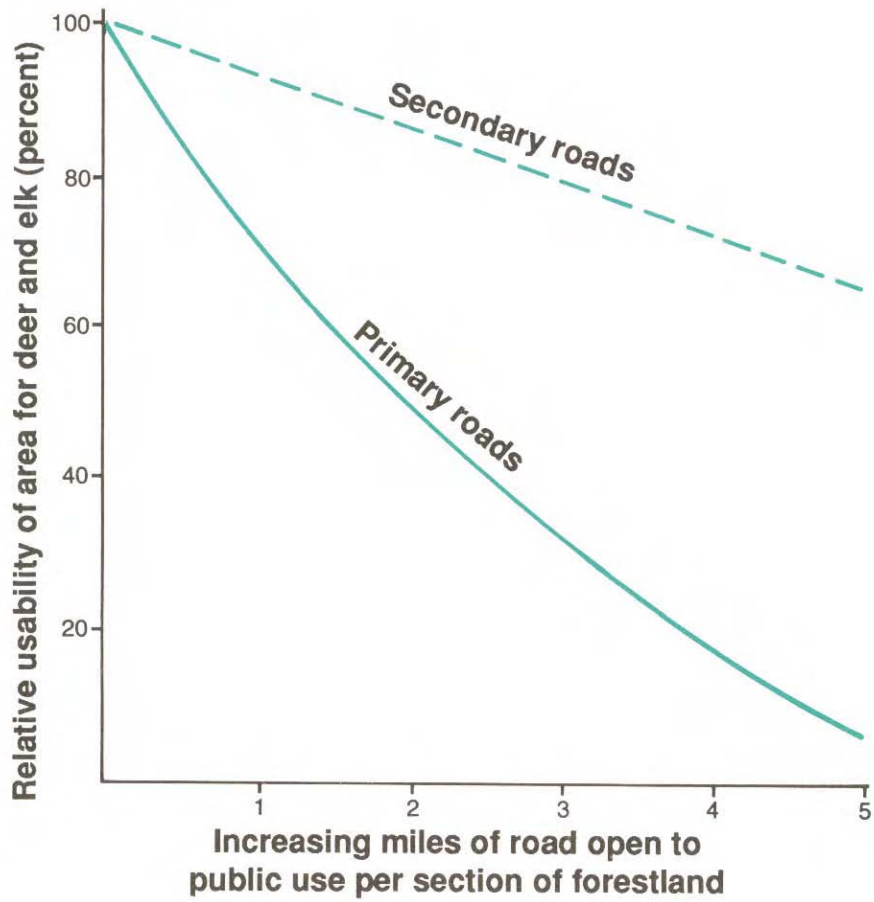

Figure 3—Generalized influence of increase in open-road density on otherwise usable deer and elk habitat (derived from Willms 1971, Witmer 1981, Witmer and others 1985)

Site preparation and regeneration—The condition of the harvest site with regard to slash concentrations and the amount of desirable forage on the site can have a major influence on the levels of use by deer and elk. Retention of large amounts of scattered slash or slash piled in windrows may impede deer and elk access to an area, but it also may enhance rodent and hare populations and associated damage. Clean site preparation with broadcast burning or scarification temporarily removes desirable forage plants, reduces vegetative competition with the planted seedlings, and reduces the attractiveness of the area for deer and elk. These conditions are short-lived and rapidly lose effectiveness as the time between site preparation and planting increases. If areas around the plantation support high densities of deer or elk, then seedlings planted on very clean sites may be browsed as a result of their high exposure.

Quality of planting stock increasingly is recognized as a critical determinant of regeneration success. Seedlings with high vigor that quickly become established after planting and grow rapidly in height beginning in the first growing season are one of the most effective tools available for dealing with deer and elk browsing. This effectiveness is further enhanced if large stock (1 -1, 2-1) are planted. Large seedlings with high vigor planted immediately after thorough site preparation can sustain low to moderate levels of browsing with minimal effects on survival and growth. Severe browsing also is less likely to cause mortality of trees with these characteristics.

Vegetative manipulation—Modification of the quantity, species composition, and nutritional value of vegetation within the regeneration area operates in several ways to reduce levels and effects of browsing damage. Treatments to prevent development of preferred forage species may reduce damage by reducing the use of the plantation, but they may have the opposite effect if surrounding areas support high populations of deer or elk Hines (1973) reported increased browsing of Douglas-fir by black-tailed deer when the availability of preferred forage was reduced in the presence of high deer numbers.

Forage seeding with either native or agricultural plant species is an alternative approach that has been widely used, but its effectiveness is poorly documented. Grasses and forbs, usually including legumes, are the plants most commonly seeded (table 1). Becker (1989) reviewed published work-to-date and concluded that seeding can substantially increase amounts and quality of forage but found little evidence of a reduction of browsing damage by deer and elk Increased damage observed in some instances, apparently, was related to seeded forage that attracted additional animals to the treated areas.

Fertilization to improve nutritional quality and palatability of forage plants can shift feeding pressure from plantation trees but also may attract additional animals to the site and result in increased damage. Fertilization of natural and human-made openings, such as fields and rights-of-way, can concentrate deer and elk feeding and may draw animals away from specific damage areas on a limited scale (Brown and Mandery 1962). Increased incidence of deer or elk collisions with vehicles could be a negative result of right-of-way seeding

Control of competing vegetation indirectly influences damage by mitigating the growth impacts of browsing by deer and elk, and it can be more cost-effective than direct

Table 1—Forage species of proven value for use In western Oregon and Washington

Forage species	References
Orchardgrass, ryegrass, white clover, birdsfoot trefoil (wildlife mix No. 2)	Smith 1980
Perennial and annual ryegrass, orchardgrass, tall fescue, white and subterranean clover	Mereszczak and others 1981
Catsear, hawksbeard, fleabane, hawkweed, phacelia and redstem fireweed	Campbell and Evans 19J78 Campbell and Johnson 1981
Many species of grass, legumes, shrubs and trees, cereal grains, lupine, sedges	State of Oregon 1980" State of Washington 1983[s]

[a] An especially useful reference
Source Witmer and others 1985

protection with repellents or physical barriers because of the consistent, positive growth response it provides (Gouriey and others 1989). Vegetation control also can improve deer habitat by changing forage species composition without increasing browsing damage on seedlings (Borrecco 1972). In instances where much of the other vegetation is removed, damage levels on plantation trees may increase, especially with high populations of animals before treatment (Boyd 1987).

Silvicultural planning—Some of the most effective steps that can be taken to manage damage by deer and elk fall into categories of administration or planning. Most of them fall into the common sense category and are part of the job of forest management. They require little extra effort or expense. At the risk of offending some readers, some of these steps are listed below:

- Utilize experience gained previously, from adjacent areas, previous years, and previous managers in anticipation of damage and planning operations.

- Know your territory or area, what species are present, when they are present, and when damage occurs. With migratory deer and elk, regeneration activities sometimes can be timed to avoid tree-animal interactions during the immediate post-planting period. Extra effort to ensure trees are firmly planted can reduce elk pulling if it is anticipated.

- Work together with your state agency biologist to understand trends in animal numbers and tree damage. Support of the local biologist is essential to obtain support for special hunts that reduce population in damage areas.

- Spread the word, through hunting maps or other means, about locations of severe damage and associated hunting prospects. Use road management to make riamane aroac ar'/'e<;<;ihlo tr> huntarc and tr> fnn^ontrato huntinn nroccuro

- Insist on quality planting stock and use the largest seedlings available and consistent with operational constraints. The track record for achieving successful reforestation with this combination is well established.

- Monitor your regeneration areas to track damage levels and determine needs for competition control or other treatments. Record successes and failures to provide future direction. As discussed above, Silvicultural treatments that change forage availability may either increase or decrease damage, depending on other local factors.

Research Needs to Support Silvicultural Control of Deer and Elk Damage

Landscape Scale Interactions of Deer, Elk, and Forestry

Silvicultural practices and their relation to the other resources of the forest, including wildlife, increasingly are being considered on a landscape, watershed, or some equally large geographic scale. This is particularly applicable for species like deer and elk, whose home ranges are large and normally include stands of differing Silvicultural status, including unmanaged conditions. It is this combination of features that determines population levels, patterns of habitat use, and occurrence of damage. Planning Silvicultural activities that consider the potential for browsing damage requires a better understanding of the response of deer and elk in space and time, especially with regard to feeding patterns.

Prediction of Deer and Elk Damage

Our knowledge of deer and elk responses to changes in food, cover, and human disturbance continues to increase, but our ability to anticipate where and at what intensity browsing will occur is limited. A quantitative method for assessing the likelihood that deer and elk will use a specific site at a level that will interfere with regeneration success would be valuable in guiding Silvicultural or other methods of damage control. This need perhaps is best addressed as a component of determining landscape-level interactions of deer, elk, and forestry.

Vegetation Manipulation

Planted conifers sometimes and in some locations are a preferred forage item, but their use more often is related to the overall availability of forage on the site. Enhancing forage levels and quality in order to increase the difference in palatability between seedlings and other available forage warrants additional research, but that research should consider the responses of deer and elk populations and the need for control. The full potential of selective manipulation of vegetation with herbicides to achieve both competition control and forage composition objectives has yet to be fully explored. The possible dual benefits of damage reduction and enhancement of seedling growth make this approach particularly attractive from an economic perspective.

Influence of Alternative Silvicultural Approaches

New Forestry, riparian zone management, retention of specific habitat components like snags and large woody debris, and other modifications of traditional management approaches are being applied, in varying degrees on public and private forestland. These practices have potentially broad implications for silviculture, wildlife, and their interactions (including damage). Programs to assess the results of these different approaches should include levels of deer and elk damage as criteria for evaluation.

Road Management

Human activity on roads negatively affects deer and elk use of habitat and leads to road-management programs designed to reduce or eliminate road use. This suggests that enhancement of levels of human activity on roads could reduce the use of particular areas by deer and elk at times of damage occurrence. Many factors limit the feasibility of this approach, but they should not preclude further testing to determine if there are specific situations where it might have potential.

Summary

The widespread occurrence of deer and elk damage to forest regeneration in the Pacific Northwest has been amply documented. On the plus side, deer and elk browsing normally is not a significant cause of seedling mortality. Deer and elk also are highly desired components of Northwest forests, and significant, ongoing management efforts are directed at maintaining and, usually, enhancing their populations. Attempts to satisfy population and silvicuttural objectives on the same land base create some unique management challenges, particularly in light of the well established relation of animal numbers to occurrence of damage. In many instances, these objectives are not compatible, and tradeoffs are necessary. The most acceptable solutions are those with the least detrimental impact on either goal and those that satisfy other societal demands, like hunting, in contrast to reducing habitat quality.

Deer and elk, because of their high profile, have received substantial attention from researchers. These research efforts provide a relatively good level of understanding of the relation of these animals to forest habitat. This knowledge suggests a number of approaches to damage control, many of which are being applied. Examples of some of the more common sense but extremely effective tools available include thorough site preparation, immediate establishment of plantations after logging, and the utilization of large, high-quality planting stock. Combined with other treatments, such as control of competing vegetation, these standard forestry activities go' a long way toward reducing browsing, or its impact, to acceptable levels.

Among the research opportunities that exist (and there undoubtedly are many more than those listed above), reducing damage through manipulation of vegetation on a broad or landscape scale and on a site-specific basis is likely to be one of the more fruitful areas of research. As the use of alternative silvicultural approaches expands, moreover, their animal-damage implications must be assessed.

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SECTION FOUR
SILVICULTURAL METHODS IN RELATION TO
SELECTED WILDLIFE SPECIES

Chapter 17
Livestock and Forest Management Interactions

RUSSELL T. GRAHAM, JAMES L. KINGERY, AND
LEONARD A. VOLLAND

Abstract

Livestock grazing on what is now public land preceded the establishment of the U.S. Department of the Interior, Bureau of Land Management, and the U.S. Department of Agriculture, Forest Service, which are the two main regulators of livestock grazing on forest lands. Livestock can be grazed on ranges in open or dense forests and on sites dominated by ponderosa pine or by western hemlock. Tree damage from livestock can result from trampling, browsing, or rubbing. There is also potential for indirect damage to trees as the result of changes in soil properties. Direct or indirect damage to conifer plantations can be minimized by controlling the number and distribution of domestic livestock and the season of grazing. Distribution can be controlled with permanent and temporary fences, range riders and herders, and placement of salt. Number of animals and season of grazing must be administratively controlled Livestock integrated into the silvicultural

RUSSELL T. GRAHAM is research forester, U.S. Department of Agriculture, Forest Service, Intermountain Research Station, Forestry Sciences Laboratory, Moscow, ID 83843; JAMES L. KINGERY is assistant professor, College of Forestry, Wildlife and Range Resources, University of Idaho, Moscow, ID 83843; LEONARD A. VOLLAND is regional ecologist, Ecology, Range and Watershed Management, U.S. Department of Agriculture, Forest Service, Pacific Northwest Region, Portland, OR 97208.

prescription potentially may become a forest-management tool instead of a forest pest. Short, intense grazing seasons in early spring or late fall could provide good sites for seedling establishment. Properly applied sheep grazing in shrub fields can weed stands and increase stand vigor and growth Livestock grazing should be an integral part of silvicultural prescriptions. What appears to prevent this integration are either real or perceived administrative constraints. Successful implementation of silvicultural prescriptions on both transitory and permanent forest ranges requires that these constraints be lifted and the conflicts between livestock grazing and other forest uses resolved.

Keywords: Silviculture, management, integration, wildlife, livestock, grazing.

Introduction

The presence of livestock on what are now public lands precedes the establishment of the U.S Department of the Interior, Bureau of Land Management, and the U.S. Department of Agriculture, Forest Service, which are the two main regulators of livestock grazing on public forest lands. With the inception of the Forest Service in 1897, regulations were established for grazing livestock on National Forest lands. In 1897, there were no laws giving individuals the "right" to graze livestock on National Forest lands, but livestock grazing was a "privilege" granted by the Secretary of Agriculture. Temporary grazing privileges were granted where they did not interfere with timber production or watershed protection. Several laws enacted since 1897 regulate the presence of livestock on public forest lands. The more important legislative acts include the Taylor Grazing Act of 1934, the National Environmental Policy Act of 1970, the Forest and Rangeland Renewable Resources Planning Act of 1974, and the National Forest Management Act of 1976.

Grazing by domestic livestock remains, to this day, an important use of public lands in the Western United States. As an activity with a long history of importance to agriculture, therefore, grazing on public lands became a politically sensitive issue as economic and environmental perspectives changed over the years.

In the early 1900s, cattle, sheep, goats, horses, and pigs grazed on public forest lands. Grazing fees were established for each kind of animal, and plans were prepared for grazing allotments on lands administered by the Bureau of Land Management and on lands administered by the Forest Service. At that time, over 1.4 million cattle and horses and over 6.1 million sheep and goats grazed for several months each year on 82 5 million acres of National Forest lands. By 1936, 40 percent of these ranges were estimated to be in unsatisfactory condition (defined as a reduction in grazing capacity for domestic livestock) (McArdle and Costello 1936). By 1979, 76 percent of the rangelands administered by the Forest Service were in fair or poor condition (Schmautz 1979). The condition of these ranges as sites for growing trees is unknown, but they most likely were not in optimum condition, even though reports suggested that livestock grazing and timber production were compatible.

Livestock can graze on ranges in open or dense forests. Open forests usually are considered permanent ranges and often are dominated by ponderosa pine or juniper with canopies of <40 percent. The more mesic forest types along the Pacific Coast and the inland West are not grazed on a permanent basis. They can, however, be converted to transitory range (land suitable for grazing of a nonenduring or temporary nature) by natural or artificial disturbances, such as wildfire or timber harvest Timber and livestock production have been and still are major uses of permanent and transitory types of ranges

Annual production of forage on ranges in open or dense forest varies between 800 and 2,700 pounds per acre. Riparian zones often are 2 to 3 percent of the area in these ranges, but they can provide 20 percent of the forage (Krueger 1983). The more productive sites for timber, furthermore, often provide the better transitory ranges. These forest ranges often are also important for wildlife (Lonner and Mackie 1983). Watershed protection and recreation often are significant resource values, so the potential for conflict among uses is acute.

Livestock Grazing and the Silvicultural System

There are two contrasting views of livestock grazing and forest regeneration: livestock grazing is compatible with forest regeneration and it benefits, under some circumstances, seedling establishment and growth; or livestock grazing is a detriment to tree regeneration, especially during the early years after planting, and livestock should be excluded from regenerated areas. The integration of livestock into Silvicultural systems should achieve a level of common ground between these two opposing views.

A Silvicultural system is a planned program of activities for forest management. Livestock are seldom part of that program. This paper outlines several methods by which livestock could be integrated into the Silvicultural system to minimize regeneration damage and serve as an acceptable tool for removing herbaceous and shrub competition from forest plantations.

The difficulty of coordinating livestock grazing and tree regeneration on the same piece of ground, however, should not be underestimated. The coexistence of livestock production and tree regeneration requires controlled grazing. In the real world of grazing allotments, open range laws, cattle dumping (the practice of releasing cattle on the open range without a permit), "grazing rights," and traditional grazing practices on public lands, the necessary level of animal control may be difficult to achieve. What is needed is a new perspective that integrates livestock grazing with other forest-management objectives.

Livestock Grazing as a Silvicultural Tool

Millions of dollars are spent each year to control competing vegetation with herbicides and mechanical methods that promote the establishment and growth of western conifers. Livestock grazing is an additional tool for controlling competing vegetation (Doescher and others 1987).

Site Preparation

Livestock grazing is a method of site preparation that can clear areas of unwanted vegetation, but only if the livestock consume 75 to 95 percent of the forage. At this level of forage utilization, however, soil damage could occur; the livestock operator would lose production, and grazing would be difficult to control. The intense grazing pressure, furthermore, may have to be repeated to achieve the desired level of site preparation. Livestock grazing for site preparation, therefore, is not recommended unless specific conditions and objectives warrant its use (such as preparing a soil surface for broadcast seeding).

Release

Livestock grazing can reduce palatable, yet unwanted shrub and herbaceous canopy coverage that can compete with planted seedlings (fig. 1) (Doescher and others 1989). Periodic grazing can release more vigorous, better-growing trees byj removing competing vegetation (fig. 2). The preferred method of achieving release by grazing, is to establish closely controlled conditions for the treatment area. Temporary fences and close inspection of the site would be required to ensure that grazing achieves the desired results. By setting up special treatment areas, additional animal production could be provided. Livestock management, furthermore, would be less encumbered by traditional use and regulations of an area.

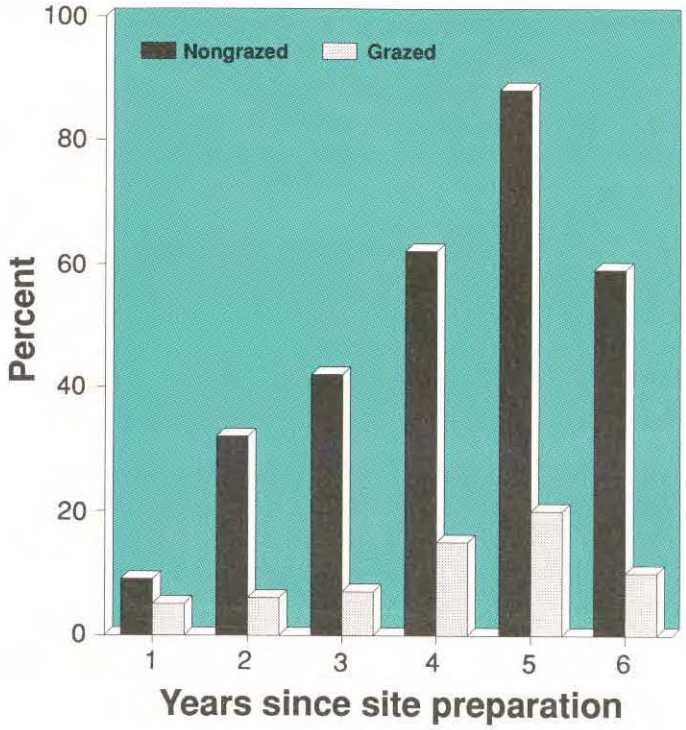

Figure 1—*Left.* Changes in total shrub and herbaceous canopy cover in a cattle-grazed clearcut and in an ungrazed clearcut for 6 years after site preparation. The clearcut is on the west slope of the Sierra Nevada near Georgetown, CA. Adapted from Allen and Bartolome (1989).

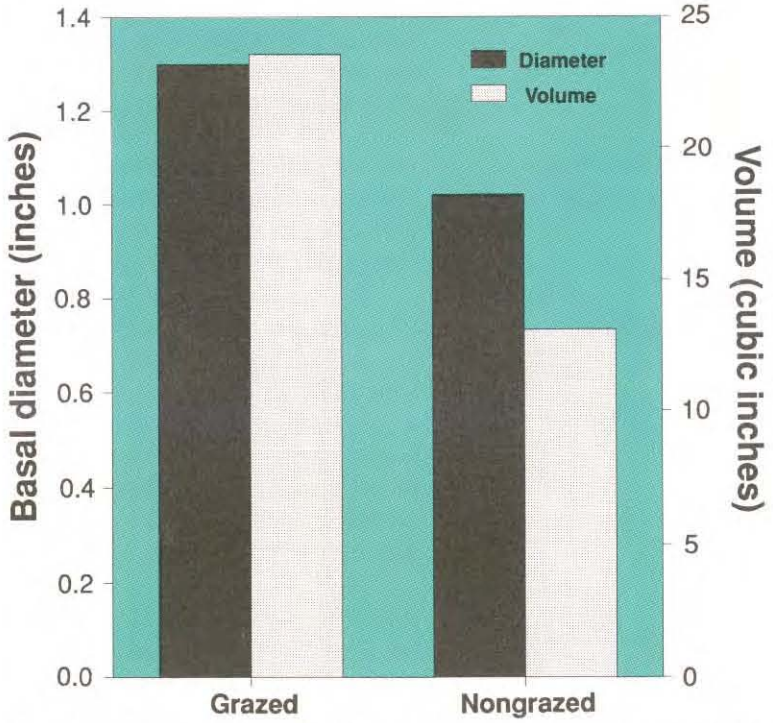

Figure 2—Tree characteristics of 5-year-old Douglas-fir growing in cattle-grazed and nongrazed areas. Adapted from Doescher and others (1989).

Livestock Damage

Livestock can inflict a variety of physical injuries by browsing, trampling, pulling, and rubbing on trees They can injure trees of seedling-through-sapling sizes, and they can impair regeneration anytime they graze forest lands. Livestock are a major cause of damage to conifer plantations in much of the intermountain portion of the Western United States, and they have a lesser impact in other areas of the West (Borrecco and Black 1990). Compaction and displacement resulting from livestock activities can destroy critical soil properties and degrade site productivity.

Browsing

Browsing—removing the terminal bud of a seedling—can reduce the height-growth of trees. If the terminal bud remains intact and lateral branches are not severely] browsed, however, little or no seedling growth is lost (Sharrow and Leininger 1983). Taller seedlings (those generally >4 ft) are less likely to have the terminal bud removed by browsing; consequently, the seedling is able to maintain height growth (fig. 3). Livestock occasionally pull a newly planted seedling rather than remove a portion of the tree. This especially occurs when soils are moist and with newly planted seedlings that have poorly developed root systems Seedlings are more susceptible to browsing in the spring during periods of rapid growth, because the tender leaves are more palatable in that season. After conifer seedlings become hardened,! they are less susceptible to browsing (Leininger and Sharrow 1989).

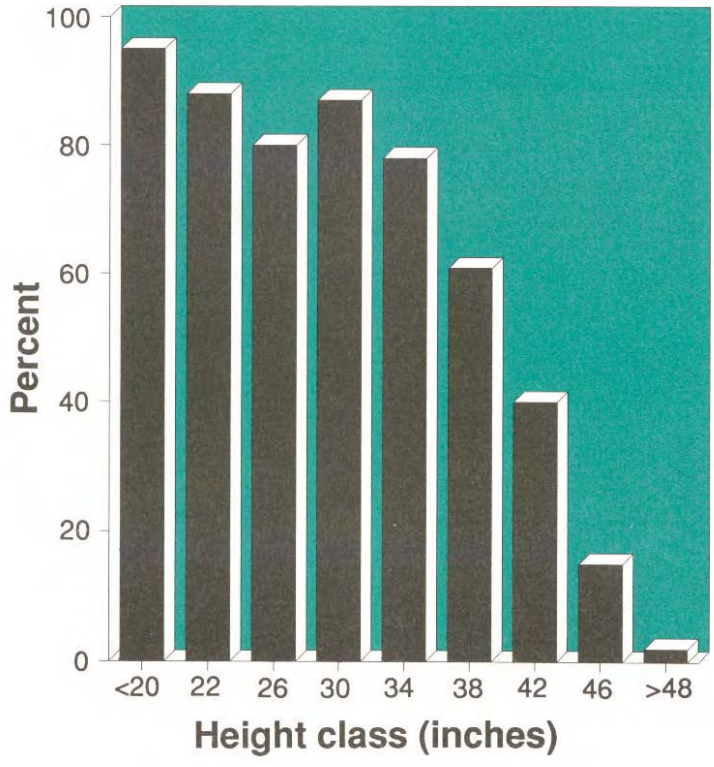

Figure 3—Proportion of Douglas-fir seedlings with terminal buds removed by sheep browsing (by height class) Adapted from Leininger and Sharrow (1989)

Trampling

In most of the western United States, trampling is the most significant damage that livestock inflict on planted or naturally regenerated seedlings. It is usually impossible for livestock to browse trees without causing trampling damage. Trampling causes different forms of damage and a variety of tree injuries. The foremost type of injury results in the death of the seedling when trampling crushes the stem or buries it in the surface of the soil. If the tree is not killed, stem scarring may weaken the tree and provide entry points for disease organisms. In some instances, trampling may only bend the stem and cause no damage to the seedling. Repeated trampling, however, eventually causes tree mortality. Younger, smaller trees generally are more resistant to trampling damage, and the pines appear to be more resistant to damage than the firs

Rubbing

Rubbing by livestock can damage larger seedlings and saplings during any season of the year. This damage can cause height reduction, bark removal, and stem disfigurement. Rubbing, like trampling, can create wounds that can be entry points for disease organisms.

Tree Species

The majority of Western species can be damaged by livestock. Douglas-fir, ponderosa pine, lodgepole pine, western white pine, and western larch frequently are browsed by cattle or sheep. All species are susceptible to damage from trampling or browsing, and the pines apparently are more prone than other species to damage from rubbing.

Damage Assessment

Plantations and naturally regenerated stands can be destroyed by uncontrolled or poorly administered grazing (Doescher and others 1987) (fig. 4) The problem arises when other environmental factors associated with livestock contribute to plantation mortality and damage. In northern Idaho, for example, a plantation failed when it was grazed by cattle, but the major cause of mortality was pocket gophers (fig. 5).

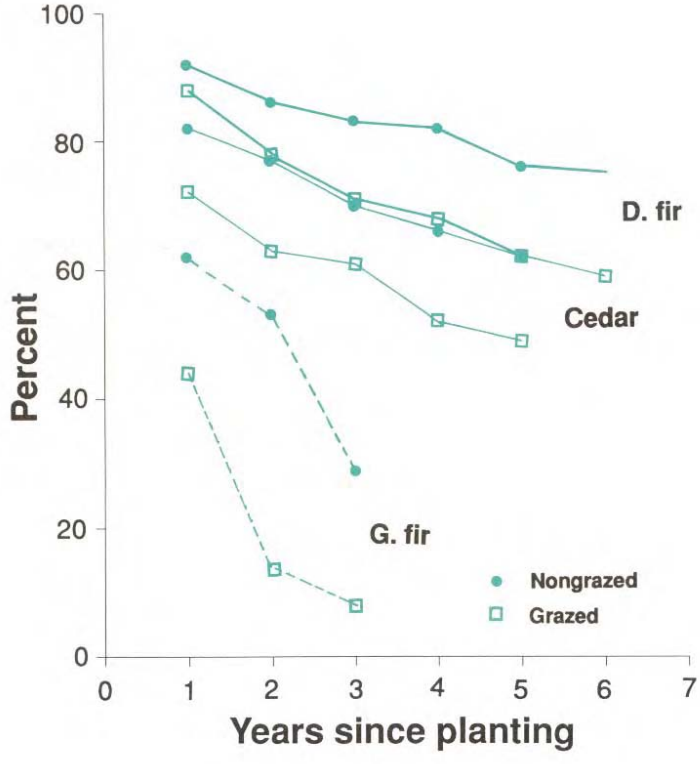

Figure 4—Survival of grazed and nongrazed plantations of ponderosa pine located on grand *MClinlonia uni flora* (G FIR), western redcedar/ *Chntonia umflora* (CEDAR), Douglas-fir/ Physocarpus *malvaceus* (D FIR) habitat types Plantations located in northern and central Idaho.

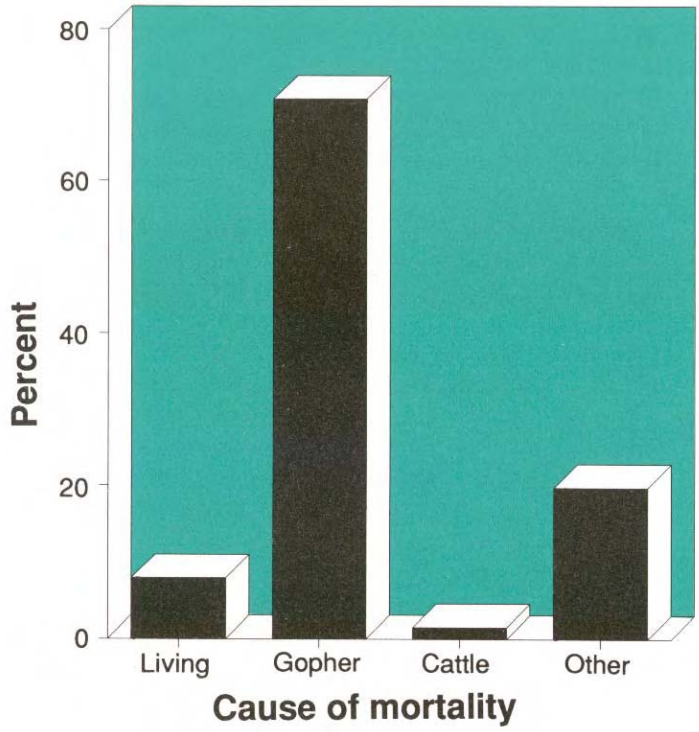

Figure 5—Proportion of ponderosa pine jliving or killed by pocket gophers, cattle, and other causes 3 years after planting on a transitory range in northern Idaho (Graham and Kingery 1990).

The cause of damage to conifer plantations should be verified and assessed as it happens. Damage from trampling or browsing by cattle or sheep is difficult to distinguish from wild ungulate damage (deer or elk) if months pass before the cause of damage is evaluated The tearing cut on trees that is characteristic of browsing by livestock is similar to cuts by deer and elk. Livestock and wild ungulates often do not occupy plantations at the same time because of the turnout dates for livestock and the migration habits of big game. Hoof prints and other signs should be evaluated to determine which animal caused the damage. Elk use handmade "scalps" (cleared areas for planted trees) as trails through plantations, and they cause trampling damage. Cattle, similarly, use dozer tracks (created during site preparation) as trails through plantations, and they cause seedling damage (Newsome and others, in press). More than one visit to a plantation, therefore, may be necessary to distinguish the difference between livestock and big-game damage.

Trees clipped by rodents have clean, sharp cuts, so it usually is easy to distinguish between damage caused by rodents and damage caused by livestock. Ste'm scars from trampling by livestock and big game, however, can resemble damage in cases where small rodents have removed bark. When trees are damaged by rodents, livestock, or big game, careful examination of the site is necessary to determine which animal destroyed the tree.

Indirect Damage

Livestock have the potential to impair regeneration indirectly by damaging the soil resource and contributing to poor tree performance. A 120-pound sheep exerts ground pressures of 9.2 pounds per square inch, and a 1,350-pound cow exerts ground pressures of 23.9 pounds per square inch when standing on uniform ground

(Lull 1959). On uneven ground or when the animal is walking, the pressures are much greater. Livestock, consequently, can compact forest soils (especially if the soil is wet) and increase bulk densities, thus impairing the root development of seedlings. On grazed lands, pressure from livestock can decrease infiltration and percolation (Wood and others 1987). Surface layers rich in organic matter are resistant to compaction from livestock, but compaction can occur at lower depths.

In addition to causing soil compaction, grazing by livestock can displace soil surface-layers. Grazing when soil conditions are wet can cause rutting. When rutted areas dry, they become hard and support little vegetation (Lull 1959). The surface layers of forest soils are rich in organic matter and are important for maintaining the short- and long-term productivity of a site (Harvey and others 1987). The compaction or displacement of these layers can have lasting effects.

The removal of vegetation by grazing slows forest succession by keeping the understory vegetation in a serai stage (Peek and others 1978). This serai stage, in combination with continual soil disturbance by grazing livestock, creates ideal habitat for pocket gophers (Teipner and others 1983) Grazing by livestock, therefore, can increase the probability of damage from pocket gophers, because it maintains pocket gopher habitat. Pocket gophers often are the major cause of damage and mortality in conifer plantations on transitory ranges that are grazed by livestock or wild ungulates (fig. 5) (Graham and Kingery 1990).

Damage Control

Livestock damage and its effect on regeneration can be minimized by controlling the numbers, distribution, and duration of livestock grazing on an area. The causes of damage to regeneration are mechanical injury caused by trampling (with repeated injuries the foremost cause of mortality), browsing of lateral and terminal shoots of trees, and indirect damage from soil compaction and displacement. Damage can be controlled with silvicultural and range-management methods. Livestock, of all the animals that cause damage and impair tree regeneration, are the problem animals that a land manager should be able to control.

Range Management Methods

Exclusion—Injury can be controlled by temporarily excluding livestock from regeneration areas. Conventional barbed-wire fences and electric-wire fences or electric-polywire fences can be used to exclude livestock from regenerated areas. The advantages and disadvantages of this method of controlling damage by livestock are listed below:

Advantages
1. Easy to implement and administer
2. Likely to succeed
3. Widely used

Disadvantages
1. Expensive
2. High maintenance cost
3. Loss of opportunity for livestock to feed
4. Livestock grazing on forest lands is socially entrenched

Season and duration—Season and duration of grazing may be specified to minimize seedling damage Grazing should end before bud burst in the spring or begin after trees become hardened in the summer or early fall. Grazing should be delayed until soil moisture conditions minimize the danger of compaction and displacement. Season and duration of grazing can be controlled with systems that rotate livestock among different pastures within an area to control the amount of time livestock spend

in a given pasture. This requires permanent or temporary fences, unless natural barriers are present. The advantages and disadvantages of this method of controlling damage by livestock are listed below:

Advantages

1. Livestock graze at proper time for tree and forage development
2. Flexible system, adaptable to many forest and grazing situations
3. May be applied on a landscape level, supplying proper cattle management over a wide area

Disadvantages

1. Costs are higher
2. May require fences to establish pastures !
3. Herders may be needed to move livestock
4. Historical use of land hinders implementation
5. Administrative costs may be high

Distribution—The distribution of livestock can be regulated with pastures, similar to the way duration and season of grazing can be controlled Livestock can be rotated through pastures to minimize animal concentrations that cause tree damage. Animal distribution also can be controlled within grazing pastures or within an entire allotment. Cow-calf pairs have traditional grazing patterns. Turning in pairs at a different location at the beginning of each grazing season will develop a different patt'ern of land use. Grazing yearlings instead of cow-calf pairs also causes more dispersed effects. Yearling cattle have no traditional grazing patterns and disperse throughout the grazing area. Within pastures or allotments, moreover, herders can move stock. The placement of salt, mineral blocks, and water developments can disperse livestock and minimize animal concentrations that cause damage. The advantages and disadvantages of this method of controlling damage by livestock are listed below:

Advantages

1. Full use of the forage resource
2. Flexible system
3. Allotments are grazed at proper time of tree and forage development
4. Landscape approach to livestock management

Disadvantages

1. Historical grazing allotments hinder implementation
2. Costs of fences, herders, and developments
3. Administrative costs

Type of livestock—Cattle and sheep have different forage needs, grazing patterns, and management requirements. Changing the class of livestock on an area would allow more flexibility in the amount and kind of forage consumed and damage caused. More flexible land management is possible with sheep, because they graze more efficiently than cattle on steeper slopes, and they are more suited to sites with a high shrub component. Sheep cause less damage from rubbing and trampling than cattle, and sheep browse to a shorter height. The advantages and disadvantages of this method of controlling damage from livestock grazing are listed below:

Advantages

1. Provides proper type of livestock for the site being grazed
2. Flexibility in the system
3. Potential increase in livestock production

Disadvantages

1. Historical use of grazing allotments hinder implementation
2. Administrative costs could be high
3. Skilled livestock operators may not be available

Grass seeding—Grass seeding can divert livestock from critical areas of regeneration and provide alternative forage for livestock within regenerated areas. Grasses that do not form sod, such as intermediate wheat grass, timothy, and orchard grass, should be used to minimize competition for moisture to the tree seedlings. Roads or the perimeters of regenerated areas could be seeded with palatable grasses to divert livestock from tree-regeneration areas and reduce the threat of damage. Seeding rates also should be reduced to minimize competition (5 to 10 lb/acre). The advantages and disadvantages of grass seeding as a method of controlling damage by livestock are listed below:

Advantages

1. Maintains soil stability
2. Encourages greater selection of forage for grazing animals
3. Assists in the control of competing vegetation for regeneration

Disadvantages

1. Cost
2. Potential competition for seedlings on sites where moisture may be limiting

Silvicultural Methods

Location and size of unit—Location and size of harvest units should be considered in relation to livestock movements within grazing allotments. Traditional grazing routes should be recognized as areas of high potential for damage from livestock. In regenerated areas grazed by livestock, damage on northerly aspects is less than on southerly aspects, and damage increases as the steepness of the slope decreases. Livestock also concentrate in small openings in the forest and increase the potential for damage to seedlings. The advantages and disadvantages of this method of controlling damage from livestock are listed below:

Advantages

1. Inexpensive
2. Integrated approach to livestock and forest management

Disadvantages

1. Stand location may not be flexible because of topography, access, or stand conditions
2. Limited effectiveness
3. May not meet management objectives

Regeneration method—Regeneration methods that minimize forage production (maintain high forest cover) decrease livestock grazing and minimize seedling damage. Livestock would graze less on sites with individual-tree selection and irregular shelterwoods than on sites with clearcuts and group selection (fig. 6). The advantages and disadvantages of this method of controlling damage from livestock are listed below:

Advantages

1. An integrated approach to livestock and timber management
2. Inexpensive

Disadvantages

1. Stand conditions usually dictate regeneration method
2. Loss of livestock forage
3. Limited effectiveness

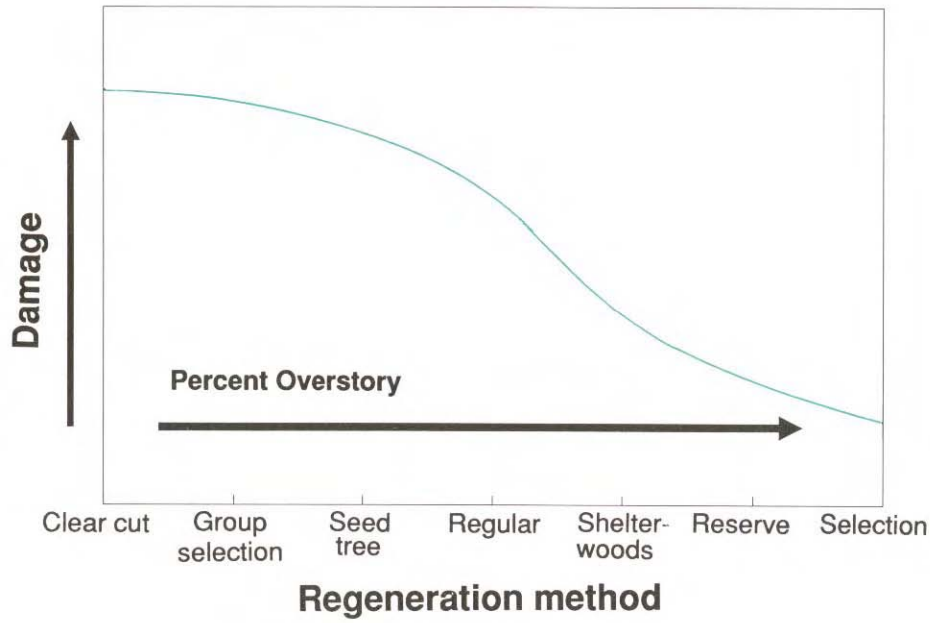

Figure 6—The relation between potential livestock damage and regeneration methods

Site preparation method—Site preparation is a major factor controlling the amount and kind of vegetation that becomes established after timber harvesting. Sites can be prepared for tree regeneration with mechanical, fire, and chemical methods. All three methods create different forage conditions, depending on the site. The method that minimizes favorable forage production also minimizes regeneration damage by livestock. The amount of large woody debris left on a site also can restrict livestock grazing in an area (fig. 7). The leaving of 10 to 15 tons per acre of large woody material after harvesting, furthermore, is highly beneficial for maintaining long-term productivity. Site preparation that develops natural corridors (dozer tracks, windrows, etc.) through regeneration areas should be avoided. These corridors often are used by livestock as travel lanes; therefore, they increase the probability of damage to regenerating trees. The advantages and disadvantages of this method of cpntrolling damage from livestock are listed below

Advantages

1. Direct impact on livestock use
2. Integrated approach to managing livestock and regeneration
3. Down woody debris is important for long-term productivity
4. Cost savings

Disadvantages

1. Administrative costs
2. Difficult to achieve desired results
3. Limited effectiveness

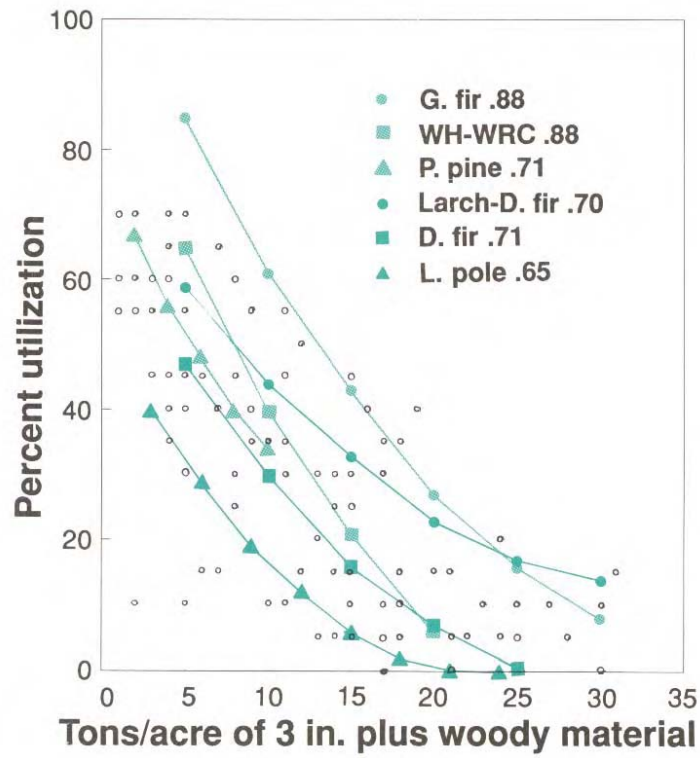

Figure 7—The percentage of utilization of forage by livestock in relation to the amount of large (>3 inches) woody material left after harvesting for common forest types of the Northern Rocky Mountains: grand fir (G Fir), western hemlock-western redcedar (WH-WRC), ponderosa pine (P Pine), western larch-Douglas-fir (Larch-D Fir), Douglas-fir (0 Fir), and lodge-pole pine (L Pole)

Planting **stock**—In areas considered at risk to livestock, planting is preferable to natural regeneration. It is important to establish trees quickly by planting vigorous, healthy trees in a manner that permits them to establish and grow rapidly. It also is desirable to plant with large stock that are less vulnerable to damage from livestock. This usually can be achieved by planting large bare-root stock (at least 2-0 seed-lings) The advantages and disadvantages of planting large stock as a method for controlling damage from livestock are listed below:

Advantages
1. Proven effective

Disadvantages
1. Cost
2. Large planting stock is more difficult to handle and plant

Protection—Physical and chemical protection has limited potential for controlling livestock damage. Plastic tubing deters livestock from browsing on trees (especially bud caps for terminal leader protection) and gives some protection from trampling. Repellents developed for wild ungulates have similar results with livestock, although their potency and retention depend on onsrte weather conditions. The advantages and disadvantages of protection as a method for controlling damage from livestock are listed below.

Advantages
1. Ease of use
2. Effective for other animals

Disadvantages
1. Cost
2 Limited effectiveness

Conclusions

In a new perspective on land management, grazing seasons and grazing intensities must be flexible if livestock are to be integrated into silvicultural systems. The silvicultural system, likewise, should include methods of determining livestock distribution, class selection, and grazing seasons that are designed to minimize tree damage. Sites where conflict between livestock and tree regeneration is suspected require careful diagnosis as to the causes of seedling damage and mortality. Rodents, big game, diseases, drought, and livestock all can interact to cause plantation failures, and it often is easy to attribute failures to one or two "obvious" causes. A complete and proper silvicultural system including grazing plans, therefore! should be prescribed to meet compatible resource objectives and prevent failure of regeneration. Good silvicultural prescriptions are needed on all sites, but where conflicts between livestock grazing and tree regeneration are likely to occur, good silvicultural prescriptions are critical.

Successful forest management requires ecologically sound silvicultural systems to produce a multitude of desired future conditions. This New Perspective of forest management will require innovative methods of producing livestock and timber. These methods must be biologically sound, socially acceptable and applicable on a landscape level. Several real or perceived administrative constraints, however, apparently hinder the development of these integrated systems of management for livestock and other forest resources. These constraints must be lifted and the conflicts among livestock grazing, timber production, and other forest uses must be resolved before silvicultural prescriptions on transitory and permanent forest ranges can be successfully implemented.

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SECTION FIVE
INTEGRATED SILVICULTURAL PRESCRIPTIONS

Chapter 18
The Process of Managing Animal Damage

WALTER H. KNAPP AND J. DOUGLAS BRODIE

Abstract

Animal damage management is part of a larger process, the silvicultural prescription. The prescription is a natural resource application of adaptive management! which outlines the existing situation, identifies steps leading to a desired future condition, and provides for monitoring and readjustment of the system where needed. The activity of animals is considered to cause "damage" only where it adversely affects the achievement of resource objectives Information from monitoring can be analyzed quantitatively to evaluate how the system is performing. This chapter presents an example of a growth and yield simulation model in conjunction with an optimization model. Recent changes in forest management require that multiple scales of analysis be incorporated within the process, and that both stand- and landscape-level factors will affect decisions regarding animal damage management

Keywords: Silvicultural systems, silvicultural prescriptions, adaptive management, economic analysis, dynamic programming, animal damage management.'

WALTER H. KNAPP is regional silviculturist, U.S. Department of Agriculture, Pacific Northwest Region, Portland, OR 97208
J. DOUGLAS BRODIE is professor of Forest Economics, Department of Forest Science, College of Forestry, Oregon State University, Corvallis, OR 97331.

Goals and Objectives

Before the silviculturist evaluates the process of managing animal damage, it is important to put the subject into proper perspective: The management of animal damage is not an independent process or a separate objective of management. Silviculturists, furthermore, should be concerned about animal damage only in the context of land and resource objectives. Our intent is not to minimize animal damage, but to meet resource objectives. This perspective lies at the heart of the definition of silviculture:

> Silviculture is the art and science of managing forest stands to meet resource objectives.

This definition does not identify a particular resource as the main objective of management, nor does it show a specific intent to minimize animal damage. If animals feed upon or otherwise impact vegetation, the result from a management perspective is damage only if it adversely impacts our capability to reach the resource objectives. The primary objectives on many lands are scenic quality, recreational values, or wildlife habitat—attributes that are not necessarily affected by animal damage.

The Silvicultural Prescription

The silvicultural prescription has become a focal point for acquiring knowledge of the stand, and for defining objectives for management, and actions needed to reach a desired future condition. The prescription provides a framework for monitoring feedback and adapting management actions to meet changing conditions and responses It can provide a basis for addressing management issues on larger, multi-stand or landscape scales. The prescription, finally, offers a useful process for integrating animal damage management into a broader management perspective (see discussion of integrated forest protection in chapter 3).

The steps toward development and implementation of a silvicultural prescription generally include:

1. **Statement of specific goals and objectives**—The objectives should be as clear and quantifiable as possible.

2. **Description of abiotic and biotic conditions**—Particular attention should be given to forest-stand structure, composition, and stability.

3. Development of desired future condition—This should not be a nebulous statement; instead, it should describe the target stand in measurable terms at key intervals into the future to allow for adequate assessment and monitoring.

4. **Development of suitable alternative silvicultural systems—**Traditional silvicultural systems have been effective in many areas, but silviculturists should not be constrained by traditional approaches; instead, they should base the recommended systems on the dynamics of stand development. An excellent coverage of forest-stand dynamics is included in Oliver and Larson (1990).

5. **Projection of alternatives through time**—Alternatives, ideally, should be projected with suitable growth and yield simulation models, but where such models are not available, the silviculturist can still make reasonable assessments of changes in structure and composition through an understanding of stand and landscape dynamics.

6. **Evaluation of alternatives**—A variety of tools are available, including decision-tree analysis (Knapp and others 1984), various expert systems, as well as more subjective approaches In the decision-tree method, the analyst identifies possible decisions and assigns probabilities of different outcomes. Probabilities may derive from data or from subjective evaluations by experts. Expert systems may be considered a subset of the broader area of artificial intelligence. Expert systems use combinations of data and expert opinion (the knowledge base) as tne foundation for recommendations. This field, apparently, has great potential for technology transfer in natural resource management, which certainly includes silviculture. Regardless of the method, the silviculturist must clearly identify the rationale behind the evaluation; otherwise, it is unlikely that later problems will be identified and corrected.

7. **Selection of best choice alternative**—If the previous step is carried out logically and with supportable rationale, then this step is straightforward. The methods described above (decision-tree analysis and expert systems) often include analysis of subjective, qualitative decision factors as well as direct or commodity-related outputs Many decisions require additional assessment of nonmarket resources. Analysts often assess opportunity costs to evaluate these differences. Opportunity costs focus on quantifiable differences—generally volume or value—resulting from selection of a particular treatment or prescription. Such techniques are useful, but they still do not provide the decisionmaker with rationale to decide if the tradeoff is worth the cost.

8. **Implementation of best choice alternative**—This often is described as the implementation plan, and it contains the operational specifics needed to get the job done.

9. **Monitoring and feedback—**These steps identify thresholds of concern where the stand or landscape is not on the path to the desired future condition. It suggests remedial action—a contingency plan—where needed. This could be a minor activity, or it could entail a revision of the silvicultural system to correct flaws.

Adaptive Management

Most of these prescription-development steps are well understood by silviculturists, but the process too often ends with the implementation phase. In many cases where monitoring has been done, silviculturists have not had well-defined standards or processes that permit a timely change of course

Monitoring of growth and survival in a plantation, (or example, often reveals an onset of animal damage. What process does the silviculturist use to assess the potential for damage, the damage itself, the species responsible for the damage, the need for control, control options, subsequent evaluation of the control treatment, and the correction to the silvicultural system? That process currently is known as adaptive management.

Adaptive management can be described as a midcourse correction process characterized by

- constant monitoring of the state or condition of a product during its development, such as the number of trees browsed by deer and the timing of the browsing activity

- distinction between normal and abnormal or unacceptable variation, often determined from quantitative analysis such as yield tables
- correction of abnormal or unacceptable variation and identification of underlying causes
- readjustment of the system where needed, such as development of modified silvicultural systems
- applicability of the concept at both the operational and the systems level (see Siuslaw National Forest case example)

Adaptive management is retrospective, but the process only works if key monitoring parameters and their threshold values are identified in advance. A description of the adaptive management process is included in Oliver and others (1991).

A Siuslaw National Forest Example

An example of adaptive management took place on the Siuslaw National Forest in western Oregon several years ago. Douglas-fir seedlings in plantations were heavily damaged by mountain beaver and elk. In response to the damage, silviculturists began to protect seedlings with plastic (Vexar) tubing and netting. The Vexar successfully protected the seedlings and the practice of tubing, consequently, became a standard reforestation procedure on the Forest.

Was the practice, however, truly effective? It was only effective on some areas, and in some respects. On many areas, even unprotected conifers were not likely to be damaged, and the desired future condition could be met without the expense of tubing. Silviculturists and wildlife biologists found that preplanting surveys and analyses could successfully predict the likelihood of damage. Important variables included stand location, treatment history, stand size, plant community and vegetative condition, and animal population and use patterns.

Silviculturists were able to distinguish between high- and tow-risk areas by following the silvicultural prescription process. Protection programs, consequently, were adjusted to cover only those areas at high risk. Silviculturists who designed the process for the Siuslaw National Forest recognized that the management objective was to establish a vigorous new stand, not to control animal damage. The objective could be met at substantially lower cost, furthermore, by using Vexar tubing or netting only where necessary.

Silviculturists, thus, identified a management system that was responsive to resource objectives. They then tested the system by monitoring the results. The system was adjusted as a result of the monitoring, and only those areas in need were treated

The story does not end here. The changing scene in forest management has resulted in new conditions. First, environmental concerns and restrictions have limited the use of fire and herbicides for vegetation management in some areas. Secondly, the size of harvest units has decreased substantially. Both of these changes have improved habitats for mountain beaver and elk by increasing the amount of edge and vegetative cover. As a result of these habitat changes, many more harvest areas need to be protected. With continuous monitoring of key conditions, however, forest managers were able to adjust the management system appropriately.

The silvicultural prescription successfully introduced adaptive management through a process of monitoring feedback and change to ensure that the Forest remained on the path toward its desired future. As the stand develops, however, the adaptive process must continue (Turpin, Thomas, personal communication).

Current Changes in Management and Silviculture

Additional changes are now taking place on all of the National Forests in the Pacific Northwest. Management practices at the stand and landscape levels are being modified under labels such as "new forestry" or "new perspectives in forest management." In many cases in western Oregon and Washington, areas that would have formerly been clearcut and burned now are left with reserved trees and little or no broadcast burning. Woody debris is left on site intentionally, and disturbance is substantially less than with traditional practices.

How will wildlife populations respond to these changes in habitats? Conversely, how will the changed habitats respond to the wildlife populations? Will we still be on a course toward our desired future condition? Silviculturists and wildlife biologists need to give special attention to these sweeping changes in management practices and conditions. Monitoring and adaptation of management practices will be more important than ever before.

Quantification of the Process

How does the silviculturist or analyst evaluate the information gathered during monitoring, and how are the results of animal damage surveys used to adjust the management system? One example has been provided by Brodie and Yoshimoto (1991), who analyzed the effects of four different prescriptions on two hypothetical Douglas-fir sites. They assessed the effects of these treatments on mortality, diameter growth, height growth, volume, value, and rotation. The prescriptions included integrated treatments (animal damage control and vegetation management), animal damage control only, vegetation management only, and no treatment. The evaluations were developed for a very high-quality site (site class I) and a good-quality site (site class II). The analysis did not include actual stand data; therefore, it is most useful as a process for evaluating the effects of damage control on volume and value.

The analysis process followed several steps:

1. For each of the different types of treatment, evaluate the changes in tree mortality, diameter loss, and height loss Although these changes were based on assumptions in this analysis, in reality they would be obtained from representative survey data.

Table 1 shows hypothetical stand conditions at age 20 that would result from the four prescriptions on the two sites. Integrated treatments comprised of vegetation management and animal damage control give maximum tree survival, diameter'growth, and height growth. Vegetation management only results in slightly higher mortality and suppression of diameter growth, while animal damage control alone adds to both mortality and diameter-growth suppression, and competition also suppresses height growth. If neither animal damage control nor vegetation management is applied, further mortality and diameter- and height-growth suppression occur.

Table 1—Hypothetical stand conditions at age 20 years with different silvicultural prescriptions on site-classes 145 and 160

Prescription	Site class 145			Site class 160		
	Trees per acre	Average diameter	Average height	Trees per acre	Average diameter	Average height
		Inches	*Feet*		*Inches*	*Feet*
Animal damage control and vegetation management	300	7.0	50	300	8.5	65
Vegetation management only	285	6.0	50	285	7.5	65
Animal damage control only	270	5.0	45	270	6.5	55
No animal damage control	255	4.0	45	255	5.5	55

Twenty-year-old stands are not merchantable and must be projected to determine long-term impacts. Economic as well as physical volume projections are required. These predictions are based on the economic values in table 2 and on the current physical condition of the stands at age 20. Note that one of the effects of lack of treatment is diameter-growth suppression and the values used include a higher unit value (per thousand board feet) with increasing average diameter of trees. No costs have been included for the vegetation management or animal damage control; therefore, the gains reported later would have to be adjusted for these costs. Break-even values for treatment versus no treatment, alternatively, could be established with these gains.

Table 2—Stumpage price for stands of various average diameters and associated economic value for long-term predictions of scenarios shown in table 1

Average diameter	Stumpage price	Regeneration cost	Thinning Stumpage	Entry cost	Interest rate
Inches	*Dollars/MBF*	*Dollars/acre*	*Relative price*	*Dollars/acre*	*Real percent*
Q	100	*200*	0.8	10	4
12	150	200	0.8	10	4
16	200	200	0.8	10	4
20	250	200	0.8	10	4

2. The growth of the stand was projected for each of the modified conditions. This analysis used SPS (stand projection system) (Arney 1985), an individual-tree, distance-independent simulation model.

Other stand-simulation models also could be used, depending on the conditions being addressed and the geographic area of interest. Models of the individual-tree, distance-independent form are well suited to stand-level analysis where detailed

information is important to the analysis. These models track species composition and stand structure as well as growth and yield.

Models that deal with the development of the early stand are particularly useful for evaluating the effects of animal damage management. These models generally project the stand's development from its inception until it reaches some benchmark height (such as breast height) or age (such as 20 years). Many of the agents affecting early stand development are random in their nature; therefore, these models tend to include some recognition of probabilities of various events or actions. Early stand-development models are not widely available at the present time, but efforts are underway to develop such tools. One recent example is PSME (plantation simulator-mixed evergreen), a young-stand growth model for Douglas-fir and hardwoods in southwestern Oregon (Harrington and others 1991).

3. The management regime that would give the best return (volume or financial) was determined with 80S (stand optimization system) for each treatment type (Yoshimoto and others 1988). 80S, a dynamic programming algorithm'that optimizes the SPS simulation, was used in the examples. In practice, steps 2 and 3 were combined. The net results are shown in table 3, which summarizes the results of the projections in terms of average diameter, rotation length, 'and soil expectation value.

Table 3—Comparison of the results of prescriptions shown In table 1 with average diameter, rotation length and soil-expectation values lor each site-class

	Site class 145			Site class 160		
Prescription	Soil expectation values	Rotation length	Average diameter	Soil expectation values	Rotation length]	Average diameter
	Dollars	*Years*	*Inches*	*Dollars*	*Years*	*Inches*
Animal damage control and vegetation management	1047	50	13.5	2169	50	16.7
Vegetation management only	789	50	126	1563	50	14.7
Animal damage control only	537	60	13.4	1147	50	13.7
No animal damage control	465	50	12.1	894	50	13.2

Additional information on diameter distribution or cash flow also could be reported. The results show fairly substantial gains resulting from treatment that should be well in excess of silvicultural cost. There also are substantial gains in average diameter; however, rotation length was sensitive to treatment in only one instance.

4. Differences in production were analyzed to determine the value of treatments. Detailed results of independent and joint treatments are shown in table [4.

Table 4— Gains from treatments attributed to independent, joint, and interaction effects when compared with no pest management

Treatment variables		Gains in mean annual increment for site class 145	Gains in mean annual increment for site class 160	Gains in soil-expectation for site class 145	Gains in soil-expectation for site class 160
		Bd ft/(acre-year)	*Bd ft/(acre-year)*	*Dollars*	*Dollars*
Vegetation management only		156	365	320	669
Animal management only		108	120	67	253
Sum	(A)	264	485	387	922
Joint treatments	(B)	270	620	577	1275
Interaction	(B-A)	4	135	190	352

The silviculturist or manager can determine from these tables the stand-level values that could be expected from the different treatments. Physical production of wood and financial return are important criteria, and these techniques can be used to determine them (tables 3 and 5).

Table 5— Rotation growth and yields for the sites and treatments

Silvicultural prescription	Growth and Yield: Site class 145			Site class 160		
	Value per thousand board feet	Rotation	Mean annual increment	Value per thousand board feet	Rotation	Mean annual increment
	Dollars	*Years*	*Bd ft/(acre-year)*	*Dollars*	*Years*	*Bd ft/(acre-year)*
Animal damage control and vegetation management	29.3	50	596	41.2	50	824
Vegetation management only	37.6	50	752	59.5	50	
Animal damage control only	42.3	60	704	47.2	50	944
No animal damage control	29.3	50	596	41.2	50	824

Table 4 also presents the physical and economic gains from the treatments applied either jointly or independently. The independent results are obtained by comparing each single-treatment alternative with the no-treatment alternative. Joint gains are determined by comparing the no-treatment alternative to the integrated-treatment alternative. Interaction gains are obtained by subtracting the sum of the independent gains from the joint gains, and they represent the additional benefit from combining pest-control strategies.

Physical gain from vegetation management is substantial (see table 4) and gain from animal damage control also is substantial, although to a lesser degree. Interaction is minor on site class 145 and substantial on site class 160.

Economic gains are relatively more substantial (as indicated in table 4). This is because cost assumptions are the same for each alternative, but the intensive treatments provide a greater number of large-diameter, higher value trees.

By adding the joint effect plus the independent effect of one treatment, we can evaluate the impact on sustainable, annual volume flow or value per acre that would result if one treatment were precluded. Data for site-class 160 in table 4 indicates that annual volume production per acre would be reduced by 255 board feet per acre per year (135 plus 120) if animal damage control were precluded. The reduction would be 500 board-feet per year if vegetation management were precluded, and 620 board-feet per year if both animal damage control and vegetation management were eliminated.

Other Considerations

In addition to providing data with which to analyze volume and value, growth and yield simulation models can provide information with which to evaluate other attributes of the stand. Some of these stand characteristics may be important for meeting non-commodity resource objectives. How does the analyst determine, for example, the point at which mortality becomes a concern? If animal damage reduces stocking in the juvenile stand, will enough trees remain to provide a closed crown canopy and thermal cover for elk or deer? The model can give a picture of the stand as it is likely to appear at some future time. The structure and species composition of the developing forest ultimately determine how successfully many objectives are met. These conditions can be tested with stand models to evaluate different management strategies, identify areas of concern, and select the regimes most likely to meet management objectives.

Models are useful tools for such evaluations, but they are merely representations of reality and must be viewed with healthy skepticism. The test always is whether trees, stands, and markets really respond as predicted.

Silvicultural Systems

Silviculturists must look beyond the biology of the stand in dealing with animal damage management. An understanding of basic Silvicultural relations is critical, but we must couple that knowledge with a broader view of Silvicultural systems.

The regeneration phase, for example, usually is the most vulnerable part of the rotation. What can silviculturist do to avoid or moderate regeneration risk, including animal damage to young stands?

Many of the plant community guidelines used in western forests include ecological assessments of animal-damage risk (from pocket gophers, for example). Local information can supplement these guides. Where high risk is identified, the silviculturist has numerous opportunities to modify the silvicultural system.

Probably the easiest and most direct method of system modification is to lengthen the rotation. It should come as no surprise that increased rotation length reduces the area regenerated each year. In a regulated forest, the effect is inverse and linear: if rotation is doubled, the acreage regenerated is cut in half. If less area is regenerated annually, therefore, presumably less animal damage will occur during the regeneration phase. This would involve considerable economic tradeoffs, but long rotations are used for various reasons on many public forests. Benefits probably would increase if areas allocated for management on long rotations coincided with areas difficult to regenerate. Similar considerations can be evaluated for other risks incurred at stand regeneration or at other times during the rotation.

Complex scheduling of stands and rotations over long time periods presents a difficult technological challenge, but new tools of analysis are becoming available to assist the land manager. At the core of these tools are Geographic Information Systems (C;S), that provide computer-based resource information and mapping capabilities across broad areas of the forest. Analysis tools that use GIS data could address spatial questions such as which stands should be managed for long rotations. The scheduling and network analysis program (SNAP) (Sessions and Sessions, 1991), for example, currently is used by analysts on forests in the Northwest to develop harvest patterns that include identification of specific stands or treatment units. It provides the capability to schedule stand treatments over space and time, and to develop corridors or connections across landscapes.

In evaluating a silvicultural system, several questions relating to animal damage management should be addressed:

- How will stand density affect the development of animal habitats?
- Are certain tree species more or less susceptible to damage?
- Will continuous high forest cover affect the habitats and behavior of problem animals?
- What is the likely response of the herbaceous layer to proposed systems?

None of these questions can be addressed independently, and the expertise of the wildlife biologist is needed to complete an evaluation. The assessment, as a whole, must be viewed from the perspective of all resource objectives and desired future conditions.

One present limitation of most analyses is that they deal only with the stand level. In today's complex forest-management scene, we must also evaluate our practices at the landscape level. Even animal-damage considerations must be viewed on the broad scale as well as within the stand. If the silviculturist is dealing with deer damage within a migration route, for example, the silvicultural system must consider more than just the need to protect individual trees or stands; the migration patterns also must be evaluated on the landscape scale.

Key Points

This chapter has addressed several key points relating to the process of managing animal damage:

- The process should be viewed as an integrated management system.
- The system is centered within the silvicultural prescription.
- Adaptive management is a cornerstone of the system, especially monitoring, feedback, and corrective action.
- Both stand and landscape scales must be addressed.
- A range of expertise and many resource specialists must be involved in an interdisciplinary approach because of the complexity of management.
- The objective of the system is to achieve a desired future condition. Animal damage must be controlled only where it would jeopardize reaching the desired future condition.

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SECTION FIVE
INTEGRATED SILVICULTURAL PRESCRIPTIONS

Chapter 19
Modeling Systems for Prescription Development

WILLIAM C. McCOMB

Abstract

Models are abstractions of real processes and relations. They enable land managers to test management strategies, follow the results through time, and synthesize pertinent information that otherwise would not be readily available Given the complexities of multiple-use management and multiple wildlife species, models are increasingly important components of land-management planning for the production of future, healthy forests.

Habitat occupancy or quality is indexed on the basis of perceived or actual changes in the presence, abundance, or fitness of a species and its relation to habitat structure and composition. Wildlife habitat relations models provide a list of species that, potentially, could occupy a habitat type. Habitat quality models can take several forms. Habitat suitability models provide an index to the potential of 'a habitat to support a given population level for a selected species. Spatially explicit models portray habitat quality over stands within a forest. Habitat development models usually are those based on stand dynamics models. At any point in time, predictions of changes in plant-species composition and structure can be evaluated

WILLIAM C. MCCOMB is wildlife biologist, Department of Forest Science, Oregon State University, Corvallis, OR 97331.

by habitat-occupancy or habitat-quality models. Spatial models linked to habitat-dynamics models can illustrate changes in habitat suitability over space and through time. Given this type of information, expert systems models can help managers plan actions to solve current or future problems. Expert systems models also may be used to diagnose problems and classify habitat quality

Models are fallible. The quality and performance of a model is dependent on the quality of the information used to develop relations within the model and their applicability to specific circumstances. Models should be thoroughly documented, reviewed, and tested before application. Models should be selected and interpreted with care to ensure that managers have the most appropriate models to complete a task.

Keywords: Artificial intelligence, decision support, expert systems, GIS, monitoring, simulation model, wildlife habitat relations, habitat suitability index

Introduction

Managers who plan activities for a forest require the most current information available to predict the types of products they can expect from that forest. Models may assist managers in predicting the production of resources. Those products often include not only timber, but also other nontimber products. This chapter introduces several different types of models and provides some examples The selection of an appropriate model is of vital importance, because models are approximations of real conditions. Managers must interpret the results of their model, and if the results do not seem to make sense, they must alter the model or find another management tool. Models only now are being assembled to help forest managers with animal damage problems, so this chapter explains several approaches to modeling that will enable land managers to begin developing a framework for models that they may need to better manage forest lands. Much of the necessary information is now at hand to provide guidance to land managers and enable them to manage timber with a high probability of controlling animal damage within acceptable limits. The challenge is to provide the land manager with information that has a high likelihood of being used and adapted to local conditions.

Models are increasingly accepted as tools for understanding complex processes and relations. A recent compendium of papers dealing with the modeling of wildlife-habitat relations is a good example (Verner and others 1986). Marcot and others (1989) differentiated among computer programs used for monitoring, modeling, or decision support. Monitoring includes documentation of management effectiveness. Keeping track of seedling survival within plantations is a type of monitoring that can provide valuable reference information for checking the applicability of a model to an area See Marcot and others (1989) for a more detailed discussion of monitoring.

Types of Models

"Model" typically connotes a complex series of equations and functions tied together in the mysterious "black box" of a computer. There are, certainly, very complex computer models, but these are just one of many types of models that can help land managers be more effective at their job. A model is simply a representation of some real condition

A map is a spatial model, but it can be a generalized representation of the system that only portrays roads, stands, topography, or geology. The computerized counterpart of a map is a Geographic Information System (GIS) that may be able to keep track of many map features and portray them in various combinations on a given map. The maps, therefore, represent the models, and the GIS simply increases the

efficiency of working with large bodies of information in maps. A GIS also has the advantage of quantitatively describing spatial patterns; therefore, it is a tool for modeling spatial relations.

Temporal models probably are quite familiar to most foresters. Stand tables and growth and yield models project stand growth into the future on the basis of a given set of conditions at stand initiation (site index and stocking density, for instance). These two types of models (maps and stand tables) are spatial and temporal models. They also are models of structure (maps) and processes (stand tables).

Decision support is the third type of modeling tool that often aids managers in their job. This book is a decision-support model in that it is a compilation (synthesis) of information from different sources that represents our state of knowledge about vertebrate pest management in managed forests. Even the information in this book, however, can be overwhelming, and managers may use a simplified version of the book (see Index or Contents) to locate the information they need Information management with expert systems-models is a new tool for more efficient retrieval of specific information. "Artificial intelligence" is the popular term for this type of procedure, but the model designer must supply all the correct information, just as the author of a book must do.

Modeling can be an important part of the scientific method. Researchers analyze a problem by researchable topics, and each topic contributes a bit of information to the solution of the entire problem. Models can take the bits of information and put them together in a manner that may help researchers better understand the structure or function of the problem. In so doing, models can identify missing or weak pieces of available information and help direct research that fills in the gaps.

Habitat Prediction

It is important for land managers to distinguish between predictions of habitat quality and habitat occupancy, because that distinction affects the type of model and tljie level of detail that they will need. Prediction of habitat occupancy requires an understanding of the probability of occurrence of a species at a site with certain habitat features but with no assumptions regarding the potential abundance of individuals at the site. If an examination of 100 Douglas-fir stands in a shrub-stage stand condition in the Coast Range, for example, shows that mountain beaver are present in 90 stands with shrub cover >20 percent, and that shrub cover on the 10 stands without mountain beavers was <20 percent, then a habitat-occupancy relation has been established. The 90 stands with mountain beavers may reflect a wide range of population densities. The amount of shrub cover may be useful for identifying those stands most likely to have mountain beaver, but it tells nothing about the level of damage that might be expected in stands with mountain beaver.

Habitat quality, typically, is defined as the potential for habitat to support a certain population. Habitat quality is linearly related to potential population density and indexed on the basis of life requisites for the species (typically attributes of food and cover). Relations between life requisites and animal abundance usually are based on indices of the abundance of a species in an area and the associated habitat features that affect the availability of food and cover. Biologists usually assume that areas with a high abundance of animals are areas with high-quality habitat. This is probably a valid assumption for some species. Low density of animal species that are strongly territorial, however, may indicate an area of high-quality habitat, because dominant individuals exclude many subordinates from the best habitat and relegate them to

areas of lower-quality habitat (see chapter 13, this volume, for an excellent example). Van Home (1979) and others, consequently, suggested that estimates of fitness (survival and reproduction) are better indicators of habitat quality than are estimates or indices of abundance. Estimates of animal fitness are often difficult and expensive to obtain, however, so animal abundance or probability of occurrence usually are used as indices of habitat quality. Land managers, however, should be aware of the problems associated with these approaches.

Predictor Variables

A feature common to models of habitat occupancy and habitat quality is the need to identify and parameterize specific habitat characteristics that correlate with the presence or abundance of a species. These, generally, are structural or compositional features that can be objectively measured and that reflect some direct or indirect association with life requisites. It is imperative, therefore, that managers understand the life history of each species being modeled before they predict what those life requisites will be and how changes will influence patterns of animal abundance. The west-side habitat effectiveness index (HEI) elk-model of Wisdom and others (1986) is a good example. Size and spacing of forage and cover areas, density of roads open to traffic, cover quality, and forage quality are combined into a habitat-effectiveness index associated with the potential population of elk in the planning area (fig. 1). Wisdom and others (1986) assumed that any of these four features could become the overriding factor that limits elk abundance in an area, so the manner in which these variables are combined (geometric mean) and the interpretation of the index must reflect this assumption.

Model Scale

Land managers should define the area over which information is needed before they select the appropriate model to help them predict changes in habitat quality or habitat occupancy over time. They also must define the level of detail for the information that they need. The stand might, at first, seem to be the appropriate scale, but the effect that within-stand features might have on habitat quality for some species should be considered (see table 2, chapter 5, this volume). Species with small home ranges (such as mountain beaver, pocket gophers, and voles) are likely to be more strongly influenced by these features than are species with larger home ranges (fig. 2).

Evaluation of habitat occupancy or quality for mountain beaver may be evaluated sufficiently for management purposes at the stand level. Aggregating information over stands, however, may be useful for predicting the potential, regional populations of mountain beaver. Information about habitat conditions over several stands may be essential to evaluate the probability of habitat occupancy or quality for other species (such as snowshoe hare) that use edges as primary habitat.

The home ranges of deer or elk often span many stands, so the probability of habitat occupancy or quality should be evaluated over large areas (1,000-6,000 acres for elk). This scale obscures the details of habitat at the stand level, and the gross characteristics and patterning of stands, edges, and habitat govern the prediction of habitat occupancy or quality (McTague and others 1989).

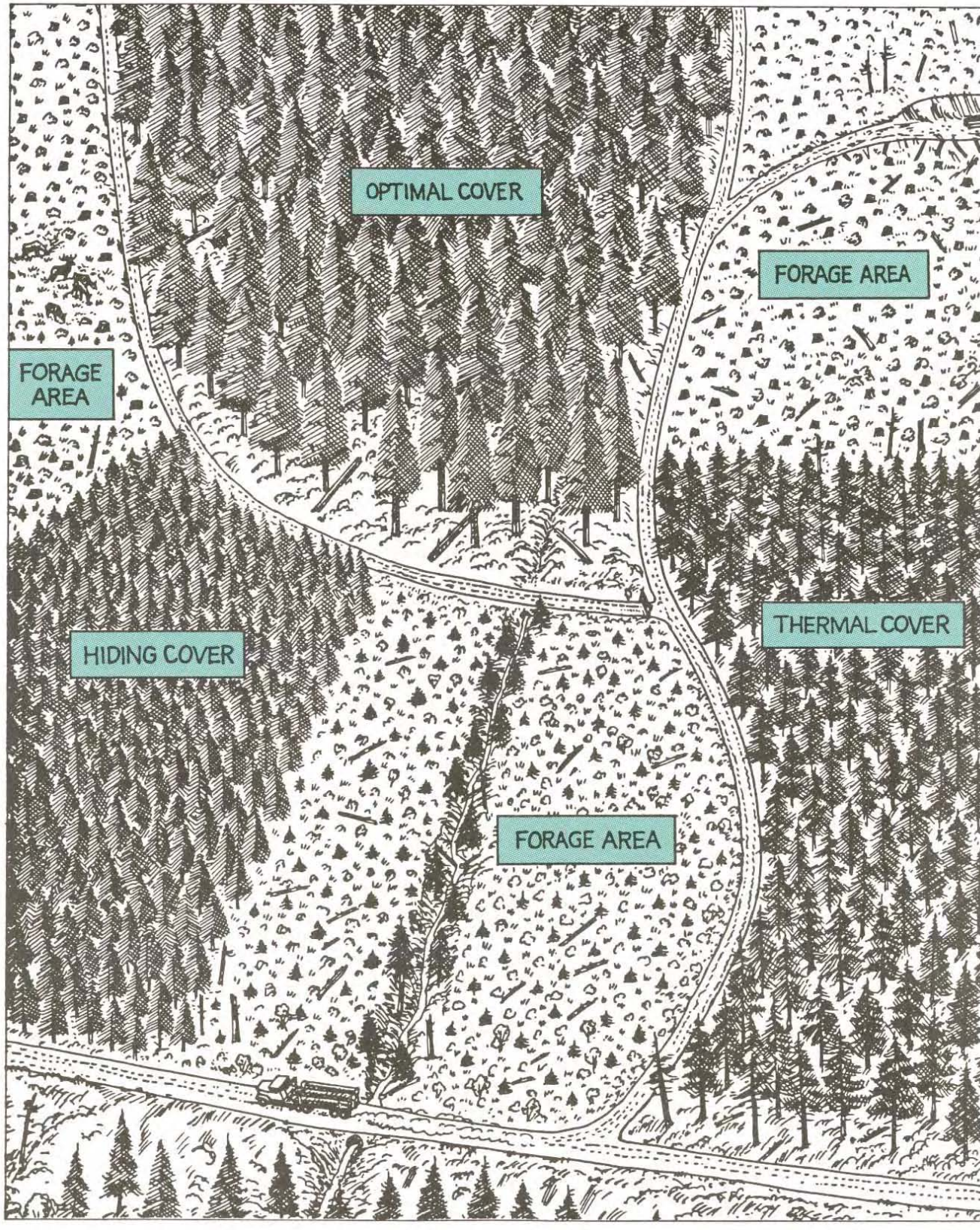


Figure 1—Landscape view of an even-aged, managed forest in western Oregon (from Wisdom and others 1986)

Figure 2—Relation between the size of the home range of an animal and the spatial scale of the model appropriate for evaluation of habitat relations

Habitat-Occupancy Models

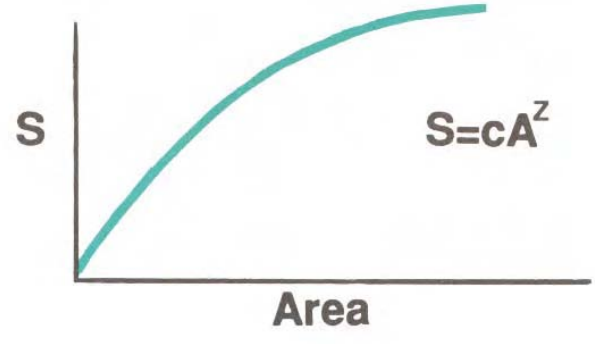
Wildlife Habitat Relations Models

One type of commonly used model that predicts the potential for habitat occupancy is the wildlife habitat relations (WHR) model first proposed by Thomas and others (1976). This model assigns species to certain stand conditions within a series of plant communities to create a list of species that could use a stand, given the stand condition, plant community, and the presence or abundance of some special habitat features (snags, logs, riparian areas, etc.).

The disk enclosed with this book includes a spreadsheet (ADM.WK1) that runs in LOTUS 1-2-3 and is based on information provided in Brown (1985) for species of common vertebrate pests in western Oregon. Forest managers concerned about ascertaining whether animal damage could occur in a stand can refer to this spreadsheet and delete the records of species not present in the target area. The spreadsheet can be sorted by the type of use that a species may make of the stand (breeding, resting, or feeding) and by the level of use (primary, secondary, or none) that each species makes of the plant community and stand condition that best describes the target stand. The spreadsheet then provides a list of the species that could occur in this stand with an estimate of home range, reproductive potential, and special habitat features for each of those species.

The disk also includes another example of a WHR model for amphibians (AMPHIB.WK1) that enables forest man-agers to create a list of nonpest species that might also be using the stand It is important to remember that the list of species represents the species that *could* occur in a stand and not the species that *would* occur in a stand Stand size, among many other environmental, site, and landscape conditions, also influences the number of species thai could occur within any given stand (fig. 3).

Figure 3—Species-area relation As stands become large, they are occupied by more species but at a decreasing rate of species accumulation S = number of species



The next step is to predict the probability of occurrence in the stand for each species. For mountain beaver, for example, chapter 11 provides information to support a guess. The BASIC program "BOOMER.BAS" on the enclosed disk, however, asks questions about the stand and predicts the probability that mountain beavers will be present in the stand. The composite prediction is based on the product of probabilities assigned to each answer to a series of questions. If all aspects of habitat are suitable (could support mountain beavers), then the composite prediction is near 100 percent; departures from suitable habitat reduce the probability of species occurrence. Once the stands with high probabilities of having mountain beaver have been identified, the number of animals that could be supported in those stands can now be predicted with a habitat-quality model.

Habitat Quality Models

Habitat Suitability Index Models

Habitat suitability index (HSI) models have been developed for a wide variety of species by the U.S Fish and Wildlife Service. They can take a number of forms, but most often they predict the quality of habitat (a suitability index) for each of several habitat' variables that influence food and cover. These suitability indices range from 0 to 1 (see fig. 4a-d for an example with southern red-backed voles) and are combined in an equation that reflects the importance of all habitat variables to the species If all habitat variables are equally important, then the model calculates a composite HSI with a simple arithmetic mean. If any one of the variables represents a limiting factor, however, then the model uses the minimum value as the HSI A geometric mean is calculated in cases where a low value for any one variable greatly reduces habitat quality bijit is not a limiting factor (Wisdom's HEI model for elk, for example). Any combination of these

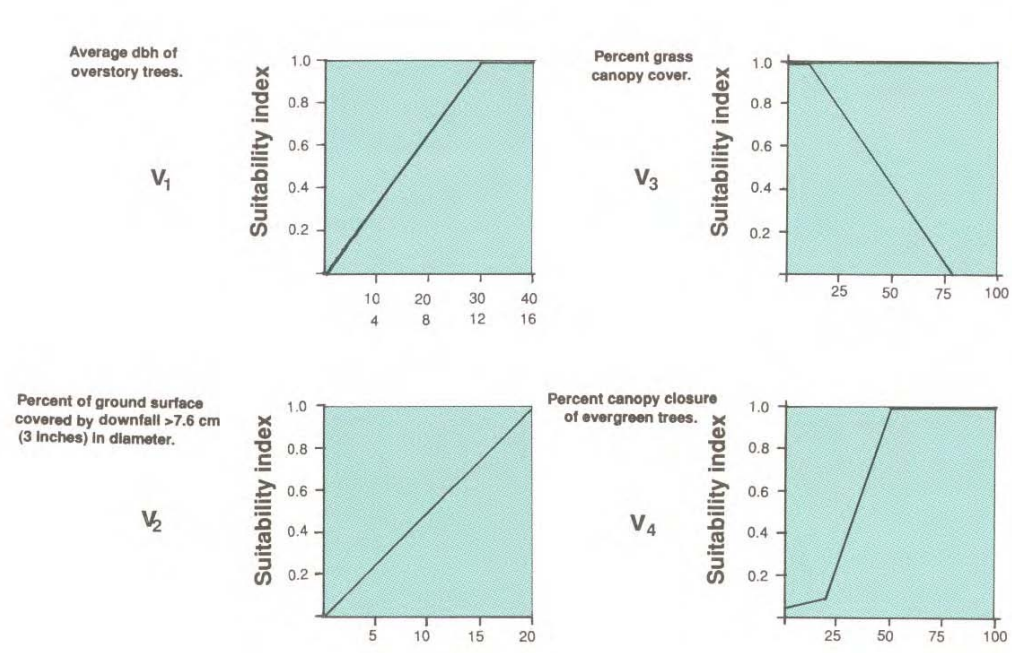


Figure 4—Suitability-index relations for red-backed voles Similar models for common pest-species are unavailable. Source U S Fish and Wildlife Service, HSI model '

techniques may be used. The values for red-backed voles, for instance, are combined as:

$$HSI = (V_1 * V_2 * V_3)^{1/3} * V_4$$

In this example, V4 is given a greater weight than the other variables in the calculation of the composite HSI score.

These types of models are widely used to evaluate habitat quality with respect to mitigation during land-use disputes. Urich and others (1983) developed a computerized version of HSI models that includes a wide range of species that inhabit Missouri. Similar models specific to Northwest forests have not yet been developed.

Pattern Recognition Models

An even simpler type of habitat-quality model is the pattern-recognition model. An example is provided in figure 5. The estimate of habitat quality is based on the pattern of answers to an evaluation An extension of this type of model is the Bayesian probability approach. The potential responses to each question are assigned a value that represents the probability of a high population or a low population. The probabilities associated with each answer are multiplied together to produce a score that is the basis for evaluating overall habitat quality (U.S. Fish and Wildlife Service 1981)

Pattern recognition model to evalute red-tailed hawk food in grasslands.

Variable 1	Variable 2
1. Percent herbaceous canopy cover: A. Less than (or =) 65% B. Greater than 65%	2. Percent of herbaceous canopy between 8 and 46 cm tall: A. Less than (or =) 50% B. Greater than 50%

Answers for pattern recognition model for red-tailed hawk food in grasslands.

Pattern Number	Food Suitability Index	Reason
1. A,A	0.2	Assumed that little food is available because low food supply for small mammals. Also vegetative cover is too thick (where it does exist) for capturing prey.
2. A,B	0.3	Little food available. However, what is available is easier to catch than in situation 1.
3. B,A	0.6	Good supply of food, yet difficult to capture.
4. B,B	1.0	Good food supply which is easy to capture.

Figure 5—Example of a pattern-recognition model for red-tailed hawk (similar models for pest species are unavailable)

Habitat-Development Models

Effective silvicultural approaches to animal damage management depend on the forest manager's ability to predict how habitat quality for certain wildlife species is likely to change after a silvicultural prescription is implemented. One of the first questions that a land manager is likely to ask is, "What is the quality of habitat for species 'x' on a given area now, and how is it likely to change over time?" There are two general types of models that predict habitat quality—static and dynamic. Static models include habitat-quality and habitat-occupancy models. Dynamic models link static models to habitat-development models to portray changes in habitat quality overtime (see Smith 1989).

Changes in habitat pattern and quantities of habitat types should be considered over a scale appropriate to species with large home ranges. Home-range size and the features that affect habitat quality or the probability of occupancy for a species determine the amount of detail needed to predict changes. These considerations, therefore, define the type of habitat-development model needed for a particular situation (fig. 2). Stand-growth and yield models often provide the basis for predicting change in stand conditions over time.

In cases where within-stand features are important to habitat quality, an individual-tree model that aggregates information among trees within a stand may be appropriate. ORGANON is a single-tree model that can be used in mixed-species stands to examine the growth and yield of individual trees within a stand. The purpose of the model is to predict timber yields, so it has only limited utility for predicting changes in habitat. Shrub growth, for instance, may be important to mountain beavers, but it would not be accurately predicted with typical models of stand growth and yieldl Several models are available that are useful for evaluating within-stand features. Shrub cover can be predicted with the COVER extension of the PROGNOSIS growth and yield model, which is a single-tree model (Moeur 1986).

Marcot's snag recruitment simulator (SRS) model is a spreadsheet that runs in LOTUS 1-2-3, keeps track of individual snags within a stand, and allows the user to examine the number of snags by size class and decay class over time. One form of snag recruitment is through tree mortality, and this information is gathered with models of stand growth and yield (such as DFSIM or ORGANON). Models for recruitment of logs also are available (Van Sickle and Gregory 1990).

A more complex modeling system, such as ZELIG (Smith and Urban 1988) or CLIMACS (Dale and Hemstrom 1984), documents the establishment, growth, and mortality of each tree (and shrub, if data are available) within a small, model plot (<0.2 acre). This model also projects the vertical complexity of foliage within the' plot—a feature that could be important to some wildlife species and communities (MacArthur and MacArthur 1961).

Changes can be portrayed on maps at incremental periods for species requiring large scale analyses or for assessments of species with small home ranges over large areas. GIS is one tool for accomplishing this objective. Map layers that include road systems could be refined with a categorization of stands into forage and cover types to identify the four features that would allow calculation of the HEI for elk over a subbasin, for example (Wisdom and others 1986, see fig. 6).

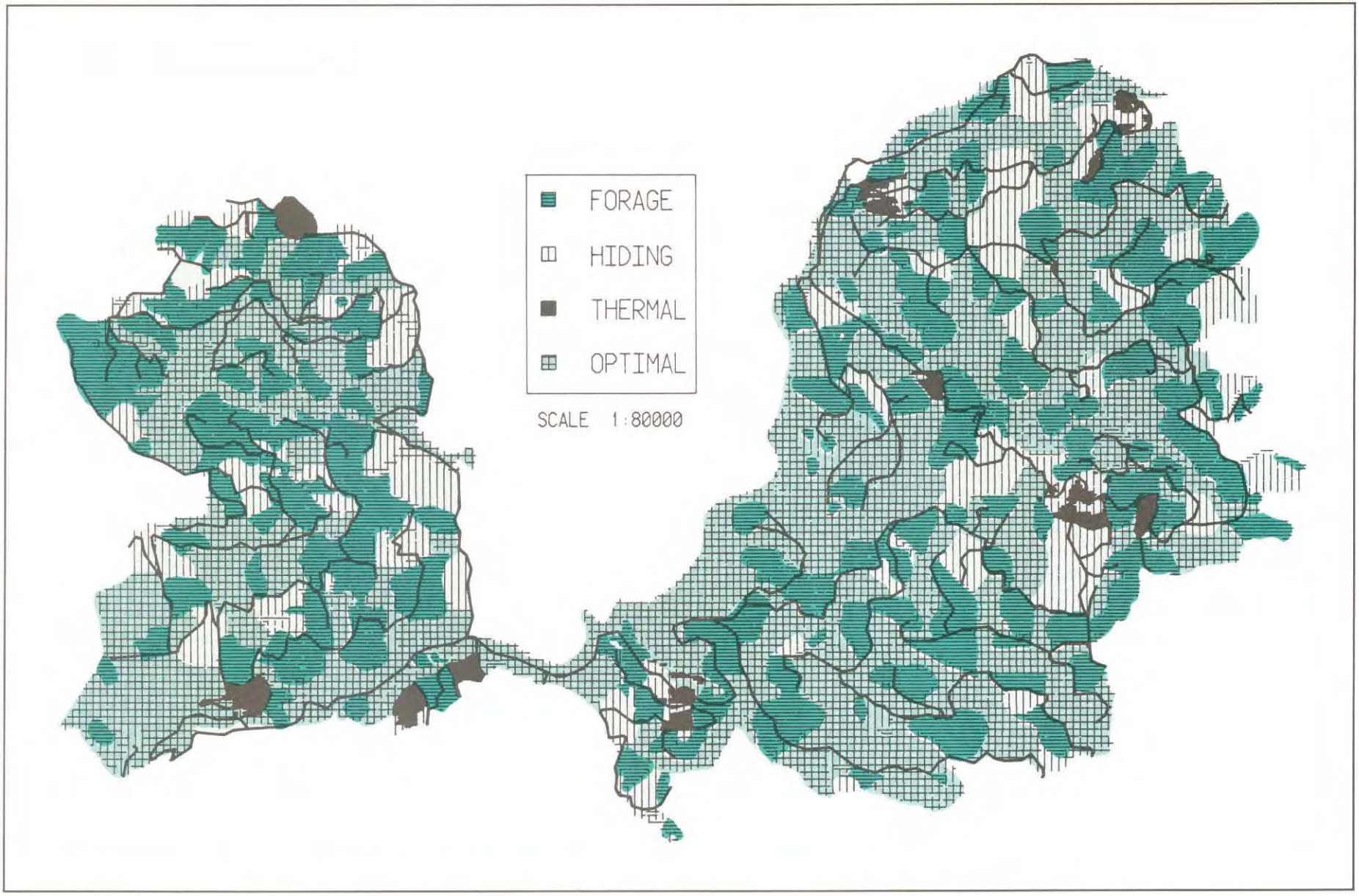


Figure 6—Distribution of forage, cover, and roads on a 12,000-acre portion of the Umpqua National Forest portrayed with ArcINFO GIS.

Simulation Models

Some simulation models have been developed to predict the movement patterns, habitat use, or population dynamics of animals. I am not aware of any model that predicts the growth of forest-pest populations, although Hobbs (1989) produced an energetics-based model for mule deer (fig. 7). Hobbs' model takes information on the availability and quality of food, deer density, weather conditions, energy intake, [and energy expenditures and predicts changes in the body size, fitness, and mortality of individuals in the population. Hobbs (1989), for instance, predicted that change in the quality of winter forage was an important habitat feature that could be manipulated to influence deer mortality. The manipulation of thermal cover had little effect. A similar type of model could be developed that would allow prediction of the change in population of forest-pest species following habitat alteration.

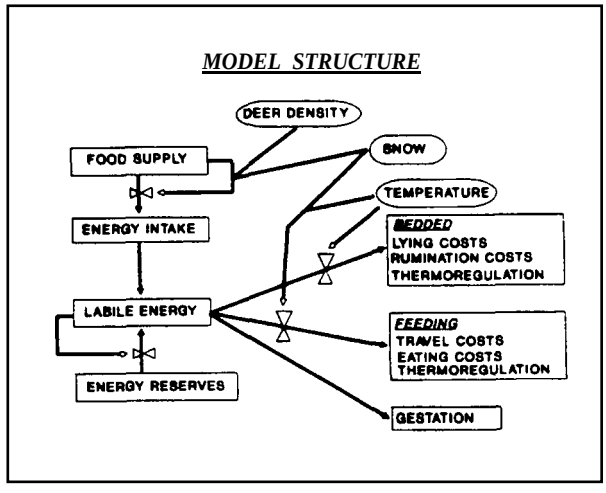


Figure 7—Flow chart illustrating the ma)or components of an energetics-simulation model for mule deer (from Hobbs 1989)

Multivariate-Statistics Models

Empirical data on habitat features can be used to predict the numbers of anima s or the probability that animals will occur. Several of these types of models have been developed for American beaver. Slough and Sadlier (1977), for instance, used regression analysis to identify the habitat features that could predict the number of beaver colonies per unit of stream length on study sites in Canada. Their model was not validated with an independent data set, so it does not yet represent a predictive model. The relation, however, could be tested elsewhere. Beier and Barrett (1987), similarly, used logistic regression to predict the probability of a length of stream being occupied by beaver on their study area in northern California. I have used discriminant analysis to separate beaver dam-sites from unused, random sites in eastern Oregon (McComb and others 1990). In all cases, a set of "predictor" variables (such as stream gradient, stream depth, hardwood cover) are combined in a linear manner (each predictor variable is multiplied by some coefficient) to produce a value that is equal to or related to the response variable (number of beaver colonies, used vs. unused sites). These types of models often work very well for the area where data were collected and less well for other conditions or locations where environments change or where other features may be more important for predicting the response variable. These models, therefore, can be useful tools in local areas, but land managers should be aware that the level of precision and accuracy of the model is unreliable for application in other areas.

Decision-Support Models

Marcot (1986) described the use of expert-systems models to aid managers in understanding wildlife habitat relations. An expert system is a computerized consultation program consisting of facts and expert knowledge that help classify, diagnose, or plan (Duda and Shortliffe 1983 in Marcot 1984). The model operator integrates information from field studies, the literature, and expert opinion to predict, for instance, what species would be associated with certain habitat conditions. Marcot (1986) provided an example of an expert system that would aid a manager in identifying species and their relative abundances within a habitat with certain features. The expert system would suggest to the manager a series of mitigative procedures to improve habitat quality for one or more selected species. An expert system also could be developed to allow the system operator to describe conditions within a stand and (based on information from research and expert knowledge) inform the operator of the likelihood that animals would damage the stand, which species might be a problem, and what immediate steps to take to solve or prevent the problem. BOOMER.BAS on the enclosed disk provides a very simple example of this type of model.

Schmoldt and Martin (1989) produced a program that allowed foresters with no advanced training in forest pathology or entomology to correctly diagnose the cause of pest problems in red pine stands, including damage from porcupines, pocket gophers, and meadow voles. The model performed as well as three forest damage experts, and it improved the ability of field foresters to correctly diagnose pest problems. The program is a series of rules that, when placed in a logical order, produce a probability estimate associated with a particular damaging agent (fig. 8). The next section of this chapter indicates how this type of model can be used in conjunction with other models to solve an animal-damage problem.

Integrating Models to Meet Land-Management Goals

Consider the following problem: the manager of a planning district is given a set of aerial photos of a 12,000-acre Oregon Coast Range basin in that district and is told to identify recently regenerated stands that would be likely to have damage by black bears. The manager would like to have a model that could be used in this or other nearby subbasins to help identify stands at risk and to suggest silvicultural steps that could be taken to prevent damage The silvicultural strategy selected, moreover, must not adversely impact other wildlife species.

The first step is to draw a flow chart of the steps needed to assemble and combine the information available to accomplish the task (fig. 9). First, the current conditions in the area should be characterized. With such a large area and collection of stands, a GIS should be used. Layers of information on stand conditions, plant communities, elevation, aspect, streams, and roads could be digitized from maps and aerial photos (after correcting photos for distortion). Next, the characteristics of the stands that might make them more or less desirable for bears should be identified. This could be something as simple as stand age, or as complex as a combination of age, growth rate (from stand tables), past treatments (precommercial or commercial thinnings), site, and aspect. These characteristics could be used to develop an index of stand effectiveness for black bear damage. A 30- to 40-year-old stand, for example, with a precommercial thin, fertilized, and on a site of high quality would receive a ranking of 1 (high), and old growth would receive a ranking of 0 (low). These relations are very important to the reliability of the model and to the interpretation of the results. They could come from the literature, expert opinion, or data from the area. They should

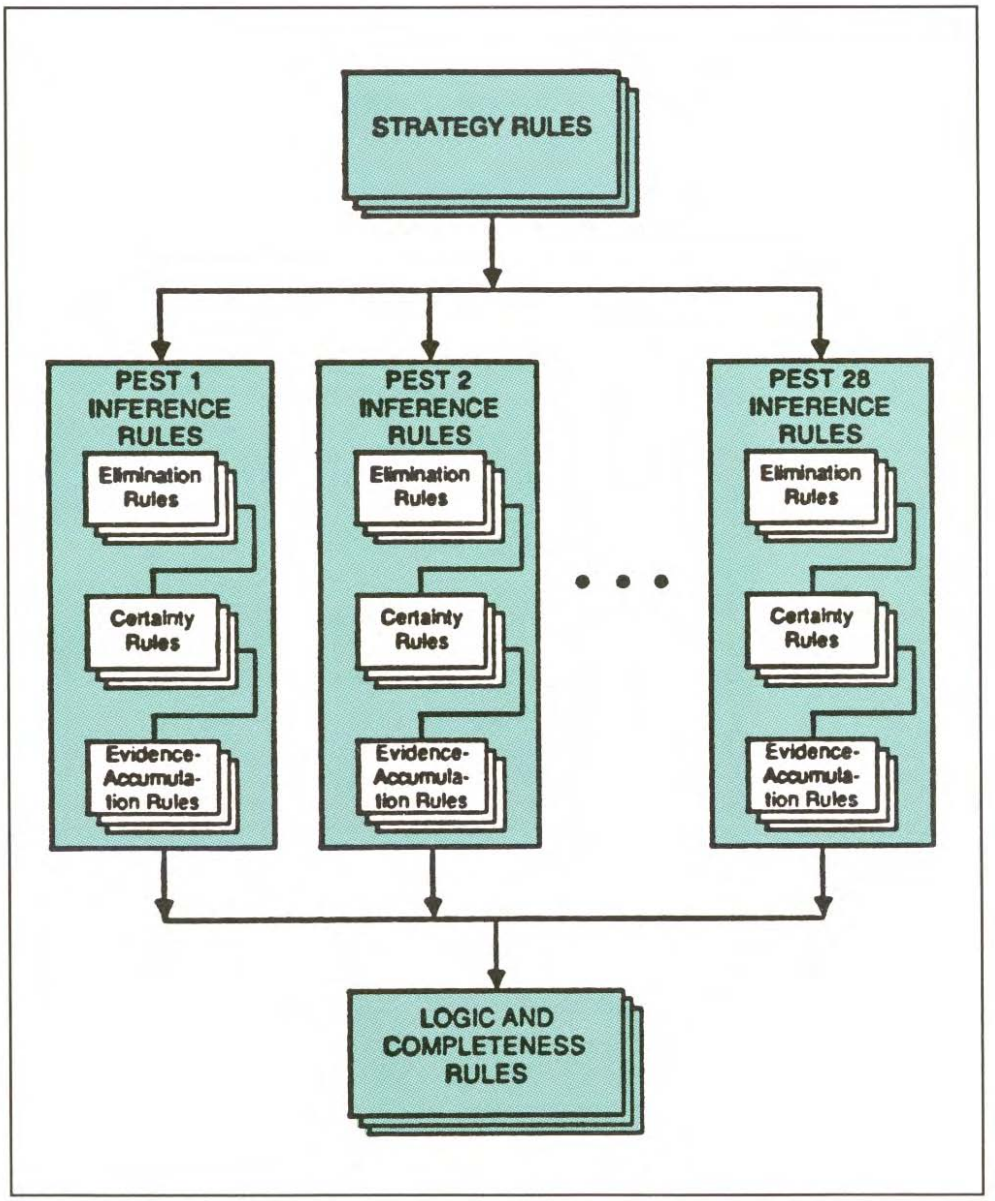


Figure 8—Structure of an expert-system knowledge base used to diagnose pest problems in red pine stands Strategy rules identify potential pests for further investigation Inference rules include elimination rules (indicating unfavorable evidence), certainty rules (assigning confidence value to one or more pests), and evidence-accumulation rules (indicating favorable evidence) Logic and completeness rules deduce facts not provided by the user and reduce the number of questions asked of the user (from Schmoldt and Martin 1989).

reflect not only the probability of damage, but also the probable level of damage and acceptable levels of damage. If only 1 percent of the trees are damaged, then long-term volume loss probably is negligible If 25 percent of the trees are damaged in the stand, however, then losses could be severe.

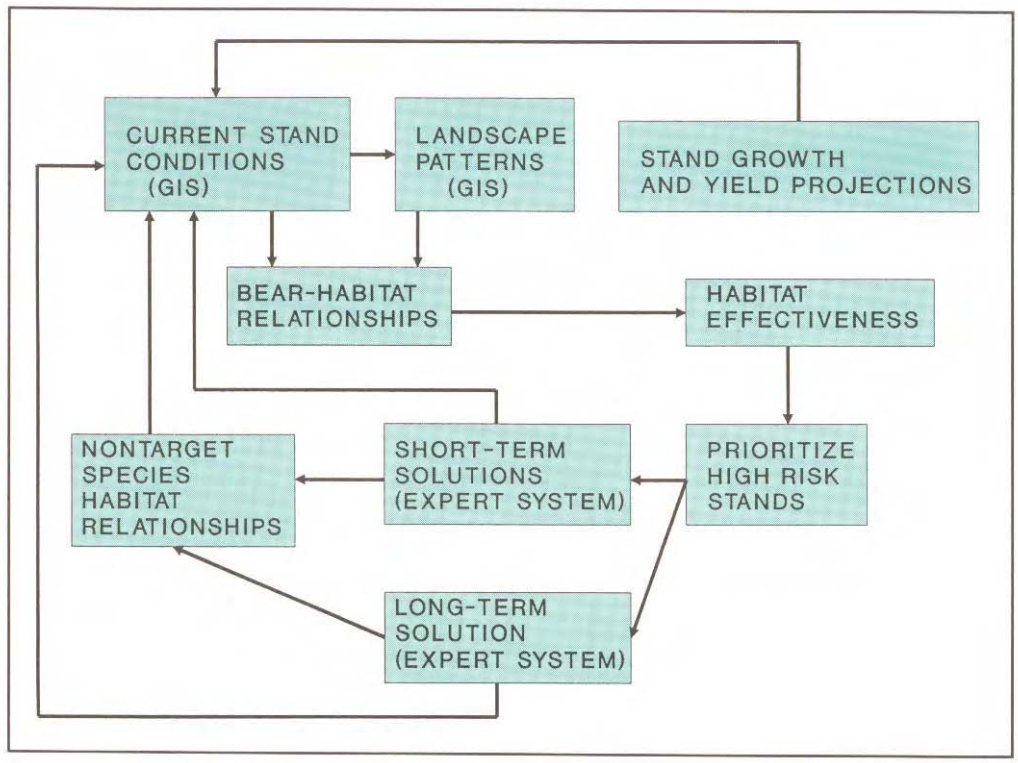


Figure 9—Flow chart to integrate information over space and time to identify stands likely to receive bear damage and suggest stand prescriptions to reduce risk of damage

Once the relations have been developed, the information can be screened and rated on the GIS, and those with high risk for damage can be identified. An expert-system model might then be used to identify the specific conditions of the stand and suggest a prescription for reducing risk in the stand The land manager, however, needs the ability to prevent damage before the rating becomes high. A regional growth-and-yield model can simulate growth of each stand within the basin for 30 to 40 years and enable the manager to change the conditions of the stands within the GIS over time to identify stands that would be at risk in the future. These stands could then be examined more closely, and prescriptions could be developed to help keep risks low. The habitat conditions resulting from the prescriptions could be stored and run through habitat suitability models for species of high interest in the area (cavity-nesters, deer, elk) to examine the changes in habitat quality for other species over the basin (Doering and Armijo 1986).

The advantages of a modeling system such as described above are as follows:

1 All the information on habitat relations, bear damage, and stand growth can be captured in one combination of tools.

2 Management strategies can be tried ahead of time, and the impacts on stand yields with and without damage can be examined.

3 It can produce information useful for examining effects on other species over time.

4. It permits modification of the system as needed

What the model will not do is work correctly all of the time. It is an abstraction of the real world. It does not include the stochastic properties of climate or fire. Models are useful, but the results should be viewed with some skepticism and believed only if they appear believable.

Most importantly, models must be well documented and tested. As models are developed from flow charts, the source of the relations in that model should be documented. A model should be as well documented as any refereed publication, so that a user can refer back to the original source of the information and revise the model as new information becomes available. The geographic limitations of the model should be clearly specified. As the model is used, its effectiveness in predicting real world situations should be monitored to identify weaknesses. Formal testing of model output is desirable, but may not be feasible, especially in the case of dynamic models that carry results out into time. The use of a chronosequence of stand conditions and animal activities may be an acceptable alternative.

Another advantage to the development and use of models is the encouragement of dialogue among the resource professionals that develop the model and among those who use the model after it is developed. Consider an expert-system model that would help a manager rate a stand for black bear damage and develop a prescription to reduce the likelihood of such damage Experts that might be consulted include wildlife biologists, harvesting specialists, economists, and silviculturists. Tree physiologists, forest mensurationists, and computer modelers or individuals with a strong quantitative background also might be consulted. Joint involvement in the development of the model among disciplines will more likely lead to joint acceptance of its output.

It is always a good strategy, finally, to have other resource professionals use and become familiar with any model that is developed A recreation planner may provide valuable insight into public acceptance of recommendations produced from a clack bear damage model, if silvicultural strategies that reduce the risk of black bearl damage can be conducted in a manner to minimize conflicts with aesthetics.

With the tremendous complexity of issues of forest resource management, including animal damage management, forest managers increasingly will be forced to rely on models to aid them in making decisions. Models can be valuable tools, but they should be used cautiously, and the results should be interpreted. Managers should recognize at the outset that models will be wrong a certain percentage of the time. Models will enable land managers to try options and make wise decisions on tne basis of their knowledge of the options, on their professional interpretations of the model output, and on the basis of how those decisions affect all forest resources and not just the timber resource.

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SECTION FIVE
INTEGRATED SILVICULTURAL PRESCRIPTIONS

Chapter 20
Social, Political, Legal, and Ethical Aspects of Animal Damage Management in Forestry

ROBERT H. SCHMIDT, DALE L. BROOKS/ AND
TERRELL P. SALMON

Abstract

Animal damage management, as practiced in today's forests, is increasingly affected by the social, political, legal, and ethical environment in the United States. Tjhese elements affect the materials utilized to manage animal damage, the silvicultural systems used to manipulate forest vegetation and thus wildlife habitat, and the human effort required to initiate and complete damage reduction programs. Failure to incorporate societal values in decisionmaking processes will lead to increased risk of program modification or failure.

Keywords: Animal damage control, vertebrate pest control, forestry, silvicul ure, animal welfare, animal rights.

ROBERT 1-1 SCHMIDT was wildlife and natural resource specialist, Department of Forestry and Resource Management, University of California, Berkeley, CA 94720 and currently is assistant professor, Department of Fisheries and Wildlife, Utah State University, Logan, UT 84322-5210 DALE L BROOKS is professor, school of veterinary medicine. University of California, Davis, CA 95616 TERRELL P SALMON is regional director, Division of Agriculture and Natural Resources-Northern Region, University of California, Davis, CA 95616

Forest management practices are more influenced by our social environment today than in any other period during the history of modern forestry. Not only are there local, state, and Federal agencies that claim at least some legal jurisdiction over timber lands, silvicultural practices, and forest products and byproducts, but members of the general public, unattached to the forest industry through employment or land ownership, are demanding and receiving a role in defining acceptable forest management practices. California voters had no fewer than three separate ballot initiatives to choose from in 1990 that would have affected forest management. In either the wisdom or confusion of the voting public, all three of these propositions (Propositions 128,130, and 138) were voted down, resulting in a fragile *status quo* for the next few years. Nobody in the California timber industry, however, expects business as usual for the future. The most draconian measure, the environmentalist-supported Proposition 130, failed to gain a simple majority by only 2.13 percentage points (47.87 percent voted yes and 52.13 percent voted no), while the industry-supported Proposition 138 lost with 28.84 percent voting yes and 71.16 percent voting no. Proponents of each of these initiatives spent over 4.5 and 10 million dollars, respectively, in their unsuccessful campaigns (Hart 1991). Change is clearly in the wind, and the scope and range of that change will be defined by the social, legal, political, and ethical constraints determined by all segments of society.

Animal damage management, as a silvicultural practice, is not exempt from the forces demanding change. One clear example of this is demonstrated with attempts to control black bear *(Ursus americanus)* damage to young stands of redwood and other species (Giusti and Schmidt 1988). For a variety of reasons, ranging from animal rights and animal welfare considerations to the attitude of disgruntled bear hunters wanting additional hunting opportunities and access to private lands, the removal of black bears from forests to reduce the damage bears inflict on young trees is an increasingly controversial issue. Private companies and public agencies are absorbing increased costs for litigation, management, and public relations related to the controversy. In California, a successful challenge to the State's attempt to issue additional bear depredation permits resulted in the suspension of the 1989 bear-hunting season and a restriction on the 1990 bear-archery season. Additional challenges to bear removal practices in California and elsewhere are anticipated.

Similar challenges face pesticide use in forest management. Aboveground uses of the rodenticide strychnine and all rodenticidal uses of sodium fluoroacetate (Compound 1080) were eliminated in 1990 when the U.S. Environmental Protection Agency (EPA) cancelled their registrations. The continued use of strychnine belowground, particularly important for pocket gopher *(Thomomys spp.)* population reduction, is in jeopardy without additional data required by the EPA supporting its efficacy and toxicology. Pocket gopher management with chemicals conceivably could be replaced by trapping over the next decade, despite the increased cost of trapping.

As a final example of animal damage management being affected by changing societal values and concerns, consider the training and value system of the incoming resource management professionals, the "new biologists." The new biologist is a product of an affluent society with good transportation and communication systems. The new biologist has political savvy and can articulate his or her opinions. Many of them have an urban upbringing, but they are feeling an urge to enjoy the country and are anxious to get back to the earth, animals, and nature. They consider themselves knowledgeable about animals, nature, and the environment, even when they have limited field experience.

At one time, we were all "new biologists," ready to improve and preserve the world, to tap Earth's resources, and to have a meaningful impact on the social, political, legal, and ethical aspects of natural resource management. The new biologist is constantly being replaced by a "newer biologist," as we have replaced those before us. Change is inevitable. We must learn to understand the depth and magnitude of these forces of change.

The goal of this chapter is not to provide "the answer." Indeed, there is no single answer or strategy that could possibly prevent the continuing evolution of animal damage management in today's forests. By defining the decisionmaking environment; however, management decisions can be made with a clearer understanding of potential ramifications and, hopefully, a refinement of uncertainty principles that influence management decisions affecting natural resource use (Holling 1978).

When this chapter was first conceived, it was envisioned that social, political, legal, and ethical aspects of animal damage management would be discussed and analyzed separately. It became clear early on that this would be an impossible task. Management of forest animal damage was, is, and always will be affected by all of these factors acting in concert and leading to conflicts and compromises. In addition, each of these fascinating topics deserves a separate volume. In this chapter, we review some of the historic patterns, present status, and future trends for each issue and comment on technological trends in tools for animal damage management. We also discuss future challenges that will affect animal damage management in tomorrow's forests.

The Social Environment

In 1990, the U.S population was over 250 million people, and immigration was the major source of population growth. As the baby boom generation aged, the median age of the U.S. population also increased. Nearly one in three Americans will be a member of a minority group by the year 2000. AIDS, crime, drug abuse, inflation, and the homeless topped the list of issues that concerned Americans in 1988 (United Way of America 1989). These factors, and many others, intertwine to set the stage for society's reactions to timber issues. Concerns over the long-term effects of timber harvesting on the health of watersheds and forest sustainability are now being debated openly

When animal damage management procedures are debated, potential solutions to complex and difficult issues may incite otherwise calm, logical people to demonstrate impatience and intolerance for alternative viewpoints. Opinions concerning these issues traditionally were based on social, religious, political, and/cultural backgrounds. No easy solutions, however, will satisfy the wide spectrum of societal opinions, animal needs, and closely related issues of natural resource'management.

Human-induced environmental change has occurred since humans first appeared on the planet Early societies did not live in such crowded conditions, so/they generated little damage and pollution in any given area, and there was sufficient space that when one area became less desirable because of human activities, people there simply moved to a new area. Natural resource exploitation was a "use it or lose it" strategy.

Environmental problems arose as people began living together in bigger groups, forming towns and cities. More "human niches" resulted in an increase in population and resource exploitation. Pollution gradually increased and first became a societal issue in the 1700s and 1800s, particularly with the onset of the industrial revolution. Fossil fuels such as oil and coal were extracted from the ground to power factories and homes while contaminating the air and the land. Raw sewage was dumped into waterways. Complaints of pollution began in earnest in the United States during the early 1900s. Since then, cleaner oil, natural gases, smoke stack scrubbers, and other technologies have helped reduce pollution. Cities now chlorinate water supplies and process sewage. More people, more technological advancements and wastes, more cars and factories, and the persistent use of fossil fuels continue, however, to compromise the world's environmental quality. Acid rain, ozone depletion, deforestation, and the combined impacts of close to 7 billion people now impact our forest lands.

As a consequence of environmental degradation or in spite of it, many people, affluent and needy alike, especially in the United States, are beginning to allocate some of their time and resources for "saving the Earth." This allocation ranges from voting preferences to sending money "to save the whales," from writing to the editor of a newspaper regarding endangered species to volunteering to lobby full time against pesticide use and nuclear waste disposal. In 1987, more than 45 percent of Americans participated in some volunteer activity (United Way of American 1989). Some portion of these activities no doubt are critical of animal damage management in forestry and elsewhere.

These social factors affect animal damage management in forests. Management of forest vegetation to manipulate food or cover and thus manage animal damage to plantations or valuable stands of commercial trees is constrained by societal concerns on herbicide use and environmental protection. As mentioned above, rodenticides and black bear hunts are being restricted in some areas. The proportion of people who purchase hunting licenses is decreasing, and wildlife agencies are concerned that deer hunting may be more restricted in the future. Deer hunting has been used in timber management to reduce browsing damage to plantations and naturally regenerated stands of timber. As a final example, the social ills listed above compete with research and operational programs for the limited pool of government and private dollars. In academia, teaching and research programs in conservation biology are expanding faster than similar programs in animal damage management.

Many of society's desires for the conveniences that provide the "good life" contribute " significantly to the various causes of environmental pollution as well as the exploitation of wild animals. Avoiding or correcting these uses, however, are considered too expensive or inconvenient by many people. The ongoing dilemma of balancing those who want changes and improvements at any cost versus those who want to maintain the *status quo* and keep costs under control will not be solved in the near future. Social trends that will affect forest management practices in the future include an increasingly urbanized population with associated concerns, declining scientific literacy rates, increased energy costs, and a decreasing natural resource base.

Society now demands that governmental representatives provide more safety guidelines and legislation to protect, preserve, and improve the welfare of 'animals and the environment. C.S. Holling (1978:135) summarized a future vision as follows:

> Enviromental decisions are made in a social setting. Of all the uncertainties of human and social behavior, the one of paramount significance to enviromental policy is the shifting nature of individual and social preferences. The profound changes in policy stemming from the rise of environmental awareness in the late 1960s are more than obvious. The point to remember is that other equally radical shifts in social goals *will* occur in the future [emphasis added].

The Political Environment

Politics is entrenched in the U.S. psyche at all levels of government, from city councils to the U.S. Congress. Governing bodies, in turn, are lobbied by a hydra-like collection of individuals and organizations who represent a seemingly infinite array of causes and concerns. In the United States, individuals and organizations have the right to participate in making laws, selecting government officials, and carrying on the functions of government. Forest-related issues are not exempt from this process and scrutiny; with the assistance of government regulators, environmental advocates, and the press, neither are forest-related industries. Agricultural concerns, historically, carried a great deal of clout in determining the shape and focus of government. These concerns easily could be labeled conservative, with a focus on protecting, stabilizing, and increasing market opportunities, consolidating political control, and (with the exception of subsidies) reducing government interference.

In recent years, individuals and local groups have demonstrated that political activism is an effective conduit of change. There is an increase in the growth and number of special interest groups. Society and budgetary concerns are pushing for decentralization of government. Public referendums increasingly are used to develop policy. NIMBY ("not in my back yard") philosophies result in additional litigation, negotiation, and planning considerations for many groups that feel affected by government or corporate decisions.

Additional destabilizing factors in the future may lead to sudden change as opposed to incremental change. Congressional representation from urban areas and from non-agricultural sources will increase. Concerns over tomorrow's variation of the northern spotted owl scenario is predictable, yet uncertainty exists as to the nature, timing, and extent of these concerns.

As far as animal damage management in timberlands, we expect an increase in initiatives and referenda sponsored by special interest groups. The outcome of these votes may affect the use of current technologies, such as hunting, trapping, and pesticide use. We expect political bodies increasingly will be influenced by urban voters. Finally, environmental protection concerns are on the political agenda for the conceivable future. All three of the issues will have direct and indirect impacts on animal damage management in the years to come.

The Legal Environment

There are numerous legal frameworks that affect animal damage management. The National Environmental Protection Act (NEPA) and its state equivalents, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), the Endangered Species Act, and even the Migratory Bird Treaty Act, among others, all have influenced the materials and methods of animal damage prevention and control in forests. A multitude of regulatory agencies have standing or jurisdiction over what can and cannot be done. These regulations can make relatively simple procedures bureaucratic nightmares. The use of rodenticides to reduce the pocket gopher population on a 1-acre plantation of ponderosa pine on USDA Forest Service land, for example, requires adherence to the NEPA process. This involves coping with public involvement and either a categorical exclusion decision, an environmental assessment, or a complete environmental impact report. Appeals require additional time. If endangered species are present on the site, the Endangered Species Act requires a Section 7 consultation with other agencies and a biological evaluation The red tape that can be involved with this 1-acre control operation, clearly, is extensive and can conceivably last for 2 or more years.

Existing laws which today do not address animal damage management may do so in the near future. The Animal Welfare Act of 1966 (with amendments) is one such law. This law currently provides for regulating the transport, purchase, sale, housing, care, handling, and treatment of animals used in research, exhibition, or as pets. Expansion of the range and scope of this law is a good bet for the future. In addition, international markets may require certification that laws and standards in existence in the importing country were followed. Pesticide residue in food products are examples of these. There is no indication that this complex of regulations will shrink in the near future. In all probability, additional regulations will affect the management of forest animal damage in the years ahead.

The Ethical Environment

"A rat is a pig is a dog is a boy." This quote by a leading animal rights activist summarizes the extreme view that some members of society have when it comes to animals. Every individual has a different set of ethical and moral rules for guiding his life. What we eat and drink, with whom we associate, our choice of religion, and our attitudes toward animals are examples of these ethical and moral rules. Our attitudes toward animals and animal use also are manipulated by these sets of rules. Thus, our society is composed of a variety of individuals with differing sets of morals, including vegetarians who reject eating meat, deer hunters who reject killing fawns or does, and pet owners who reject selling unclaimed dogs to research institutions (Schmidt 1990a).

A democracy allows for freedom of expression and the opportunity for nonconventional viewpoints. This has certainly encouraged the formation and growth of the animal rights movement. The philosophical strength behind the animal rights paradigm lies in the belief that all animals, human and nonhuman alike, have a moral equality that should defy separation. One leader of the animal rights movement has summed it up as a "equal consideration of interests" (Singer 1980). Simply stated, the animal rights philosophy dictates that the use of nonhuman animals in biomedical research, food and fiber production, recreational uses such as hunting and trapping, zoological displays, and controlling animal damage, among others, is totally inappropriate unless it is ethically and morally proper to subject humans to the same or equivalent treatment.

The animal *rights* philosophy, however, is not to be confused with the animal *welfare* philosophy (Schmidt 1990b). Proponents of animal welfare do not promote equal rights for nonhuman and human animals; instead, they simply desire to reduce pain and suffering in animals. Animal welfare advocates are not opposed in principle to livestock production, predator management, and management activities related to forest animal damage, but they seek to ensure that these activities *sire* performed and accomplished in a manner that reduces, minimizes, or eliminates animal suffering.

Because the animal rights movement is philosophically opposed to many activities currently performed on forest lands, little compromise is anticipated over the next decade and beyond. The relatively small yet vocal minority of "animal rightists" have neither political power nor the heart of the social majority. However, they do stimulate public debate about the role and use of animals in our society. This heightens popular sensitivity to issues related to animal welfare. To date, there are no legal precedents granting animals individual rights.

Animal damage management certainly is affected by these ethical considerations. Because of the focus on the welfare of individual animals, control methodology focusing on population reduction has been criticized as being overly broad and not directed toward problem animals. The use of strychnine and anticoagulants for rodent control has been criticized as being cruel and inhumane. In California, the 1990 archery season for black bears was rescinded by judicial order because the environmental impact statement prepared on the bear hunting season failed to consider the pain and suffering of wounded animals.

Ethical considerations related to environmental protection also affect animal damage management. Silvicultural systems that recommend clearcutting, vegetation suppression, or debris removal as habitat modification to discourage future animal damage have been perceived by some people as environmentally destructive. These people view foresters and other personnel involved in animal damage management as being insensitive and uncaring with no consideration for the suffering of animals or the depletion of natural resources.

Technological Trends

Many factors will affect the types of technology and Silvicultural systems available to forest managers in the next century. The social, political, legal, and ethical trends discussed above will have a mapr impact on the management of forest animal damage, as will the continuing trend toward multiple use of forest laipds, consideration of cumulative impacts, and, of course, economics (Salmon and Lickliter 1983).

Pressure to reduce industry dependence on acute toxicants, such as strychnine and zinc phosphide, will continue because of concerns regarding selectivity and humaneness. This pressure will come from special interest groups opposed to the use of any pesticide for controlling vertebrates, and it will affect the manufacturing, regulation, and use of these toxicants. Anticoagulant use also is being opposed, albeit at a reduced level of intensity. These trends will continue despite the economic attractiveness of pesticide use It is difficult, however, to foresee a time when all pesticide use will be abolished; rather, the emphasis will be on more selective use and coordination with nonpesticide alternatives. The potential for new pesticide developments to control forest animal damage is small because of the limited market for the materials and the relatively high costs of development and registration.

Recreational and professional trapping and shooting also are under assault as tools for animal damage management and their use probably will be restricted. Some species will be removed from the pool of species that can be hunted or trapped, as was the case with the California mountain lion in 1990 with the passage of Proposition 117. There also will be a continued refinement of the trapping and shooting systems available. The development, marketing, and increasing acceptance of the "soft-catch" or "padded" trap is the clearest example of this trend.

Repellents for protecting seeds, seedling, saplings, and mature trees from wildlife damage have theoretical potential, but few successful products currently are registered. Deer repellents have proven somewhat successful and their use probably will increase. Repellents for other species are in need of significant research and development. The use of repellents to solve wildlife damage problems in forestry probably would meet with few social or political complaints. Physical barriers are available for the protection of individual seedlings, and fences effectively control deer damage in plantations. These damage control strategies are not without significant costs, however, and continued use and development largely will depend upon the availability of less costly technologies.

Cultural practices undoubtedly will increase in utility and effectiveness in the coming years as more sophisticated silvicultural systems are developed Their ability to deal with microsite damage locations, animal dispersal patterns, and economic considerations remain to be seen. This volume reviews and summarizes the potential of silvicultural methods to limit animal damage and it is clear that dependence on silvicultural practices to control wildlife damage is premature. Biological control and advances in damage management through biotechnology are alternatives that will probably remain unexplorted until funding for basic research and development becomes available. The impetus for this funding and the funding for refining the tools currently being used, will be some combination of public, governmental, and industry pressure.

Future Challenges

Where does this leave animal damage management? First, recognize that the changes that affect animal damage management are not operating in a vacuum, and that the entire mosaic of human society and the world environment is changing. This evolution is natural and expected. What is unknown is the specific direction and strength of these changes. It must be recognized that animal damage management is an extremely small slice of the multidimensional human niche. Professionals in animal damage management must work to define future social, political, legal, and ethical trends, and to devise management schemes that are successful within these new environments.

Nobody can guarantee what the future will bring We should expect uncertainty and surprise in our future activities as in all complex systems. The United Way of America (1989) has analyzed current social, economic, technological, and political developments and has condensed them into identifiable factors that are shaping our society.

Two conclusions are especially pertineni to professionals in animal damage management. The first conclusion separates individual and institutional roles in our society.

> Individuals are taking on a greater share of responsibility in many areas, and are relying less on large institutions. The growing emphasis on wellness activities is an example of the shift of responsibility for personal health away from doctors and hospitals and more toward the individual. Individuals are also taking on more responsibility for their employment and careers, exemplified by the growth of entrepreneurial activity, self-employment, and multiple careers. *Individuals are less willing\to wait for large institutions to provide opportunities, and more willing to act on their* own [p. 4, emphasis added].

A second conclusion focuses on the rebirth of social activism.

> After a decade of concentration on business and economic growth, the public-agenda pendulum is swinging decisively in the direction of social concerns. Environmental degradation, deterioration of public infrastructure, … pervasive homelessness, lack of affordable housing, racial tensions, and extensive child poverty are some of the issues which are gaining increased attention. *Accompanying this shift is likely to be less tolerance for business actions which the public perceives as harmful to society,* such as financial actions which harm the economy and pollution which threatens public health [p.8, emphasis added].

It will be realistic and productive to focus animal welfare concerns on animal damage management systems. The forestry profession needs to demonstrate that it is a caring, progressive, professional, and socially responsible profession. Professional societies and agencies can clarify this role through position statements, activities, and testimony. This clarification must not focus simply on current activities. It must, in order to maintain its leadership into the future, focus on upgrading management technologies to make them socially acceptable, progressive, and a role-model for other professional natural resource management organizations and agencies. We need a spectrum of qualified points of view from biologists, foresters] agriculturalists, conservationists, sociologists, ecologists, environmentalists, resource policy analysts, veterinarians, and others who can provide realistic and thoughtful alternatives for solving the challenges facing society. Even more, we need to send *a* message that these various interests need to unite and work together to solve problems of natural resource management. We will continue to use conventional technologies for managing animal damage. Research on silvicultural options to reduce this damage should be a high priority for funding agencies.

Professionals in animal damage management need to chart a future course that is mindful of society's needs, plausible in the political environment, operable within the constraints imposed by legal statutes, and respectful of evolving ethics. It is a serious challenge. The challenge starts today.

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APPENDIX

Glossary

Acute rodenticide—Toxic compound specifically formulated to kill rodents from a single feeding

Animal damage—In simplest terms, the result of any kind of anima activity that causes economic losses by reducing or delaying total forest yield. In general, any effect of animal feeding deemed deleterious to some management objective or objectives

Barking—The removal of bark from a stem. Bark may be either stripped off as by a bear, abraded as by deer or elk polishing their antlers, or gnawed away as by porcupine

Bioassay—Determination of the relative strength or specificity of a substance (a contact repellent, for example) by comparing responses of test animals.

Bole—The trunk or stem of a tree.

Broadcast burn—Intentional burning of debris on a designated unit of land by allowing fire to spread over an entire area where debris has not been piled or windrowed.

Browsing—Feeding on woody vegetation by deer and elk that leaves a ragged, splintered break where a shoot is removed. These animals cause this type of injury because they possess only lower incisors

Budburst—Opening or flushing of vegetative buds or beginning of shoot and foliage growth

Bud clipping—The removal of buds as in grouse injuries to seedlings.

Clearcut method—A regeneration method that removes all trees over areas at least 2 acres or larger with the objective of producing an even-aged forest by either natural seeding or artificial regeneration

Clearcutting—Silvicultural system in which the entire standing crop of trees is cleared at one time over a considerable area followed by regeneration efforts to produce an even-aged forest In practice, much unsalable material may be left standing.

Clipping—Smooth, oblique cuts caused by rodents and rabbits feeding on woody shoots. These animals possess prominent chisel-like incisors and must tilt their heads to the side in order to clip a stem.

Control—In wildlife management, the process of managing populations of a species to accomplish an objective The term usually is used in the sense of reducing population numbers of a wildlife problem species to prevent or decrease the impact of that species

Contact repellent—A material that is applied as an external coating to the foliage and stems of seedlings to repel animals

Cutting—Gnawing by rodents to sever a large stem (as when beaver fell trees, (or example). Leaves multiple teeth marks on the cut surfaces

Debarking—See barking.

Direct seeding—Manual or mechanical sowing of tree seed on an area, either in spots or broadcast.

Droppings—The fecal material (especially pellets) of animals are useful, supplemental field-signs in the identification of animal injuries

Ecosystem—Any complex of living organisms and their environment.

Efficacy—Effectiveness as a rodenticide, ability of a product to control the specified target species or to produce the specified action

Even-aged—Term (or a forest in which all trees are nearly the same age (±10 percent of age at maturity) Trees in even-aged stands may be quite different in size.

Even-age management—The application of a combination of actions that results in the creation of stands in which trees of essentially the same age grow together Cutting methods that produce even-aged stands include clearcut, shelterwood, or seed-tree.

Formulation—Active ingredient packaged with various other materials produced by a manufacturer of pesticides

Fuel load—The dry weight of combustible materials per unit area (usually expressed as tons per acre).

Girdling—The more or less continuous removal of bark around a stem as by a porcupine or pocket gopher

Group selection—A harvest-regeneration method used in uneven-age management. Trees are removed in small groups ranging in size from 0.25 to 2 acres.

Habitat—The sum total of environmental conditions of a specific place occupied by a wildlife species or a population of such species.

Habitat modification—Alteration of habitat primarily to limit damage to seedlings either by reducing suitability of habitat or by providing alternate (buffer) forage species for the problem species of wildlife

Herbicide—A chemical capable of killing plants or suppressing their growth and development.

Manual release—The cutting by hand of plants to free chosen trees from immediate competition that is overtopping or closely surrounding them.

Manual site preparation—The clearing by hand of slash and unwanted vegetation from selected spots and otherwise manually preparing the site for reforestation.

Mechanical site preparation—The clearing by mechanical means of slash and unwanted vegetation from selected spots and otherwise mechanically preparing the site for reforestation.

Model—Formal description that represents a system or process

Multiple-dose bait—Poisonous bait that requires a sustained dosage over a period of time to produce death An example is an anticoagulant.

Natural regeneration—The renewal of a tree crop by natural seeding or sprouting.

Permanent range—Land suitable for grazing and not subject to loss through successional changes.

Phytotoxic—Injurious and sometimes lethal to plants

Plant association—The stable or unchanging plant community that occupies (or could eventually occupy) the site after completion of the successional process.

Plant community—Any assembly of plants living together. No particular ecological status is implied.

Pole—A still-young tree from the time its lower branches begin to die until the time when the rate of height-growth begins to slow down and crown expansion becomes marked.

Prescribed burn—The controlled application of fire to wildland fuels in either their natural or modified state to reduce the total amount of fuel and achieve designated objectives.

Reforestation—The natural or artificial reestablishment of a tree stand on forest land.

Regeneration—Young trees on an area that represents the early stages in the renewal of a forest stand.

Regeneration (harvest) method—The type of cutting or harvest method used to obtain a new stand (even-age management) or new trees (uneven-age management).

Regeneration survey—Any effort (particularly if done in a planned and organized manner) made to assess the amount, distribution, and condition of regeneration present on a specified area.

Release—The removal of plants by any of several means to free chosen trees from immediate competition that is overtopping or closely surrounding them

Repellent—A substance so obnoxious to animals as to deter them from attacking the seed or plant to which it has been applied

Residual vegetation—The decimated vegetation remaining after the main stand of vegetation has been removed through harvest or otherwise.

Root clipping—The cutting or clipping of roots (as by pocket gophers, for example).

Rotation—The planned number of years between the formation or regeneration of a crop or stand and its final cutting at a specified age of maturity.

Sapling—Loose term for a tree no longer a seedling but not yet a pole.

Scalps—Areas cleared of competing vegetation and used for planting trees.

Scarification (of soil)—Disturbing the forest floor and topsoil in preparation for natural regeneration, direct seeding, or planting

Seed-tree harvest (cutting)—Removal of mature trees from an area in one cut, leaving a small number of seed-bearers or seed trees singly or in small groups.

Seed-tree method—A regeneration method that in one or more thinning or harvest operation removes mature trees from an area and leaves a small number of high quality seed trees singly or in small groups The primary function of the residual trees is to provide seed.

Seedling—In general, a young tree grown from seed, from germination up to the sapling stage.

Selection cutting—The cutting method in which individual trees or small groups are removed annually or periodically from an uneven-aged forest.

Shelter-wood harvest (cutting)—Regeneration cutting in a mature 'stand to establish a new crop under the protection of the remaining stand. Trees are removed in several stages to establish a new, even-aged crop under the protection of the older stand

Shelter-wood method—A regeneration method that in one or more thinnings or harvest operations removes mature trees from an area and leaves enough trees to affect the site environment for establishment of seedlings. The function of the residual trees is modification of the environment near the ground.

Silviculture—The science and art of managing forests to meet resource needs

Silvicultural system—A process whereby forests are tended, harvested, and replaced to result in production of crops of distinctive form. Systems are classified by the method of felling that removes the mature crop with a view to regeneration.

Single-feeding (single-dose) bait—Toxic bait that produces death from one dose. Also called acute toxic bait

Single-tree selection—A harvest-regeneration method used in uneven-age management in which trees are removed on the basis of their individual maturity or to promote growth and maturity of neighboring trees. The objective is to produce a stand with trees of all sizes and ages within areas less than 2 acres in size.

Site preparation—Preparing an area of land for regeneration establishment.

Stand—A plant community, particularly of trees, sufficiently uniform in species composition, arrangement of age-classes, and condition to be a homogeneous and distinguishable unit

Stand establishment—Developing a tree crop to the stage at which the young trees may be considered established (safe from normal adverse influences).

Stocking—With reference to forest stands, a more or less subjective indication of the number of trees as compared with the desirable number More precisely, a measure of the proportion of the area actually occupied by trees (as distinct from their stand density), or the percentage of area stocked as compared with either maximum or normal tree densities.

Stock type—A class of nursery stock produced by one or more of the basic production methods over a particular length of time.

Succession—The gradual replacement of one plant community by another until ecological stability is attained or until disturbance reinitiates the cycle.

Systemic repellent—A chemical that is absorbed and translocated to all parts of the seedling (or tree) and that limits the plant's acceptance as food by animals.

Thinning—A felling made in an immature stand primarily to accelerate diameter growth; also, a selection made to improve the form of the trees that remain.

Toxicity—Poisonous quality, especially its degree or strength.

Transitory range—Land suitable for grazing of a nonenduring or temporary nature.

Translocation—Movement of dissolved substances through the vascular tissue of a plant

Uneven-aged—Term for a forest composed of intermingled trees that differ widely in age and size.

Uneven-age management—The application of a combination of actions needed to simultaneously maintain continuous, high-forest cover, recurring patches of regeneration of desirable species, and the orderly growth and development of trees through a range of diameters or age classes. Cutting methods that develop and maintain uneven-aged stands include single-tree selection and group selection.

2-0 seedlings—Seedlings aged 2 years in the seed bed and none in the transplant bed

APPENDIX

List of Common and Scientific Names

Plants

Alaska yellow-cedar	*Chamaecypans nootkatensis*
Alder	*Alnus* spp.
Alfalfa	*Medicago* spp.
Aquatic liverworts	*Riccia* spp
Arrowhead	*Saggitaria* spp.
Aspen	*Populus tremuloides* ,
Bearclover	*Chamaebatia foliolosa*
Beargrass	*Xerophyllum tenax*
Big trefoil	*Lotus ugliginosus*
Bigleaf maple	*Acer macrophyllum*
Bitterbrush	*Purshia tridentata*
Blackberry	*Rubus*spp.
Blue huckleberry	*Vaccinium globulare* !
Bracken fern	*Ptendium aquilinum*
Broad-leaf aster	*Aster radulinus*
Brome	*Bromus* spp
Bull thistle	*Cirsium vulgare*
California black oak	*Quercus kelloggii*
Canyon live oak	*Ouercus chrysolepis* \
Cascades azalea	*Rhododendron albiflorum*
Cascara	*Rhamnus purshiana*
Cherries	*Prunus* spp.
Chewings fescue	*Festuca rubra* spp.
Chinkapin	*Castanopsis chrysophylla*
Coastal Douglas-fir	*Pseudotsuga menziesiiivar menziesii*
Coastal redwood	*Sequoia sempervirens*
Coffeeberry	*Rhamnus* spp.
Common whipplea	*Whipplea modesta* \
Devil's club	*Opiopanox horridum*

Dogwood	*Cornus nuttain*
Douglas-fir	*Pseudotsuga menziesii*
Elderberry	*Sambucus* spp.
Engelmann spruce	*Picea engelmannn*
European red elderberry	*Sambucus racemosa*
False dandelion	*Agosens*spp.
False dandelion	*Hypochaeris radicata*
Fescues	*Festucaspp.*
Fireweed	*Epilobium* spp.
Firs	*Abies* spp.
Foxglove	*Digitalis purpurea*
Giant chinkapin	*Castanopsis chrysophylla*
Gooseberry	*Ribesspp.*
Grand fir	*Abies grandis*
Grass	*Gramineae spp*
Greenleaf manzanita	*Arctostaphylos patula*
Groundsel	*Senecio* spp.
Gumweed madia	*Madia gracilis*
Hard fescue	*Festuca longifolia*
Hawthorns	*Crataegus* spp.
Huckleberry	*Vaccinia in spp.*
Incense-cedar	*Libocedrus decurrens*
Interior Douglas-fir	*Pseudotsuga menziessli* var *glauca*
Juniper	*Jumperus* spp.
Loblolly pine	*Pinus taeda*
Lodgepole pine	*Pinus contorta* var. *latifolia*
Low dogbane	*Apocynum pumilum*
Lupine	*Lupinus* spp.
Madrone (Pacific)	*Arbutus menziesii*
Manzanita	*Arctostaphylos patula*
Maples	*Acerspp.*
Milk kelloggia	*.Kelloggia galiodes*
Mistletoe	*Arceuthobium* spp.
Modoc morning-glory	*Convolvulus polymorphous*
Morning-glory	*Convolvulus nyctagineus*
Mountain maple	*Acerglabrum*
Noble fir	*Abies procera*
Oaks	*Quercus* spp.
Orchardgrass	*Dactylis glomerata*
Oregon grape	*Berberis nervosa*
Oregon white oak	*Quercus garryanna*
Pacific madrone	*Arbutus menziesii*
Pacific silver fir	*Abies amabilis*
Pine	*Pinus spp*
Pinemat	*Ceanothus diversifolius*
Ponderosa pine	*Pinus ponderosa*
Pondweeds	*Potamogeton* spp.
Poplars	*Populus spp.*
Prickly lettuce	*Lactuca serriola*
Prickly sowthistle	*Sonchus asper*

Red alder	*AInus rubra*
Red fir	*Abies magnifica*
Red huckleberry	*Vaccinium parviflorum*
Redwood	*Sequoia sempervirens*
Ryegrass, annual	*Lolium annuum*
Ryegrass, perennial	*Lolium perenne*
Sage	*Salvia* spp.
Salal	*Gaulthena shallon*
Salmonberry	*Rubus spectabilis*
Sedge	*Carex* spp.
Shasta red fir	*Abies magnifica*
Sierra plum	*Prunus subcordata*
Sitka spruce	*Picea sitchensis*
Skunk cabbage	*Lysichitum americanum*
Smooth brome	*Bromus inermis*
Smooth cat's ear	*Hypochoeris glabra*
Snowbrush	*Ceanothus velutinus*
Spreading snowberry	*Symphoricarpos acutus*
Spruce	*Picea* spp.
Subalpine fir	*Abies lasiocarpa*
Subalpine needlegrass	*Stipa columbiana*
Subterraneum clover	*Trifolium Subterraneum*
Sugar pine	*Pinus lambertiana*
Swordfern	*Polystichum munitum*
Tanoak	*Lithocarpus densiflorus*
Thimbleberry (western)	*Rubus parviflorus*
Thinleaf huckleberry	*Vaccinium membranaceum*
Thistle	*Cirsium* spp
Timothy	*Phleum pratense*
Trailing blackberry	*Rubus ursinus*
True firs	*Abies* spp.
Velvet grass	*Holcus lanatus*
Vine maple	*Acer circinatum*
Water lilies	*Nymphea* spp.
Western bracken fern	*Pteridium aquilinum* var. *pubescens*
Western hemlock	*Tsugp heterophylla* [1]
Western larch	*Lanx occidentalis*
Western redcedar	*Thuja plicata*
Western white pine	*Pinus monticola*
Wheatgrass	*Agropyron intermedium*
White clover	*Trifolium repens*
White fir	*Abies concolor*
White spirea	*Spiraea betulifolia*
White spruce	*Picea glauca*
Whitebark pine	*Pinus albicautis*
Willow herb	*Epilobium paniculatum*
Willows	*Salix* spp
Wirelettuce	*Stephanomeria* spp.
Woolly nama	*Nama lobbii*
Yellow salsify	*Tragapogon dubius*

Animals

Alaskan hare	*Lepus othus*
American pika	*Ocotona pnnceps*
Antelope jackrabbit	*Lepus alleni*
Arctic hare	*Lepus arcticus*
Badger	*Taxidea taxes*
Bark beetles	*Dendroctonus* spp.
Bear	*Ursus* spp
Beaver (American)	*Castor canadensis*
Black bear (northern Rockies)	*Ursus americanus cinnamomum*
Black bear (southern Rockies)	*Ursus americanus altifrontalis*
Black-tailed deer	*Odocoileus* hem/onus *columbianus*
Black-tailed jackrabbit	*Lepus californicus*
Bluebird	*Sialla* spp.
Bobcat	*Lynx rufus*
Boreal redback	*Clethnonomys gappen*
Botta's pocket gopher	*Thomomys bottae*
Brown bear	*Ursus arctos*
Brush rabbit	*Sylvilagus bachmani*
Bushy-tailed woodrat	*Neotoma cinereus*
California redback	*Clethrionomys gappen*
California vole	*Microtus californicus*
Camas pocket gopher	*Thomomys bulbivorocous*
Chipmunks	*Eutamiasspp.*
Corvids	*Corvidae*
Cottontail rabbit	*Sylvilagus floridanus*
Coyote	*Canis latrans*
Deer	*Odocoileus* spp.
Deermice	*Peromyscus* spp.
Desert (Audubon's) cottontail	*Sylvilagus audubonii*
Douglas squirrel	*Tamiasciurus douglasii*
Douglas-fir tussock moth	*Orgyia pseudotsugata*
Dusky-footed woodrat	*Neotoma fuscipes*
Eastern cottontail	*Sylvilagus floridanus*
Elk	*Cervus* spp.
Ermine	*Mustela erminea*
European (brown) hare	*Lepus europaeus*
European rabbit	*Oryctolagus cuniculus*
Feral cats	*Felis domesticus*
Feral dogs	*Canis familians*
Ferruginous hawk	*Buteo regalis*
Finches	*Carpodaucus*spp.
Fisher	*Martes pennanti*
Flying squirrel	*Glaucomys sabrinus*
Fox	*Vulpes spp.*
Gray-tailed vole	*Microtus canicaudus*
Great horned owl	*Bubo virginianus*
Grizzly bear	*Ursus arctos horribilus*
Grosbeaks	*Hesperiphona spp.* (and other genera)
Ground squirrels	*Spermophilus* spp.

Grouse	*Dendragapus* spp.
Hares	*Lepus*spp.
Hawks	*Accipitridae* and *Falconidae*
Heather vole	*Phenacomys intermedius*
Jack rabbit (black-tailed)	*Lepus californicus*
Juncos	*Junco* spp.
Long-eared owl	*Asia otus*
Long-tailed vole	*Microtus longicaudus*
Long-tailed weasel	*Mustela frenata*
Lynx	*Lynx canadensis*
Marbled murrelet	*Brachyramphus marmoratus*
Marsh rabbit	*Sylvilagus palusfris*
Marten	*Manes americana*
Mazama pocket gopher	*Thomomys mazama*
Meadow mice	*Microtus spp.*
Meadow vole	*Microtus pennsylvanicus*
Mole	*Scapanus* spp
Mongoose	*Herpestes auropunctatus*
Montane (mountain) vole	*Microtus montanus*
Mountain beaver	*Aplodontia rufa*
Mountain lion	Fe*l*/s *concolor*
Mountain phenacomys	*Phenacomys intermedius*
Mountain pocket gopher	*Thomomys monticola*
Mourning dove	*Zenaida macroura*
Mule deer	*Odocoileus hemionus*
New England cottontail	*Sylvilagus transitionalis*
Northern goshawk	*Accipiter geltilis*
Northern pocket gopher	*Thomomys talpoides*
Nuthatches	*Sittidae*
Nuttall's (mountain) cottontail	*Sylvilagus nuttalli*
Olympic salamander	*Rhyacotnton olympicus*
Oregon vole	*Microtus oregoni*
Osprey	*Pandion hiliatus*
Owls	*Strigidae*
Pacific phenacomys	*Phenacomys albipes*
Pigmy rabbit	*Sylvilagus (Brachylagus) idahoensis*
Pileated woodpecker	*Dryocopus pileatus*
Pocket gophers	*Thomomys* spp.
Porcupine	*Erethizon dorsatum*
Rabbits	*Sylvilagus* spp
Red deer	*Cervus elaphus*
Red fox	*Vulpes vulpes*
Red squirrel	*Tamiasciurus hudsonicus*
Red tree vole	*Phenacomys longicaudus*
Red-backed vole	*Clethrionomys californicus*
Red-tailed hawk	*Buteo jamaicensis*
Richardson vole	*Microtus richardsoni*
Rocky Mountain elk	*Cervus elaphus nelsoni*
Roe deer	*Capreolus capreolus*
Roosevelt elk	*Cervus elaphus rooseveiti*

Short-tailed weasel	*Mustela erminea*
Shrews	*Sorex* spp.
Skunk	*Spilogale* spp., *Mephitis* spp.
Snowshoe hare	Lepus *americanus*
Song sparrow	*Melospiza melodia*
Sparrows	*Zonotricha* spp. (and other genera)
Spotted frog	*Rana pretiosa*
Spotted owl	*Strix occidentalis*
Spruce budworm	*Choristoneura occidentalis*
Swallows	*Hirundinidae*
Swamp rabbit	*Sylvilagus aquaticus*
Tailed frog	*Ascaphus truei*
Townsend pocket gopher	*Thomomys townsendii*
Townsend's vole	*Microtus townsendii*
Tree phenacomys	*Phenacomys longicaudus*
Tree squirrels	*Sciurus* spp.
Tree squirrels	*Tamiasciurus* spp
Voles	*Microtus* spp.
Water vole	*Microtus richardsoni*
Weasel	*Mustela* spp.
Western grey squirrel	*Sciurus gnseus*
Western pocket gopher	*Thomomys mazama*
White-crowned sparrow	*Zontncha leucophrys*
White-headed woodpecker	*Picoides albolarvatus*
White-sided jackrabbit	*Lepus callotis*
White-tailed deer	*Odocoileus virginianus leucurus*
White-tailed jackrabbit	*Lepus townsendii*
Wild turkey	*Meleagris gallopavo*
Wilson's warbler	*Wilsonia pusilla*
Wolverine	*Gulo gulo*
Wood duck	*Aixsponsa*
Woodpeckers	*Picidae*
Woodrats	*Neotoma* spp
Wrens	*Trogodytidae*

APPENDIX

English to Metric Conversion Factors

English Unit	X	Conversion Factor		Metric Unit
Inch	(in)	25.40	millimeter	(mm)
		2.54	centimeter	(cm)
Foot	(tt)	0.30	meter	(m)
Yard	(yd)	.91	meter	(m)
Mile	(mi)	1 60	kilometer	(km)
Ounce (avdp)	(oz)	28.34	gram	(g)
Pound (avdp)	(lb)	45359	gram	(g)
		.45	kilogram	(kg)
Ton	(ton)	.90	tonne	(t)
Ounce (fluid)	(oz)	.02	liter	(l)
Pint	(Pt)	47	liter	(l)
Quart	(qt)	.94	liter	(l)
Gallon	(gai)	378	liter	(l)
Square inch	(in^2)	6.45	square centirr ieter	(cm^2)
Square foot	(ft^2)	929.03	square centin ieter	(cm^2)
		09	square meter	(m^2)
Acre	(acre)	.40	hectare	(ha)
Cubic inch	(in^3)	16.38	cubic centimeter	(cm^3)
Cubic foot	(ft^3)	.02	cubic meter (sitere)	(m^3)

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This book examines the potential of silvicultural approaches for managing animal damage in forests at two levels' management of free-to-grow stands and site-specific practices that foster prompt and successful regeneration. Introductory chapters provide a historical perspective of animal damage management in the Pacific Northwest, describe the elements of an integrated approach to forest protection, review the principles of vegetation management and wildlife management, and examine the influence of silvicultural practices on habitat and animal damage Individual chapters are devoted to the ecology and control measures appropriate to problem species of wildlife and livestock that damage forest stands Coverage includes the influence silvicultural practices on habitat, populations, and damage The book focuses on the potential of silvicultural practices to limit animal damage, but it also includes information of chemical repellents, mechanical banners, and direct control measures Other chapters deal with the development of integrated silvicultural prescriptions, including modeling systems, to limit animal damage A concluding chapter discusses social, political, legal, and ethical aspects of animal damage

Keywords Animal damage management, integrated forest protection, wildlife problem species, livestock grazing, modeling, silviculture, Pacific Northwest.

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