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AIMing for Healthy Forests: Active, Intentional Management for Multiple Values

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Preface

Conservation: the protection, preservation, management, or restoration of wildlife and of natural resources such as forests, soil, and water.

–*The American Heritage Dictionary of the English Language*

Why this book? In the last 50 years, societies everywhere have undergone rapid change in all aspects of life. New technology and globalization have accelerated use of natural resources, led to abandonment of customs and adoption of new lifestyles, and brought about changes in political systems and the roles of governments. This dynamism has produced closer ties among nations, placed nations in competition, and magnified the discrepancies in material well-being between developed and underdeveloped nations. Similarly, within nations, subcultures have drawn apart, each reacting to the challenge of meeting its own needs and perceived threats to its own values and beliefs in rapidly changing social environments. Even within the Pacific Northwestern United States, there are substantial subcultural differences that are displayed vividly in public arenas and in interactions with governments at various levels. Here, and elsewhere, differences are played out in disputes over disposition and conservation of natural resources.

Increasing human populations, large-scale immigration, large institutions, and a global economy have facilitated impersonal international exploitation of human and natural resources. Environmental problems are real, pervasive, and radically altering the conditions of life on Earth. Effects include global warming, decreasing oceanic productivity, desertification, ground-water depletion, and various forms of persistent pollution. These conditions raise substantial ethical questions of intragenerational equity and social justice (have versus have-not nations and groups within nations) and intergenerational equity (the kind of world we will leave to future generations), as well as questions of effects on the general health and welfare of people. For example, adult asthma has increased fourfold in the Seattle area over the last 10 years as a result of particulates from diesel emissions and cargo ship bunker fuel pollutants.[1] Such problems are international in scope and will require international, national, and regional action for resolution.

A less spectacular and much less recognized problem is degradation of ecosystem function through neglect, unwise use, poor management, and lack of social consensus on how best to manage and conserve ecosystems. Not only is social consensus lacking, but there is also lack of consensus, even discourse, among the various sciences that inform the political and management processes that govern ecosystems. Ecosystem management is fragmented. Urban growth management, waste management, designation of transportation corridors, water use, and extraction of nonrenewable resources are largely made independently of efforts to conserve biological diversity and ecosystem function. The principal exceptions are instances where legislation protects wilderness, parks, refuges, or endangered species. Even within the Pacific Northwest, there is lack of coherence in management and lack of management on private, industrial, state, tribal, and federal forests. *Management of different ownerships is informed by different worldviews, values, and subsets of pertinent scientific information.*

Even the small stage of the Pacific Northwest is changing rapidly in response to globalization. Traditional low-intensity forestry on public, industrial, and family-owned forests may become economically unsustainable and, in the interim, environmentally and socially undesirable. Costs of producing wood given wages, workers' rights, and environmental protection are too high to compete with imported wood, whether from labor-intensive and publicly subsidized extraction from unmanaged forests or highly mechanized, intensively managed pine plantations.

Thus, local and regional publics are faced with a new problem, one that appears not to be amenable to national or international, top-down solutions: How do we maintain the life-support functions (ecological services) of our natural and managed ecosystems, restore function to degraded watersheds, and provide the various other values from farms, forests, and rivers that we and our fellow citizens would like to receive and keep available to future generations? How do we reconcile our increasing demands for diverse and seemingly competing values: clean air; high-quality and large quantities of water, food, wood, fiber, fish, recreation, open space, wildlife, wilder-

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[1] Welch, C. 2004. Bush cut some diesel pollution but let big ships keep spewing. *Seattle Times*. http://seattletimes.nwsource.com/html/politics/2002048167_bushship28m.html. September 28, 2004.

ness, wildness, biological diversity; and respect for the rights of other species to exist (already codified in the Endangered Species Act; Migratory Bird Treaty Act; National Forest Management Act; and other federal, state, and local laws and regulations)? Can we reconceive the natural-cultural agricultural mosaics of the preindustrial age and match the new concept to our present and future needs? At best, these mosaics contributed to sustainability—clustered dwellings (villages) imbedded in forest reserves, wetlands, small fields (fallow and cultivated), and pastures matched to soils and topography and integrated into a mosaic that maintained environmental quality and renewable resources. These arrangements often contributed to intragenerational equity with a fair spatial distribution of agricultural fields and pastures—fair because fields were small and ownerships scattered providing incentive to community cooperation in planting and harvest and equitable in distances traveled for cultivation. We cannot return to preindustrial farming economies (some of our fellow citizens have and will), but we can intentionally integrate wetlands, forests, and other native ecosystem types, managed to perpetuate their natural values, into our urban, suburban, agricultural, and transportation matrix. However, as we move out from our highly developed population centers can we intentionally maintain forests managed for multiple values—to provide clean air, clean water, diverse biotic communities, wildness, and natural aesthetics and opportunities for physical and spiritual renewal? And, in the process, buffer our fragile wilderness areas and other nature reserves? Finally, can we come to some consensus on total landscape management and provide limits to the growth of urban and suburban areas and to the destruction of managed and natural forests?

This book seeks to inform the deliberations of dedicated and well-informed citizens interested in the conservation of forest ecosystems at the local, state, and regional scales by using the Pacific Northwest as an example. Citizens are defined here as the various interested private individuals, interest groups, land managers, technical staffs, regulatory agency staff, local governments, tribal representatives, and other active agents who are likely and disposed to participate in collaborative learning and collaborative management efforts. Many of these people will be paid professionals in the various disciplines related to conservation, natural resources management, community development, organizational development, governance, and economics. But many will also be citizen volunteers (often professionals in unrelated or related fields as well) who operate at a professional level in collaborative management efforts. This book is not designed, however, to be used as a how-to recipe or tool for collaborative management. Instead, it is meant to provide an overview of collaborative management, forest ecology, and conservation at a professional or postgraduate/continuing education level.

It is at the local and within-state level that collaborative learning and collaborative management can take place and that a social consensus can be achieved, which will restore trust among parties now in adversarial relationships. Forestry, like collaborative learning, collaborative management, and consensus building is based in social sciences. Success in integrated management rests on understanding cultures, worldviews, modes of communication and learning, personalities, personal development, and group dynamics as much as they depend on understanding biogeography, landscape ecology, ecosystems, evolution, ecotypic adaptation to local conditions, and self-organizing biotic communities. Few are equipped with the cognitive breadth to pay adequate attention to the details of sociology, psychology, and ecology in conflict-laden natural resource arenas. Often the mind that revels in technical, ecological detail is refractory to psychology and sociology. Mutual understanding of environmental, economic, and social challenges in natural resource management, restoration of trust, and consensus on what constitutes environmental, social, and economic sustainability must be achieved before the general public can be motivated to support sustainable forest management through their market and political decisions. This might include the willingness to pay higher prices for products, subsidize sustainable management through higher taxes to compensate socially minded land managers and state-land trusts for their contribution to general well-being, and purchase valuable forest ecosystems (or their development rights) that are no longer perceived by their owners to be economically viable wood-producing enterprises. People value and benefit from forests, whether as individuals or part of private, industrial, state, tribal, or federal organizations. The ecological services derived from forests—clean air and water, open space, waste assimilation, climate regulation, wildlife habitat, recreation opportunities, and so on—have more value than the marketable commodities. We must recognize and pay for these services if we are to maintain our quality of life and to provide options for equivalent quality lifestyles to future generations (fig. i).

AIMing for Healthy Forests

The focus of this book is active, intentional management (AIM) of forest ecosystems: taking AIM so as to provide general sustainability and to achieve the full range of social, economic, and environmental goals society has for its forests. Management is active when it uses the full range of tools available for landscape, watershed, and local ecosystem management, including a variety of tools beyond the scope of this work: (1) removing roads and/or improving roads, establishing effective transportation systems, and other ecological engineering practices; (2) removing or replacing culverts, stabilizing eroding road cuts, placing instream structures, and other hydrological management; (3) identifying areas of soil or geologic instability, limiting activities to those appropriate to these areas, and other geomorphological planning; (4) identifying and protecting unique ecological or biological areas and other site-specific conservation of unique elements of biological diversity; and (5) identifying and establishing nature reserves, wildlife refuges, and wildernesses. These activities are becoming institutionalized in agency regulations and state forest practices rules, and many will be cited as sources in this book. This is not to say that issues surrounding roads, unstable slopes, and preservation of biological diversity have been resolved; they have not, and this book will not attempt to resolve them either. Instead, the book focuses on ecological forestry that includes silviculture, direct wildlife habitat improvements, restoration of biological diversity, and maintenance of dynamic local ecosystems in mosaic landscapes where biological diversity and ecological processes are maintained by (1) a composition that emphasizes biologically complex stages of forest development and (2) a dynamic condition in which locations of seral stages change with time as local ecosystems go through cycles of development and renewal.

Figure i Aiming to conserve biodiversity for future generations—Calum Maki, the author's grandson, enjoys a day hiking and hanging out with his grandparents near Granite Lake in the Gifford Pinchot National Forest, Washington. Photo by R. Carey.

The focus is also on intentionality—developing management systems that purposefully set out to address the values of a pluralistic public, reconcile various conservation philosophies, and integrate multiple scientific disciplines. In the last two decades, substantial research and practice in organization function and business practices have led to some general conclusions about how to organize any management effort—for example, decentralized management, with resources going to the front line where lead managers can most clearly identify the stakeholders and the nature of their demands. The relationships among people at each step in management processes need to be carefully and fully negotiated, such that each side of the junction has rights, responsibilities, and accountability for the decisions made. And, importantly, people must be free to make decisions. For instance, neither environmentalist, nor regulator, nor manager can sit back and demand—all must put forth, engage, and contribute to resolution. No "line officer" or executive higher-up in an agency or organization hierarchy can violate the social and psychological contracting such hard-won consensuses entail with an imperious veto. It is this kind of veto that contributes to developing the present air of intense mistrust. To be intentional, management must be collaborative and based on collaborative learning. No one, nor any one group or group of agencies, has a monopoly on facts or truth or the capacity to integrate various social and economic public values and effectively communicate that integration. Nor can such values be aggregated regionally and then homogenized and directed downward again and still be appropriate. National and regional priorities can be transmitted downward by the actions of legislatures and auditors appointed for that purpose. Regional inventories, analyses, and policies provide useful information, but multilayered planning just gets in the way. In multilayered planning scenarios, most of the resources go to regional planning and to support technical staff at the regional level, well-removed from local specifics.

Just as cookbook silviculture cannot achieve diverse goals in the diverse Pacific Northwest landscape, neither can top-down socioeconomic formulations. Thus, we need to begin to decentralize planning and management by shifting human and financial resources to the front lines and drawing on the diverse local publics and their knowledge of needs, wants, desires, and ecology. Collaborative management means incorporating representatives of all stakeholders and management by consensus, not by compromise. It will be difficult when there are so many groups at odds with each other; the redeeming feature of such conflict is that it can only be overcome by true creativity.

This is not a book on psychology or sociology, but conservation and forest management entail as much, if not more, social science as ecological and economic sciences. Thus, the book covers cognitive psychology, the psychology of personality, psychological contracting, worldviews, cultural streams, social contracting, and the roots of conservation philosophies, in hope that understanding the sources of differences in perception, learning, knowing, communication, beliefs, and values will help ease the pain and increase the joy of collaboration. The pain will diminish as fear, distrust, poor communication, unwarranted assumptions, and defensiveness wane, and joy will increase as discovery reveals the unique human qualities, life experiences, and sincerity of each of one's collaborators. Not all personalities will function well in collaborative management settings; ones that do not can still play valuable roles in collaborative learning and information providing. Here again, we do not have to start from scratch. There is a huge literature, a variety of methods, and a profession of facilitation that has developed over the past 50 years to bring together individuals and groups in conflict. The Pacific Northwest has a decades-long history of attempts at collaborative management, including the Quincy Library Group, the Applegate Partnership, and various Forest Service provincial advisory committees.

Finally, this book seeks to fill the need for integration across scientific disciplines whose various worldviews suggest profoundly different priorities and approaches to ecosystem management. A landscape ecologist expresses the need to manage landscapes within the range of historical variation; a conservation biologist sees the world as composed of reserves and connecting corridors; forest ecologists emphasize biological legacies, biodiversity, ecosystem processes, and management of various "structures;" an evolutionary biologist fears loss of genetic diversity, even within a subspecies or an individual tree; a forester dreams of highly efficient fiber production and technological agroforestry; wildlife biologists variously focus on snags, elk and deer, Neotropical migratory birds, or spotted owls. Traditional economists have their views, quite different from those of the ecological economist. Social scientists hover around the edges, working with communities and other social institutions. How can such a cacophony be brought into some kind of harmony?

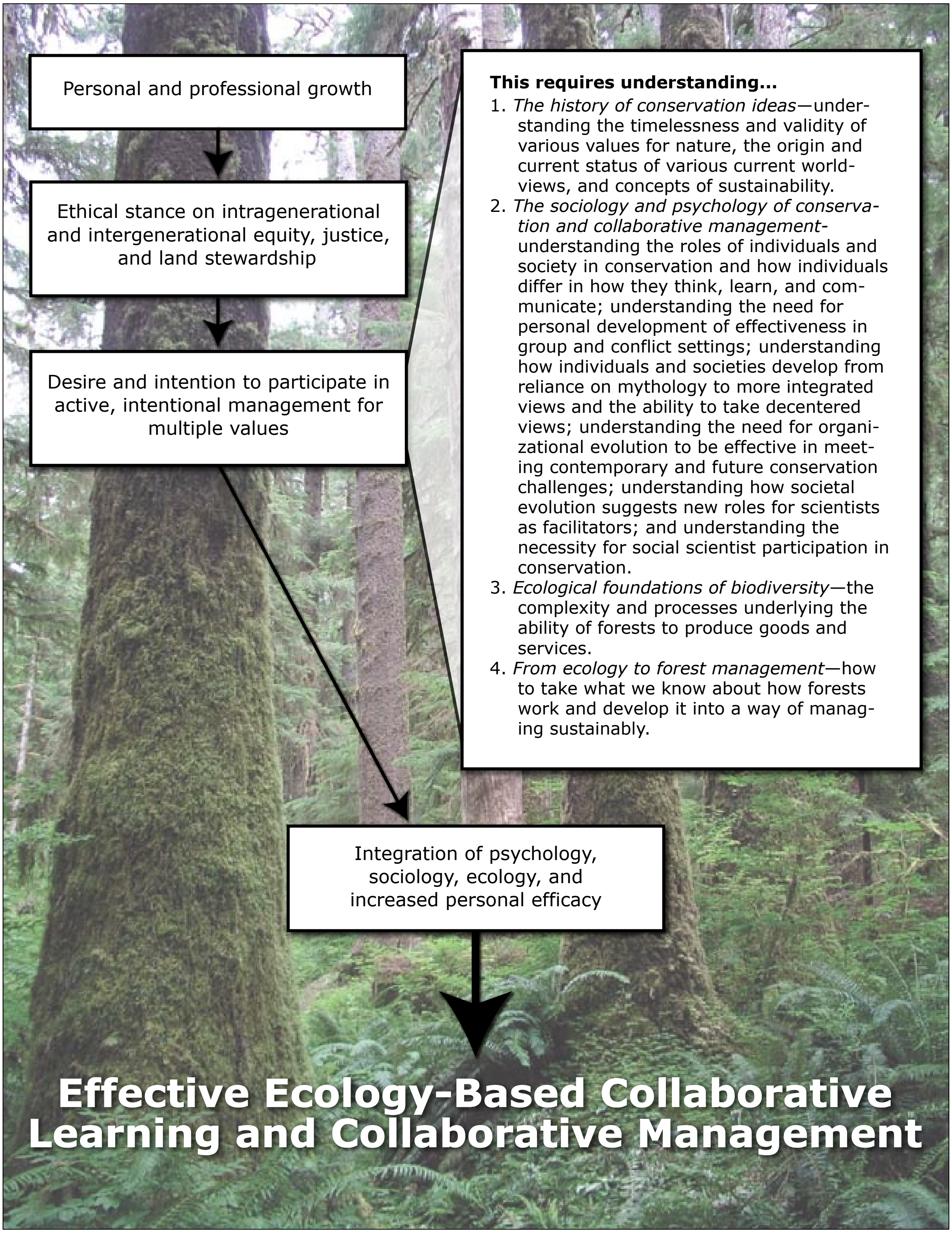
Systems theory helps. Pragmatists have always turned to systems concepts, and there is a long history in ecology from Eugene P. Odum to C.S. Holling, with the current version being called Panarchy theory. Beyond Panarchy is Ken Wilber's holarchy in which everything is a whole in itself, composed of parts, each part a whole in itself, and each whole contributing to a larger whole, which, again, is a part of yet another large whole; thus, everything is a whole/part and can be placed in hierarchy that is free of subordinate-dominant relationships. A characteristic of holarchies is that complexity increases with each level, and one can distinguish between levels in that the lower level is essential to the higher, but the higher is not essential to the lower. For example, the natural environment is essential to an economic system of resource use, but if the economic system is removed, the environment remains. An economic system of resource sharing is essential to developing a complex society, but the nature of that society could change markedly while the economic system remains intact. Markedly change the economic system and society must change. Panarchy insists ecosystem management must be viewed within the context of human social and economic systems. Holarchy suggests that not only is such hierarchy appropriate but that ecosystems, individual humans, and cultures exhibit patterns of development. These patterns suggest that collaborative management not only necessitates understanding ecosystem function and human wants and needs but also requires personal growth and social development. This means moving away from self-centered thought on a personal level and tribal- or interest-centered thought on social and scientific-discipline levels and moving toward decentered views. When the individual and group can step away from self and their natural tendency to pursue a dominator hierarchy and observe the world in its whole-parts—a move from magic-mythic, mythic-rational, and economic rational thinking to what Wilber calls vision-logic—then we have a chance of achieving a common vision and consensus on solutions to complex problems. Therefore, there is a systems focus to this book. This book is not offered as a panacea or a difficult and complex solution to our conservation problems, or even a handbook of methods. Rather, this book provides hopefully one basis for collaborative learning and collaborative management of forested ecosystems (figs. ii, iii).

I dedicate this book to Robert H. Giles Jr., who in the late 1960s taught me how to think—systems thinking, hierarchical structures, and deconstructing complex problems; to Robert G. McLean, who introduced me to ecological fieldwork and invited my participation in multiple investigations of complex ecological systems (pathobiogeocenoses); to Jerry F. Franklin, who introduced me to Pacific Northwest old-growth forests and who has been a 20-year source of inspiration and discussion; and to Chuck DeRidder, who taught me the value of openness to others, teamwork, understanding cognitive differences among people, and the need for examining the structure and function of human organizations.

I wish to acknowledge the following for their support and funding: Nancy Diaz, Issue Coordinator, Sustainable Management Strategies; John Laurence, Program Manager, Ecosystem Processes Program; and Jamie Barbour, Program Manager, Focused Science Delivery Program. I also thank other members of the Ecological Foundations of Biodiversity Team, especially Todd Wilson and Thinh Nguyen, for their assistance and valuable suggestions. I thank Annette Wilson for the attention to detail she has paid in editing drafts of this book, and her creativity in designing tables, figures, sidenotes, and general layout.

Andrew B. Carey

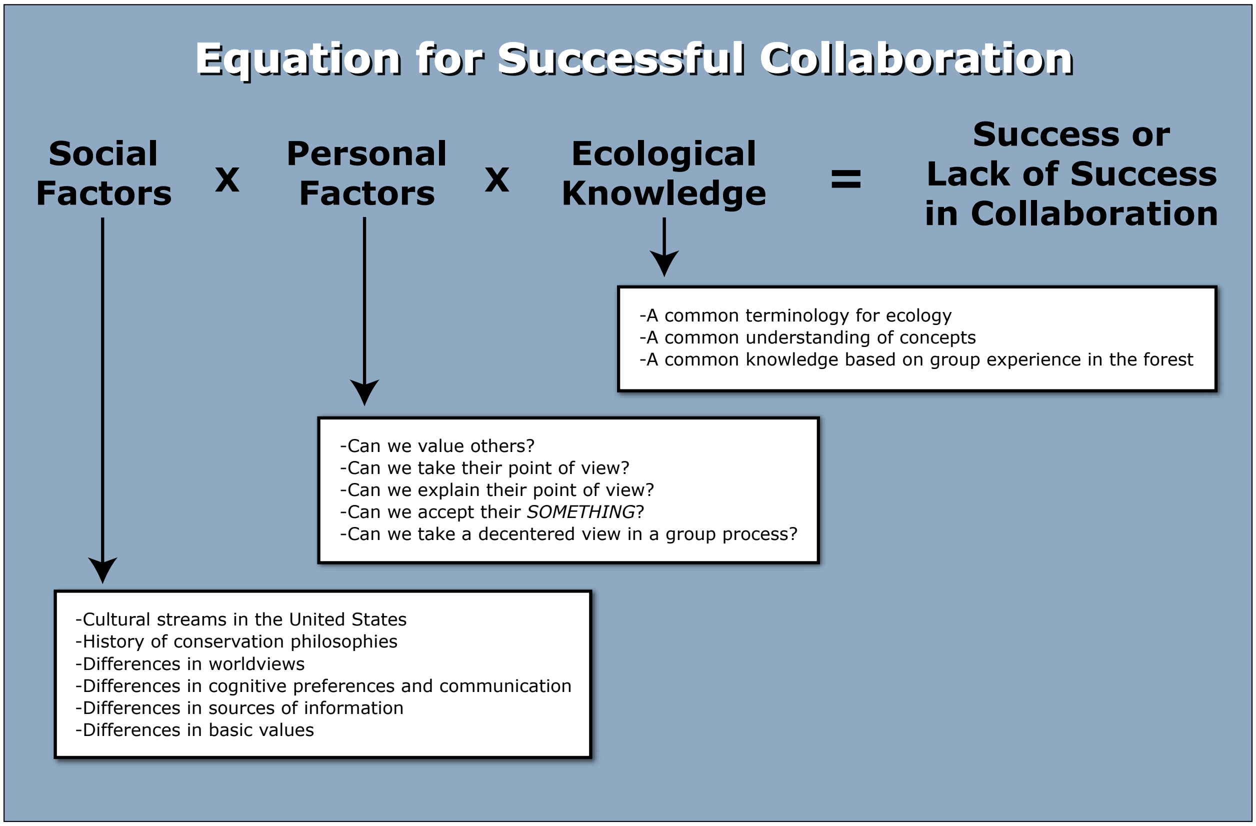
Figure ii



This requires understanding...

1. *The history of conservation ideas*—understanding the timelessness and validity of various values for nature, the origin and current status of various current worldviews, and concepts of sustainability.
2. *The sociology and psychology of conservation and collaborative management*-understanding the roles of individuals and society in conservation and how individuals differ in how they think, learn, and communicate; understanding the need for personal development of effectiveness in group and conflict settings; understanding how individuals and societies develop from reliance on mythology to more integrated views and the ability to take decentered views; understanding the need for organizational evolution to be effective in meeting contemporary and future conservation challenges; understanding how societal evolution suggests new roles for scientists as facilitators; and understanding the necessity for social scientist participation in conservation.
3. *Ecological foundations of biodiversity*—the complexity and processes underlying the ability of forests to produce goods and services.
4. *From ecology to forest management*—how to take what we know about how forests work and develop it into a way of managing sustainably.

Figure iii



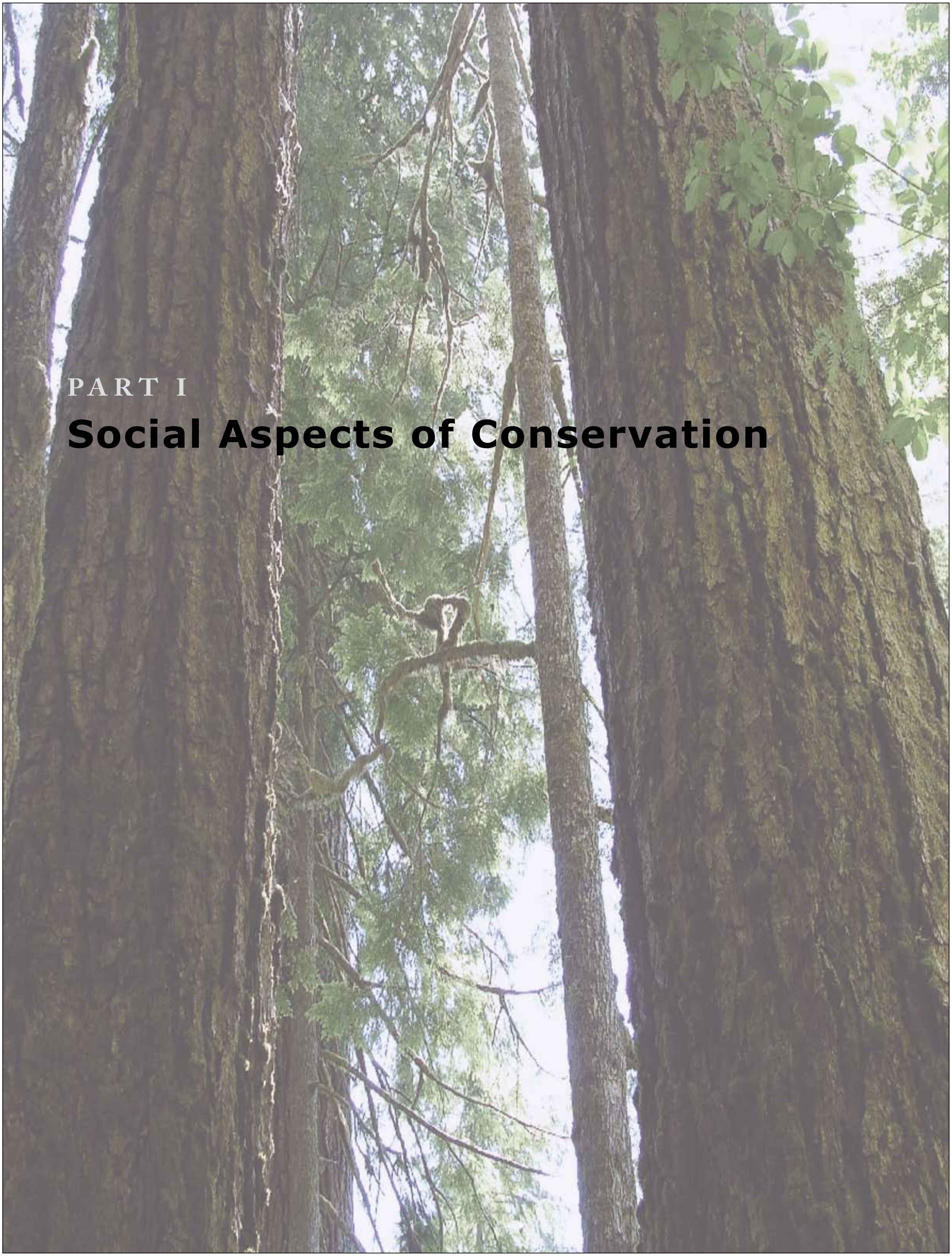
Equation for Successful Collaboration

Social Factors x Personal Factors x Ecological Knowledge = Success or Lack of Success in Collaboration

-A common terminology for ecology
-A common understanding of concepts
-A common knowledge based on group experience in the forest

-Can we value others?
-Can we take their point of view?
-Can we explain their point of view?
-Can we accept their *SOMETHING*?
-Can we take a decentered view in a group process?

-Cultural streams in the United States
-History of conservation philosophies
-Differences in worldviews
-Differences in cognitive preferences and communication
-Differences in sources of information
-Differences in basic values



PART I

Social Aspects of Conservation

PART I **Key Points**

- Conservation of nature has a long history in human societies and is common to virtually all philosophies of the use of natural resources.
- Society derives diverse values from forests, and forests form a large part of the life-support system for human societies.
- Groups differ in value emphasis in forest management, but practically all recognize sustainability as key to human welfare.
- Reconciliation of differences in values may be achieved best by collaborative learning and collaborative management at the local level.
- The ability of individuals to participate effectively in collaborative management not only depends on their willingness to do so, but also on their ability to take a decentered view of conflicts that arise.

CHAPTER 1

Conservation and Biodiversity

This book is about conservation in the context of sustainability—environmental, economic, and social. Before addressing the environmental and economic aspects of conservation, I must first place conservation in a larger, overarching social context of the United States and, more particularly, the Pacific Northwest. Conservation calls for more than the application of technology; it requires a collective purpose (Leopold 1949). But our society is diverse. Perhaps our society's most fundamental aspect is its promotion of each individual's right to define his or her self—personally, socially, occupationally, culturally, politically, spiritually, and philosophically. Each of us is free to perceive and report reality in our own way. Our common language, English, promotes such individualism. The conceivers of the Oxford English Dictionary, the first comprehensive dictionary of the English language, recognized and accepted English as an ever-changing language, and they made their dictionary a continuing effort (1879-present) to inventory, not prescribe the language (Winchester 1999). To them, word meanings were not static but continuously wandering, twisting, and turning over time. Human diversity, dynamic language, and different ways of learning prompt defining reality in terms of one's self over reliance on scholarship and formal discourse to achieve a shared view. Even our tendencies toward safekeeping and cultural conservatism, determinants of our past evolutionary fitness, fail to stem this drive toward autonomy.

Our emphasis on individualism extends into science, where rejecting an existing hypothesis and creating new theories are valued over affirming hypotheses and synthesis (Wilson 1998). Furthermore, "For every expert there is an equal and opposite expert" (Clarke 1998). Even more problematic, ecology is grounded in words, not in the precision of mathematics. Because of the imprecise and changing nature of words in English, the science of ecology has been slow to advance in comparison to mathematical sciences and their precise, unvarying definitions (Haskell 1940). Disputes become based on semantics and caricatures of concepts developed by embellishment, selective editing, and oversimplification (Partridge 2000). Furthermore, scientific perception is theory bound—two different and equally objective scientists can observe the same natural system and provide very different descriptions of what they observed, depending on the language they choose, the assumptions they make, and the values that motivate them. These descriptions may or may not be contradictory. Because scientific claims are not value free, science, especially ecology, is rife with disputes rooted in conflicting values and epistemologies (Woolley and McGinnis 2000) (sidenote 1). Furthermore, the imprecision of the English language led an eminent and well-published psychiatrist, Stoller (1985), to conclude that no matter how mightily he strove for clarity, there would still be *multiple*, *valid* interpretations of what he wrote.

Sidenote 1—Four types of restorationists participated in three widely separated river restoration efforts (Woolley and McGinnis 2000):

- **Categorical:** regards restoration as factually necessary and ethically mandated to a state prior to human settlement; sees restoration as an article of faith
- **Conditional:** believes restoration may be justified and technically feasible only if competing claims can be addressed; emphasizes private property rights, local control, tradeoffs, and cultural values
- **Ecophilosopher:** distrusts science and technology and is critical of values for restoration and community needs; has the deepest feelings for wilderness and preservation; does not believe nature can be restored; believes restoration is impossible and its products false; sees restoration as an act of human domination over nature
- **Ecosocietal:** thinks restoration is a philosophy and political enterprise and must involve society and community restoration

Ecology, the science of relationships between organisms and their environment (Pickett 2000), has progressed through iterative compilations of natural history observations, verbal conceptual models, and mathematical formulations, with occasional important contributions from experiments. Imprecision and a variety of words have led to hypotheses and theories that are often challenged because of superficiality, circularity, and infallibility (Peters 1976, 1978; Quinn and Dunham 1983). This considerable ambiguity in the use of terms has produced a science that lacks clear baselines, boundaries, explicated concepts, and theoretical rigor (Partridge 2000) (sidenote 2). Such concerns led the distinguished ecosystem ecologist, R.V. O'Neill (2001) to ask, somewhat tongue-in-cheek: "Is it time to bury the ecosystem concept?" citing backlash from the "apocalyptic fervor of the environmental movement of the past decades." It is now too late for science to define authoritatively concepts related to conservation; science no longer has the moral authority to do so in our culture. The privilege accorded science in the modern world relied on science being objective in describing how the world works; in the postmodern world, a single truth does not exist.

Sidenote 2—Many find conservation concepts ambiguous; this ambiguity, however, may be perceived because many of these concepts are multidimensional and metaphoric. Pickett (2000) defines ecosystem as "an ecological community together with its environment, functioning as a unit." Pickett and Cadenasso (2002) found that "ecosystem" is a fundamental ecological concept that is complex and subtle with

Science of intrinsic quality now needs narratives with explicit values—not just facts—particularly as it faces multilevel complexity in environmental issues (Allen et al. 2001). Traditionally, scientists and conservationists have worked independently of each other, as well as the people affected by their decisions (Adams and McShane 1992). Today, various "concepts are at large in the world, shaping conservation thought and policy" (Callicott et al. 1999) (side note 3). Many find the terminologies of conservation to be ill-defined, nakedly value laden, irritating, and even contentious, whereas others find them normative, meaningful, and even uplifting. Often conservation concepts are described as buzzwords and rhetorically dismissed as lacking substance. Even so, these terms are in the public lexicon, the culture of conservation, written policy, laws, and treaties, and they have inescapable consequences for stakeholders, regulators, managers, and policymakers.

Humans search for simple and clear principles, without uncertainty. Our behavior is shaped of necessity by concerns that are personal, immediate (short term), and certain (Daniels 1989, Ornstein and Ehrlich 1989). These characteristics reflect an intuitive tendency to parse our environment and experiences into discrete, bounded wholes. Some of this may be "hard-wired" in our brains and is one reason that umbrella concepts have such appeal (Anderson 2001) (sidenote 4). Nature, however, is simultaneously mechanistic and stochastic, and thus, presents substantial ambiguity and complexity, just as many conservation concepts do.

Ambiguity is unsatisfying and can lead to unwarranted rejection of concepts and searches for nonexistent certainty and specificity. Thus, *conservation of biodiversity* can be a useful concept to some (e.g., Carey and Curtis 1996, Hansen et al. 1991, Reid and Miller 1989),

layers of meaning. Ecosystem has three uses: meaning, model, and metaphor. Its meaning is usually a technical definition, which requires detailed definition for each application. As a model, it embodies details that are needed to address real or hypothetical situations. As a metaphor, it informs scientific discussions, common parlance, and public dialogue. The earliest definition of ecosystem is "a biotic community and its associated physical environment in a specific place" (Tansley 1935). This implies a nested hierarchical system—size can vary, but it must have an explicit spatial extent, specified and bounded—and this is the way that prominent ecologists of the past (Tansley, Odum, and Likens) perceived ecosystems. In modeling, ecosystem has been used for diverse foci, including energy and nutrient cycling, autecology of organisms, community ecology, biodiversity, and ecological economics. Thus, ecosystems have four domains that need to be specified: components, spatiotemporal scale, physical boundaries, and connections among components. These components can be geophysical, biological, and social. Boundaries can be chosen as a matter of convenience to follow geomorphological divides (most common), to understand a political entity, to recognize changes in rates of ecosystem processes, or to measure changes in frequency of some ecological phenomena.

The Procession of Species, a yearly artistic pageant where community members celebrate their relationships with each other and with the natural world. Photo by A. Carey.

Sidenote 3—Concepts at large in the world shaping conservation thought and policy that are generally either ill defined or defined differently by various groups (Callicott et al. 1999):

- Adaptive management
- Biological diversity
- Biodiversity
- Biological integrity
- Conservation
- Ecological integrity
- Ecological restoration
- Ecological services
- Ecological sustainability
- Ecosystem health
- Ecosystem management
- Flagship species
- Functional groups
- General sustainability
- Keystone species
- Habitat fragmentation
- Minimum viable populations
- Source-sink dynamics
- Survey and manage species
- Sustainable development
- Umbrella species

only to be rejected in the same scientific arena as useless because it lacks a universal specific meaning (Lautenschlager 1997). Similar treatment has been accorded to *niche*, *habitat*, *ecosystem*, *keystone species*, *ecosystem management*, *conservation*, and most other terms in the debate over disposition and management of our natural resources (Carey 1981, Morrison 2001, Whittaker et al. 1973). Therefore, common words used in this book are defined according to their primary definition in the fourth edition of *The American Heritage Dictionary of the English Language* (Pickett 2000) but with reference to the online *Oxford English Dictionary* for history of usages. Additional definitions of technical terms are provided in the text, sidenotes, and glossary. The purpose in providing these definitions is to give participants in collaborative learning and collaborative management a source of common language, if they care to use it. No one should presume to mandate definitions.

The focus on semantics is not whimsical (Hardin 1969). Semantics, rather than logic or science, accounts for much of the current debate about *conservation*—the protection, preservation, management, or restoration of wildlife and of natural resources such as forests, soil, and water (Pickett 2000). In this debate, terms become *normative*—of, relating to, or prescribing a norm or standard (Pickett 2000). Thus, there is active competition to have one's definition become accepted by a majority because thereby a social standard comes into being. Partisans of a single normative concept try to vanquish the rest in a battle of definition of buzzwords in the arena of power politics (Callicott et al. 1999). Commonly, "good science is that which supports one's political position and interests" (Woolley and McGinnis 2000).

Freudenburg (2002) refers to this politics of language as "navel warfare" (as in gazing at one's navel), concluding that exaggeration of differences between both environmental and resource sociology produces a divide where synergy could exist. Viewing the environment in terms of profit produces resource managers instead of environmental managers. Viewing a need to preserve broader ecosystems fosters protection and restoration over environmental management. Academics exhibit the "best of minds, the worst of minds" in the debate. At best, they use highly developed abilities to spot patterns, think abstractly, construct models, and work and play with models. At worst, they take mental models too seriously and forget the original purpose. Debate over management choices, rather than focusing on opportunities for synergy, often focus on false dichotomies (Haynes and Monserud 2002, Haynes et al. 2002). Conflict over policy has evolved into nonlistening conversations with the same nearly century-old arguments of Gifford Pinchot and John Muir being restated with little new in the way of reconciling principles (Callicott et al. 1999). Realizing the futility in searching for decisive terminology and, instead, embracing ambiguity and seeking understanding and communality will help achieve consensus in management debates. In the following sections, this book will offer some temporary clarity in terms and concepts.

Conservation inescapably entails some aspect of conserving biodiversity. *Biodiversity* is the variability among living organisms on the earth, including the variability within and between species and within and between ecosystems (Pickett 2000). Many variations on this definition exist that are reflective of various worldviews and conservation priorities. The definition of biodiversity prompts the question: Why conserve biodiversity? The simple answer is multifold: legal mandates; social and cultural mandates; instrumental values such as wood products, medicines, and ecosystem services; and importance to sustainability. Loss of biodiversity, along with ozone depletion and greenhouse warming of the Earth's atmosphere, are global environmental problems dominating environmental discussions (Norton 1994).

The most common related questions are: What should we save—genes, species, or ecosystems—and how many, where, when, for how long (Amaranthus 1997, Franklin 1993b)? To many, deciding what elements to preserve is a policy decision to be based on societal priorities. To others, it is a profoundly ethical and moral question. Are any species superfluous? We do not know, and it is possible we will never know for sure. Most species are unknown. And as Tacitus (54–119 AD) said "*Omne ignotum pro magnifico*," or anything unknown is assumed wonderful (Bigg 2000), at least by a significant proportion of stakeholders. Based on current knowledge, the odds are that there is enough redundancy that loss of a species could be inconsequential (to species other than itself and its obligative symbionts). Are some species more influential than others? Of course, they are. In any case, given our vastly incomplete knowledge of species, conservation must focus on surrogates for the totality of genes and species. Even if we do the impossible and identify and describe the ecologies of all species, it would be far beyond our cognitive capabilities (even aided by computers) to use all that information; we must formulate and apply some first (general, basic) principles.

A less common question, but perhaps more important is: How can we restore and maintain biodiversity in our humanly inhabited natural-cultural mosaic landscapes? In other words, how do we manage for biodiversity? There are four basic options: ecological reserves;

Sidenote 4—Anderson (2001) describes three pairs of evolved abilities and their corresponding difficult cognitive tasks:

- **Packaging information: recognizing things as discrete; classifying and naming categories**

  Difficult task: Dealing with continuous processes (working across scales; managing problems without clear boundaries)

- **Focusing on frequencies: counting instances; interpreting counts as frequencies**

  Difficult task: Using decimal probabilities (estimating probabilities of single events; working with probability theory)

- **Telling stories: telling stories to share experience; using cases as a basis for decision-making, problem-solving, and learning**

  Difficult task: Making decisions in the absence of experience (solving unique problems; communicating theory and abstractions)

Interestingly, the evolved abilities and corresponding difficult cognitive tasks also relate to the IQ measure, with lower, initial points earned for recognizing types and using past experiences to solve similar problems and applying past experience to novel problems (evolved abilities) and subsequent additional points earned for creating novel solutions to novel problems (more difficult cognitive task). In other words, evolved abilities form the basis for low to average IQ, and the corresponding difficult cognitive tasks are characteristic of high IQ.

active, intentional, ecosystem management; reserves and management in combination; and total landscape management (Carey 2003a, 2003c). The belief that we can achieve our conservation goals simply through passive management, however, is fallacious (Agee 2002). And finally, how do we measure success? Here, the answer is least clear. There is no single measure. There is no agreement on a suite of measures. Various people suggest monitoring species persistence (often rare, cryptic, and threatened species), invasion by exotic species, diversity of various groups of vertebrates and fungi, functional groups of plants and invertebrates, keystone species, biotic integrity, ecosystem structure, ecosystem processes, or landscape structure and dynamics. Norton (1994) said: "Whilst it is not seriously questioned that there is an incumbent moral obligation for us to sustain biological diversity for the benefit of future generations, we still have to find the rationale for consensus and to articulate it in a specific and operational manner." Dombeck (1997) added: "Just how do we maintain the health of the land? By working with people who use and care for the land."

CHAPTER 2

Culture and Conservation

Biodiversity was introduced into the scientific lexicon by Walter G. Rosen in 1986 during the national forum on biodiversity for educators and policymakers and quickly became integrated into the national vocabulary (Weber and Word 2001). But human fascination with the diversity of life certainly arose with human consciousness and continued throughout the evolution of human culture from hunting and gathering to agriculture to the present (Wilber 1995). Exploitation of natural diversity allowed the development of increasingly intricate social and economic systems (Diamond 1998, Hutchinson 1965). Aldo Leopold (1897–1948) wrote: "Wilderness is the raw material out of which man has hammered the artifact called civilization" (Leopold 1949).

The diversity of living things captivated early ecologists. Hutchinson (1965) recounts the studies of variation in Lepidoptera (butterflies) by Gilbert Henry Raynor (1854–1929) that led to the discovery of sex-linked inheritance almost concomitantly with Mendel's discovery of the genetic basis for inheritance. Fascination with the diversity of life led to the theory of evolution that underlies modern biology and biomedicine. The question of why there are so many species dominated ecology in the first half of the 20th century (Hutchinson 1959) and led to the concept of the multidimensional niche (Hutchinson 1957), community ecology (Whittaker 1975), and statistical-mathematical ecology (Pielou 1975, 1977, 1984).

Emphasis on conservation of biodiversity (nature, including biological diversity and ecosystems) certainly preceded 1986 by more than 50 years. Aldo Leopold (1949) formulated the *Golden Rule of Ecology* with "A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise." Leopold's writings contained many of the words and concepts (integrity, stability, health) that are now being used and contested in the great debate on how to conserve our natural heritage. He certainly recognized our different values (table 1): "I am amazed to learn what diverse characters different men impute to one and the same tree" (Leopold 1949). Leopold also acknowledged the countervailing tendencies of human nature and the paradoxes therein: "But all conservation of wildness is self-defeating, for to cherish we must see and fondle, and when enough have seen and fondled, there is no wilderness left to cherish" (Leopold 1949).

Still, we find ourselves in polarized, adversarial positions about conservation. The last 20 years has seen an explosion of philosophical, scientific, and technical discussions of conservation (Woolley and McGinnis 2000). What is important in conservation? How real is the need to conserve biodiversity? How might we best attempt to conserve our natural heritage? How should we implement adaptive management? What kinds of things should we measure and monitor? What research will best serve the conservation community, interested publics, and society at large? These are a few of the questions we need to address. A review of how we got here might help.

A History of Conservation Ideas

Donald Worster (1994) recounts five roots for today's ecology: *Arcadianism*, *Christian pastoralism*, *Arcadian imperialism*, *Thoreau's Romantic ecology*, and *Darwinian ecology*. Worster is summarized here, not to bore the reader with esoterica, but to highlight the power of ideas and demonstrate how most historical ideas about nature are still extant in contemporary culture. These ideas are far more than artifacts of the interaction of culture and nature. They may be psychologically fundamental (archetypal) and biologically based (evolutionarily selected), as suggested by some Jungian psychologists for the multiple bases of temperament and personality (Myers and McCaulley 1985, Ornstein 1993). If so, it is even more important to understand them because simple, rational discourse is unlikely to reconcile their differences.

Arcadianism and the Ecology Movement

In the mid-18th century, Gilbert White, a curate in Selborne, England, founded Arcadianism, advocating a simple, rural life and restoring man as part of nature. Ludwig von Bertalanffy later described this view as holism. Through recent Arcadian reactions against technology and the scientific paradigm, the ecology movement appeared with spokespersons like Rachel Carson, Paul Sears, Barry Commoner (sidenote 5), and James Connell. In 1935, Sears defined conservation as restoring biological order, maintaining the health of the land and well-being of the Nation, and establishing a lasting equilibrium of man with nature (Worster 1990).

Sidenote 5—Barry Commoner formulated the Four Laws of Ecology (Partridge 2000):
- Everything is connected to everything else.
- Everything must go somewhere.
- Nature knows best.
- There is no such thing as a free lunch.

Table 1—American values regarding forests and grasslands and their importance

Value	Mean (out of 5)
Individual values:	
People should be more concerned about how public lands are used.	4.8
I'm glad national forests are there even if I never see them.	4.7
Future generations are as important as the current generation in public lands decisions.	4.5
Wildlife, plants, and humans have equal rights.	4.3
Natural resources must be preserved even if some must do without.	4.1
Forests have a right to exist for their own sake.	4.1
We could get by with less and leave more for future generations.	4.0
Individual values group mean	4.2
Management values:	
We should conserve now to allow development in the future.	4.0
We should provide jobs.	3.2
The primary use of forests is products useful to people.	3.0
We should use economic decisionmaking.	2.9
We should harvest more.	2.9
Management values group mean	3.0
Public values and objectives:	**Objectives**
Improve and protect forests.	4.7
Protect ecosystems for wildlife habitat.	4.6
Preserve forests without timber harvest.	4.2
Preserve wilderness.	4.2
Allow for diverse uses.	4.1
Preserve cultural uses.	3.8
Provide resources to people.	3.6
Public values and objectives group mean	4.2

Source: Shield et al. 2002.

Christian Pastoralism, the Imperial View

This philosophy strips nature of all spiritual qualities. Nature's chief function is to serve the needs of man. With the imperial view of nature, modern man's most important end is domination over the Earth. An example is Francis Bacon's man-made paradise based on science.

Arcadian Imperialism

This root began in Carl von Linné's (1707–1778) *Systema Naturae*, the first of a series of tracts on rationalistic religion. Arcadian imperialism stresses the hand of God in nature, nature as cyclically static with symphonic precision, and all things for the sake of man—using other species vigorously, eliminating undesirable species, and promoting useful species. Ultimately, the Earth must be managed for maximum output. In the Age of Reason, this was the utilitarian philosophy.

Thoreau's Romantic Ecology

Henry Thoreau (1817–1862) was Gilbert White's inheritor. His view was fundamentally ecological, focusing on relations, interdependences, and holism. Thoreau's purpose was to reconstruct the actual condition of where we dwell to that of three centuries ago, in order to produce a single interrelated whole arranged by nature in perpetual balance. Thoreau's major efforts dealt with the phenomenon of forest succession—accepting nature as a teacher and accommodating oneself to her rhythms. This return to wilderness redefined man's place in nature. It was also a return to paganism with its fascination of the natural world and focus on animism and holism. Thoreau's Romantic ecology produced an ecological perspective—nature as a system of necessary relationships that cannot be disturbed without changing the equilibrium of the whole.

Darwinian Ecology

Charles Darwin (1809–1882) and his contemporaries, the botanist Alexander von Humboldt, the geologist Charles Lyell, and the demographer Thomas Malthus, had a holistic but less harmonious view of nature. Humboldt studied the geography of plants, grouping species into dominant life forms and in relation to their surrounding conditions. He constructed vegetation zones based on relationships between altitude, latitude, and vegetation. Darwin studied the severe environment of the Galapagos and the different roles assumed by various finches, turtles, and lizards. Humboldt and Darwin looked at nature comparatively, with a geographical approach, and formulated assemblages and systems. Nevertheless, both placed science within a larger framework of feeling and sensibility and, in the process, converted their contemporaries from Romanticism to science as religion. Charles Lyell observed the continuing play of natural physical forces and the nonpermanence of nature as well as long accumulated works of nature and periodic mass extinctions. He studied the fierce competition among species for space and food and rejected the Linnaean faith of lasting balance in nature. Thomas Malthus's essay on populations provoked Darwin's ideas of natural selection of the fittest and evolution of new species. Donald Worster (1994) suggested that Darwin's reading of Malthus's essay may have been the single most important event in the history of Anglo-American ecological thought and led to constructing a science to meet one's own emotional and psychological needs.

From Ecology to Conservation

Ecology has its roots in White, Linnaeus, Humboldt, Lyell, and Darwin. Ernest Haeckel, a disciple of Darwin, coined the term with reference to biogeography, and C. Hart Merriam contributed concepts of life zones and habitats. At the turn of the century, Victor Shelford called ecology the science of communities, and A.G. Tansley emphasized dynamic ecology and successional development of communities. Frederic Clements formulated a coherent and elaborate system of ecological theory, now often inaccurately portrayed (see Partridge 2000 for a discussion on how idealized concepts are important to science but often discredited through distortion or reductionism). Clements stressed that vegetation is essentially dynamic and that succession is not aimless, but a steady flow toward stability along a sere with its direction and progression determined by climate. He also introduced the concept of a climax stage based on the Spencerian philosophy of cosmic evolution, in which all phenomena progress toward differentiation and integration, from homogeneity to heterogeneity, and from differentiation to interdependence.

In the early 1930s, the American Dust Bowl and the economic collapse of stock markets produced a public and scientific willingness to subordinate economics to broader values. This included ecological integrity, as in the conservation philosophy articulated by Aldo Leopold:

> The fallacy that economic determinists have tied around our collective neck, and which we now need to cast off, is the belief that economics determines all land-use. This simply is not true. An innumerable host of actions and attitudes … is determined by the land-users' tastes and predilections, rather than by his purse (Leopold 1949).

Leopold continued, "The bulk of all land relations hinges on investments of time, forethought, skill, and faith rather than on investments of cash. As a land-user thinketh, so is he" (Leopold 1949).

At the same time, Leopold was a pastoralist devoted to husbandry: "…two spiritual dangers in not owning a farm … supposing breakfast comes from the grocery store, and … heat comes from a furnace" (Leopold 1949). He described, "… definitions of … a conservationist … [are] best … written not with a pen, but with an axe … what a man thinks about while chopping or while deciding what to chop" (Leopold 1949). In his 1933 text on game management, Leopold wrote: "Effective conservation requires … deliberate and purposeful manipulation…" (Leopold 1933). This philosophy is not dissonant. Just as Aldo Leopold harvested a lightning-struck oak for firewood two generations ago, contemporary Pacific Northwest forest activist, Andy Stahl, harvested his own mature oak to turn into cabinetry. One presumes that wilderness advocate John Muir had no compunction about burning wood in his wilderness campfires. What is most relevant in choices about using natural resources relates to frequency, intensity, scope, and scale of use.

Whereas Leopold focused on restoration of degraded, abandoned farmland in his famous treatise, *A Sand County Almanac*, his contemporaries, ecologists Roger Smith and Paul Sears focused on climax grassland communities. They argued that climax communities should be left unmanaged because they are resilient. However, the concept of untouched climax communities was antitechnology, and botanist Henry Gleason responded with his individualistic concept of plant associations as accidental groupings and repudiating succession (later expanded into a grand theory by Hubbell in 2001). Gleason described climaxes as haphazard, imperfect, and shifting, implying that climax communities were not special and need not be protected. Tansley chimed in rebutting monoclimax in favor of multiclimaxes (edaphic, biotic, fire, anthropogenic).

Progressive conservation was part of the political movement of Teddy Roosevelt. Gifford Pinchot supported doing away with reserves: "Forestry is handling trees so that one crop follows another." Efficiency and productivity were applied to public lands for the first time. John Muir opposed Pinchot's progressive agronomic perspective, as John Grinnell protested Leopold's predator control. Debate on how to integrate ecology into conservation was widespread. Ecological pragmatism sought to preserve natural checks and balances. Olaus Murie accepted the need for management but opposed emotional persecution of varmints.

Leopold's 1949 description of a land ethic ushered in the Age of Ecology by establishing a scientific, ecological, biocentric, and communitarian ethic that challenged the economic ethic. A concept of natural rights was derived from the Declaration of Independence. The Rights of Nature extended to all species and even to the Earth itself. Leopold suggested that unless man recognized the rights of the entire Earth, he might find his own survival threatened—"… the first principle of conservation: to preserve all parts of the land mechanism …" (Leopold 1949). He emphasized, "To keep every cog and wheel is the first precaution of intelligent tinkering" (Leopold 1949). Aldo Leopold's philosophy, however, remained agronomic even while reconciling rival worldviews. Worster (1994) explains: "Every generation writes its own description of the natural order which generally reveals as much about human society and its changing concerns as it does about nature."

In 1927, Charles Elton promulgated the sociology and economics of animals and five principles describing the economy of nature: (1) the food webs of producers, consumers, key industries, and interdependencies; (2) food size determining organism size; (3) pyramids of numbers; (4) the niche as occupation, especially what the organism is eating; and (5) competitive exclusion. A few years later, G.F. Gause promoted competition as the law of nature, and A.G. Tansley disputed synergy and the concept of community and favored ecosystems as physical systems of material exchange. In the 1940s, Ray Lindeman merged the ideas of Elton, Tansley, Chancey Juday, and Edgar Transeau into the *Trophic-Dynamic Aspect of Ecology*, describing the energy pathways (Worster 1994).

The 1960s "New Ecology" reflected the values of the modern economic order—corporate society with interdependence, primacy of efficiency and productivity, and a managerial ethos. A new breed of mathematical ecologists arose, including G. Evelyn Hutchinson, Robert MacArthur, and Eugene P. Odum as the scientists of natural

Sidenote 6—The other most important publication in biology in the 20th century was James Watson and Francis Crick's 1953 paper on the structure of DNA (Hardin 1969).

economics. Odum (1969) postulated that all ecosystems have a strategy of development directed toward achieving as large and diverse an organizational structure as possible based on mutualism, cooperation, and symbiosis, embellishing Clements' theories. This bioeconomic ecology owed a great deal to its larger cultural milieu but did not satisfy the communalism of Leopold's fellowship.

Then there came about a resurgence of philosophical idealism and a quest for transcendence, eternal harmony, and cosmic love. James Lovelock and Lynn Margulis wrote the Gaia theory. Rachel Carson, Paul Ehrlich, Barry Commoner, and Edward O. Wilson perceived an Earth in crisis. Rachel Carson's *Silent Spring* was one of the two most important publications in biology in the 20th century (Hardin 1969) (sidenote 6). The Ecological Society of America issued that *Silent Spring* "created a tide of opinion which will never again allow professional ecologists to remain comfortably aloof from public responsibility … its effect on public opinion, national scientific policy, and … professional societies … can hardly be overstated" (Hardin 1969). That well-meaning interventions in natural systems have caused great and unforeseen harm has the practical implication that "we can never do merely one thing" (Hardin 1969).

In the 1970s and 1980s, the focus of ecology moved to disturbance theory (Connell and Slatyer 1977, Drury and Nisbet 1973, Pickett and White 1985b). These "disturbance boosters" were population biologists, not ecosystem scientists, and as such focused on trees and not the forest. In doing so, they perceived no synergy and no emergent properties (Worster 1990). Constant change and incessant disturbance satisfied them ideologically more than Odum's ecosystem, with its stress on cooperation and social organization. Disturbance theory is more consonant with individuality, private enterprise, social Darwinism, and the generational transition from the politically conscious generation of the 1960s to the yuppie generation of the 1980s. The rise of disturbance theory is a triumph of reductive population dynamics over holistic consciousness and of social Darwinist entrepreneurial ideology over a commitment to environmental preservation. Edward Lorenz developed the scientific study of chaos in 1961, and the promulgation of nature as fundamentally erratic was a revolution against all principles, laws, models, and applications of classical science (Gleick 1987, Worster 1990). Robert May discounted the relationship between diversity and stability, John Wiens wrote of stochasticity, and Paul Colinvaux was antimanagement (Worster 1994).

This trend continues today—Hubbell (2001) presents a grand *Unified Neutral Theory of Biodiversity and Biogeography*. The wedding

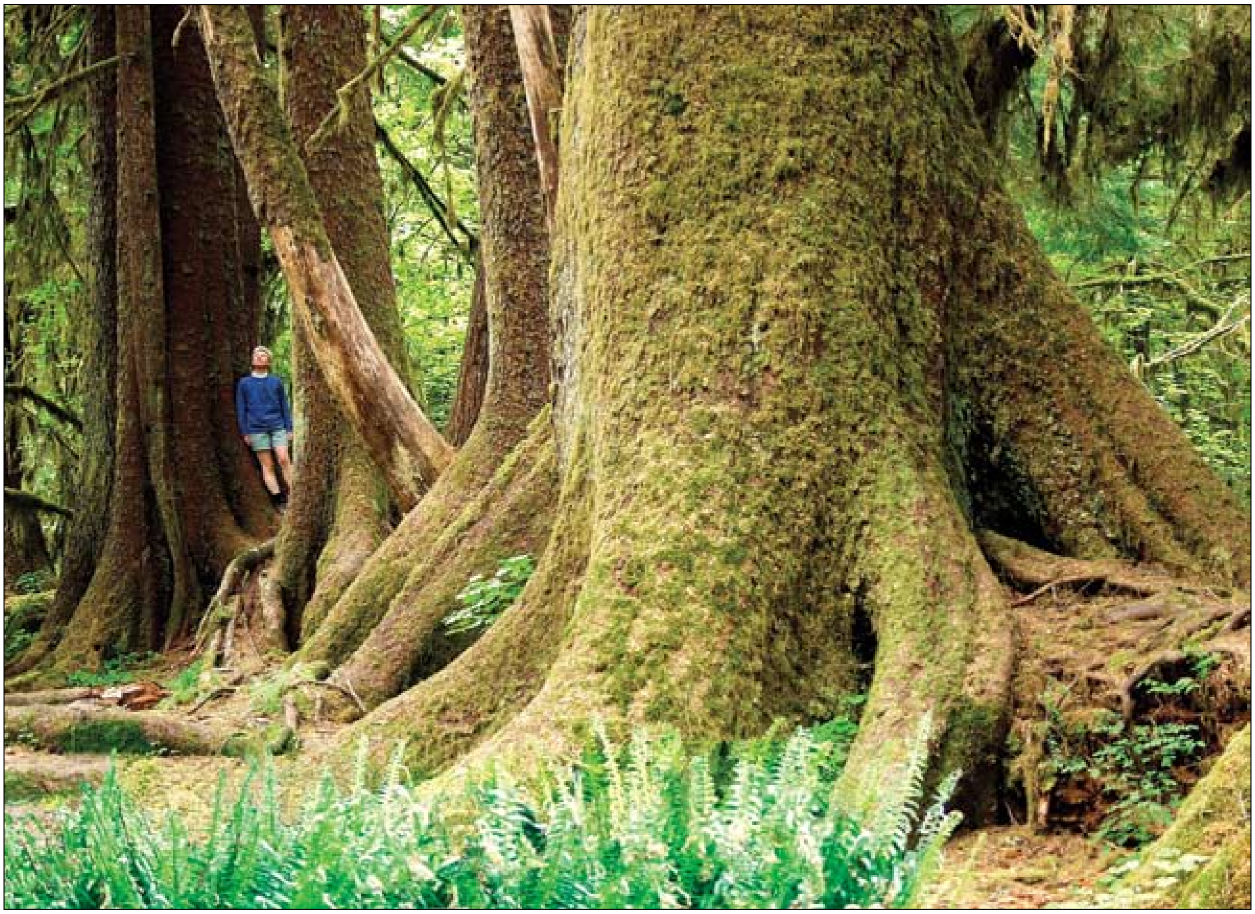


Figure 1—Regine Carey, the author's wife, leans against an old-growth tree in the Hoh Rainforest, Olympic National Park. Photo by A. Carey.

of evolutionary ecology and population biology produced conservation biologists and the cognitive dissonance they embody—nature is a finely tuned watch and every piece is important in a chaotic world with each species population being independent and with no emergent properties. The logical consequences of this train of thought are profound (Partridge 2000). Why preserve old-growth forests (fig. 1) if they are simply haphazard collections of independent species? What constitutes environmental degradation, or even environmental destruction, in a world of disturbance and chaos?

The history of ecology reveals interdependence between scientific thought and values of the contemporary society. Science and culture are not independent—science actually follows culture. History documents continuing threads over centuries in how people think about their relationship to nature and how science seems to spiral upwards cycling among philosophies but always gaining in complexity. The recapitulation of Worster's history only briefly describes the diverse and rapid intellectual and scientific development of ecology within the adult lifetime of today's senior academicians, scientists, administrators, and managers active in the conservation

Figure 2—Models of enduring human communities and their interactions with nature: (A) Maasai boys, on the Maasai Mara, prepare for induction into manhood by collecting, without weapons or snares, birds for their headdresses. The Maasai are herdsmen, and with the Kikuyu farmers and other agriculturally specialized ethnic groups, they partitioned the landscape into ecological zones and developed sustainable agronomic practices adapted to those zones. Colonization reorganized African societies and imposed European agricultural models on the landscapes with sometimes-disastrous results. (B) A cultural mosaic of suburban development, small farms, and industrial forest near Olympia, Washington. (C) A sustainable cultural landscape of farming communities, farms, and forest in Germany. Guttau was officially founded in 1238; the photograph is circa 1985 (from the collection of Regine Timm Carey). Herr Willi Timm, bauer and jaegermeister, managed the landscape for harvestable populations of grains, rapeseed, pheasant, partridge, hare, fox, roe deer, and red deer. (D) The rapidly growing urban area of Olympia, the state capitol of Washington, and its adjacent cities of Lacey and Tumwater (the first area in Washington settled by Americans of European ancestry) are having increasingly severe impacts on the South Puget Sound natural-cultural mosaic of Douglas-fir forest, native prairies, oak woodlands, kettle wetlands, riparian areas, and salt-water shoreline. Photos A, B, and D by A. Carey; Photo C courtesy of R. Carey.

arena. Quite contrary to the unspoken philosophy underlying disturbance ecology, Worster (1990, 1994) concludes:

- Nature works by the principle of interdependency—no organism or species can survive without the aid of others, and humans depend on other life forms.
- No single model, but a wealth of models represents nature. History reveals models of enduring human communities that created rules to govern behavior based on intimate local experience (fig. 2). Science cannot take the place of moral reasoning, and science needs to be critiqued from time to time to avoid its promotion of a few of our darker ambitions toward nature.
- Change is not only real but also various. Some changes work against us. Some changes are in our own enlightened self-interest, and some are consistent with our ethical reasoning.
- We can no longer locate nature in some timeless state of perfection.

Partridge (2000), in an independent analysis, drew similar conclusions. Odum (1969), Holling (1994, 2001), and other systems theorists also support this markedly different view of the world.

Contemporary Themes in Conservation

Our society supports multiple concurrent and overlapping themes in conservation. Most are overtly value laden (Callicott et al. 1999). Americans are moving from environmental beliefs and values based on technology to those based on ecology and human relations; 75 percent consider themselves to be environmentalists (McDonough 2003). One broad theme is a general social concern for quality of life relative to the environment in which we live (see also Czech et al. 2001, Ehrenfeld 2002) (sidenote 7). Environmentalism includes concerns about clean water, clean air, industrial pollutants, automobile emissions, home contaminants, food preservatives, toxic waste dumps, global warming, open space, wastewater treatment, watersheds, parks, and all other things potentially affecting human health and quality of life, such as oil drilling, mining, extensive clearcutting, use of chemicals in forestry and agriculture, tropical deforestation, desertification, destruction of major fisheries, and global loss of biodiversity. Ecosystem health is the public value considered by many to be a useful, perhaps essential, concept in formulating environmental policy; the concept reflects value-based assumptions more than science (Lackey 2001). Thus, broad-based anthropocentric environmentalism may have real influences on conservation of natural resources.

Although there is growing public concern, environmental issues are nearly absent from national political campaigns and rarely shape individual voter preferences because of low issue salience, small perceived differences between candidates, and the tendency of environmental concerns to cut across traditional and more powerful cleavages including political party identification (Guber 2001). Thus, legislature has been scaling back wildlife protection and pollution control since 1994, despite the National Election Study that confirmed environmental values (Guber 2001). Because of low voter interest and low levels of political knowledge and information, most voters fail to perceive party differences, even on important matters of public policy. Bengston et al. (2001) examined 1,500 online media stories and concluded that ecosystem management (and, one presumes, conservation) is on the downside of the attention cycle. Interest rose in the early 1990s, declined in the mid-1990s, and leveled out with 78 percent of all attitudes favorable (in other words, ecosystem management was noncontroversial); but still most people have little or no knowledge of ecosystem management, including the concepts of ecosystem health, conservation of biodiversity, sustainability, complex systems, adaptive management, or

Sidenote 7—Czech et al. (2001) found gender influences conservation attitudes. Women ascribe greater value to nonhuman species than men and exhibit greater concern for species conservation relative to property rights. But like men, they consider ecological importance as the most important factor in prioritizing conservation efforts for individual species. Priority percentages—female/male (N = 643):

- Economic growth—74/76
- Democracy—82/83
- Property rights—75/77
- Ecosystem health—84/79
- **Conservation of species**—80/75
- Resources for the future—88/85

Sidenote 8—Kellert et al. (2000) reported that community forest management is extensively promoted for ecological, social, and economic reasons. The rationale is often compelling, but there is little data on its success. A review of five case studies worldwide revealed serious, widespread deficiencies based on criteria of equity, empowerment, conflict resolution, knowledge and awareness, biodiversity protection, and sustainable resource use. The ideal characteristics of community forest management are:

- Involving community members and local and indigenous institutions in management
- Devolving power and authority from central to more local and indigenous institutions and people
- Reconciling objectives of socioeconomic development, conservation, and environmental protection
- Legitimizing local or indigenous resource and property rights
- Including traditional values and ecological knowledge in modern resource management

collaborative management (Bengston et al. 2001). Television entertainment shows decreasing attention to environmental topics since a peak in 1993–1994, with a virtual absence of the topic on prime time network shows (McComas et al. 2001).

The lack of national public interest, the concentration of forest products manufacturing in fewer multinational corporations controlling larger areas of forest, the lower commitment of absentee owners to community stability, and the lack of commitment of multinational corporations to long-term maintenance of forested ecosystems or mill communities and their employees led Krogman and Beckley (2002) to suggest community forestry and demands for socially and ecologically responsible forest management as alternatives to corporate forestry (sidenote 8). Community forestry is a situation where community benefits are enhanced relative to standard industrial forest models and can be achieved through value-added investments in communities and progressive local hiring policies. A broad spectrum of value-added investment types is possible: school forests, urban forests, county and municipal forests, forestry cooperatives, model forests, and others devoted to local control and local benefit. Buyout of corporate lands can lead to increased community cohesion through maintaining employment and fair and congenial working conditions by the new owner. Heightened sensitivity to ecosystem health and provision of multiple benefits to communities provide greater ecological stewardship of forest land. Alternatively, communities can participate in collaborative management of federal, state, industrial, and private land by using a variety of tools and mechanisms, including tax benefits, conservation easements, forest stewardship certification in the market place, and others.

Within the arena of conservation of forests and rangelands, Callicott et al. (1999) found a plethora of normative concepts including biological diversity, biological integrity, ecological restoration, ecological services, ecological rehabilitation, ecological sustainability, sustainable development, ecosystem health, ecosystem management, adaptive management, and many more. They suggested that these terms, with their various meanings, could be interpreted by reference to two new schools of conservation philosophy: compositionalism and functionalism (table 2). In contrast to previous schools of preservationism and resourcism, which were mutually exclusive, compositionalism and functionalism are complementary, forming a continuum, and could lead to a more unified philosophy of conservation. Although some remain skeptical, Callicott et al. (1999) asserted "these concepts are at large in the world shaping conservation thought and policy."

Compositionalism

Compositionalists perceive nature primarily through population-level and evolutionary ecology and consider humans as separate from nature. Terms in a compositionalist glossary, such as biodiversity, integrity, and restoration, are norms associated with reserves. Compositionalism is essentially an entity-oriented biological approach—beginning with organisms that are aggregated into populations, which interact in biotic communities in maintained reserves. Emphasis is often on identifying areas of high species richness and preserving them (e.g., Ricketts et al. 1999). Protection of hotspots of biodiversity is appealing because it does not require changes in our daily living or the way we behave toward poorer nations and the other 99 percent of the land (Ehrenfeld 2002). Humanly inhabited and exploited areas are relegated to the functionalists. Compositionalists posit all species have equal rights to persist in nature; productivity, stability, resistance, and resilience in nature are partly a function of species diversity, functional redundancy, and niche differentiation; and the consequences of losing any one species or groups of species are not predictable and could be disastrous. They assert that reliance on isolated reserves in a semideveloped matrix is inadequate to stem the tide of an unprecedented wave of extinctions arising from habitat conversion by rapidly expanding human populations. Compositionalists support large, buffered, and connected reserves and deem a return to historical disturbance regimes as vital. Buffer zones are

Table 2—**Differences between contemporary conservation philosophies**

Philosophy	**Compositionalism**	**Functionalism**
Human-nature relationship	▪ Humans are separate from nature; humans defile and destroy nature	▪ Humans are part of and embedded in nature
Branch of ecology	▪ Evolutionary ecology • Organisms • Species • Communities • Ecosystems	▪ Ecosystem ecology • Energy flow • Nutrient cycling • Processes • Function
	Complementary approaches to conservation	
Conservation concepts	▪ Preservation of: • Biological diversity • Ecological integrity ▪ Ecological restoration ▪ Reserves ▪ Ecosystem health	▪ Ecological services ▪ Adaptive management ▪ Ecosystem management ▪ Sustainability

Source: Adapted from Callicott et al. 1999.

necessary because "… it is impossible to secure enough public land to protect all biodiversity" (Soulé and Terborgh 1999).

Functionalism

Functionalists perceive nature primarily by means of ecosystem-level ecology and consider humans as part of nature. Terms in the functionalist glossary are associated with humanly inhabited and exploited areas. Functionalism is a process-oriented approach—beginning with solar energy and the physical system with biotic organisms as moments in interlocked processes of energy transfers and nutrient cycles, indifferent to specific taxonomic identity. Functionalists postulate there is little evidence that a particular number of species is required for any particular ecosystem function or that ecosystems function better with more species than with fewer; if abundance or diversity of a particular functional group changes, it suggests the ecosystem has changed relative to that function; and maintaining ecosystem function through the presence and vitality of functional groups is more practical than attempting to maintain a large number of species without regard to their function (Huston et al. 1999).

A Fusion of Complementary Approaches

Can compositionalism and functionalism be used to form an integrated coherent approach to managing the total landscape? Conservation of biodiversity is more feasible when its goal is not conflated with that of wilderness preservation (Sarkar 1999). Aldo Leopold wrote, "Ability to see the cultural value of wilderness boils down [to] … intellectual humility," and moreover, we need "… a militant minority of wilderness-minded citizens … available for action" to ensure wilderness preservation (Leopold 1949). However, Leopold also believed that healthy ecosystems can incorporate human inhabitants, economic exploitation, and management, and that "there are degrees and kinds of solitude" (Leopold 1949).

The current battle over ecological dogma is distressing (Callicott et al. 1999, Hardin 1969). For example, claims that landscapes unaltered by humans existed in North America at the arrival of Europeans are often (not always) fallacious—the Europeans' diseases preceded their explorations, decimating indigenous populations and obscuring evidence of the aboriginal influence on the landscapes

Annette Wilson hikes along an old-growth forest trail in the Olympic National Forest, near Quinault, Washington. Photo by T. Wilson.

(Krech 1999, Pyne 1997, Reid 1996, Wright 1992). The long history of human interactions with nature reveals that landscapes that have not experienced important human influences are the exception. Wright (1992) described the civilizations of the Iroquois, Cherokee, Aztec, Maya, and Inca in the Americas. The history of agriculture and technological development in agriculture has been documented in Europe, too—e.g., the Ystad Project in Sweden (Malmer 1991). Ystad documents human land use to 6,000 years ago by pre-Neolithic hunters and gatherers, herding and slash-and-burn agriculture 3,000 to 5,000 years ago in the Neolithic Bronze Age, permanent field farms 1,000 to 3,000 years ago in the Iron Age, advanced field farming 500 years ago, and artificial fertilizer farming in the present (Berglund 1991).

Information on aboriginal interactions with the biophysical environments of the Americas now abounds. Aboriginal overkill eliminated 31 genera of North American mammals 11,000 to 17,000 years ago (Martin 1973). Humans in Mesoamerica practiced intensive agriculture well before the Europeans adopted this practice (Wright 1992). The Spanish reintroduced the horse to the Americas 500 years ago, and the horse quickly became widespread and domesticated by indigenous peoples. An estimated 400,000 horses were grazing the prairies of eastern Washington when Lewis and Clark arrived. There was ample evidence of a long history of prescribed burning to maintain prairies, oak woodlands, and shrubland-conifer savannahs in western Washington and Oregon when settlers from the Eastern United States first arrived (Thysell and Carey 2001b). Thus, conservation strategies minimizing human intervention may fail because the objective of maintaining a natural ecosystem may be nonsensical or oxymoronic—excluding human influence is not natural (Reid 1996). Moreover, conservation is almost never the preservation of primeval conditions, but rather a means of maintaining critical functions of the primeval system (Allen et al. 2001) and its capacity to adapt to future change (Holling 1986).

Nevertheless, one cannot simply maintain or restore ecological processes and conserve biodiversity—some such processes are generic and can be performed by weedy species (Soulé 1986). Most conservationists are somewhat in the middle of the compositionalist-functionalist continuum, and many shift back and forth in emphasis depending on circumstances. The keystone species concept provides a nexus of evolutionary and ecosystem ecology (Callicott et al. 1999). The goal of evolutionary ecology is to explain and predict the behavior of individual organisms and populations because natural selection acts exclusively on individuals. The trophic structure of biotic communities, then, should be accounted for by the exclusive application of evolutionary theory. However, evolutionary ecologists studying the dynamics of populations and communities have found foraging behavior and life histories depend on ecosystem characteristics as well as interactions with other species populations. Because ecological processes occur at discrete temporal scales, they create discrete scales in space (landscapes composed of patches composed of microhabitats). For example, the ecological process of competition between northern flying squirrels and Townsend's chipmunks (see appendix for scientific names) for the same truffles occur at very local scales where both species are present. This might be a shrub patch within a forest, or in other words, a microhabitat within a patch within a landscape. Other processes, particularly hydrologic processes like waterflow, may occur at much larger scales, such as landscapes (watersheds) within multiple landscapes. Ecosystem ecologists have found efforts to model and predict some ecosystem functions are foiled because species do matter. Community ecologists must fuse the ecosystem and evolutionary approaches to ecology in order to predict accurately the impact of particular species on particular food webs, key biotic communities, or to predict the outcome of human development projects. Thus, a synthesis already is underway. This synthesis of paradigms is necessary for the development of conservation strategies that integrate reserves and other protected areas with the rest of the biosphere.

Callicott et al. (1999) concluded that emphasis on preservation of biodiversity and ecological restoration is appropriate for wilderness areas, wildlife refuges, national and state parks, world heritage sites, and international biosphere reserves. This list is somewhat problematic in that many wildlife refuges are intensively managed with agricultural crops to provide concentrated food supplies for migratory wildlife, and parks often explicitly were set aside legislatively for human enjoyment and edification, which are not necessarily incompatible with maintenance of biodiversity but are perceived as such by many. Co-opting parks and refuges to meet extreme philosophical tenets would exacerbate divisions among conservationists rather than reconcile differences. Callicott et al. (1999) suggested that the functionalist emphasis on ecosystem health, ecological services, adaptive ecosystem management, and ecological sustainability, is more suited to inhabited and exploited areas than to reserves. They state: "The really innovative idea in contemporary conservation is the functionalist ideal, which conceives of human economics as embedded in the larger and more enduring economy of nature."

The point is to adapt human economics to ecological exigencies in order to achieve a mutually sustaining relationship between humans and the ecosystems they inhabit and on which they clearly depend; however, Wilber (1995) would argue the embedment is in the opposite direction. Of course, the really exciting idea is social evolution with its best end products being lasting institutions, durable friendships, stable communities, accumulated wisdom, and gentle and productive cooperation that promote local conservation with continuity, passed from parent to child and friend to friend (Ehrenfeld 2002).

Conservation, Forest Management, and Sustainability

The science of ecology has had a popular impact unlike that of any other science; it has been ubiquitous, and it has changed the language of politics and philosophy (Worster 1990). Concerns about forest conservation and sustainability are producing ecological forest management systems across the biosphere (e.g., Hunter 1999, Larson and Danell 2001, Mönkkönen 1999, Swedish National Board of Forestry 1990, Virolainen et al. 2001, Wikstrom and Eriksson 2000, Yang 1997). Trees and forests are important to Americans for their ecological contributions and their economic value ($200 billion/year). But the ecological contributions are more valued by a culture concerned with aesthetic qualities, pollution, and sustainability; changing values are reflected in the growing dichotomy between commodity-focus forestry and environmental and restoration management (McDonough 2003). Sustainability is a word that evokes positive associations and that is claimed and shaped by proponents of various conservation philosophies to their own goals. Pacific Northwest neo-conservation biologists argue that achieving sustainability (meeting human needs without compromising the health of the ecosystem) should be the principal goal of conservation, whereas orthodox conservation biologists do not welcome a paradigm shift from wilderness to sustainability (Callicott and Mumford 1997). Ecosystem management is often held as the means to achieve environmental sustainability in managed forests. Ecosystem management asks forest stewards to manage lands for commodities, amenities, and native biological diversity. Ecosystem management, however, can conflict with commodity interests, wilderness advocates, and outdoor recreationists; this term also is co-opted by narrow interests to legitimize narrow goals (Knight 1996).

Forestry and Conservation

Concern about a global biodiversity crisis arose in the late 1970s (Noss and Kranz 2001, Wilson 1999a). By 1993, more than 600 species had been listed as threatened or endangered in the United States. The Endangered Species Act of 1973 has had less effect than expected because remedial action is not triggered until a population is in serious trouble (Orians 1993). And federal agencies, first in a state of "future shock," then "midlife crisis," failed to adapt to rapidly changing societal demands (Bengston 1994, Kennedy and Quigley 1998). R.E. Wolf, a key congressional staff member for important federal conservation legislation (Multiple Use Sustained Yield Act, Wilderness Act, Resources Planning Act, and National Forest Management Act) labeled USDA Forest Service behavior as a "corruption of the Resources Planning Act" (Wolf 1989) (table 3). The new environmental paradigm was environmental sustainability, skepticism of science and technology, finite natural resources, limits to substitution, and public involvement (Bengston 1994). Classic forestry concepts of multiple use and sustained yield were not useful to contemporary, ecologically informed, biocentric conservation (Callicott and Mumford 1997). The Forest Service was a model machine bureaucracy, but complex, challenging, and important policy issues are ill served by command-and-control paradigms (Lackey 2003).

In the Pacific Northwest and Alaska, the diverse high values of forests have intensified conflict, and the public has become more polarized and distrustful; the polarization is manifested in Forest Service alternatives of zoning for different uses and attempting to identify compatibilities between wood production and other values (Peterson and Monserud 2002). Command-and-control paradigms not only polarize the public, but also engender top-down centralized decisionmaking and attendant public resistance, rarely use new scientific and technical information, and reinforce policy and scientific reductionism (Lackey 2003), yet such policies based on these paradigms persist (Mills et al. 2002) (sidenote 9). Kimmins (2002) reported similar future shock in forestry in Canada (sidenote 10).

Perry (1998) defined forestry as the scientific management of forests for continuous production of goods and services, but cited the National Research Council as concluding that existing knowledge was inadequate for sound forest management in 1990. Perry (1998), and many others, concluded that the social sciences, including sociology, aesthetics, ethics, spirituality, economics, history, and so on,

Table 3—**Traditional forest management versus ecosystem management**

Traditional forest management	Ecosystem management
▪ Maximize commodities	▪ Leopold land ethic and sustainable commodity production
▪ Maximize net present value	▪ Maintain future options
▪ Sustained yield	▪ Long-term ecosystem sustainability, maintaining aesthetics, socially acceptable
▪ Forest management as an applied science	▪ Forest management as a social science
▪ Instrumental values	▪ Instrumental and intrinsic values
▪ Focus on outputs	▪ Focus on inputs and processes
▪ Timber focus	▪ Species focus
▪ Timber in short supply	▪ Loss of biodiversity
▪ Reductionistic view	▪ Systems view
▪ Stand-level focus	▪ Ecosystem-landscape-level focus
▪ Plan and manage by ownership	▪ Plan and manage by ecosystem
▪ Economic efficiency	▪ Cost effectiveness and social acceptability

Source: Adapted from Bengston 1994.

Sidenote 9—Achieving science-based national forest management (Mills et al. 2002):

- Decisionmakers (line officers) and the public fully appreciate the contributions of science to land management.
- Forest Service scientists and professionals provide the science needed for decisions.
- Policy-relevant science is readily available and easy to use.
- Available science is fully used by decisionmakers.
- The consistency of land management with available science is evaluated.
- Science is recognized as important but only as one piece of information considered in a decision.

Sidenote 10—Kimmins (2002) defined future shock as the point at which the rate of change in society exceeds the willingness and ability for institutions to adapt to change.

are critical to forest management. Furthermore, as Kimmins (2002) stated, forestry is about people—their needs and desires—not fundamentally about biophysical issues. At present, North American forestry seems archaic and too narrowly focused to conduct forest ecosystem management.

Technical ecosystem management is broadly interdisciplinary, requiring specialists in forest ecology, plant ecology, silviculture, forest insects and diseases, wildlife, biodiversity, geology, forest engineering, and on and on. The forestry profession is in trouble because of resistance to change and maintaining an archaic forestry dogma including the economic myth of soil rent theory and short rotations (Curtis and Carey 1996, Maser 1994). Soil rent theory has six flawed primary assumptions (Maser 1994): (1) the depth and fertility of soil is constant, (2) the quantity and quality of precipitation is constant, (3) the quality of air is constant, (4) biological and genetic diversity are nonessential, (5) the amount and quality of solar radiation are constant, and (6) climate is constant.

Overarching the technical aspects of ecosystem management is social forestry, the science of sustainable forest management for multiple values—a new environmental management that needs to develop and use credible, ecologically based forest ecosystem management models based on both experience and theoretical models (Kimmins 2002). Administrative and legal challenges to forest management in the United States convinced Jack Ward Thomas (Chief of the U.S. Forest Service, 1993–1996) in 1996 that "… the overriding de facto policy for the management of federal lands is the protection of biodiversity" (MacCleery and Le Master 1999). Huge areas of federal land were allocated to reserves that permit little or no active management under the assumption that natural regulation will maintain a natural balance. Since then, timber sales on national forests have dropped 70 percent (since a 1985 benchmark), and 23 percent of the forests (about 17 million hectares or roughly the size of Washington state) have been set aside. Nationwide, in 1999, only 35 percent of total land holdings (48 percent of productive forest lands) in the National Forest System and 15 percent of land holdings in the Pacific Northwest were available for timber harvests. Rangelands have been subject to the same pressures for conservation, and grazing on federal lands is beginning to decrease (Davis 2001, Samson and Knopf 2001).

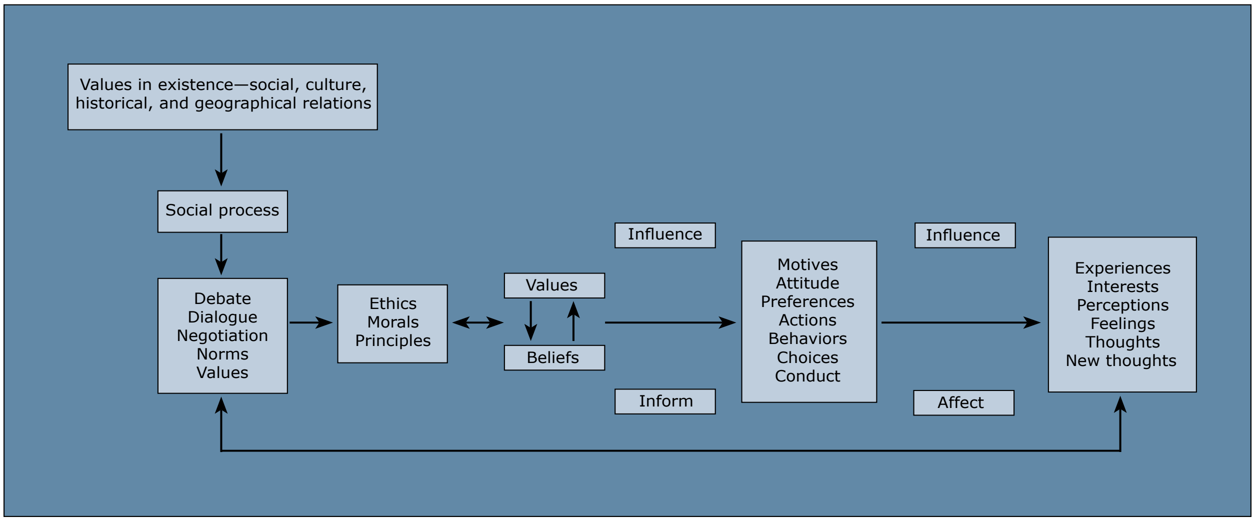
Narrow-focus forestry wrought profound changes on other continents also. For example, forestry in Fennoscandian forests began in the 1700s; numerous species were red-listed in the 20th century. In the 1990s, Nordic countries implemented forest conservation efforts of mimicking natural disturbance regimes, setting aside reserves, and implementing a corridor-and-stepping-stone strategy (Mönkkönen 1999). Now, however, conservation goals are becoming more elusive. O'Brien (2003) assessed people's values and their importance to forestry in England through a review of the literature. He found that the values people hold for the environments are multiple and complex and produce conflicts when not considered by managers. The English public is increasingly interested in having their views heard, being involved, and being consulted on environmental matters. Dominant themes are lack of trust in elected representatives, feelings of powerlessness in the face of globalization, ethical and social impacts of increased technology, and a call for justice in environmental decisionmaking; issues very similar to North American issues. He concluded forests should be managed for multiple values not multiple uses (sidenote 11) (fig. 3). Values, however, must be assessed through mechanisms like citizen juries, focus groups, indepth interviews, and collaborative management. During a tour of restoration projects in Denmark, Sweden, and Germany in 2001, Danish and German foresters defined forestry as a social science, with values assessment and collaborative management beginning with one-on-one tea sessions and culminating in community meetings.

Sidenote 11—Management for Multiple Values (O'Brien 2003): Forests should be managed for multiple values rather than multiple uses. Instead of focusing on the forest as a resource to be used, managing for multiple values posits that respect is given to human and forest communities in order to provide a wide range of benefits. Management for multiple values highlights the ethical dimension of management, incorporates moral judgments, and brings together different interests and expertise. Values are (1) formed out of a social process of dialogue and debate; (2) influenced by social, cultural, historical, and geographic relationships between society and the individual; and (3) informed by ethical and moral judgments.

Reserves and Conservation

Modern conservation philosophy now questions the concept of "protected area" as a throwback to equilibrium ecology. Twenty years of emphasis on protected area systems is now suspect on the bases of minimum viable population analyses demonstrating the

Figure 3—Schematic representation of value formation: Thus, values can shift, be contested, be multiple and renegotiated, be reviewed, and be reinterpreted through discursive processes, or revised meanings and understandings (O'Brien 2003).



inadequacy of many protected areas and of climate change bringing about ecological change (Reid 1996). There is growing consensus that management of nonreserved lands is as important for conservation, if not more so, than maintaining a patchwork of reserves and corridors (Carey et al. 1999c, Hunter 1999, Reid 1996). A concept of "total landscape management" is emerging that incorporates an intentional approach including designating wilderness and parks; protecting fragile areas; promoting ecological forest management; providing tax incentives, conservation easements, and green certification to private landowners; assessing development fees; and growth (of socioeconomic systems) management.

New Conservation Objectives

The very objectives of conservation have become more elusive in recent years (Reid 1996). What should the overarching concern be? The majority of efforts to preserve biodiversity have focused on species, subspecies, and populations. It is fundamentally impossible to deal with more than a small fraction of nature on a single-species basis. A 1997 symposium on global conservation of mammals asked, "Has the panda had its day?" (Entwistle and Dunstone 2000) and concluded that success of single-species approaches has not been great, that one-quarter of all mammals are threatened with extinction, despite the aesthetic, scientific, and economic values people place on mammals. They suggest conservation must rapidly move away from protectionism to integrated wildlife and landscape conservation within the context of human use. Moving beyond reserves and corridors and managing for ecosystems and landscapes is the only comprehensive way to address conservation (Franklin 1993b). Some fundamental concern is needed that guides the relationship between humanity and nature that addresses our acknowledgment that the biosphere's capacity to support life must be maintained (Reid 1996).

Increasingly, that concern is seen as maintaining biotic integrity and ecosystem health (Regier 1993). The notion of ecological integrity is rooted in the integration of ecological concepts with human values. The emergent normative goal of human-environmental relationships, then, is to maintain the integrity of a combined natural-cultural ecosystem through ecological understanding and an ethic that seeks proper relationships. The concept of ecosystem health, however, is more contentious because achieving such an overarching ecological objective may fail because of unpredictability of ecological systems and ignorance of those aspects of system behavior that are predictable (Reid 1996). We clearly want to maintain ecological services important to humanity, and we want to maintain biodiversity to keep options open for future generations (sidenote 12). Reid (1996) suggested that the objective of conservation should not be ecological but social—e.g., maximize human capacity and the capacity of the biosphere to adapt to change.

Of course, all human choices, from designation of reserves to urbanization, serve human objectives. Designating reserves enhances self-esteem through perceived altruism and peer positive reinforcement. Urbanization buffers people from the more unpredictable whims of nature. Perhaps the most practical goal would be to buffer people from the fear of loss of control over one's life promoted by rapid and socially destabilizing technological and environmental developments, while maintaining options for future generations. Maslow's (1987) hierarchy of needs (fig. 4) provides insight into the fundamental bases of conservation-utilization philosophies, ties attitudes to economic or security status and self-actualization, and highlights intragenerational equity. Three major ecologies must be integrated for a sustainable resolution of contemporary conservation concerns and conflicts: (1) an environmental ecology that is sustainable, (2) a social ecology that is satisfying, and (3) a spiritual ecology that is soulful (Elgin and LeDrew 1997).

Sidenote 12—Ecological services are economically valuable, diverse, and marginally marketable. Costanza et al. (1997) listed the value of 17 ecosystem services in 16 biomes around the world at an average of $33 trillion per year. Krieger (2001) estimated the value of forest ecosystem services—climate regulation, waste treatment, and food—to be $64 million per year in the United States alone. De Groot et al. (2002) listed 23 different ecosystem functions—natural processes that provide goods and services that directly or indirectly satisfy human needs. Eight categories of ecosystem services are soil stabilization and erosion control, air quality, climate regulation, carbon sequestration, biodiversity, recreation and tourism, nontimber products, and cultural values (Krieger 2001).

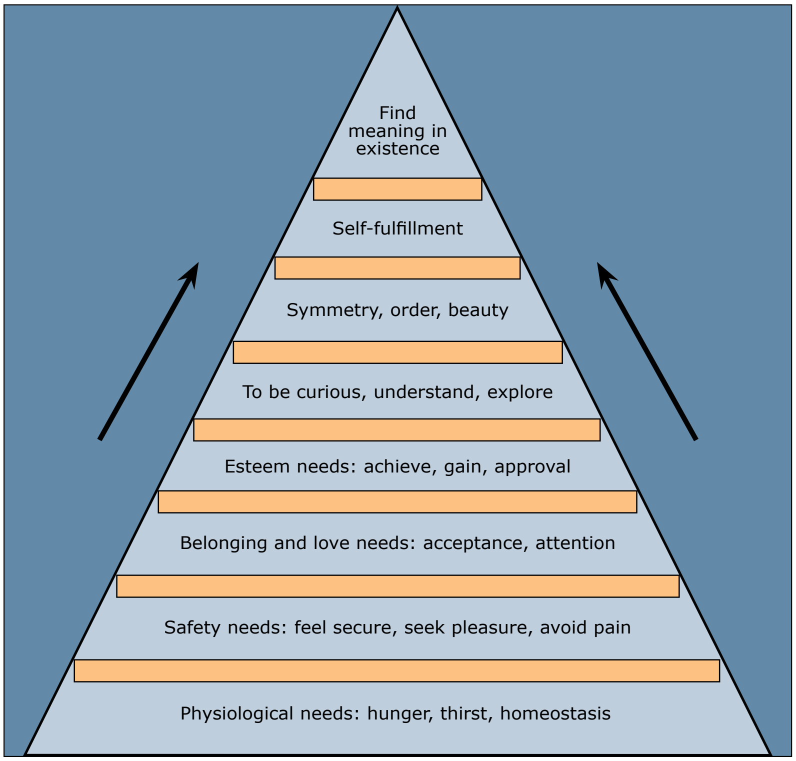


Figure 4—Maslow's hierarchy of human needs (adapted from Maslow 1987).

General Sustainability

It is widely recognized that forests should be managed for sustainability (Daily and Ehrlich 1996, Dasgupta et al. 2000, di Castri 2000). The concept of sustainable forestry dates from 18th-century concerns about soil productivity (Farrell et al. 2000, Hilborn et al. 1995). A broader concept of sustainability derives from John Stuart Mill, Thomas Malthus, Paul Ehrlich, Garrett Hardin, and Herman Daly. In 1981, the International Union for the Conservation of Nature and Natural Resources produced a World Conservation Strategy and called for ecologically sound use of natural resources. In 1987, the World Commission on Environment and Development adopted the idea that economic development and environmental protection are compatible and called for sustainable development of Third-World countries. In 1992, the United Nations Conference on the Environment and Development adopted sustainability and elicited widespread acceptance by governments. After these events, however, sustainability was subordinated to development, supported by economists, and opposed by humanists and ecologists (Clark 1995). The reason for this schism, Nelson (1995) reported, is that economics is not only a science, but also a set of values often at odds with other natural and physical sciences. Economics is a social science concerned about the interactions and welfare of people. Animals, plants, the physical state of the world, and other material conditions do not enter into considerations—only what people do counts. Emphasis on development promoted fears about overexploitation because history demonstrates universal overexploitation in development of natural resources (Hilborn et al. 1995). A new discipline of ecological economics arose to address these concerns. But as in other conservation disciplines, conflicting values implicit in mainstream economics and in ecological economics reflect deep underlying theological differences. And both theoretical economists (Nelson 1995) and theoretical ecologists (Clark 1995) are too abstract-thinking to produce ideas of practical consequence for policy decisions or intellectual generalizations to inform policy well. What is actually delivered is metaphysics, morals, personal convictions, and, in some cases, religion.

The debate over values pertinent to sustainability produced the concept of general sustainability (Goodland 1995). General sustainability has three components: environmental sustainability, social sustainability, and economic sustainability. Environmental sustainability seeks to improve human welfare by protecting sources of raw materials (the natural capital) and ensuring that sinks for human waste are not exceeded. To be sustainable, harvest rates of renewable resources must stay within regeneration rates and not diminish the capacity of the environment as a sink. Conservation of biodiversity is generally accepted as part of environmental sustainability, but there is no agreement on how much and at what cost. In any case, people must live within limitations imposed by the biophysical environment and the finite capacities of the global support system. Social sustainability is achieved by systematic community participation and strong civil society. The cohesion and norms of a civil society are social capital and moral capital. Human capital must be maintained by investments in education, health, and nutrition. Economic sustainability is keeping capital intact. Together these form a general sustainability that maintains the life support systems of the atmosphere, water, soil, and environmental services. General sustainability also has a strong component of both intragenerational and intergenerational equity. Thus, general sustainability includes poverty reduction through qualitative development, redistribution of wealth, sharing of resources, population stability, and community solidarity, but not through increased consumption of materials and energy from the environment, returned to the environment as waste. Morally undesirable gross inequities throughout the world are also biophysically unsustainable. Thus, to perpetuate poverty has deleterious, irreversible impacts on the biophysical component of Earth's life support system. Poverty around the world has long been associated with dense populations, deforestation, unconstrained mining, erosion, desertification, poor farming practices, overgrazing of livestock, and pollution (lack of sanitation systems, polluting factories based on cheap labor, etc.). These inequities also hinder cooperation among parties of different socioeconomic status (Daily and Ehrlich 1996). Thus, in essence, sustainability is a normative paradigm for improving the quality of human life within the carrying capacity of the ecosystem without compromising the ability of future generations to meet their needs. Sustainability is a global concern with enormous social and political ramifications if it is to be achieved. Of course, the ramifications of not achieving sustainability are equally enormous (fig. 5).

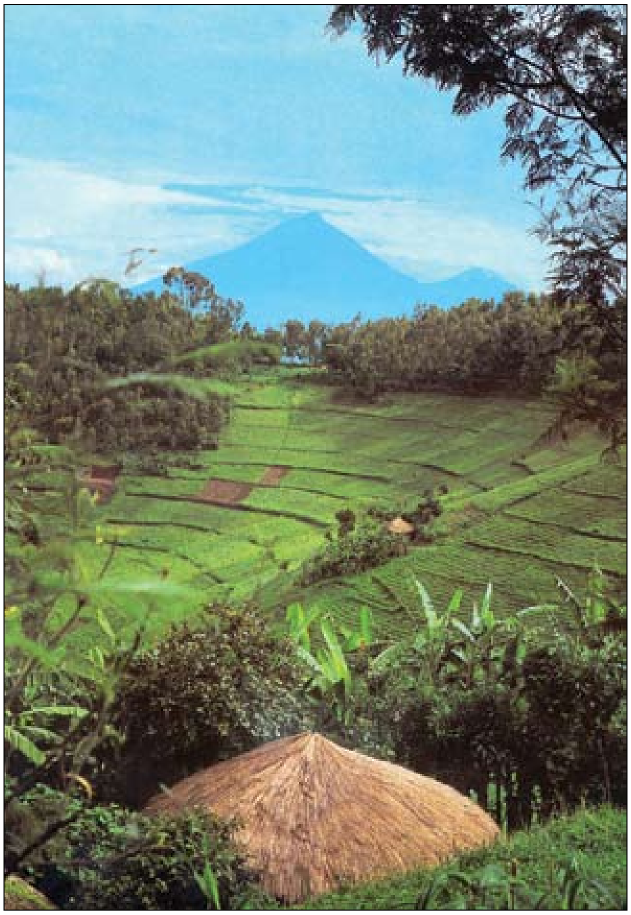


Figure 5—The rich environment of the central African highlands supports a rich flora and fauna. In Rwanda, over 95 percent of the arable land has been developed for agriculture. Strong international efforts have been made to develop economic diversification through ecotourism geared around reserves for mountain gorillas (Parc National des Volcans) and other primates (Forêt de Nyungwe). Large human populations and colonialism induced social inequity between the Hutu and Tutsi ethnic groups and resulted in genocide. Photo courtesy of Rwanda Tourism.

In 1994, Albert A. Bartlett hypothesized that the population of the Earth had exceeded the Earth's carrying capacity for the average standard of living and proposed Bartlett's Laws for Sustainability (Goodland 1995):

- Growth in human populations or in rates of consumption cannot be sustained.
- The larger the population and rates of consumption, the more difficult the transition to sustainability.
- About 50 years are required for populations to respond to a change in total fertility.
- Carrying capacity and sustainable mean standard of living are inversely related.
- Sustainability requires population size be less than carrying capacity for a given standard of living.
- Beneficiaries of growth are few, but costs are borne by all (the tragedy of the commons).
- Growth in consumption of nonrenewables dramatically decreases their life expectancies.
- Increases in efficiency of utilization produces savings wiped out by modest population increases.
- Rates of pollution greater than natural cleansing capacity mean it is easier to pollute than clean up.
- Humans always will depend on agriculture and forestry; land and renewables always will be essential.

Increased population size is the single greatest and most insidious threat to representative democracy, general sustainability, and conservation. Reserving land for nonhuman species limits the amount of land available to support people. And the current production is exhausting natural capital. Depletion of essential resources and degradation of land and atmosphere are seriously damaging the biosphere and its future biophysical carrying capacity for people. Faith in the ability of technology to solve humanity's problems, paralleled by polarization by extreme statements intended to dramatize, make it difficult to "paint a richer picture" and achieve consensus on appropriate courses of action (Costanza et al. 2000). Still, there are guiding principles for managing the environmental portfolio: (1) protect capital, live off interest; (2) hedge investments, do not put all eggs in one basket; (3) do not risk more than you can afford to lose; and (4) buy insurance—do not harvest everywhere and not even close to the sustainable limit.

Policies of diverse organizations, from the USDA Forest Service to the nongovernmental Forest Stewardship Council and Pacific Forest Trust to the professional Ecological Society of America (Christensen et al. 1996) and industrial American Forest and Paper Association (Heissenbuttel 1996), emphasize that sustainable ecosystems are essential to the health and support of human societies and quality of life. Although carefully crafted definitions of sustainability have been offered (Goodland 1995), none have received universal acceptance. The concept, like other conservation concepts, means different things to different people (Clark 1995, Goodland 1995, Gowdy 2000, Hunter 1999, Lindenmayer et al. 2000, Nelson 1995, Reid and Miller 1989, Wilson 1999a). Emphasis varies among sustained yield of wood products, maintenance of long-term site productivity, intergenerational equity, social justice, and conservation of biological diversity (Angermeier and Karr 1994, Christensen et al. 1996, Hunter 1999, Soulé and Terborgh 1999). Disagreements include debates about (1) limits to economic and human population growth (Barrett and Odum 2000, Czech 2000, Davidson 2000), (2) the relationship of biodiversity to ecosystem stability (Tilman 1996, 1999; Wardle et al. 2000), (3) the spatial and organizational scale at which conservation should focus (Folke et al. 1996, Franklin 1993b, Orians 1993), and (4) property rights (Geisler and Daneker 2000, Lee 1993). Polarization extends from sustainable development and resource extraction on the one hand to preservation of genetic diversity through establishment of ecological reserves on the other. Our current debate is counterproductive because it is based on untestable assumptions embedded in deeply held worldviews and ethical beliefs (Costanza et al. 2000, Worster 1994). Nevertheless, the public is beginning to formulate cultural definitions of the term (Ray 1996) and demand sustainability through the market place, political processes, administrative appeal processes, and the courts. Examples include purchase of green-certified wood products, payment of carbon credits, donations to nonprofit organizations for the purchase of conservation easements, state and federal legislation, litigation, and international agreements and treaties (Costanza et al. 2000, Daily and Ellison 2002, Harwell et al. 1999, Kennett 1998).

Ecosystem Management

Ecosystem management is variously asserted as being an evolutionary step in natural resource management, a cooperative solution to resource management problems, a public deliberation on values, and a dispersion of power and authority in the natural resource management arena (Lackey 1998, 2001; MacCleery and Le Master 1999). Ecosystem management grew out of the multiple-use-sustained-yield management of the 1960s during a period of increasing demands on federal lands followed by conflict, legislation, and litigation (table 4). Nonsustainable timber management led to markedly reduced area of forest land and amounts of timber available for harvest. Rather than encompassing theoretical developments in ecology and philosophical developments in conservation, ecosystem management remains a pragmatic tool—a means to an end in meeting human needs while maintaining the health and productivity of ecosystems. Ecosystem management expands the range of values considered by multiple use-sustained yield management and requires consideration of social, economic, and environmental interactions at a variety of spatial scales (MacCleery and Le Master 1999). Different groups use it with different meanings; such ambiguity promotes debate and limits acceptance. Debates over the utility and purpose of ecosystem management bring to light fundamental (and historical) differences in values and beliefs and highlight where the scientific basis of ecosystem management may be lacking. Thus, ecosystem management provides an opportunity for values clarification, expressing beliefs, identifying scientific uncertainties, and convening diverse interests into collaborative management groups, and, finally, creating opportunities for novel and creative solutions to persistent problems at local scales.

Ecosystem management is not a technical exercise of structuring decisionmaking around self-defining ecosystems to promote absolute preservation; rather, it is a set of normative principles and operational guides for managing human activities so that they coexist with ecological processes deemed worthy of protection over

Table 4—A comparison of multiple-use-sustained-yield management and ecosystem management

Multiple-use-sustained-yield	Ecosystem management	Both
▪ Featured species	▪ Biological diversity	▪ Sustainability
▪ Resource productivity	▪ Ecosystem health	▪ Meet the needs of the people in the long term with a sustained yield of goods and services
▪ Multiresource management	▪ Integrated management	
▪ Multiple use, site by site	▪ Systems, integrated, holistic	
▪ Site-specific management	▪ Landscape management	
▪ Stand-level focus	▪ Multiple-scale focus	
▪ Efficient production	▪ Range of natural variability	
▪ Line-staff organization	▪ Public-private partnerships	
▪ Planning by function	▪ Multidisciplinary planning	
▪ Respond to research findings	▪ Adaptive management	

Source: Adapted from MacCleery and Le Master 1999.

the long term (Kennett 1998). Some proponents claim ecosystem management is founded on five global precepts: (1) equity between human and nonhuman communities; (2) moral consideration for both humans and other species; (3) respect for cultural diversity and biological diversity; (4) inclusion of women and minorities; (5) inclusion of nonhuman nature in a code of ethics; and (6) ecologically sound management consistent with continued health of both humans and the environment (Lackey 1998, 2001). Each of these precepts can be contested—e.g., (1) not equity among species, but interdependence; (2) moral consideration for human intra- and intergenerational equity requires wise use, but does not require a precept of equity among species; (3) all management (not just ecosystem management) in contemporary democratic societies is bedded in systems that incorporate pluralism and diverse cultures; (4) better to focus on intra- and intergenerational equity and sustainability in a code of ethics; and (5) better to recognize limits to system capacity.

In addition, ecosystem management is based on four major assertions that also are contested (Lackey 1998). First is the assertion that ecosystems are real and, thus, ecosystems can and should be managed. Some assert that ecosystems lack clear spatial definition and are imbedded systems, with management practical only at certain scales, with different approaches at each scale. Thus, given that humans are limited cognitively, management cannot be fully successful. Nevertheless, ecosystems are as real and tangible as anything in life, and cognitive limitations and uncertainty can be addressed with intentional systems management (Carey et al. 1999c).

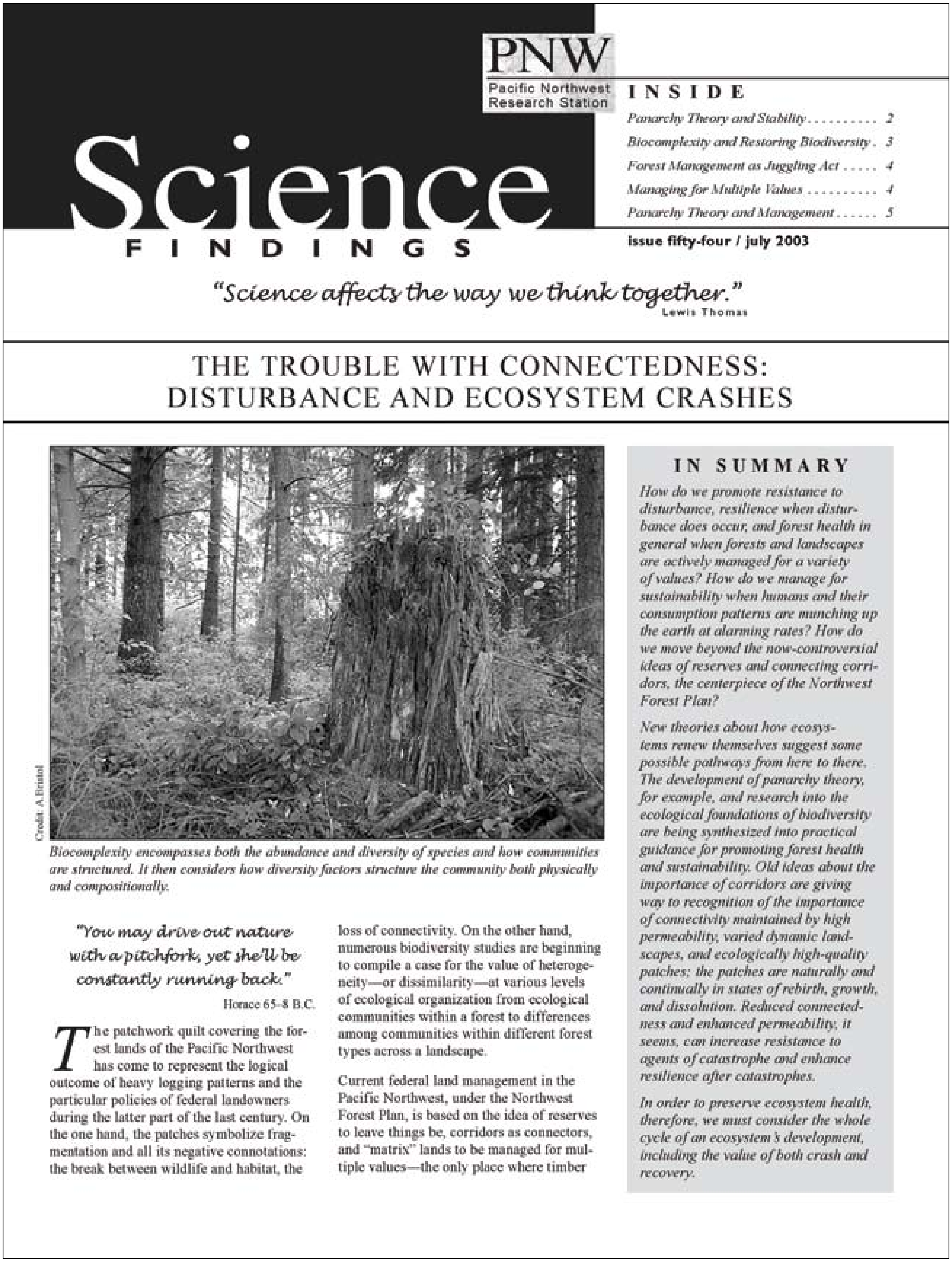
The second assertion is that natural, undisturbed ecosystems are inherently preferential to disturbed ecosystems. Additionally, native species are more important than exotic species and, therefore, biological diversity should not be reduced. In reality, few ecosystems have not been historically altered or influenced by people, exotic species include some of our most aesthetically and commercially valued ornamental and food plants (fig. 6), and native diversity often can be enhanced by intentional management (e.g., Carey 2003a, 2003c; Carey and Curtis 1996; Thysell and Carey 2001a).

The third assertion is that everything is connected to everything else (callout 1). Thus, ecosystem management would be

(continued on page 44)

Figure 6—A highly diverse, cultivated landscape unit: Regine Carey's Olympia, Washington, 0.4-hectare garden and surrounding 1.5-hectare managed woods contains over 140 species of cultivated and wild plants and 35 species of indigenous birds and has been highlighted in regional tours of natural gardens. Photo by A. Carey.

Callout 1—A. Carey's *Science Findings* July 2003, page 1



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Science FINDINGS

INSIDE

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"Science affects the way we think together."
Lewis Thomas

THE TROUBLE WITH CONNECTEDNESS: DISTURBANCE AND ECOSYSTEM CRASHES

Credit: A.Bristol

Biocomplexity encompasses both the abundance and diversity of species and how communities are structured. It then considers how diversity factors structure the community both physically and compositionally.

"You may drive out nature with a pitchfork, yet she'll be constantly running back."

Horace 65-8 B.C.

The patchwork quilt covering the forest lands of the Pacific Northwest has come to represent the logical outcome of heavy logging patterns and the particular policies of federal landowners during the latter part of the last century. On the one hand, the patches symbolize fragmentation and all its negative connotations: the break between wildlife and habitat, the loss of connectivity. On the other hand, numerous biodiversity studies are beginning to compile a case for the value of heterogeneity—or dissimilarity—at various levels of ecological organization from ecological communities within a forest to differences among communities within different forest types across a landscape.

Current federal land management in the Pacific Northwest, under the Northwest Forest Plan, is based on the idea of reserves to leave things be, corridors as connectors, and "matrix" lands to be managed for multiple values—the only place where timber

IN SUMMARY

How do we promote resistance to disturbance, resilience when disturbance does occur, and forest health in general when forests and landscapes are actively managed for a variety of values? How do we manage for sustainability when humans and their consumption patterns are munching up the earth at alarming rates? How do we move beyond the now-controversial ideas of reserves and connecting corridors, the centerpiece of the Northwest Forest Plan?

New theories about how ecosystems renew themselves suggest some possible pathways from here to there. The development of panarchy theory, for example, and research into the ecological foundations of biodiversity are being synthesized into practical guidance for promoting forest health and sustainability. Old ideas about the importance of corridors are giving way to recognition of the importance of connectivity maintained by high permeability, varied dynamic landscapes, and ecologically high-quality patches; the patches are naturally and continually in states of rebirth, growth, and dissolution. Reduced connectedness and enhanced permeability, it seems, can increase resistance to agents of catastrophe and enhance resilience after catastrophes.

In order to preserve ecosystem health, therefore, we must consider the whole cycle of an ecosystem's development, including the value of both crash and recovery.

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can be harvested. But behind this kind of management, according to Andy Carey, research biologist with the Pacific Northwest Research Station, is a deeply held belief in the value of connectedness (everything is connected to everything else), equilibrium (static forest structures), and the "balance of nature." This belief does not allow us to design ecosystems that can adapt to long-term trends such as climate change.

What, then, are we to think of connectedness? Is it a good thing or a bad thing?

First, a definition. Despite all we learned about the values of sound connections between ecosystem components—a good thing—in the 1970s and 1980s, it is important now to recognize that too much connectedness between simplified ecosystems can render them highly vulnerable to catastrophic disturbance, Carey says. Not such a good thing.

In this sense, connectedness refers to tight coupling through homogeneity. Consider plantation monoculture an extreme case. Across a commercial private forest plantation, the likelihood of disease spreading, for example, is far higher than across a diverse, patchy landscape. A less extreme example is a nonplantation landscape where fire has been suppressed, where biodiversity is potentially undermined by the dominance of fewer species and the ecosystem is at high risk owing to large, connected fuel loads.

KEY FINDINGS

- The forest ecosystem study demonstrates that managing for ecologically appropriate spatial heterogeneity at a variety of scales promotes diversity in vascular plants, fungi, invertebrates, birds, small mammals, and carnivores.
- That study and others collectively demonstrate that spatial heterogeneity and compositional diversity reduce overall connectedness of ecosystems across a landscape. This increases both resistance to agents of catastrophe and ability to recover after disturbance.
- Reduced connectedness allows competing species to exist on a fine scale, prevents single predators from extirpating prey, inhibits the spread of diseases such as root rot and Swiss needle cast, reduces susceptibility to windthrow, inhibits the establishment and spread of invasive exotic plants and animals, and allows quick system recovery after ice and windstorms.

A certain degree of connectedness, Carey suggests, is healthy. As adaptation occurs, all the parts of a system can then bend and move as needed. But in an overly connected system, a kind of rigidity between the parts can occur, rendering the whole much more vulnerable to the dramatic shifts of catastrophic disturbance.

"You only have to look to epidemiology to see what happens if everything is too closely connected," says Carey. "The value of happy-and-peaceful-everything-is-connected-to-everything-else made a nice little story back in the sixties and seventies but in truth it's just a disaster waiting to happen."

The recent international spread of severe acute respiratory syndrome, exacerbated by the connection of continents by airplanes, is a chilling example.

What do we get when we turn the idea of connections on its head, throw in the complex roles of disturbance and effects of human activity, the truth of Nature's lack of a plan, and time? One possible scenario is described by panarchy theory.

PANARCHY THEORY AND STABILITY

Simply put, panarchy theory, developed by Gunderson and Holling (2002), addresses ideas of stability. How do ecosystems absorb, buffer, or generate change?

The two widely accepted phases of ecosystem dynamics are exploitation, in which rapid colonization of recently disturbed areas occurs, and conservation, the slow accumulation and storage of energy and material. Panarchy theory adds two more stages. The first is release, or "creative destruction," in which accumulations of biomass and nutrients become increasingly susceptible to disturbance and are suddenly released by such agents as forest fire, insect pests, or intense grazing. The second is reorganization, which brings processes into play that work toward preparing the system for the next phase of exploitation in a potentially different setting of climate and disturbances.

Panarchy theory is constructive for considering some of our remaining land management options today and can help change them profoundly, Carey believes.

"Our traditional forest management approach has emphasized homogeneity and low diversity, engineering efficiencies with single species in which you predictably plant, fertilize, spray herbicides, harvest, and in effect, keep everything highly connected. Under such a system, any loss by disturbance becomes catastrophic, and the ability to recover less likely."

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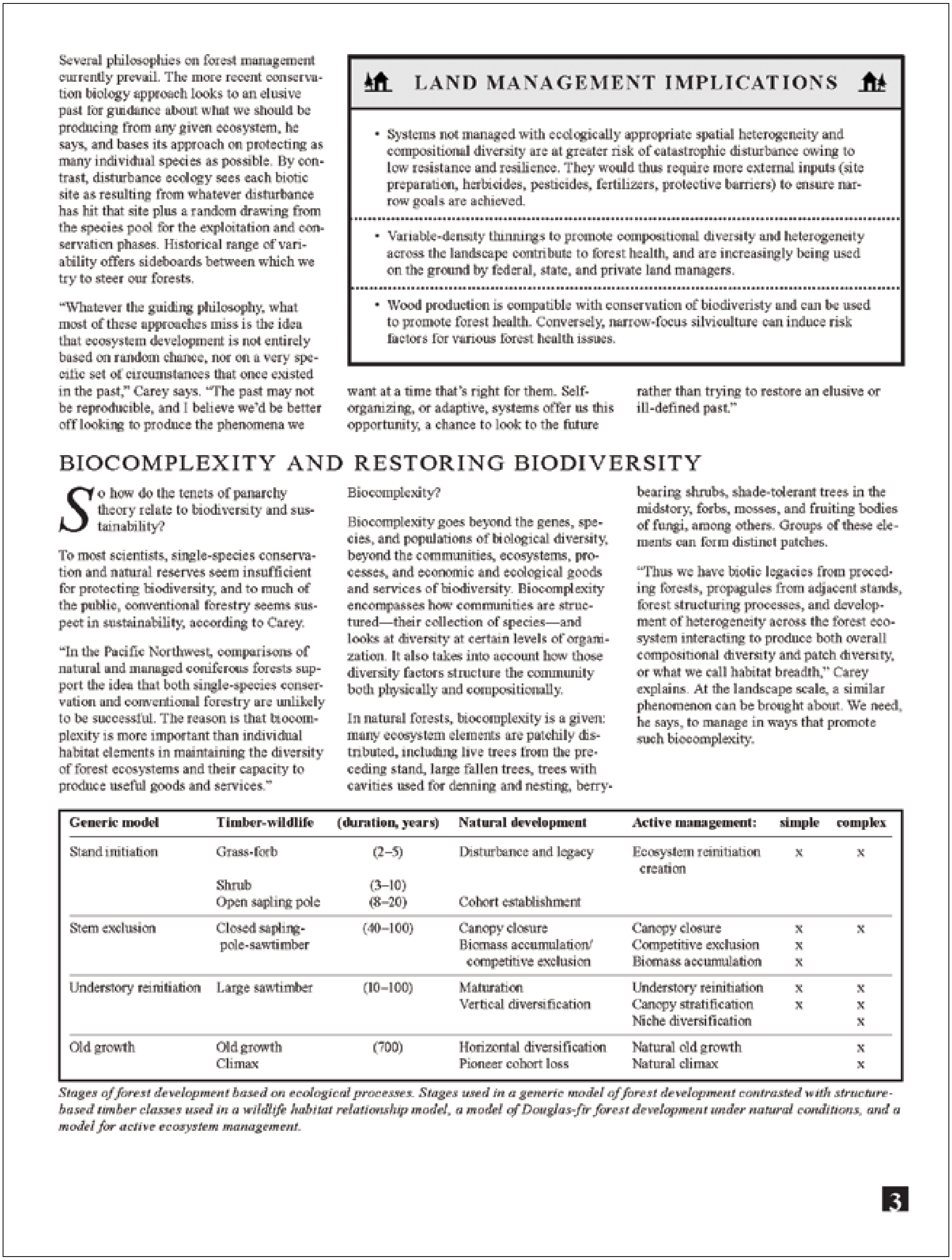

Several philosophies on forest management currently prevail. The more recent conservation biology approach looks to an elusive past for guidance about what we should be producing from any given ecosystem, he says, and bases its approach on protecting as many individual species as possible. By contrast, disturbance ecology sees each biotic site as resulting from whatever disturbance has hit that site plus a random drawing from the species pool for the exploitation and conservation phases. Historical range of variability offers sideboards between which we try to steer our forests.

"Whatever the guiding philosophy, what most of these approaches miss is the idea that ecosystem development is not entirely based on random chance, nor on a very specific set of circumstances that once existed in the past," Carey says. "The past may not be reproducible, and I believe we'd be better off looking to produce the phenomena we want at a time that's right for them. Self-organizing, or adaptive, systems offer us this opportunity, a chance to look to the future rather than trying to restore an elusive or ill-defined past."

LAND MANAGEMENT IMPLICATIONS

- Systems not managed with ecologically appropriate spatial heterogeneity and compositional diversity are at greater risk of catastrophic disturbance owing to low resistance and resilience. They would thus require more external inputs (site preparation, herbicides, pesticides, fertilizers, protective barriers) to ensure narrow goals are achieved.
- Variable-density thinnings to promote compositional diversity and heterogeneity across the landscape contribute to forest health, and are increasingly being used on the ground by federal, state, and private land managers.
- Wood production is compatible with conservation of biodiveristy and can be used to promote forest health. Conversely, narrow-focus silviculture can induce risk factors for various forest health issues.

BIOCOMPLEXITY AND RESTORING BIODIVERSITY

So how do the tenets of panarchy theory relate to biodiversity and sustainability?

To most scientists, single-species conservation and natural reserves seem insufficient for protecting biodiversity, and to much of the public, conventional forestry seems suspect in sustainability, according to Carey.

"In the Pacific Northwest, comparisons of natural and managed coniferous forests support the idea that both single-species conservation and conventional forestry are unlikely to be successful. The reason is that biocomplexity is more important than individual habitat elements in maintaining the diversity of forest ecosystems and their capacity to produce useful goods and services."

Biocomplexity?

Biocomplexity goes beyond the genes, species, and populations of biological diversity, beyond the communities, ecosystems, processes, and economic and ecological goods and services of biodiversity. Biocomplexity encompasses how communities are structured—their collection of species—and looks at diversity at certain levels of organization. It also takes into account how those diversity factors structure the community both physically and compositionally.

In natural forests, biocomplexity is a given: many ecosystem elements are patchily distributed, including live trees from the preceding stand, large fallen trees, trees with cavities used for denning and nesting, berry-bearing shrubs, shade-tolerant trees in the midstory, forbs, mosses, and fruiting bodies of fungi, among others. Groups of these elements can form distinct patches.

"Thus we have biotic legacies from preceding forests, propagules from adjacent stands, forest structuring processes, and development of heterogeneity across the forest ecosystem interacting to produce both overall compositional diversity and patch diversity, or what we call habitat breadth," Carey explains. At the landscape scale, a similar phenomenon can be brought about. We need, he says, to manage in ways that promote such biocomplexity.

Generic model	Timber-wildlife	(duration, years)	Natural development	Active management:	simple	complex
Stand initiation	Grass-forb	(2–5)	Disturbance and legacy	Ecosystem reinitiation creation	x	x
	Shrub	(3–10)				
	Open sapling pole	(8–20)	Cohort establishment			
Stem exclusion	Closed sapling-pole-sawtimber	(40–100)	Canopy closure	Canopy closure	x	x
			Biomass accumulation/ competitive exclusion	Competitive exclusion	x	
				Biomass accumulation	x	
Understory reinitiation	Large sawtimber	(10–100)	Maturation	Understory reinitiation	x	x
			Vertical diversification	Canopy stratification	x	x
				Niche diversification		x
Old growth	Old growth	(700)	Horizontal diversification	Natural old growth		x
	Climax		Pioneer cohort loss	Natural climax		x

Stages of forest development based on ecological processes. Stages used in a generic model of forest development contrasted with structure-based timber classes used in a wildlife habitat relationship model, a model of Douglas-fir forest development under natural conditions, and a model for active ecosystem management.

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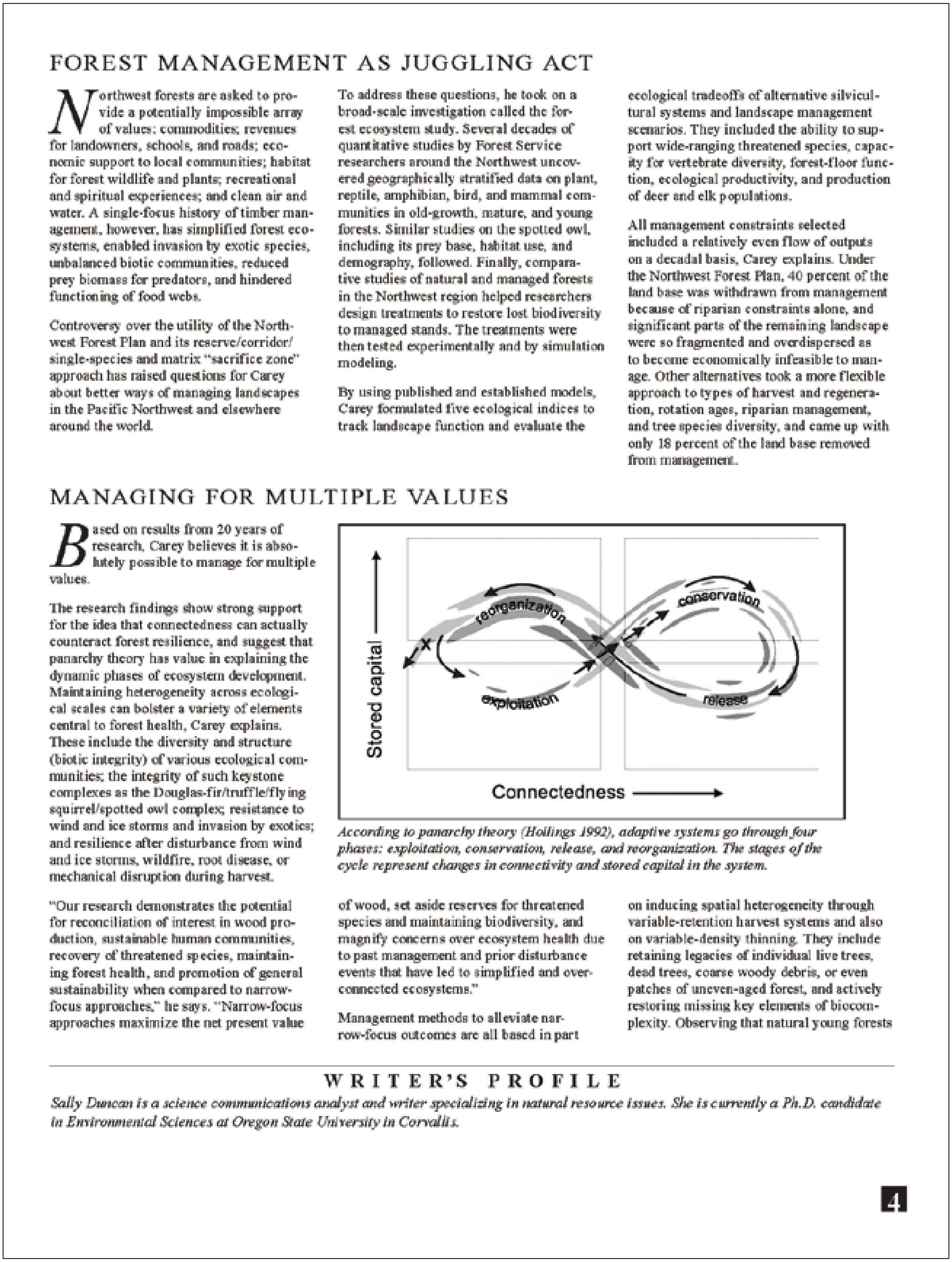

FOREST MANAGEMENT AS JUGGLING ACT

Northwest forests are asked to provide a potentially impossible array of values: commodities; revenues for landowners, schools, and roads; economic support to local communities; habitat for forest wildlife and plants; recreational and spiritual experiences; and clean air and water. A single-focus history of timber management, however, has simplified forest ecosystems, enabled invasion by exotic species, unbalanced biotic communities, reduced prey biomass for predators, and hindered functioning of food webs.

Controversy over the utility of the Northwest Forest Plan and its reserve/corridor/single-species and matrix "sacrifice zone" approach has raised questions for Carey about better ways of managing landscapes in the Pacific Northwest and elsewhere around the world.

To address these questions, he took on a broad-scale investigation called the forest ecosystem study. Several decades of quantitative studies by Forest Service researchers around the Northwest uncovered geographically stratified data on plant, reptile, amphibian, bird, and mammal communities in old-growth, mature, and young forests. Similar studies on the spotted owl, including its prey base, habitat use, and demography, followed. Finally, comparative studies of natural and managed forests in the Northwest region helped researchers design treatments to restore lost biodiversity to managed stands. The treatments were then tested experimentally and by simulation modeling.

By using published and established models, Carey formulated five ecological indices to track landscape function and evaluate the ecological tradeoffs of alternative silvicultural systems and landscape management scenarios. They included the ability to support wide-ranging threatened species, capacity for vertebrate diversity, forest-floor function, ecological productivity, and production of deer and elk populations.

All management constraints selected included a relatively even flow of outputs on a decadal basis, Carey explains. Under the Northwest Forest Plan, 40 percent of the land base was withdrawn from management because of riparian constraints alone, and significant parts of the remaining landscape were so fragmented and overdispersed as to become economically infeasible to manage. Other alternatives took a more flexible approach to types of harvest and regeneration, rotation ages, riparian management, and tree species diversity, and came up with only 18 percent of the land base removed from management.

MANAGING FOR MULTIPLE VALUES

Based on results from 20 years of research, Carey believes it is absolutely possible to manage for multiple values.

The research findings show strong support for the idea that connectedness can actually counteract forest resilience, and suggest that panarchy theory has value in explaining the dynamic phases of ecosystem development. Maintaining heterogeneity across ecological scales can bolster a variety of elements central to forest health, Carey explains. These include the diversity and structure (biotic integrity) of various ecological communities; the integrity of such keystone complexes as the Douglas-fir/truffle/flying squirrel/spotted owl complex; resistance to wind and ice storms and invasion by exotics; and resilience after disturbance from wind and ice storms, wildfire, root disease, or mechanical disruption during harvest.

According to panarchy theory (Hollings 1992), adaptive systems go through four phases: exploitation, conservation, release, and reorganization. The stages of the cycle represent changes in connectivity and stored capital in the system.

"Our research demonstrates the potential for reconciliation of interest in wood production, sustainable human communities, recovery of threatened species, maintaining forest health, and promotion of general sustainability when compared to narrow-focus approaches," he says. "Narrow-focus approaches maximize the net present value of wood, set aside reserves for threatened species and maintaining biodiversity, and magnify concerns over ecosystem health due to past management and prior disturbance events that have led to simplified and overconnected ecosystems."

Management methods to alleviate narrow-focus outcomes are all based in part on inducing spatial heterogeneity through variable-retention harvest systems and also on variable-density thinning. They include retaining legacies of individual live trees, dead trees, coarse woody debris, or even patches of uneven-aged forest, and actively restoring missing key elements of biocomplexity. Observing that natural young forests

WRITER'S PROFILE

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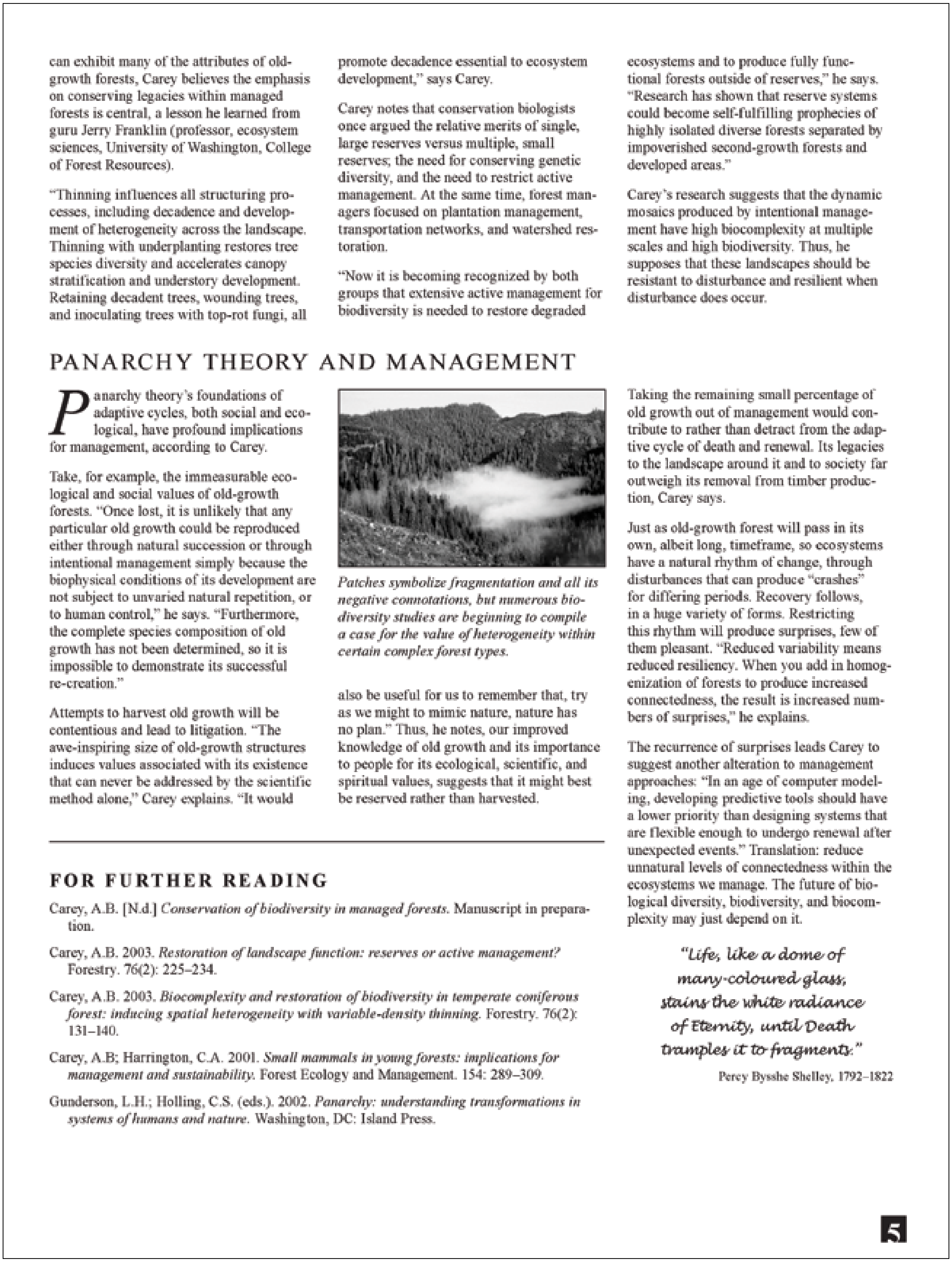

can exhibit many of the attributes of old-growth forests, Carey believes the emphasis on conserving legacies within managed forests is central, a lesson he learned from guru Jerry Franklin (professor, ecosystem sciences, University of Washington, College of Forest Resources).

"Thinning influences all structuring processes, including decadence and development of heterogeneity across the landscape. Thinning with underplanting restores tree species diversity and accelerates canopy stratification and understory development. Retaining decadent trees, wounding trees, and inoculating trees with top-rot fungi, all promote decadence essential to ecosystem development," says Carey.

Carey notes that conservation biologists once argued the relative merits of single, large reserves versus multiple, small reserves; the need for conserving genetic diversity, and the need to restrict active management. At the same time, forest managers focused on plantation management, transportation networks, and watershed restoration.

"Now it is becoming recognized by both groups that extensive active management for biodiversity is needed to restore degraded ecosystems and to produce fully functional forests outside of reserves," he says. "Research has shown that reserve systems could become self-fulfilling prophecies of highly isolated diverse forests separated by impoverished second-growth forests and developed areas."

Carey's research suggests that the dynamic mosaics produced by intentional management have high biocomplexity at multiple scales and high biodiversity. Thus, he supposes that these landscapes should be resistant to disturbance and resilient when disturbance does occur.

PANARCHY THEORY AND MANAGEMENT

Panarchy theory's foundations of adaptive cycles, both social and ecological, have profound implications for management, according to Carey.

Take, for example, the immeasurable ecological and social values of old-growth forests. "Once lost, it is unlikely that any particular old growth could be reproduced either through natural succession or through intentional management simply because the biophysical conditions of its development are not subject to unvaried natural repetition, or to human control," he says. "Furthermore, the complete species composition of old growth has not been determined, so it is impossible to demonstrate its successful re-creation."

Attempts to harvest old growth will be contentious and lead to litigation. "The awe-inspiring size of old-growth structures induces values associated with its existence that can never be addressed by the scientific method alone," Carey explains. "It would also be useful for us to remember that, try as we might to mimic nature, nature has no plan." Thus, he notes, our improved knowledge of old growth and its importance to people for its ecological, scientific, and spiritual values, suggests that it might best be reserved rather than harvested.

Patches symbolize fragmentation and all its negative connotations, but numerous biodiversity studies are beginning to compile a case for the value of heterogeneity within certain complex forest types.

Taking the remaining small percentage of old growth out of management would contribute to rather than detract from the adaptive cycle of death and renewal. Its legacies to the landscape around it and to society far outweigh its removal from timber production, Carey says.

Just as old-growth forest will pass in its own, albeit long, timeframe, so ecosystems have a natural rhythm of change, through disturbances that can produce "crashes" for differing periods. Recovery follows, in a huge variety of forms. Restricting this rhythm will produce surprises, few of them pleasant. "Reduced variability means reduced resiliency. When you add in homogenization of forests to produce increased connectedness, the result is increased numbers of surprises," he explains.

The recurrence of surprises leads Carey to suggest another alteration to management approaches: "In an age of computer modeling, developing predictive tools should have a lower priority than designing systems that are flexible enough to undergo renewal after unexpected events." Translation: reduce unnatural levels of connectedness within the ecosystems we manage. The future of biological diversity, biodiversity, and biocomplexity may just depend on it.

FOR FURTHER READING

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"Life, like a dome of
many-coloured glass,
stains the white radiance
of Eternity, until Death
tramples it to fragments."

Percy Bysshe Shelley, 1792–1822

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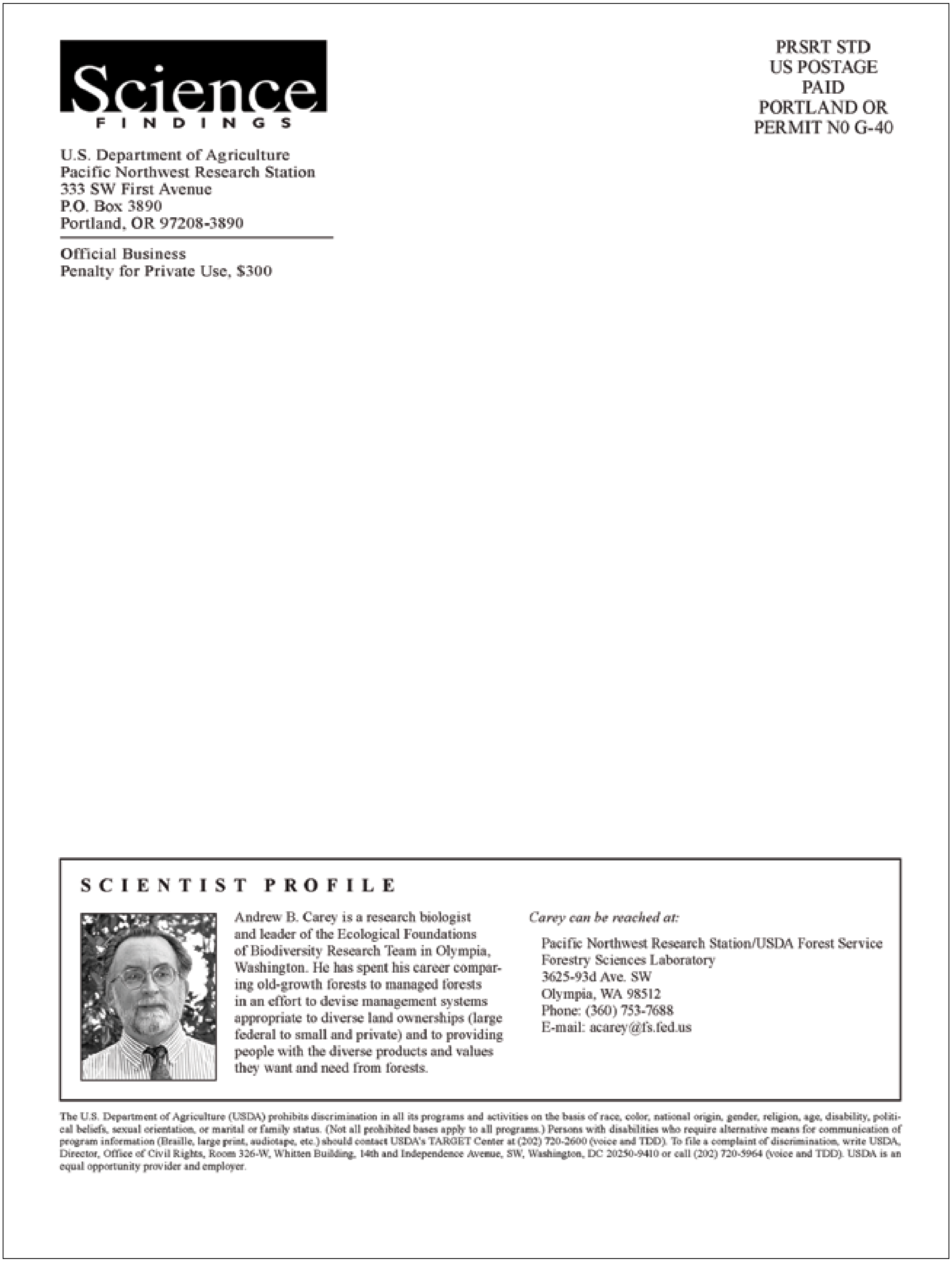

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done best across large geographical areas. In reality, landscape character is conditioned by climatic, geomorphic, and biogeographic factors rarely modified by ecosystem management and determined by the array of biotic communities that compose the biotic landscape. The spatiotemporal arrangement of these communities determines the quality of the landscape for any particular purpose or sets of purposes through time (Carey et al. 1999c), and management at both stand and landscape levels is appropriate (Carey 2003a, 2003c).

The fourth and final assertion is that there is a moral imperative for ecosystem management—the benefits and costs of management are accruable to all ecosystem components, not solely to people. This crucial assertion requires global action. An equally crucial assertion is that people have a moral requirement for intra- and intergenerational equity (Goodland 1995) that requires even stronger action.

Ecological worldviews are in contest with profound implications for ecosystem management (MacCleery and Le Master 1999, Partridge 2000, Reid 1996). For most of history, people had direct and personal connections to the land as their source of sustenance. In developed nations, personal connections between resource consumption and production have been severed for most people. Linkages between "food and fields, forests and hearth, and home" are nonexistent. A common view assumes that natural ecosystems have a natural balance or equilibrium not found in managed ecosystems, that pristine nature is sacred, and that landscapes should be separated into those substantively modified by people and those not. Paleobiology belies this view (Reid 1996). An emerging view challenges assumptions of natural equilibrium and classification of landscapes as natural or humanized. This view argues that the natural world is dynamic, and holistic management is needed to sustain natural and cultural systems. Huge areas of federal land are allocated to reserves under the worldview of natural balance. This belief in an "order of nature" characterized by integrity, stability, equilibrium, and self-regulating mechanisms has led to a library of national and international policies, laws, and regulations (Partridge 2000).

Ecologists and philosophers have challenged each of these beliefs, which pose important questions. Are romantic images of nature and reserves a sufficient basis to assume reserves and wilderness can be maintained as envisioned? Will human intervention be needed to maintain the health and biodiversity of reserves? If there is no natural equilibrium, stability, or self-regulation, are extinction, loss of biodiversity, limits to growth, and sustainability important? Can a fundamentally noninterventionist policy achieve the goal of maintenance of biodiversity? What emerging knowledge will give insight into holistic integration of humans and nature? What are the ramifications of not exploring new ways of thinking about active resource management? These questions call for a better articulated form of ecosystem management. It is past time to rethink ecosystem management (Reid 1996).

There is another unfinished agenda for ecosystem management (MacCleery and Le Master 1999). This agenda includes problems of fragmentation of wild and cultivated lands by residential subdivision and urban development; degradation and loss of forest and grassland communities once maintained by frequent, low-intensity fires; loss and fragmentation of late-seral forest by timber harvesting and narrow-focus forestry; degradation and loss of riparian and wetland communities; damaging effects of air pollution on forests and wetlands; displacement of native species by exotics; loss of rare and unique types of ecosystems; and deforestation in developing nations. This is the agenda of total landscape management and global cooperation. United States federal agencies manage over 120 million hectares of public land (approximately a half million square miles or twice the combined area of Washington, Oregon, and Idaho). Many of these agencies are in varying stages of crisis because of unclear or contradictory agency missions, internal malfunctions, and lack of responsiveness to foreseeable problems (Samson and Knopf 2001).

Ecosystem management requires some measures of effectiveness. Ecosystem health is the most commonly referenced measure of ecosystem management effectiveness (Lackey 2001). There is, however, no universal conception of ecosystem health. Some find the concept too value laden, too abstract, and too contentious. Many perceive health concepts to be relegated to individuals and not appropriate to populations, communities, and systems. Such a perception shows a lack of knowledge in the fields and institutions of epidemiology, disease prevention through environmental management, public health, and occupational safety and health and in the fact that the roots of landscape ecology lie in landscape epidemiology (Carey and McLean 1983; Carey et al. 1978, 1980a, 1980b). Many conclude that because there is no consensus, the concept is not useful—conclusions all too similar to those drawn for almost all conservation concepts. Nevertheless, ecosystem health can be defined as the preferred state of ecosystems modified by human activity (Karr and Chu 1999). The concept of ecosystem integrity (the unimpaired condition of ecosystems not influenced by people) can be used to set benchmarks by which management effectiveness can be measured. The biotic integrity of key communities and keystone complexes are especially useful when benchmarks are defined by natural ecosystems that exhibit longevity, resistance to disturbance, resilience in recovering from disturbance, and capacity to provide valued goods and services, including conservation of biodiversity (Carey et al. 1999c) (table 5). The utility of ecosystem health includes comparing alternative desired future states, comparing alternative pathways to that state, and measuring progress from a past state toward the future state.

With no consensus on process management or total quality management that incorporates natural benchmarks (Rummler and Brache 1995, Schein 1994), effective measures of change, and carefully defined management goals, conservation biologists suggest using a natural variability concept (Landres et al. 1999, Lindenmayer et al. 2000, McIntyre and Hobbs 1999). This approach asserts that the range in natural variation in past conditions and processes provides adequate context and guidance for managing ecological systems today and in the future, and disturbance-driven spatial and temporal variability is a vital attribute of ecological systems. The use of natural variability began out of a search for a legally defensible strategy for maintaining biodiversity and threatened, endangered, and sensitive species. It is also used where maintaining biotic integrity is the primary goal. However, the proposition that natural variation provides for the maintenance of biotic communities is oxymoronic. Natural variation emphasizes random processes that result in random or haphazard assemblages of the regional species pool, unlike biotic communities that are assemblages based on interactions among species conditioned by the environment. Either an assemblage is a random collection, or it is a biotic community developing from interactions among species in the context of the immediate or nearby environment. The nonequilibrium-stochasticity paradigm imposes no particular value on any species or any set of species, nor any mechanistic basis for biotic integrity (Landres et al. 1999). Thus, further examination of the natural variability concept is in order. The concept has seven premises:

- Human activities diminish the viability of many species.
- History implies that a “coarse filter,” or an array of vegetative conditions mimicking historical conditions, could maintain biological diversity.
- A coarse-filter strategy requires few external subsidies and is more cost effective than other strategies.
- Natural variability is a useful reference for evaluation of the environmental impacts of people.

Table 5—A comparison of unique species and ecosystem health under two management approaches, timber focus and biodiversity focus

	Management focus	
Ecological measure	**Timber**[a]	**Biodiversity**[a]
Unique species[b]	0	14
Ecosystem health[c]	32	98
Vertebrate diversity	64	100
Forest-floor function	12	100
Ecological productivity	19	94

[a] Both pathways include an even flow of timber from a landscape maintained as a shifting, steady-state mosaic.

[b] Unique species is the total number of species of wildlife unique to the particular management focus.

[c] Ecosystem health is a percentage of the maximum possible in a fully regulated forested landscape. Ecosystem health was calculated as the average of the modal percentages of maximum potential vertebrate diversity, forest-floor function, and ecological productivity (measures functional groups) summed from stand values.

Source: Adapted from Carey et al. 1999c.

- Natural variability provides context that is important to understanding driving factors.
- Environmental factors and disturbances are strong, lasting, and key structuring factors.
- Spatial heterogeneity itself is an important component of ecological systems.

Problems associated with these premises are many and profound. First, the premise that a retrospective view will focus on the set of factors ultimately responsible for biodiversity is questionable. Cursory retrospective investigations have produced mixed results at best. Nor does this approach identify key variables that can be monitored to determine if biodiversity goals are being met. At best, monitoring implementation of the strategy is possible (e.g., hectares cut per year, number of watershed analyses completed, or number of reserves set aside on paper). Research can help identify key factors and their function, but then this new knowledge abrogates the need for relying on a coarse filter. Second, the premise that there exist areas with ecological conditions relatively unaffected by people and that the range of natural variation in these areas is appropriate to other areas with more substantial human influence is tenuous at best. Some of the most pristine forests in the world, however, are Pacific Northwest old-growth forests, which might well produce useful benchmarks for management to conserve biodiversity. Extrapolating beyond the sampling universe is always risky. Pristine environments, when they exist at all, generally are harsher (steeper, higher, drier, wetter, colder) than managed environments. Third, the premise that the biodiversity of a large area is a product of the full range of natural variation there as opposed to a more limited set of conditions is unsupported. Stochastic disturbances by definition are unlikely to uniformly maximize or maintain diversity; some conditions produced will be very conducive to native diversity, some may be quite inimical. Fourth, the range of natural variability, when imposed on a managed landscape may fail to produce desirable future conditions or produce the goods and services desired from that landscape. More intentional ecosystem management may have a better chance of accomplishing human goals, including maintenance of biodiversity. Fifth, the natural variability concept assumes a consensus can be reached on managing for stochastic disturbance, when such a consensus is likely to become increasingly improbable with increasing human demands on a landscape. Sixth, given increasing human populations, increasing demands on natural resources, and decreasing areas of wild and quasi-wildlands broken into much smaller areas than existed prior to European settlement of North America, it may be neither possible nor prudent to try to re-create the disturbance regimes of more than 300 years ago (Carey et al. 1999c, Reid 1996). McCool and Kruger (2003) described this approach as "management that proceeds with little scientific understanding of consequences and uses assumptions about the 'intrinsic goodness' of the management activity."

More complex, diverse, and integrated organic management models than range in natural variation are necessary to understand and adapt ecosystem management to a globalized environmental and sociopolitical world (Kennedy and Dombeck 1999). The 20th-century agency-machine bureaucracy approach that could implement range-of-natural-variation ecosystem management is no longer appropriate. General sustainability, complex systems management, social values, stewardship, and collaborative management hold sway (table 6). There is considerable public skepticism about government, science, and technology. Still, public acceptance is essential to every resource management decision of public agencies (Shindler et al. 2002). The conflicting roles that management agencies have been directed to play in the past—resource protection and provision of commodities—have made them vulnerable to social criticism. Past commodity production without understanding what was necessary to maintain biodiversity produced violations of the public trust. These violations have ranged from breach of the social and psychological contracts with individuals and communities that depended on renewable resources for economic activity and management that violated the spirit and intent of federal legislation such as the Multiple Use-Sustained Yield Act and Endangered Species Act to failures of regulatory agencies to enforce laws and regulations (judged "capricious" by federal courts). Range-of-natural-variation ecosystem management potentially has significant, perhaps irreversible, consequences to the environment and to human communities that depend on the environment for sustenance, security, shelter, spirituality, and leisure. It increases the anxiety of long-term rural residents who feel increasingly alienated by an apparently remote and insensitive federal government, overwhelmed by growing global economic complexity, antagonized by an enlarging environmental elite, and alarmed by vacillating land management policy (McCool and Kruger 2003). At best, public judgments are always provisional, never absolute or final because social acceptance is a process, not and end product. Acceptable practices and policies must be biologically and physically feasible, economically efficient, equitable, culturally acceptable, and operationally practical (Shindler et al. 2002). If management for the range of natural variation is attempted, lost trust may never return.

Total Landscape Management

The myth of untouched nature works against protection of the real world that is shaped jointly by human activities and nature. Two-thirds of terrestrial Earth is covered by agriculture, grazing, and

Table 6—**The 20th-century machine model vs. the 21st-century organic model of natural resource management**

20th-century machine model	21st-century organic model
▪ Sustained yield/economic efficiency	▪ Sustainable healthy ecosystems
▪ Resource inventory	▪ Systems monitoring
▪ Intensively managed plantations	▪ Multifaceted, multivalued forests
▪ Omnipotent foresters	▪ Interdisciplinary teams, public participation
▪ Focus on a stand	▪ Focus on hierarchy of scales, stand-region
▪ Anti-entropy imperative	▪ Open, accepting, adaptive organization
▪ Science illuminates the path	▪ Science as one of a set of values
▪ Top-down goal setting	▪ Bottom-up field and community planning
▪ Implementation of complex law	▪ Simplify, humanize, facilitating regulation
▪ Local-regional focus	▪ Local community within national and global context

Source: Adapted from Kennedy and Dombeck 1999.

managed forests (Farina 2000). Economic globalization is producing new disturbance regimes and new driving forces. The market economy is one of the oldest human adaptations to the unpredictability of local environments and to high spatial variability in the distribution of resources (di Castri 2000). Recognition of market economies is essential to the integration of economics and ecology. Human activity is now the predominant evolutionary force (Palumbi 2001).

Both natural and human disturbance affects the fragility and resilience of cultural landscapes. The susceptibility of an ecosystem to undergo changes in composition and structure because of perturbation (fragility) and its ability to recover to its prior state after disturbance (resilience) is as important in managed landscapes as in natural landscapes. Biological diversity may be higher in cultural landscapes than in remnants of natural landscapes, depending on landscape heterogeneity and purpose of cultivation (see fig. 6). If land is properly managed and zoned, humanity can use biological resources without diminishing the biota's capacity to meet future generation's needs (Reid and Miller 1989). Intentional management can produce highly diversified ecological systems that are sustainable (Carey et al. 1999c) (fig. 7). The resilience of cultural landscapes is often enhanced by reduction in vulnerability to natural environmental stresses such as flooding and fire by regulating waterflow and by removal of dry biomass. The challenge is to maintain cultivated

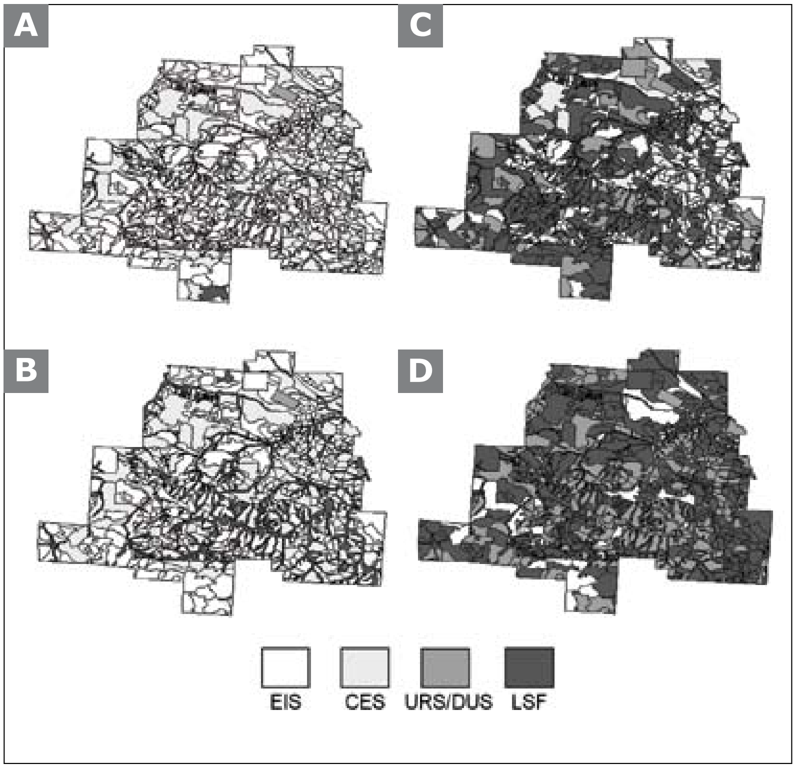

Figure 7—Seral-stage arrangement and composition of the Clallam River Planning Area after regulation and 300 years of simulated management for (A) timber production with minimal riparian protection; (B) timber production with wide buffers emphasizing small streams; (C) biodiversity with a 30 percent late-seral forest goal, by using a mix of timber management and biodiversity management and variable riparian management zones; (D) maximum biodiversity by using a mix of 70- and 130-year rotations with biodiversity management and variable riparian management zones. Seral-stage categories are ecosystem initiation (EIS), competitive exclusion (CES), understory reinitiation and development (URS/DUS), and late-seral forest (LSF: niche diversification and managerially fully functional forest) (Carey et al. 1999c).

landscapes with human co-adaptation within the global economic landscape (Farina 2000). Unconstrained growth and development bodes poorly for sustainability (see fig. 2D). Throughout Europe and North America, major aquatic, forest, grassland, and cultural ecosystems have been degraded (Farrell et al. 2000, Regier and Baskerville 1986). Redevelopment (restoration) of degraded landscapes requires global thinking and local action. The transition from development to redevelopment (exploitation to husbandry) necessarily involves substantial tension among governments, industries, and publics that is heightened by a mutual lack of trust. Redevelopment requires geographic control in implementation of management—plans must specify where local events will take place in order to achieve the desired regional effect.

Culture and Contemporary Players in Conservation

Human societies and the Earth form a complex system that is subject to abrupt shifts from one pattern of behavior to another. The Earth and its people may well be at the crux of social transformation. Which world lies ahead? The 2050 project (Hammond 1998) visualized three scenarios: Market World, Fortress World, and Transformed World. In Market World, economic reform and technological innovation produces rapid economic growth, and the global economy delivers modern technologies and products to all countries resulting in prosperity, peace, and stability. In the Fortress World, market growth fails to redress social wrongs and prevent environmental disasters; large portions of humanity are left out of prosperity; the economy stagnates and fragments producing enclaves of wealth and prosperity within misery, desperation, violence, and conflict. In the Transformed World, fundamental social and political change produces market forces that lead to power sharing and social coalitions that produce local community-based decisionmaking. Which scenario will come about? Each has profound implications for conservation of biodiversity and the knowledge needed to inform it.

Cultural Streams in the United States

American culture is distinct from other cultures of the world but is still internally heterogeneous (Ray 1996). American culture can be characterized by two primary variables: socioeconomic status and cultural change. This cultural variable can be divided into three subcultures—the traditionalists, modernists, and cultural creatives—each contemporary, but each reflecting an era-specific dominant worldview (past, present, and potential future). Traditionalists include conservative, religious, low-income and low-educated elderly people as well as upper middle class cultural and economic conservatives; together these two groups constitute 30 percent of the adult population of the United States. Their numbers are generally in decline (an aging population), but are being bolstered by intense recruitment by the religious right. The traditionalists are particularly interested in family values, have a low regard for civil liberties, and differ internally among socioeconomic classes in support for big business. The modernists are the current cultural mainstream. The media emphasizes their malaise about what the modern world has come to be. They make up 47 percent of the population. They have a wide range of incomes but average almost twice the income of the traditionalists. They include factory and office workers, engineers, doctors, and business people. One in eight in this group are free-market conservatives with a materialist focus on status and success with a heavy work ethic. They are likely to be opposed to ecological sustainability. The cultural creatives (24 percent of the total population) are primarily upper-middle income and middle aged; a majority (60 percent) are women. They can be subdivided into two groups, the greens and the core cultural creatives. The core holds both person-centered and green values. They are concerned with spirituality, self-actualization, self-expression, and new ideas. Core cultural creatives are leading-edge thinkers; women outnumber men 2:1. Greens (13 percent of the total population) have values centered on the environment and social concerns. Certain values cut across all the major subcultures. More than 50 percent of each group believes in financial materialism, rebuilding communities, eliminating violence against women and children, xenophilism (attraction to foreign peoples and cultures), and voluntary simplicity. Moreover, these more universal values include nature as sacred, general green values, and ecological sustainability (table 7). More than 80 percent of cultural creatives are concerned with rebuilding communities, treating nature as sacred, general green values, and ecological sustainability (Ray and Anderson 2000). To summarize these findings in different words, American culture overall is characterized by beliefs in social, economic, and environmental sustainability.

Leadership by Nongovernmental Organizations

Conservation organizations have long been active lobbyists and litigants for their causes, but now have moved more directly into the research, technology transfer, and management arena. The Nature Conservancy, Forest Stewardship Council, Northwest Ecosystem Alliance, Pacific Forest Trust, and many others have wrested land management and conservation leadership from both state and federal agencies. The Nature Conservancy received $37 million in federal funding in 2000. Coalitions, such as The Nature Conservancy and the Malpai Borderlands Group as well as The Nature Conservancy and Red Canyon Ranch, have achieved credibility outside, above, and beyond the traditional ranching-range science-federal and state agencies community (Jensen 2001). It seems these and other (Daily and Ellison 2002, Johnson et al. 1999) coalitions can effectively resolve conservation issues that are not simply conservation questions but ultimately questions of cultural values—such as whether or not ranching should continue. Coalitions of nongovernmental organizations are driving conservation policies and conservation activities internationally. In Central America, a coalition of The Nature Conservancy, The World Resources Institute, the World Bank, and

Table 7—**Values of American subcultures expressed as percentages of each of the three main cultural streams ascribing to major values (percentages greater than or equal to 65 percent are in bold type)**

Values	Traditionalists	Modernists	Cultural creatives
Religious	**70**	36	31
Traditional relationships	55	25	26
Financial materialism	61	**82**	51
Cynicism about politics	29	48	19
Secular	15	42	29
Success is high priority	11	36	12
Hedonism	5	12	4
Rebuild communities	**86**	**84**	**92**
Fear violence	**84**	**75**	**87**
Xenophilism	**69**	63	**85**
Nature as sacred	**65**	**72**	**85**
Green values	58	59	**83**
Ecological sustainability	52	56	**83**
Voluntary simplicity	**65**	53	**79**
Relationships important	**65**	49	**76**
Feminism in work	45	56	**69**
Altruism	55	32	58
Idealism	36	32	55

Source: Adapted from Ray and Anderson 2000.

others along with the United Nations, Netherlands, and Germany have begun a 40-year project to establish a system of reserves and corridors that transcends eight countries—"one of the largest, most ambitious conservation initiatives in the world" (Kaiser 2001). The Central America project is a leap beyond the past sustainable development-conservation initiatives in the Third World (Food and Agriculture Organization of the United Nations 1990). Forest Stewardship Council certification confers a credibility and stature that also transcends any associated with state or federal management or research; thus, in the last 2 years, the Washington Department of Natural Resources, the Fort Lewis U.S. Army installation, and a number of private land and forest products marketing groups in the Pacific Northwest have sought certification. The Pacific Forest Trust has pursued paying landowners for conservation easements and the practicality of trading in carbon credits (see also Daily and Ellison 2002). The Northwest Ecosystem Alliance, with contributions from the general public and "Microsoft millionaires," purchased key, ecologically significant timber rights on the Loomis State Forest from the Washington Department of Natural Resources. The alliance, with a coalition of environmental groups, is now attempting to build local coalitions of all stakeholders to promote watershed restoration and ecological forestry through collaborative management.

Charity is a new force in environmental issues (Jehl 2001). The Pew Charitable Trust, a $4.8 billion foundation, is the largest grantmaker to environmental causes focusing on forest protection, global warming, and marine conservation. The trust spent $52 million in 2001, compared to a USDA Forest Service investment in research of $242 million (U.S. Department of Agriculture 2003). Other foundations—David and Lucille Packard Foundation, Ford Foundation, Robert W. Woodruff Foundation, and W. Alton Jones Foundation—allocate more than $700 million per year to grants related to the environment and animals.

Professional and scientific societies (American Fisheries Society, Ecological Society of America, Society of American Foresters, Society for Conservation Biology, The Wildlife Society, and others) now routinely issue white papers, policy statements, editorials, and testimony to legislative bodies and urge their members to lobby actively on conservation issues. "Deep ecologists" claimed the moral high ground by asserting the spiritual value of wilderness and wilderness for its own sake (Reid 1996). However, a more transcendent cultural trend now incorporates the spiritual value of the oneness of self, family, community, and nature (Maser 1994, Ray 1996, Wilber 1995).

Managing Public Lands

The federal government has lost its historical grip on the West that began with the imperialism of Manifest Destiny under Thomas Jefferson and Teddy Roosevelt and that was perhaps irreparably diminished by declining budgets under Ronald Reagan (Behan 2001, Kemmis 2001). The USDA Forest Service received fewer and fewer resources with which to assert its jurisdiction or fulfill its obligations. The adherents of exploitive philosophies, in some cases the actual descendants and in other cases the ideological descendants of the homesteaders, cattle barons, lumber pirates, and mining interests that initially settled the West following the Homestead Act of 1862, the Timber Culture Act of 1873, and the Desert Land Act of 1877, are pitted against the descendants of the environmentalist heirs of the preservation philosophy underlying the creation of Yellowstone National Park in 1872, the "midnight reserves" of 1907, the National Environmental Policy Act of 1969, and the Wilderness Act of 1964. Even with the National Forest Management Act of 1976, which sought to maintain a natural resource and conservation posture, federal land managers have found themselves increasingly paralyzed by appeals and litigation.

Towering Douglas-fir giants in Olympic National Forest, near Quinault, Washington. Photo by T. Wilson.

There seems to be a growing consensus across political lines that centralized authority for natural resource decisionmaking must be replaced with decentralized collaborative stewardship (Behan 2001, Kemmis 2001, Kennett 1998, Lewis 2001, Prugh et al. 2000, Rey 2000). Our common goals for conservation of natural resources include a society that works for our descendants and us ecologically, economically, morally, culturally, and politically (Prugh et al. 2000). What sustainability is really about is the scope, quantity, richness, and benignity of human culture, the biosphere and the economic life we make from it, and the distribution of those economic and social benefits now and over time. Communities are the primary locus of responsibility for creating a sustainable world, and a sustainable society must be built on a foundation of local communities. Thus, we need a politics of engagement, not consignment. Strong democracy makes communities stronger and more reflective. Communities, then, must create the vision, broad stakeholder base, wide citizen engagement, tolerance for pluralism, and adaptability to changing circumstances that governmental agencies have not been able to create alone. Amenity migrants (rock climbers, hunters, fly fishers, skiers, and others) to the New West define themselves avocationally, in contrast to the wave of immigrants that became the cowboys, loggers, and miners of the Old West. Both are tied to the land. The Secure Rural Schools and Community Self Determination Act recoupled local citizens with federal lands by establishing local advisory groups for each national forest and Bureau of Land Management unit, with financial support for stewardship investments on federal lands where local consensus can be achieved (Rey 2000). Rey (2000) posited some guiding principles for this stewardship: (1) continuous process improvement in reducing impacts of commodity production on the land; (2) a change from the doctrine of "the infallibility of nature left to its own devices" to a philosophy of "man as part of a dynamic environment with changing ecosystems;" (3) policies that favor people and ecosystems, not one or the other; (4) change from a doctrine of primacy of national interest groups with decisionmakers selected from national organizations to a doctrine of local community control.

Managing Private Lands

Both governmental and nongovernmental organizations are more and more influencing management on private lands through regulation, incentives, conservation easements, and outright purchases to place the lands in trusts or public ownership. Even industrial forest-land managers are finding themselves being held accountable to public values (Loehle et al. 2002). Nearly 175 million hectares of privately owned forest land (58 percent of all forest land) in the United States is increasingly threatened by population growth, urbanization, and development (Best and Wayburn 2001). For example, in the Pacific Northwest, the Pacific Forest Trust has implemented conservation easements worth $80 million on about 12,000 hectares of land and provides conservation advisory services on an additional 500,000 hectares (Pacific Forest Trust 2001).

Property Ownership and Conservation

Land ownership in the United States is a mosaic of legal interests that are conditional rather than absolute (Geisler and Daneker 2000). Our public lands are a great reservoir of pride, mystique, and national identity. Federal, state, and local governments own about 42 percent of all U.S. land. Most federal lands, however, are split estates where permittees have acquired ownership rights. In the United States, there exists an "almost defiant conceit" that private ownerships are the highest and best use of land and the center of American civil liberties, lifestyle, and individualism." But the federal government has secured rights to 1.2 million hectares of private land through leases, agreements, and easements. Achieving conservation through government regulations, thus raises issues of (1) the constitutionality of property regulation without restriction in terms of "uncompensated takings," (2) privatization, and (3) ethics of ownerships, social justice, land tenure, stewardship, equity, and fairness. In other words, the overriding issue is the fundamental balance between rights of individuals and those of society. Most private lands, however, have a perpetual social mortgage. For example, the U.S. Department of Agriculture subsidizes conservation on private lands with about $1 billion per year. Even more alternatives to private and public property have emerged, are evolving, and are rapidly growing. In third-sector property, ownership is neither public nor private; property serves to meet broadly defined social needs as well as individual needs, not merely to increase wealth. The locus of control is local and management is decentralized. Third-sector property is social property, with value generated by public action, not by an individual property owner. Third-sector properties include a variety of community land trusts, limited equity cooperatives, conservation easements, and many other innovative schemes.

One alternative theory of public ownership, the General Land Ordinance of 1785, created 60 million hectares of state school trust lands in 22 states compared to 30 million hectares eventually allocated to national parks, 40 million hectares to wildlife refuges, 75 million hectares to national forests, and 115 million hectares to the Bureau of Land Management (Souder and Fairfax 2000). About 5 million hectares are in tribal trusts; 175 million hectares of forest land are privately owned (Best and Wayburn 2001). An unknown amount of land is held in trusts or easements by pension funds, conservation organizations, and other groups. Such trusts separate title, benefit, and management control. The obligations that bind the trustor, settler, trustee, and beneficiary are called fiduciary relationships. The principles of trusts are clarity, accountability, enforceability, perpetuity, and prudence. Trustees must meet exacting requirements of fairness, openness, honesty, and full disclosure. Intergenerational equity is mandatory requiring that the productive capacity of the trust be maintained in perpetuity—the framework for sustainability. In contrast, federal lands are not trust lands, there is limited accountability, oversight is congressional, and both agencies and legislators seek benefits for their constituents and conceal the extent to which different user groups are subsidized. Public mistrust and dissatisfaction with federal land managers may lead to placing more federal lands into trusts (Behan 2001, Kemmis 2001, Rey 2000). Other trusts include public trust (the sovereign's duty to protect public values in tidelands and waterways), land trusts with the focus to protect land from development, and charitable trusts. It seems the concept of land ownership in the United States is almost as dynamic as other parts of U.S. society. As pressures from growing populations increase demands and expectations from forests, one emerging mechanism for conservation seems to be creation of trust lands (and community forests) as replacements for public and industrial lands.

CHAPTER 3

Individuals, Society, and Conservation

Human impacts on the global biosphere now control many facets of ecosystem function (Palumbi 2001). In addition to altering global ecology, technological and human population growth also affects evolutionary trajectories, dramatically accelerating evolutionary change in other species, especially in commercially important pest and disease organisms. There are, perhaps, 1.4 million living species known to science and as many as 14 million in total (Wilson 1999a). Most (98 percent) birds are known; 1.5 percent of algae have been described; and bacteria constitute a black hole, with less than 1 percent of species described. On the other hand, more than 98 percent of the species that have ever lived have vanished, and many ecologists believe we are facing an unprecedented wave of extinctions owing to habitat destruction, spread of exotic species, pollution, overharvesting, and disease. The importance of biodiversity is twofold (Wilson 1999a): (1) the more species living in an ecosystem, the higher its productivity and the greater its ability to withstand drought and other kinds of environmental stress, and (2) biodiversity contributes to clean water, enriched soils, clean air, pharmaceuticals, crops, and fibers. However, care must be taken not to confuse the issues around biodiversity and to create subterfuges for the economic importance of noncommodities, even if these resources have noneconomic aesthetic values, such as a beautiful landscape (Ehrenfeld 1976). Maintaining biodiversity can be seen as a moral obligation to avoid destroying creation (Wilson 1999a). All environmental problems are innately ethical, seeking a right relationship between people and other living things and between generations. Every society has three forms of wealth—material, cultural, and biological—and the responsibility not to diminish this wealth for future generations.

Human health and well-being fundamentally depend on a clean and steady supply of water and fertile soil to produce renewable resources for food, fiber, and other products (Szaro et al. 1999). We have gone from a world relatively empty of humans to one full of humans. Ecosystem services necessary to the function of Earth's life-support systems are also necessary for economic production and human welfare (Costanza et al. 2000). There is a consensus among a broad spectrum of scholars that the scope and magnitude of environmental problems threatens the sustainability of Earth's life support systems (Dasgupta et al. 2000). At the Earth Summit in Brazil 1992, there was universal agreement that conservation of biodiversity is a serious global concern. However, there was intense disagreement on how to balance conservation with social, economic, and sustainable-use factors (Szaro 1996). This disagreement is in part due to the principles of sustainable governance (responsibility, scale-matching, precaution, adaptive management, full cost allocation, and participation) (Costanza et al. 2000), which are at odds with the law of the commons, the psychology of large groups that leads to diffusion of responsibility, gross socioeconomic inequities within and among nations, histories of racial discrimination and economic exploitation, the lack of universal democratic government, variation in worldviews of nature, intentional and unintentional obfuscation, a predominance of free-market economics, self-interest, and greed. Davidson (2000) believes the Malthusian-Ehrlich-Meadows-Daly limits to growth paradigm is not useful ecologically or economically and politically hinders conservation. Its use has been similar to "crying wolf" and blaming the poor.

A tapestry paradigm (fig. 8) is a useful alternative to the limits and optimist paradigms. It is clear that (1) humans can destroy the environment, (2) any specific natural resource is finite, and (3) biological and physical systems underlie all economic activity and provide constraints. However, biophysical limits have rarely limited economic growth because ways are found to adapt and continue to expand. Continued economic growth has not caused collapse, but has continued environmental degradation. The limits paradigm focuses on resources, consumption, and human population. Examination of social structures of production and consumption offer greater hope for understanding and slowing environmental destruction. In the tapestry paradigm, economic growth means increased efficiency of material use (less waste and more recycling) and value-added manufacturing (developing systems that, e.g., harvest trees, make lumber and pulp, recycle waste chemicals from the pulp, use sawdust and trim slabs for fuel, produce furniture, and so on). Economic development provides for increased human welfare without increased use of resource or increased production of waste. The difference between growth and development is at the heart of general sustainability (Goodland 1995). Alleviating human misery and poverty is essential to solving global environmental problems. In the United States, there is not as profound a connection between poverty and conservation because social institutions are well developed and the economy is diversified and based more on development than on growth in use of renewable resources (imports substitute for growth and shift the negative effects of growth to other societies). Nevertheless, progress in conservation in the United States still depends on progress in developing a general—environmental, economic, and social—sustainability.

At the heart of ecological productivity is biodiversity. Biodiversity is an inherent property of all ecosystems. Most management issues are concerned with a small proportion of total biodiversity—ensuring adequate levels of ecosystem function is more important than the total number of species. Moreover, species diversity can change in response to both natural processes and human actions. Changes in species diversity usually indicate that either physical or biotic conditions have altered; these alterations may have impacts

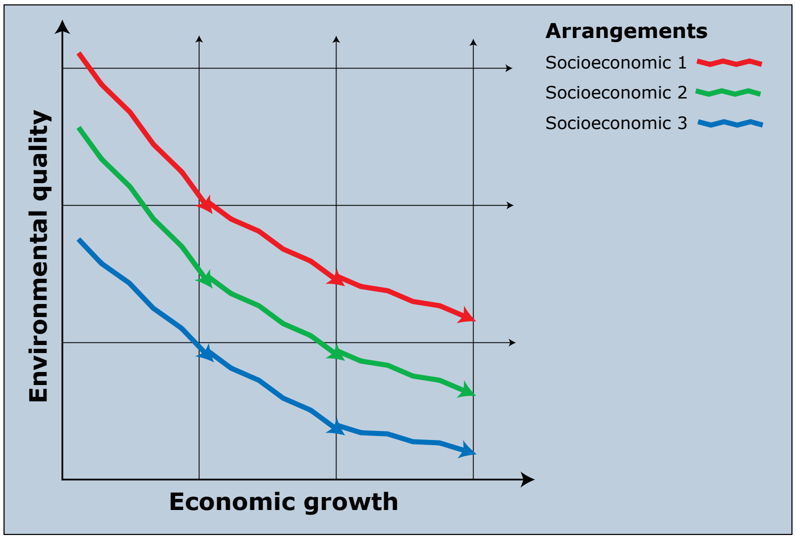

Figure 8—The tapestry paradigm, an alternative to limits to growth: Managing the socioeconomic structure of production can contribute to sustainability through development rather than growth (adapted from Davidson 2000). Under all three socioeconomic arrangements, increased growth leads to decreased environmental quality. However, socioeconomic arrangement 1 provides much higher environmental quality for a given level of growth than arrangements 2 or 3.

on human welfare. Species diversity is influenced by the physical conditions of climate, nutrient availability, physical structure or heterogeneity, and environmental disturbance. Biological interactions include competition, predation, mutualisms, parasitism, and disease. Thus, biodiversity is a complex function of the interaction of physical and biotic factors. This suggests that the severity of impacts of management on species diversity should be evaluated in relation to the background of natural influences on species diversity. Invasion and spread of nonnative species are leading threats to genetic and species diversity in wildlands and also have potential to adversely affect human welfare. Sustainable resource management requires understanding factors that regulate species diversity, specifically those factors that either increase or decrease genetic and species diversity.

> I know no safe depository of the ultimate powers of society but the people themselves and if we think them not enlightened enough to exercise their control with wholesome discretion, the remedy is not to take it from them, but to inform their discretion by education (Thomas Jefferson in a letter to William Charles Jarvis, September 28, 1820, cited in Maser et al. 1998).

Ways of Thinking, Learning, and Knowing

The ways people dwell in the natural world inspire the ways they understand, explain, and look at nature because both sociology and nature influence their conceptions and attitudes toward nature (Rozzi 1999). We have inherited ways of thinking based on millennia of slow growth or no growth (Ehrenfeld 2002) and selective pressures from immediate, highly certain, threats to individual survival (Ornstein and Ehrlich 1989). Kaufmann et al. (1994) summarized the tension from mixing short-term and long-term aspects of human-ecosystem interaction: in the short run are the demands for goods, services, and economic livelihood; in the long run are opportunities for subsequent generations. The resolution must be a shift in focus from sustaining production of goods and services to sustaining ecological, social, and economic systems. But we need to understand how to get people to agree on some common visions.

Social consensus can be thwarted by people's different ways of knowing. One form of knowledge rarely considered has to do with meanings of place; these meanings are exemplified in traditional aboriginal environmental knowledge and management systems (Sherry and Myers 2002). These systems constitute credible worldviews that incorporate an information base, a paradigm, norms and customs, objectives, social sanctions, and extensive teaching. In contrast, our modern state worldview incorporates selective data-based science, value-free problemsolving, professional administration, written laws and regulations, and top-down control. Sherry and Myers (2002) say the state worldview is a predatory model of hunter behavior combined with the tragedy of the commons that results in competition, individuality, property, and control, compared to the Gwitchin model of everything is alive, we are all relatives, use of the environment is a privilege, take only what you need and use what you take, with the individual and collective obligated to act responsibly for the benefit of future generations (see also Ford 2001, Krech 1999, Striplen and DeWeedt 2002, Wright 1992). Ancient conceptualizations defined ecosystems both in terms of discrete geographical boundaries (e.g., a watershed) and abiotic and biotic factors including people (Berkes et al. 1998). For example, Pacific Northwest family groups claimed watersheds as their domains, 15th-century Turks instituted watershed conservation, 15th- and 16th-century Inca developed a regional general sustainability, 17th-century Chinese planted trees for river conservation, and 17th-century Swiss used watersheds in an integrated fashion. Traditional ecological knowledge incorporated concepts of unpredictability, uncontrollability, nonlinear processes, multiple equilibria, and surprises. Traditional knowledge also depicted ecosystems as alive, encompassing people and, in some cases, spirits of animals, other natural objects, and human ancestors. The land was alive and full of life force (Berkes et al. 1998). Of course, peoples in every time and place exhibited intelligence, self-interest, flexibility, and ability to make mistakes (Krech 1999), but rarely as much self-interest, greed, and disdain of equity as the European invaders of the "New World" (Wright 1992).

Culture is the "hidden hand of land use planning" (Geisler and Daneker 2000). Race, class, and gender influence attitudes toward the environment within cultures (Taylor 2002). The cultural landscape defines the physical landscape. Culture is a people's cumulative way of life, material and nonmaterial. Culture comprises morals, art, custom, language, religion, law, property rights, and other group values. It marks the corners and edges of places—which will be sacred and which will be sacrificed. The French preferred long, linear boundaries resembling alleyways, whereas the English preferred polygons. Thomas Jefferson invented the Township-Range-Section grid of modern American land boundaries (Geisler and Daneker 2000). Culture defines the aesthetics and ethics of the lands. For example, in ancient Israel, land holdings were reshuffled every 50th year. Native Americans often had communal ownership. John Locke asserted that land was a gift to all from God but subject to sole ownership if changed or improved, a concept adopted in the United States in disposing of its large, federal landholdings. Deep within American culture exists two contrasting prescriptions for individual happiness and public interest (Geisler and Daneker 2000): (1) private ownership as a practical extension of possessive individualism and (2) public ownership of land and natural resources as a superior, long-term form of stewardship and an ecologically sound land ethic. This dissonance most likely arose from the European experience. In 1600, the population of France and England was hundreds of times greater than the 4 to 7 million Native Americans; Europeans had profoundly altered their landscapes—they had cleared over 205,000 square kilometers of forest for agriculture, and then an additional 65,000 square kilometers in the next century to satisfy demand for charcoal for smelters and naval supplies for ships (Krech 1999).

Individual experience can be as fundamental as culture. Yukio Mishima (2003) declared that the physical experience of nature and matter ("sun and steel") has profound effects on the mind. Knowledge gained from physical experience is diverse: practical action in nature leads to the discovery of knowledge, knowledge acquired by labor becomes second nature, and everyday thinking and action lead to common sense. Informal attempts to resolve conflicts about management of nature in the Pacific Northwest have spawned numerous anecdotes about how field trips provide physical and mental experiences of actual places and organisms that can override position-based thinking based on worldviews. A concept rejected as false based on habitual thought, worldview, or culture can be easily grasped when personally experienced. Perhaps, separation of the physical self from the nature at hand and developing attitudes, opinions, and worldviews by using primarily the mind and mutually reinforcing interpersonal communications helps account for the extreme differences in views about how and what to conserve in nature. The late David Bohm (1994) made a compelling proposal that body, emotion, intellect, and reflexive reactions based on memory together constitute much of our thought. Through repetition, emotional intensity, and defensiveness, reflexive thought becomes hard-wired in our consciousness. Bohm asserted that thought and knowledge are primarily collective phenomena—our belief in our own uniqueness and originality is often an illusion. Thus, he notes that flow of meaning among individuals is more fundamental than any individual's particular thoughts. Cognitive psychologists have long recognized that the mind works like a file cabinet; each significant new experience creates a folder of emotion and reaction; every subsequent similar experience opens that folder and reinforces the behaviors in it. As experience accumulates, it becomes more difficult to add folders (and perspectives) because there will be one with some similarity to the current event. A strong (positive or negative) experience that contradicts the information in the folder is required to create new reactions (ways of thinking). For example, space becomes place through experience, cultural transmission of meanings, and defining events or moments (Beckley 2003). Perhaps this is how the collective field trip is experienced—a positive social event, aimed at reconciliation, in an aesthetic, natural environment, ideally with one or more good interpreters of nature and people's ways of thinking.

Experiences of the few can sway entire cultures when artfully expressed. We spend our lives immersed in stories—those in newspapers, books, television programs, plays, motion pictures, politicians' speeches, ministers' sermons—that entertain, inform, teach, and deeply move us (Simpkinson and Simpkinson 1993). These stories tell us "who we are and how we relate to the world." The stories of the Kalahari Bushmen provide them with potent reminders of the way in which inner and outer, individual and community, and human community and natural world are inextricably linked. Even though it seems that the Western contemporary world finds it difficult to hear the "words of the ancestors," African, Asian, Native American, and Scandinavian myths and fairy tales have provided a treasure trove from which great interpreters—Joseph Campbell, Bruno Bettelheim, Robert Bly, Clarissa Pinkola Estés, Michael Meade—relate to us our basic relationships with each other and the world. Roman Catholic biographies of saints tell stories of exemplary lifestyles in the face of adversity. In the Pacific Northwest, from Cougar, Washington, to La Grande, Oregon, small restaurants and country stores sell books and pamphlets on local history, logging, ranching, settlers, and Native Americans (see e.g., Trosper 1985, 1987, 1992, 1995; Wallace 1997, 1998). These stories instill local pride and belonging and reinforce cultural values through shared experiences. Native Americans sometimes refer to stories as a "map in the head," a metaphor for finding the place that connects chaos and order (Peat 1993).

Peat (1993) believes "science is the creation of stories that interpret the interconnectedness of the universe." Examples range from Charles Darwin to John Muir to Aldo Leopold to Rachel Carson. Despite few having experienced the environments that led Darwin to his theories of evolution, Darwin's metaphors are now established cultural messages. Compelling metaphors can combine

A variety of colors of fallen leaves blanket the forest floor in a riparian area of the North Fork Quinault River, Olympic National Park. Photo by A. Wilson.

with worldviews to provide a perspective of nature that may be either reinforced or found to be unsupportable in the experience of nature. The "tree of life" relates the common biological origins of all species, suggests kinship that requires ethical respect, and promotes the intrinsic value of all life. The "web of life" relates the value of biodiversity for human survival and an environmental ethic that produced ecological economics, utilitarian approaches to conservation, and the concept of interdependence. But more than culture (and mythologies), metaphors, experience, and science shape the four major views of the natural world that Regier (1993) identified: (1) the free-market economist who promotes development, (2) the environmental economist who practices conservation, (3) the naturalist preservationist who values ecosystem health, and (4) the extentionist preservationist who sees all species as equal and who values wilderness.

Subcultural philosophies and individual preferences for particular ways of thinking (cognitive preferences) cause people to self-select occupations and vocations and underlie the conduct of the sciences that inform various worldviews and influence the understanding that results from research. Both within the subculture of scientists and within culture as a whole, individuals exhibit preferences for thinking that readily accept some kinds of information and reject or discount other, often equally valid, kinds of information (Coulson and Strickland 1983, Herrmann 1996, Mintzberg 1975) (sidenote 13). Economists, engineers, and the "rational economic man" will seek, analyze, and apply hard data amenable to linear, reductionistic thinking. A sociologist, nurse, teacher, or musician will accept statements of feeling and qualitative evaluation of ethics and aesthetics more readily than the analytic, linear thinkers. A policeman, minister, and agency line officer will look to tradition, rules, regulations, and laws. Holling et al. (2002a) report that conservationists emphasize ecology and evolution (abstract integrative thinking that produces idealized states of nature) and ignore economics that emphasizes synergy, human ingenuity, enterprise, and flexibility. Economists and developers emphasize free market models (according to a narrow economic dogma emphasizing rational, linear thinking and analysis of a narrow set of variables) and ignore the uncertainties of nature. Sociologists and community activists place faith in community and social organizations (with a thinking that emphasizes care for people and interpersonal relationships) and presume nature presents no limits to the imagination and initiative of local groups. All these views are correct, but they are all partial, too simple, and lack an integrative framework (Holling et al. 2002a).

Sidenote 13—The Myers-Briggs Type Indicator and Herrmann Brain Dominance Assessment have long been used by organizations as a tool to encourage discussion about personality, temperaments, and preferences in the various ways of thinking. Both help to improve understanding of self and others, enhance communication, encourage teaching and learning, and build partnerships. Participants of collaborative management may consider using these helpful tools.

For further reading:

- **Keirsey, D.; Bates, M. 1984.** Please understand me: character and temperament types. Del Mar, CA: Prometheus Nemesis Book Company. 210 p.
- **Herrmann, N. 1996.** The whole brain business book. New York: McGraw-Hill. 334 p.

Or visit the following Web sites:

- www.hbdi.com/
- www.myersbriggs.org/

These contrasting alternative views of nature, like the metaphor of a group of blind men examining an elephant (each limited to a particular anatomical part) would be amusing if not for the consequences to nature, local economies, communities, and the spirit of individuals.

Thus, it should be no surprise that experiential learning becomes essential in tempering worldviews based on thought. And group experiential learning may be the key to finding creative integration of worldviews in formulating pragmatic and potentially successful approaches to conservation (table 8). Political strategies of various groups (1) attempt to change the terms of political discourse, one emphasizing nature as natural resources, another nature as the human environment; (2) constitute tangible forums within civil society to use the communicative power of public opinion—yet some forums will be convened by offroad vehicle activists, others by environmentalists, and yet others by economic-development interests; (3) draw upon government fears of political instability—demonstrations, civil disobedience, and violence are being used routinely by diverse interests; and (4) create paragovernmental activity, such as the Forest Stewardship Council and the timber industry establishing competing sustainable forestry standards and certification, conservation groups and industry both offering school curricula and extension services, and innumerable other approaches (Schlosberg and Dryzek 2002).

Table 8—**Five alternative views of nature**—Balance leads to Malthusian determinism; anarchy leads to a conclusion that spatial heterogeneity is the critical ingredient for persistence in an unstable world.[a]

View	Stability	Processes	Policies	Consequences
Nature flat	▪ None	▪ Stochastic	▪ Random	▪ Trial and error
Nature balanced	▪ Globally stable	▪ Negative feedback	▪ Optimize, return to equilibrium	▪ Pathology of surprise
Nature anarchic	▪ Globally unstable	▪ Positive feedback	▪ Precautionary principle	▪ Status quo
Nature resilient	▪ Multiple stable states	▪ Exogenous input and internal feedback	▪ Maintain variability	▪ Recovery at local scales or adaptation; structural surprises
Nature evolving	▪ Shifting stability landscape	▪ Multiple scales and discontinuous structures	▪ Flexible, actively adaptive, probing	▪ Active learning, new institutions

[a] Resilience leads to an emphasis on keystone species and key functional groups and abiotic and biotic processes; evolution leads to systems approaches. Sustainable relationships between people and nature require ecosystem resilience and a shift from command-and-control to adaptive management.

Source: Hollings et al. 2002a.

Incorporating critical reviews of historical interactions between people and nature at regional scales helps to extend the collective experience. Holling et al. (2002a) recounted four resource management failures: (1) collapse of fisheries in spite of widespread public support and highly developed science; (2) moderate stocking of cattle in semiarid rangelands that increased vulnerability to drought; (3) pest control that led to pest outbreaks becoming chronic; and (4) flood control and irrigation that incurred large economic and ecological costs. They concluded that the observed pattern of failure is one of resources appropriated by powerful minorities capable of influencing public policy to provide perverse subsidies that lead to resource depletion. The fundamental cause of failure is the political inability to deal with the needs and desires of people and with rent seeking by powerful minorities. Contributing causes are the narrowly focused ways that many, including scientists and analysts (especially ecologists, economists, and institutional analysts), perceive and study the natural world and provide unintended opportunities for political manipulation (sidenote 14). The fundamental cause is the "Pathology of Regional Resource and Ecosystem Management," and the contributing cause is the "Trap of the Expert." The former reflects the detachment from nature, place, and communities; the latter, ways of thinking. Holling et al. (2002a) added that obstacles arise from multiple, competing scientific perspectives and disciplinary hubris.

Sidenote 14—"Pathologies of regional resource management"—Northern California provides a rich tapestry of conflicts and pathologies in regional resource management and the emergence of a variety of communal solutions to environmental problems. Judi Barr (1994) tells her personal, tragic story of an activist crippled by a car bomb, but resolute in seeking justice in conflicts over redwoods. David Harris (1996) relates a story of Pacific Lumber Company's hostile takeover and the resultant social and ecological turmoil caused by a shift from stewardship to exploitation. Ted Simon (1994) presents a case history replete with differences in culture, worldviews, politics, cognition, and personality in his story of Richard Wilson's personal evolution from republican-patrician-entrepreneurial rancher to community activist and conservation group leader (and eventually head of the California Department of Forestry) in his fight to save his ranch, Round Valley, and Covelo, California, from inundation as a water reservoir for Los Angeles. Simon brings a perspective eye, a sympathetic ear, and a decentered view to his subjects. His ability to perceive and describe compassionately the diverse characters in conflict in his story arose, perhaps, from his own personal evolution during a 4-year exploration of the length and breadth of the major continents of the world, alone, on a motorcycle (Simon 1981)—a journey during which his very survival necessitated acceptance, understanding, and adaptation to diverse cultures, religions, and individuals.

Three philosophical positions underlie the accumulation of new knowledge known as science (Czech 2001): (1) realism, wherein the goal is to build knowledge of reality by following a clear rationale and subjecting it to critique; (2) idealism, wherein paradigms provide knowledge independent of reality; and (3) empiricism, wherein all knowledge originates in experience. Thus, a holistic philosophy of science requires the use of ontology, epistemology, logic, aesthetics, and morals (Czech 2001). Pure science is the search for knowledge for its own sake. Moral science, however, is accountable to the society that hosts it. The moral philosophy is that science should seek knowledge with a goal of improving the human condition, a consideration often overlooked. Humans, however, have a great appreciation for the aesthetics of other species, and the majority of Americans approve of the Endangered Species Act. Americans value conservation of other species as highly as economic growth or property rights. Thus, public institutions have an obligation to gather knowledge and take action to protect species from endangerment. Knowledge, however, transcends scientific knowledge and includes mathematical proofs, memorized experiences, common sense, intuition, metaphysics, and art as a way of knowing. Camille Paglia (1990), e.g., demonstrates the knowledge in art. Scientists, technologists, and managers do not have a monopoly on knowledge, cognition, or intelligence. Traditional ecological knowledge of indigenes includes a wealth of local observations at the level of populations and species over long periods that produce holistic perceptions of the natural environment and the place of humans in nature (Ford 2001). Conventional science usually is limited to investigations in a small area during a limited time and, thus, is not well suited to recognizing, analyzing, and responding to emergent properties of complex systems. Thus, various sources of knowledge are required before an integrated view of a complex and self-organizing system such as an ecosystem or a society can be gained.

People have preferences in their ways of thinking (fig. 9) that influence the way they perceive the world or any particular problem, information they will assimilate readily, and the processes by which they arrive at decisions (Carey 1997). For example, an engineer (analytical thinker) might prefer a modeling process using a linear programming model, whereas a holistic health care consultant (people-oriented thinker) might prefer a group decision process including the patient. The ways in which worldview and cognition affect how people perceive issues around biodiversity were amply illustrated at the proceedings of the 1982 national symposium on how to implement the diversity provisions of the National Forest Management Act (NFMA) (Cooley and Cooley 1984). The former Chief of the

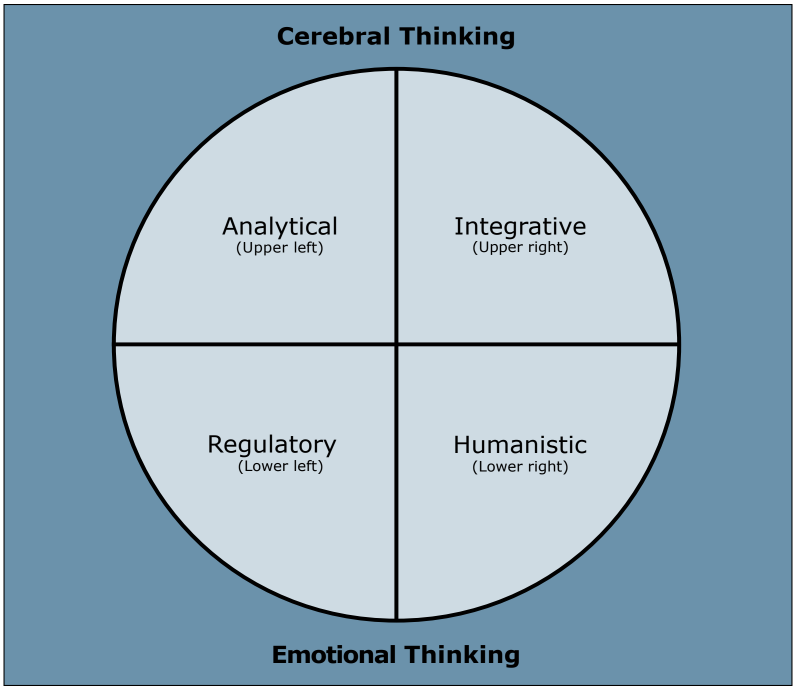

Figure 9—Ways of thinking: each person uses all four ways, but generally emphasizes one or two in decision-making (adapted from Herrmann 1996).

USDA Forest Service, Max Peterson (1984), recalled the diversity provisions of NFMA as arising simply from concerns about loss of flowering dogwoods from roadsides in Arkansas because of conversion of hardwood forest to conifers. This not only illustrates the importance of forest aesthetics to the public, but also the downside of an analytical, linear thinking style that is especially prominent in engineers and traditional economists (Carey 1997). This thinking style can be quite reductionistic. In this case, the major impetus for the NFMA seems to have been forgotten. The Monongahela clearcutting controversy resulted in litigation that halted timber harvesting on national forests, produced draft prescriptive legislation that would direct Forest Service management activities, and led to NFMA as an alternative to the prescriptive legislation. Another high-level career Forest Service employee recalled that NFMA was actually a combination of a House bill requiring diversity of tree species and a Senate bill requiring a diversity of plant and animal communities—protecting biological diversity as a means of ensuring that biological systems can respond to unanticipated changes as an insurance policy (MacCleery 1984a). Orie Loucks, an academician at the conference, traced the concern about diversity to the writings of Aldo Leopold and subsequent research by Simpson (1949), Preston (1948), Loucks (1970, 1984), Whittaker (1972), Terbogh (1974), and Pielou (1975).

An environmentalist recounted the history of diversity requirements in other legislation including the Multiple Use Sustained Yield Act, National Environmental Policy Act, Endangered Species Act, Sikes Act, and Resource Policy Act and in the Council on Environmental Quality 1980 report that warned of imminent large-scale species loss (Kirby 1984). Another academician traced the American history of land use changes wrought by people and the effects on diversity, including the mythology of pristine nature and the extinctions of Pleistocene fauna by people invading North America (Golley 1984). A third academician recounted a detailed historical account of events leading to NFMA citing the litigation Izaak Walton League vs. Butz that led to the Monongahela decision, the subsequent prescriptive legislation drafted by Senator Jennings Randolph of West Virginia, the wrangling in the House to produce a bill without a diversity provision, and, finally, the efforts of Senator Hubert Humphrey of Minnesota (Humphrey Bill, Senate Bill S3091) (Webb 1984). Yet a fourth academician described three origins for the concerns about diversity in NFMA (Cooper 1984): (1) Aldo Leopold's land ethic; (2) ecologists' concerns about the relationships between diversity, especially functional diversity, and system stability; and (3) the concerns of the conservation community for rare and endangered species and community types. He left out the concerns about aesthetics and dogwood and the original impetus, the concern of West Virginia hunters about their favored game animals. A fifth academic ecologist expanded the concept to six aspects (Odum 1984): (1) diversity above and below the species level, genetic diversity, and functional diversity; (2) landscape-level diversity and concerns about monocultures; (3) diversity and stability, resistance, and resilience; (4) invisible diversity below ground; (5) diversity and the life support value of forests; and (6) diversity and urbanization. A Forest Service scientist raised similar concerns (Franklin 1984). Managers at the symposium searched for operational meanings and baselines (MacCleery 1984b; Salwasser et al. 1984a, 1984b). No one examined the social evolution of conservation concepts beyond those of the United States, the various cultural values centered on diversity, or the spiritual values that even ancient cultures found in natural diversity.

Individuals usually emphasize one or two of the four major cognitive preferences; very few people use all four equally. Thus, each person has a degree of self-limited access to information. The combination of cognitive preferences and subculturally (e.g., scientific vs. religious vs. agrarian) defined ways of knowing (fig. 10) leads to massively incomplete understanding of problems and their solutions. Interpersonal and intercultural differences can lead to failures in communication and cooperation, polarization, and litigation. Simon (1994) provides an example (see sidenote 14). Groupthink

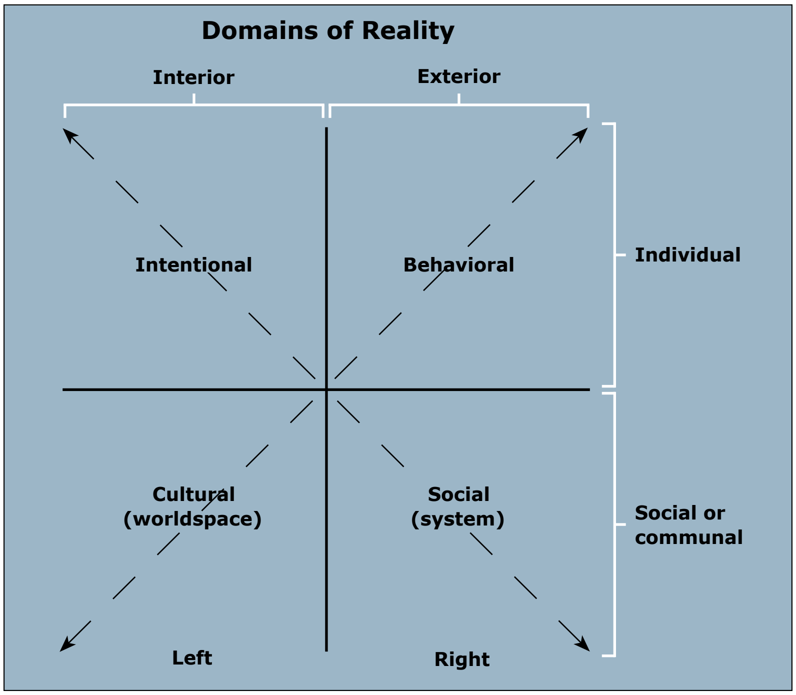

Figure 10—Domains of reality or different ways of knowing about the world: The right half of the quadrants can be seen and described in *It* language. However, the left half cannot be seen and must be described in *I* or *We* language. The left half must also be interpreted in the context of worldspace and intentions (adapted from Wilber 1995).

(Janis 1982) commonly arises in homogeneous groups and appears to have dominated the Forest Service through much of its history (Kennedy 1988). Cooper (1984) accurately prophesized: "Inevitably somebody is going to ask the Forest Service if it has done what the law requires ... So, despite the fact that forest managers do not want more direction, I think they are eventually going to have it."

Despite differing worldviews and different preferences for one or more of the various ways of thinking, a variety of conclusions emerged from the national diversity symposium (Cooley and Cooley 1984) and can be viewed, in my opinion, as currently still applicable (shown below in regular type) or as mistaken in the long run (italics):

- Providing for diversity is essential to maintain flexibility and options for the future.
- Research is needed to provide a stronger conceptual basis and expanded database for conservation.
- Baselines for diversity should be identified at national, regional, and local scales.
- *Diversity indices should be used as analytical tools, not to define diversity* (universally accepted definitions still elude us).
- *Diversity should be treated as an effect of management, not as an objective* (biodiversity is now a major objective).
- Certain guidelines (e.g., managing dead wood components) should be formalized.
- *The existing process adequately considers diversity in multiple-use planning* (plans and regulations are still being challenged and revised in efforts to address biodiversity).
- Information to provide for diversity should be integrated to provide a better database.
- Functional diversity, especially that of faunal communities associated with forest floors and soils, should be given greater attention.

Even so, the view of diversity as a relatively trivial concern about flowering dogwoods prevailed as agency policy as Cooper (1984) prophesized. The people first asked, then sued, and continued to provide stronger and stronger direction to an agency that did not want direction. A recent attempt to formulate a framework for national forest management (USDA Forest Service 2000) identified four key concepts: (1) sustainability as the overall goal in accordance with the Multiple Use Sustained Yield Act; (2) extensive cooperation, and collaboration with public and private entities; (3) integrating science more effectively into the planning process; and (4) eliminating burdensome analytical requirements. This new planning rule affirmed ecological, social, and economic sustainability as the overall goal; maintenance and restoration of ecological sustainability as the first priority; greater public collaboration with expanded management choices, trust building, conflict management, and informed decisionmaking; a commitment to the viability of all species; regional assessments; and monitoring. However, this rule also attempted to codify one conservation philosophy, conservation biology, and has already been rejected. It may well be past the time when centralized rule making for natural resources management is acceptable to the public as a whole. The public has a "pervasive distrust of the agency" and is disillusioned because of the inadequacy and inappropriateness of previous planning and the resultant adversarial atmosphere with its extremist positions (Committee of Scientists 1999).

Critical Theory and Green Political Thought

For the first time, we are faced with the collective responsibility for the consequences of our actions on a *global* scale. In this new millennium, loss of biodiversity has accelerated, global climate change is advancing, and social institutions are not attempting to develop an ecologically sustainable society. The social learning capacity of society must be used if we are to respond globally to ecological degradation. We must develop ecological norms and an ecological ethic that can work within a pluralistic, postmodern world, and we must accommodate a wide range of cultural viewpoints with their conflicting notions of what is profane and sacred, what is truth and heresy, and what it means to be human (Brulle 2002, Dryzek 1997). Is this hope utopian? How can we do this?

Brulle (2002) argues that critical theory can be used to good purpose here. Jürgen Habermas developed a Theory of Communicative Action. In previous historical eras, justification for ethics was based in metaphysics and spiritual belief systems that produced a philosophical definition of the good life. Modern society, however, has produced a pluralism of individual lifestyles and forms of life that collectively maintain a multiplicity of ideas of the good life and a breakdown of classical ethics. In other words, today there is no one uniquely privileged mode of life. Habermas's analysis of language suggests that norms of speech use define rational, universal moral principles, and, thus, might help identify these principles. Furthermore, communication creates and maintains social order;

thus, critical analysis of language can help us move toward a more civil society. Truth, normative adequacy, and sincerity enable communication and tie the individual's personal identity to the interaction. Thus, Habermas linked rationality, law, and constitutional democracy. Brulle (2002) quotes Habermas: "The only regulations and ways of acting that can claim legitimacy are those to which all who are possibly affected could assent as participants in rational discussions."

Legitimate expectations of reciprocal behavior in a modern, pluralistic society now take the form of rational law, and law can no longer be legitimated by metaphysical arguments. Legitimate law emerges only from the discursive opinion and will of equally enfranchised citizens. Citizens must see themselves as authors of the laws to which they are subject, and they must see public decisionmaking as a process of self-determination through open and rational discourse. Thus, even the normative content and structure of a representative democracy arise from the structure of linguistic communication. All citizens have basic individual rights: freedom of speech, equal protection under the law, and freedom of political association. All have basic sociological and ecological rights to the provision of living conditions.

Critical theory is a sociological inquiry that provides critical assessment of existing social institutions compared to standards of rationality; it is a procedure that does not determine what is a moral, ethical, good life or ethical standards for treatment of nature. Critical theory recognizes that there are many different forms of reasoning about the value of nature that inform multiple ethical arguments—there is no one universal argument for preservation of nature that will fit all cultures. For example, critical theory concludes that ecological rights are concerned solely with protecting aspects of nature strictly for human utilitarian purposes, but no more than this. Ecological ethics are a concern about what is a good life and outside critical theory. Democratic decisionmaking considers treatment of nature as a significant ethical concern because it is clear humanity and nature are interdependent and that the dependence of nature on our actions is evident. Ecology can provide information on impacts on the natural environment but holds no special competence in providing moral or aesthetic reasoning. There are limits to the use of science and biology in regard to human ethics. Furthermore, *without* fixed natural categories, fixed boundaries between nature and culture, fixed human nature, and fixed overall direction in the life process, it is impossible to make nature into a source of ethical and political prescriptions (but see Wilber 1995 below).

Big leaf maple. Photo by T. Wilson.

Critics say critical theory cannot adequately integrate concern for nonhuman nature because it only considers development of norms between humans. Robyn Eckersley provided a persuasive critique (Brulle 2002). Critical theory has benefits for human affairs—public participation enhances deliberations about preserving nature and community decisions should be democratic. But there are limits to its use—critical theory does not restructure ground rules of decision-making to provide any explicit recognition of nonhuman interests, it fails to justify preservation of species without utilitarian value, and its aesthetic values are selective and anthropocentric. Eckersley suggests that critical theory needs to develop a concept of nature as an end in itself, an expanded ethic that includes nonhuman needs, a science-informed moral line of argument, a recognition of the autopoietic intrinsic value theory that all organisms have self-directedness, and a principle for inscribing ecocentric norms into procedures of discourse as a matter of morality and justice (e.g., the precautionary principle).

Brulle (2002) rebuts the criticisms. All our knowledge of nature is socially constructed, and there is no authentic human representative of nature to speak for those nonhuman species. Seeing nature as a self-maintaining system is based on an application of systems ecology to construct a philosophy of nature that Brulle feels was robustly critiqued by evolutionary ecologists in the 1980s and 1990s (but see Gunderson and Holling 2002, Wilber 1995). Systems theory claims nature evolves through generation, diffusion, and selective retention of random mutations in a process of continual adaptation. Critics of systems ecology say nature is a chaotic system not self-regulating and thus one cannot use science to tell what a natural community or ecosystem is, never mind define what the essence of nature really is. Brulle (2002) states that the autopoietics of nature and the endowment of agency to nature is not a universal and objective idea grounded in ecologic science, rather it is a social construction of nature that suits a particular political aim; therefore, preserving nature means preserving a particular construct of what nature is supposed to be. Systems theorists (e.g., Wilber and Holling), however, have gone far beyond the arguments that Brulle rebuts to consider the physical Earth, nature, economic systems, and societies as parts of larger wholes. Indeed, Brulle states the artificial dichotomy between humans and nonhuman nature is scientifically and historically inaccurate. He says: "Healing the rift between human beings and the natural world … is not a matter of joining what was once put asunder, but of getting the relations between human beings right first" (Brulle 2002). Thus, there is no necessary conflict between ecocentric norms and critical theory. However, Wilber (1995) insists on an even broader, decentered view—that of the holarchy (see below).

The Role of Place in Conservation

A sense of place plays a fundamental role in the ways people conceptualize, practice, and disagree over conservation. Strong and direct connections exist between self-identity, place, and how individuals perceive and value the environment (Beckley 2003, Cheng et al. 2003, Mitchell et al. 1993). Places are the fundamental means by which we make sense of the world and through which we act. Social group identity and place are tied together and influence the group strategic behavior in natural resources politics. Thus, choice of geographic scale of place is a strategic key element of natural resources decisionmaking because conservation politics is as much a contest over place meanings as a competition among interest groups over scarce resources (Cheng et al. 2003), at least between local interest groups. Places invoke rich and powerful emotions and sentiments that influence how people perceive, experience, and value the environment; the feelings evoked are stored as "felts" and become integral parts of thought. Place-based stories recall and reinforce such felts and thoughts. The strong emotions and thoughts associated with places require even more attention on the part of professional managers than conflicts associated with competition for use of scarce resources; the interactions with the public quickly move into psychological and social contracting (Rousseau 1989), as opposed to legal contracts associated with competitive bidding for timber sales. Violation of a social contract is much more serious than cancellation of a business contract, and violation of psychological contracts can do irreparable harm to relationships (Levinson et al. 1962). Because places are not merely physical backdrops of human activity, but rather help people find order and meaning in the world, community-based collaborative partnerships are especially important in encouraging people of diverse backgrounds and opposing perspectives to work together to find common ground and common vision. Thus, a politics of place emphasizes place-based collaboration and problemsolving, whereas a politics of interest emphasizes legislative/agency/command-and-control planning influenced by powerful coalitions. Cheng et al. (2003) offer these propositions:

- People's perceptions and evaluations of the environment are expressions of place-based identity and deeply personal connections with history and meaning.
- People perceive and evaluate the environment as different places rather than an assemblage of individual biophysical attributes.
- Social groups that seemingly emerge around using, protecting, or altering the physical attributes of a location may be engaging in more fundamental processes of assigning significant social and cultural meanings to that place.
- People's evaluations of, and responses to, conservation proposals are influenced by their identification with social groups organized around particular meanings of the places involved.
- Groups intentionally manipulate the meanings of places, hoping to influence the outcome of conservation controversies.
- The geographic scale of a place can change people's perceived group identification and, therefore, influence the outcomes of a natural resource controversy.

Attachment to place is based on the specific attributes of that place (e.g., community attachment, recreation-site attachment). Attachment influences public land management, regional economic development, and wilderness preservation (Beckley 2003). Rural residents' attachments to their communities include attachments to the geological, biophysical, and landscape attributes of their regional ecosystem. Attachments of visitors to rural areas include sociological (rural residents, cottage owners, recreationists) as well as the biophysical characteristics of the place. Thus, the human values in attachment to place have tremendous consequences for policy issues in that people make "irrational" decisions to stay in regions with failing economies (Simon 1994 provides a vivid example; see sidenote 14). Whereas some people are attracted to and attached in a positive sense to a community or landscape, others are stuck in place—attached in a negative sense, because they lack the social network, specialized ecological knowledge, or marketable labor skill to survive anywhere else. Attachments to place are complicated; top-down centralized decisionmaking is extremely problematic because it is direction from those who are unfamiliar and empirically uninformed, making application of generalized principles to the specific place—a recipe for unmitigated disaster (Beckley 2003). The sustainability of a community or place has much more to do with people's attachment to it than with standardized indicators of social sustainability.

Communities and Conservation

Community attachment implies an attachment to a defined geographic space, but there are also communities of interest (Beckley 2003). Communities of interest are bound by shared values or interests rather than shared space. Sociocultural attachments are interactions of length of residence (fig. 11), position in social structure, and stage in human life cycle. Attachments are stronger to more democratic and tranquil places than to repressive places with social strife; but beyond security concerns, attachment is a very complex phenomenon.

Human migrations are adding to the complexity of conservation policy (McCool and Kruger 2003). Rural areas in many parts of the Western United States had dramatic population growth in the late 20th century, fueled by environmental amenities, deteriorating urban conditions, and back-to-the-land movements. This growth stressed the capacity of rural communities. Amenity migrants often developed stronger attachments to place than long-time rural residents (McCool and Martin 1994). But at the same time, USDA Forest Service District Rangers and other agency high officials spent less time in rural communities and were relocated during downsizing and consolidations into larger communities distant from

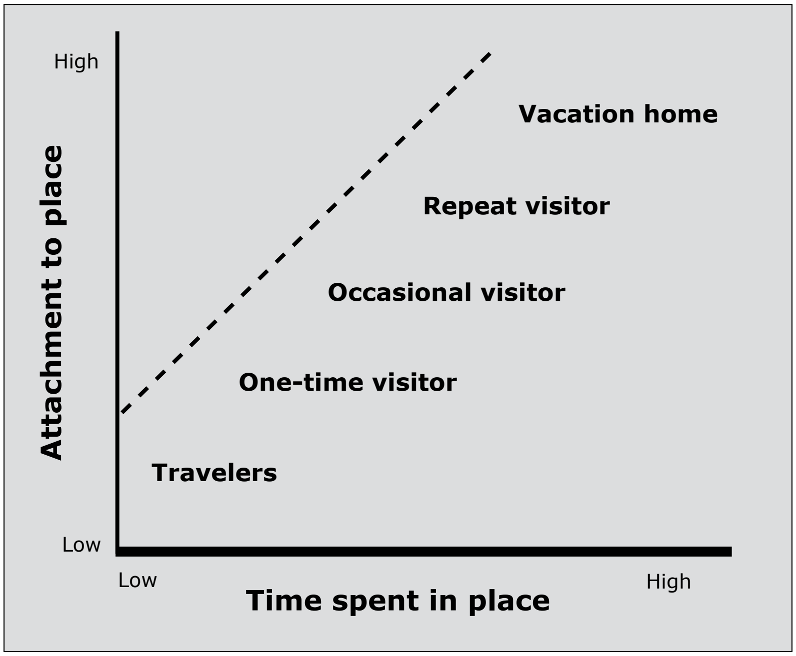

Figure 11—Time spent in place by different types of users (X-axis) may influence attachment to that place (Y-axis). Hypotheses about the time-attachment relationships made are (1) degree of attachment can be quantitatively measured; (2) degree of attachment varies with sociocultural factors, ecological factors, landforms, and cover types; (3) attachment changes with positive and negative changes in ecological and sociological factors; (4) degree and nature of attachment varies with size of unit of analysis; (5) attachment is a function of the length of time; (6) attachment is a function of cultural background; (7) attachment is a function of breadth and depth of knowledge; (8) attachment is a function of the nature of knowledge; and (9) degree of attachment reflects positive affective attachments (magnets) versus neutral or negative contexts (anchors) (adapted from Beckley 2003).

the forest (McCool and Kruger 2003). This restructuring seems to have reversed the processes of broadening discourses and changing mindsets of agency officials in response to increased public contact required by the National Environmental Policy Act (Carey 1997) and led to increased contact and conversations with agency peers and neighbors and community members not necessarily involved in conservation issues and matters of place. Migration raises other important considerations (McCool and Kruger 2003). For example, amenities are increasing in importance in rural areas and public lands offer environmental amenities. In addition, underrepresented, yet growing numbers of minority groups may have different wants and needs than earlier participants in conservation conflicts.

Communities are especially important in conservation because they are at the front line of stewardship and sustainability and represent collections of interests and concerns that are demanding more meaningful roles in conservation planning (Kruger 2003). Public acceptance is essential to every conservation decision made by a public agency (Shindler et al. 2002). The reasons social acceptance is important include (1) conservation decisions are rarely about applying objective science to a specific event; (2) citizens have a right of consultation about the conservation of public resources; (3) absence of public understanding and support makes it difficult to implement any decision in a democracy, especially when the public is pluralistic and highly differentiated (sidenote 15); and (4) social acceptance provides opportunities for discussion and change. Local communities of place and attached communities of interest are where the "rubber meets the road." Achieving social consensus requires public places to discuss and learn, opportunities for citizen participation, and trust building. Forums are needed for working through shared community values about fairness. Citizens do not trust conservation agencies—they doubt their sincerity and credibility, and they deeply distrust experts and institutions. To rebuild trust, citizen-organization interactions must be based on inclusiveness, sincere leadership, innovation and flexibility, early commitment and continuity of commitment, sound organizational and planning skills, and efforts that result in action (Shindler et al. 2002). A key is genuine dialogue. Interviews with people in Arkansas, California, Oregon, Colorado, Missouri, Montana, New Mexico, South Dakota, Tennessee, and Wyoming, despite generally cordial relationships between the USDA Forest Service and local communities, stressed the need for agency-community relationship building, funding and legal authority for relationship building, training in relationship building for Forest Service employees, and cultivation of intra- and interagency working

Sidenote 15—Shindler et al. (2002) asserted that (1) most people believe sustainable ecosystems are desirable; (2) many believe it is possible to supply forest products and maintain the integrity of the forest; (3) people expect managers to produce multiple benefits; (4) people know what they want (clean air and water, affordable wood products, decent jobs, recreation, scenic vistas), but managers frame choices poorly; and (5) people support a balanced, ecologically responsible approach to forest management.

relationships (Frentz et al. 2000). Collectively, these studies suggest an urgent need for the application of organization development theory and practice to conservation collaborative management, including sensitivity training, appreciative inquiry, conflict management, facilitating group dynamics, and a whole host of other well-developed methods for effecting change, bringing about transformation, and extracting creativity from conflict (French et al. 1994).

Social and Personal Evolution

Developing a common vision means moving away from polarized, position-based thinking, adversarial and litigious processes, and win-lose or compromise solutions that leave major dissatisfactions unresolved. "What we need is a collective dream large enough to encompass and transcend all our small individual dreams in a way that gives them meaning and unity" (Maser 1994). Collaborative management requires an informed and supportive public. It requires institutions that value justice, equity, decentralized collaborative decisionmaking, and pragmatic problem solving (Wondolleck and Yaffee 2000). It requires scientists who are willing to engage humbly in collaborative learning and facilitate collaborative management

A mouse-eye view of the canopy in an old-growth forest on the Olympic Peninsula. Photo by T. Wilson.

by providing relevant theoretical, empirical, and pragmatic science. Collaborative management requires the purpose of consensus; willingness to reveal, listen, and understand; and stamina to do arduous work. Both knowledge and emotion are shared through communication (tone of voice, body language, and attitude). Every person has the right to simplicity and clarity in communication and an obligation to communicate simply and clearly (Maser et al. 1998). Yet, the ability to communicate simply and clearly is not always easy, and it requires hard work. Social sustainability—the civil society—requires individuals to undergo personal growth through a shift in consciousness from self-centeredness to other-centeredness (Maser et al. 1998) (sidenote 16), or as Wilber (1995) shows, decenteredness (see sidenote 14). Care and respect for each other is essential—"be gentle with one another, be gentle with nature, be humble" (Maser 1994). Collaborative management requires individuals to develop and actualize both their autonomy and their communality. In other words, individualism is good, bring it to the table, but set aside ego and strive for the common good. An aspect of communality important in collaborative management is a sense of community—a group of people with shared interests living under and exerting some influence over the same government in a particular locality and having a common attachment to that physical place and its social environment. A true community involves a sense of place, a history, and trust (Maser et al. 1998) (sidenote 17): "For one's community to be sustainable and our democracy to be lasting, we must individually and freely be willing to recognize and abide by the common good in our decisionmaking." However, there are communities of place and communities of interest that can be in competition. For example, the goals of the water-needy communities of interest in southern California conflicted greatly with the river-based communities of place in northern California. This is particularly true of federal lands where national, regional, and local interests abound. Both communities must be participants in the collaborative management process. An overarching framework is needed for progress in reconciling diverse views, values, and interests.

Sidenote 16—Maser et al. (1998) listed Erik Erikson's eight stages of human development:

- Trust vs. mistrust
- Autonomy vs. shame and doubt
- Initiative vs. guilt
- Industry vs. inferiority
- Identity vs. identity confusion
- Intimacy vs. isolation
- Generativity vs. stagnation
- Integrity vs. despair

Sidenote 17—Maser et al. (1998) said a resident community serves five purposes: (1) social participation that produces self worth, safety, and shared values; (2) mutual aid in time of individual and family need; (3) economic production, distribution, and consumption that provides jobs and commodities; (4) socialization, or educating people about cultural values and norms; (5) social control, the means for maintaining cultural values and norms. Resident communities can be damaged by vested local-internal interests and by outside interests (overharvesting by outsiders, corporate clearcutting, and temporary government employees).

Frameworks—In a systems, holarchic view, there are three great realms of evolution: matter, life, and mind (Wilber 1995). Most of us are familiar with Darwinian evolution. Systems thinkers recognize evolution as the increasing differentiation, integration, structural organization, and complexity that offsets the Second Law of Thermodynamics, in other words, the forces that promote order versus those that lead to disorder. Theorists call this evolution the self-organizing system. To be part of a larger whole means that the whole supplies glue that holds the system together, glue not found in the isolated parts alone. Most of us are less familiar with the concepts of evolution of self and society. But many examples abound. For instance, in social systems, men seem to emphasize rights and justice in moral development as this social glue; women feel rights and justice must be supplemented with care and responsibility. It is easier to grasp social evolution than it is personal evolution within the greater social evolution. The following discussion recapitulates Ken Wilber's (1995) systems view of evolution as it applies to matter, life, *and the mind*. He describes the processes of evolution of self, society, and culture.

Wilber (1995) distinguishes between two types of hierarchies that occur within human systems. Domination hierarchies are repressive and pathological; actualization hierarchies are integrative and maximize system (cultural, societal, and personal) potential. The cure for a pathological hierarchy (e.g., a machine bureaucracy) is an actualization hierarchy (e.g., intentional collaborative management), not heterarchy (multiple use with uses in different places) that is just heaps of uses, not wholes of integrated uses. In a heterarchy each element contributes equally, but separately to the health of the whole within each level of the hierarchy. Heterarchies have differentiation (different uses) without integration. Holarchies, on the other hand, have differentiation with integration that brings a common and deeper purpose. Actualization involves a ranking, or subjective valuation, of increasing holistic capacity. Ranking is disturbing to believers in extreme equality and autonomy—they consider value ranking equivalent to oppression. Finding value in the world, however, is inherent in the human situation; qualitative distinctions are built into human orientation. Indeed, to deny value is in itself a value; denying ranking is in itself a ranking. Thus, contexts and frameworks produce values and meanings and may produce the sense that some actions, lifestyles, and ways of feeling are higher than others more readily available to us. *This provides us with informed choice*. Affirming life and freedom by repudiation of qualitative distinctions may be motivated by the strongest of moral ideas (freedom, altruism, universalism), but in reality is deep incoherence, self-illusion, concealing from oneself the sources of one's own judgments.

In understanding systems, it is useful to remember that matter, life, and mind are all part of the same holarchy of integrated whole/parts (*holons*). Holons display fundamental capacities in constant tension that create a novel holon with emergent properties—a wider, deeper whole. In other words, each holon, e.g., a person, seeks to preserve his or her autonomy and rights (agency), counterbalancing autonomy with search for communion (participation, joining, and bonding). These are the Taoist principles of yin (communion) and yang (agency), rights vs. responsibilities, individuality vs. membership, personhood vs. community that are set against self-dissolution vs. self-transcendence. Dominance by any one of the tendencies is pathological. But it is key to recognize that each emergent holon transcends but nevertheless includes its predecessor; nothing is lost while much may be gained: *development is envelopment, not succession*. In nature, e.g., invasion of an abandoned agricultural field may set up a succession of biotic communities, one replacing another in a more or less predictable series. But development of a new Douglas-fir forest following catastrophic destruction of an old forest, with its attendant biological legacies, sets in process a series of stages of forest development (envelopment), each stage encompassing the preceding stage, increasing differentiation and integration. Each developmental level produces greater depth (number of levels) but has less span (number of *new* components in the new level) and is not necessarily correlated with size (spatial extent). The variety of shrews in the forest floor is far less than the variety of insects they consume or the variety of organisms and detritus the insects consume. However, destroy any holon and all the holons above it are destroyed, but none of the holons below it. Destroy a biotic community (shrews) and that particular ecosystem is gone; but the insects and their food (lower level ecological systems) remain. Destroy all humans and the biosphere still exists but the economies and societies disappear. Destroy the biosphere and humans disappear. Thus, holons with less depth (fewer levels) are more fundamental, but less significant. Holons coevolve. The holon of the individual is inseparable from the social holon, defined by its own particular form and pattern. Evolution of holons has directionality: increasing differentiation, variety, complexity, and organization. All autonomy is relative, but relative autonomy increases with evolution. In systems language, attractors in basins of attraction pull the system to a future endpoint (the omega point). In the terminology of Holling et al. (2002b), basins of attraction determine alternate stable states of ecosystems. It should be clear that systems theory easily envelops and integrates the polarized views and false dichotomies of earlier theories of organization and succession of biotic communities.

Many of our conservation issues are due to fractured worldviews; we lack a common vision. We need a vision that encompasses and transcends our individual visions. A beginning lies in a holistic view of a three-level world. Level 1 consists of physical and physiochemical systems in the realm of matter; it forms the broad base of a pyramid. Level 2 holds the organizational levels of biological systems in the realm of life. Any level 2 holon embraces *its entire* level 1 world. Level 3 holds the organizational levels of sociocultural systems in the realm of society. The pyramid is narrower at the top (relative abundance decreases). Each holon within the pyramid depends on a whole series of intricate relational exchanges with the social environments of the same level of structural organization. The greater the depth of a holon, the more precarious its existence—fewer of them can be produced and maintained relative to the number of predecessors.

In the evolution of the mind, the human brain emerges from the genetic, metabolic, and neural biosphere. Paul MacLean (1985) described the brain as composed of three physical parts: a reptilian brain (the brain stem that provides autonomic and instinctive behavior), a paleomammalian brain (the limbic system that controls visceral and emotional reactions), and neomammalian brain (the neocortex that supports language and logic and the self-reflexive mind). In the emergent, nonphysical realm of the mind, size (spatial extent) gives way to *intention*. The social environments of the human are family, village, town, city, and state. There is no compelling biological reason (reproduction of bodies) for organization at the village level and above, but these higher organizations provide the symbols and tools necessary for reproduction of culture through symbolic communication. Thus, with evolution, kinship gave way to cultureship as the brain remained unchanged for 50,000 years and cultural development proceeded from the mind.

Of course, with greater structural complexity, more things can go horribly wrong. Atoms do not get cancer, but animal tissues do. Evolution producing greater transcendence and greater differentiation can go too far and fail to adequately integrate the emergent differences into a coherent whole. Some theorists postulate that most of humankind's problems came with the invention of farming. People began to alter the biosphere for their own gratification, created a written language that ensconced power in dogmatic text, and produced agricultural surpluses that led to economic control, slavery, and the subjugation of women. These theorists idealize the hunter-gatherer society; but that society was rarely egalitarian and often warlike. Wilber (1995) labels this kind of thinking as the "way-back machine looking for the Garden of Eden"—a thought process highly related to managing for the range in natural variation from some preagricultural period and mimicking stochastic disturbance processes. The problem was not the development of agriculture but the lack of integration and the development of dominator hierarchies in the evolution of agrarian societies.

Coincident with the external process of social evolution is the interiority of the evolution of the mind—from irritability to sensation, perception, impulse, image, symbol, and concept. The *within* of things relates to consciousness, cognition, perception, and spontaneity. Karl Popper refers to the "making and matching" of new epistemological domains. Jürgen Habermas, in his studies of communication and the evolution of society, developed a Theory of Communicative Action with epochs of human evolution based on worldviews: archaic, magic, mythic, and mental (Brulle 2002). Thus, shared values constitute the exterior culture and worldview constitutes the interior of the social system. A shared cultural worldspace must be interpreted: What does it mean versus what does it do? Wilber (1995) gives the example of a Hopi rain dance as expressing a sacred connection with nature and a request (meaning) and producing social solidarity and cohesion (function). Meanings provide understanding; functions provide explanations.

Subtle reductionism reveals four dimensions of interpretation (see fig. 10)—intentional, behavioral, cultural, and social developments—not the single dimension of materialistic and mechanistic function of gross reductionists. The interior is dialogical, dialectical, and empathetic with major issues related to meaning, interpretation, and sincerity (truthfulness). The external deals with propositional and empirical validity criteria that determine truth (Wilber 1995). Thus, thoughts have meanings to individuals that are sustained by a network of exterior norms and linguistic structures existing in a shared culture. In other words, a shared worldspace is necessary for communication of meaning among individuals. This raises the question of cultural fit of individual meanings and values with the culture that helps produce them. Background and culture allow individuals to form meaning, and relational exchange allows communication between people. Thus in the lower left quadrant (cultural worldspace), validity criteria are truth, truthfulness, and mutual understanding; in the lower right quadrant (social system), the criteria for validity relate to functional fit—what does it do? All this exists within a holarchy of value, beauty, meaning, motivation, understanding, intention, and consciousness. Using reductionism to suborn the interior (lower left) to the exterior (lower right) fragments worldviews and reduces individuals to role and function. However, the four quadrants can be usefully collapsed into three: the right two composing Karl Popper's objective world of *It*, the upper left, the subjective world of *I*, and the lower left, the cultural world of *We*.

Jürgen Habermas then postulates the three validity claims of truth (*It*, objects), truthfulness-sincerity (*I*, subjects), and rightness-justice (*We*, intersubjectivity). Plato similarly identified true (objective, propositional truth), beautiful (the individual aesthetic), and good (cultural appropriateness and justice). Kant's critiques are pure reason (*It*), personal aesthetic judgment (*I*), and practical reason (*We*). And, finally, the three jewels of Buddha: Dharma (*It*), Buddha (*I*), and Sangha (*We*). The key here, in terms of conservation, is that *we cannot escape these three worlds*—the objective (*It*), the subjective (*I*), and the social (*We*)—and their different claims to truth—propositional truth, normative rightness, and subjective truthfulness. Each can be exposed to evidence and checked for actual validity in collaborative learning environments. These are the three fundamental functions of language—Intentionality (*It*), Truth (*I*), and Rightness (*We*). Each can be exposed to evidence and checked for actual validity in collaborative learning environments. These functions form the basis for active, intentional management (AIM) and the use of intentionality in evaluating conservation plans (Carey et al. 1999c). Wilber (1995) concluded that before we can attempt an ecological healing, we must reach an individual understanding and mutual agreement on the best way to collectively proceed.

Human nature—Evolution of the three-part brain allowed the evolution of symbols and concepts in the mind and the evolution of the family group and tribe. Reconciling the differentiation of social labor (e.g., hunting) and nurturance of young produced the "familization" of the male, the single enduring task of all subsequent civilization. Although, Gilmore (1990) suggests that familization is but one part of a much more complex social phenomenon. Nevertheless, early female horticulturalists produced 80 percent of the food and shared considerable public power with men. With development of the plow and an agrarian society, males produced the bulk of the food and dominated the public sphere; even reigning deities switched from a Great Mother to a Great Father focus. Thus, sex-based differentiation resulted in dissociation that produced an extreme sexual polarization. It would be some time before a new integration of men and women could be conceived in an utterly new worldspace. Michel Foucault observed that people, when discontent with the present, seek some cheap archaism—an imagined form of past happiness (e.g., the early-agrarian

Colorful birds, such as this male rufous hummingbird, spark interest in wildlife and help connect people to nature. Photo by A. Wilson.

Eden preceding the European settlement of North America)—devoid of dangers and inequalities (Wilber 1995).

In the battle of worldviews, each stage of development transcends and includes, negates, and preserves its predecessors. So the major structures of all the worldviews—magic, animism, mythology, rationality, vision-logic—may exist together, or in part in various degrees of integration, in any one individual, any group, or even side by side, unintegrated, in society. The first major development with familization of men and conventional kinship relationships was a magical-animistic culture within which people used preoperational thinking that works with images, symbols, and concepts, but not complex values and formal operational thinking. Thinking emphasized representations of sensory objects in the external world, close to the body. Morally, people exhibited physical pragmatism and a naïve instrumental hedonism. Norms were expressed in terms of good vs. bad, right vs. wrong and interpreted as punishment, reward, and exchange of favor. This culture is described as magical because there was little differentiation between the mind and body, and mental images and symbols could be confused with physical events; mental intentions were believed to be capable of altering the physical world. This culture was animistic because physical objects were considered to be alive and to possess intentions of their own. Collective identity was with a common ancestor and personal identity was with a particular tribe (Wilber 1995).

The next development was the mythological culture—societies organized through a state that required a more abstract identity and an expansion of the world of gods. Mythology was enveloped in turn by the mythic-rational culture, which incorporated the purposive rationality of scientific and technical knowledge, the formal rationality of mathematics, and the interpersonal-practical rationality of morality and communication. The rationality added was formal operational cognition—thinking about thinking, reflecting on one's own thought processes, transcending them, and taking a perspective different from one's own, entertaining hypothetical possibilities, being highly introspective, and justifying thoughts and actions by reviewing reasons and evidence for one's beliefs.

Empires produced modern states that formally recognized each other, the separation of church and state, the emergence of a global market economy, and the rise of rational culture. Egoic-rational thinking began more than 2,000 years ago, but reached fruition in 16th-century Europe. Socrates said know thyself, look within; Cicero echoed "Cognosce te ipsum," and later philosophers asked what is there to know and how can I know it? Religions did likewise—Jesus said the kingdom of heaven is within, and Buddha said penetrate yourself. These were radically new thoughts and marked a conceptual change from individuals as the roles they play in society to individuals as free subjects. Socially this was translated into (a) free and equal subjects under the law, (b) morally free subjects, and (c) politically free subjects (callouts 2, 3).

New integration brought women to the fore as public and historical agents. This integration, of course, allows both liberal and radical feminism as well as women's special rootedness in the biosphere:

> … A million years of rich tradition of the wise woman who feels the currents of embodiment in nature and communion and celebrates it with healing rituals and knowing ways of connecting wisdom that does not worship merely the agentic sun and its glaring brightness but finds in the depths and organic dark the ways of being linked in relationship, that puts care above power and nurturance above self-righteousness, that reweaves the fragments with concern, and midwifes communion and the unsung connections that sustain us each and all. And finds, above all, that being self is always being a self-in-relationship (Wilber 1995).

It bears repeating, that each development envelops and maintains preceding developments; the use of animism, magic, and mythology as "as ifs," not literally, can be transcendental—the real function of mythology. In other words, a properly interpreted myth can help us get in touch with our roots and our foundations, including the archaeological layers that lead to our present awareness. We can gain new perspectives from the interpreted mythologies of ethnic groups other than our own, be they African, European, Asian, or Native American. They can become empowering, enriching, and energizing because they touch archetypal structures while simultaneously robbing them of their worldview. For example, The Men's Movement, led by Robert Bly, played out myths in an "as if" fashion, transcending them with rationality. Camille Paglia (1990), in her groundbreaking monograph, traces the evolution of the female persona in art over the ages and women's historical and new public agency. Finally, Paul Ray (1996) documents the contemporary leadership of women in the emerging, integrative, transformational subculture that holds community and sustainability as primary values. Genuine spirituality is the primary measure of depth in worldviews. The depth of reason is the capacity for universal pluralism, insistence on universal tolerance, grasp of global-planetary perspectivism, insistence on universal benevolence and compassion—a genuine spirituality.

The majority in rational societies tend to settle in mythic-rational (including religious-rational and dogmatic-rational) worldviews, using the power of rationality to prop up a particular divisive, imperialistic mythology and an aggressively fundamental program of systematic intolerance. Thus originates much of the contemporary public discourse in the United States. A modern solution to these deharmonizing discourses is the democratic state with its all-important separation of church and state that removes the worldviews of the would-be pathological dominator holons from the organizing regime of society that is defined by a rational tolerance of *everything but intolerance*. This robs the mythic holons of their power to govern exclusively and to push their mythic-imperialistic expansionism via military means—but it does not always prevent them from agitating to tilt the state toward their own fundamentalist values as has happened so successfully in recent years. Where myths govern, military expansion is the rule (Wilber 1995).

The rationality of a universal, noncoercive outlook produces a vision-logic, a system of seeking truth, the relations of idea within idea and truth within truth, all seen in the integral whole. Vision-logic can hold contradictions in the mind; unify opposites; and weave together what otherwise appears to be incompatible notions, negated in their partiality but preserved in their positive contributions. This is *Reason*, and it is the stuff of collaborative learning and collaborative management. The worldspace of vision-logic is existential. Vision-logic has integrative power, which requires an a-perspectival mind (open to all truths) vs. a rational-perspectival mind; in other words, no single perspective is privileged. Vision-logic produced the international labor movement—the only global social movement in history. The strength of that movement was its commitment; the weakness was its lack of spirituality. The green culture (see also Ray 1996) similarly is potentially powerful but makes a similar mistake of reductionism. Its two central notions are (1) the sphere of the mind is part of the biosphere and (2) the web-of-life systems theory; they are, Wilber says, in the first, wrong, and the second, subtly reductionistic. A more integrative approach is needed; Wilber calls it Planetary Transformation. Gunderson and Holling (2002) offer the Panarchy theory. Global transformation is necessary to protect the global commons, regulate the worldwide financial system, and maintain a modicum of international peace and security.

(continued on page 94)

Reason is the stuff of collaborative learning and collaborative management.

Callout 2—*The Declaration of Independence*

IN CONGRESS. July 4. 1776.

The unanimous Declaration [illegible] States of America.

In CONGRESS, July 4, 1776
The unanimous Declaration of the thirteen united States of America,

When in the Course of human events, it becomes necessary for one people to dissolve the political bands which have connected them with another, and to assume among the powers of the earth, the separate and equal station to which the Laws of Nature and of Nature's God entitle them, a decent respect to the opinions of mankind requires that they should declare the causes which impel them to the separation.

We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness. —That to secure these rights, Governments are instituted among Men, deriving their just powers from the consent of the governed, —That whenever any Form of Government becomes destructive of these ends, it is the Right of the People to alter or to abolish it, and to institute new Government, laying its foundation on such principles and organizing its powers in such form, as to them shall seem most likely to effect their Safety and Happiness. Prudence, indeed, will dictate that Governments long established should not be changed for light and transient causes; and accordingly all experience hath shewn, that mankind are more disposed to suffer, while evils are sufferable, than to right themselves by abolishing the forms to which they are accustomed. But when a long train of abuses and usurpations, pursuing invariably the same Object evinces a design to reduce them under absolute Despotism, it is their right, it is their duty, to throw off such Government, and to provide new Guards for their future security. —Such has been the patient sufferance of these Colonies; and such is now the necessity which constrains them to alter their former Systems of Government. The history of the present King of Great Britain [George III] is a history of repeated injuries and usurpations, all having in direct object the establishment of an absolute Tyranny over these States. To prove this, let Facts be submitted to a candid world.

He has refused his Assent to Laws, the most wholesome and necessary for the public good.

He has forbidden his Governors to pass Laws of immediate and pressing importance, unless suspended in their operation till his Assent should be obtained; and when so suspended, he has utterly neglected to attend to them.

He has refused to pass other Laws for the accommodation of large districts of people, unless those people would relinquish the right of Representation in the Legislature, a right inestimable to them and formidable to tyrants only.

He has called together legislative bodies at places unusual, uncomfortable, and distant from the depository of their public Records, for the sole purpose of fatiguing them into compliance with his measures.

He has dissolved Representative Houses repeatedly, for opposing with manly firmness his invasions on the rights of the people.

He has refused for a long time, after such dissolutions, to cause others to be elected; whereby the Legislative powers, incapable of Annihilation, have returned to the People at large for their exercise; the State remaining in the mean time exposed to all the dangers of invasion from without, and convulsions within.

He has endeavoured to prevent the population of these States; for that purpose obstructing the Laws for Naturalization of Foreigners; refusing to pass others to encourage their migrations hither, and raising the conditions of new Appropriations of Lands.

He has obstructed the Administration of Justice, by refusing his Assent to Laws for establishing Judiciary powers.

He has made Judges dependent on his Will alone, for the tenure of their offices, and the amount and payment of their salaries.

He has erected a multitude of New Offices, and sent hither swarms of Officers to harass our people, and eat out their substance.

He has kept among us, in times of peace, Standing Armies without the consent of our legislatures.

He has affected to render the Military independent of and superior to the Civil power.

He has combined with others to subject us to a jurisdiction foreign to our constitution and unacknowledged by our laws; giving his Assent to their Acts of pretended Legislation:

For Quartering large bodies of armed troops among us:

For protecting them, by a mock Trial, from punishment for any Murders which they should commit on the Inhabitants of these States:

For cutting off our Trade with all parts of the world:

For imposing Taxes on us without our Consent:

For depriving us, in many cases, of the benefits of Trial by Jury:

For transporting us beyond Seas to be tried for pretended offences:

For abolishing the free System of English Laws in a neighbouring Province, establishing therein an Arbitrary government, and enlarging its Boundaries so as to render it at once an example and fit instrument for introducing the same absolute rule into these Colonies:

For taking away our Charters, abolishing our most valuable Laws, and altering fundamentally the Forms of our Governments:

For suspending our own Legislatures, and declaring themselves invested with power to legislate for us in all cases whatsoever.

He has abdicated Government here, by declaring us out of his Protection and waging War against us.

He has plundered our seas, ravaged our Coasts, burnt our towns, and destroyed the lives of our people.

He is at this time transporting large Armies of foreign Mercenaries to compleat the works of death, desolation and tyranny, already begun with circumstances of Cruelty and perfidy scarcely paralleled in the most barbarous ages, and totally unworthy the Head of a civilized nation.

He has constrained our fellow Citizens taken Captive on the high Seas to bear Arms against their Country, to become the executioners of their friends and Brethren, or to fall themselves by their Hands.

He has excited domestic insurrections amongst us, and has endeavoured to bring on the inhabitants of our frontiers, the merciless Indian Savages, whose known rule of warfare, is an undistinguished destruction of all ages, sexes and conditions.

In every stage of these Oppressions We have Petitioned for Redress in the most humble terms: Our repeated Petitions have been answered only by repeated injury. A Prince whose character is thus marked by every act which may define a Tyrant, is unfit to be the ruler of a free people.

Nor have We been wanting in attentions to our British brethren. We have warned them from time to time of attempts by their legislature to extend an unwarrantable jurisdiction over us. We have reminded them of the circumstances of our emigration and settlement here. We have appealed to their native justice and magnanimity, and we have conjured them by the ties of our common kindred to disavow these usurpations, which, would inevitably interrupt our connections and correspondence. They too have been deaf to the voice of justice and of consanguinity. We must, therefore, acquiesce in the necessity, which denounces our Separation, and hold them, as we hold the rest of mankind, Enemies in War, in Peace Friends.

We, therefore, the Representatives of the united States of America, in General Congress, Assembled, appealing to the Supreme Judge of the world for the rectitude of our intentions, do, in the Name, and by the Authority of the good People of these Colonies, solemnly publish and declare, That these United Colonies are, and of Right ought to be Free and Independent States; that they are Absolved from all Allegiance to the British Crown, and that all political connection between them and the State of Great Britain, is and ought to be totally dissolved; and that as Free and Independent States, they have full Power to levy War, conclude Peace, contract Alliances, establish Commerce, and to do all other Acts and Things which Independent States may of right do. And for the support of this Declaration, with a firm reliance on the protection of divine Providence, we mutually pledge to each other our Lives, our Fortunes and our sacred Honor.

Callout 3—*The Bill of Rights*

Congress of the United States
begun and held at the City of New-York, on Wednesday the fourth of March, one thousand seven hundred and eighty nine.

THE Conventions of a number of the States, having at the time of their adopting the Constitution, expressed a desire, in order to prevent misconstruction or abuse of its powers, that further declaratory and restrictive clauses should be added: And as extending the ground of public confidence in the Government, will best ensure the beneficent ends of its institution.

RESOLVED by the Senate and House of Representatives of the United States of America, in Congress assembled, two thirds of both Houses concurring, that the following Articles be proposed to the Legislatures of the several States, as amendments to the Constitution of the United States, all, or any of which Articles, when ratified by three fourths of the said Legislatures, to be valid to all intents and purposes, as part of the said Constitution; viz.

ARTICLES in addition to, and Amendment of the Constitution of the United States of America, proposed by Congress, and ratified by the Legislatures of the several States, pursuant to the fifth Article of the original Constitution.

Article I—After the first enumeration required by the first article of the Constitution, there shall be one representative for every thirty thousand, until the number shall amount to one hundred, after which the proportion shall be so regulated by Congress, that there shall be not less than one hundred representatives, nor less than one representative for every forty thousand persons, until the number of representatives shall amount to two hundred; after which the proportion shall be so regulated by Congress, that there shall be not less than two hundred representatives, nor more than one representative for every fifty thousand persons.

Article II—No law varying the compensation for the services of the Senators and Representatives, shall take effect, until an election of Representatives shall have intervened.

Article III—Congress shall make no law respecting an establishment of religion, or prohibiting the free exercise thereof; or abridging the freedom of speech, or of the press; or the right of the people peaceably to assemble, and to petition the Government for a redress of grievances.

Article IV—A well regulated Militia, being necessary to the security of a free State, the right of the people to keep and bear Arms, shall not be infringed.

Article V—No Soldier shall, in time of peace be quartered in any house, without the consent of the Owner, nor in time of war, but in a manner to be prescribed by law.

Article VI—The right of the people to be secure in their persons, houses, papers, and effects, against unreasonable searches and seizures, shall not be violated, and no Warrants shall issue, but upon probable cause, supported by Oath or affirmation, and particularly describing the place to be searched, and the persons or things to be seized.

Article VII—No person shall be held to answer for a capital, or otherwise infamous crime, unless on a presentment or indictment of a Grand Jury, except in cases arising in the land or naval forces, or in the Militia, when in actual service in time of War or public danger; nor shall any person be subject for the same offence to be twice put in jeopardy of life or limb; nor shall be compelled in any criminal case to be a witness against himself, nor be deprived of life, liberty, or property, without due process of law; nor shall private property be taken for public use, without just compensation.

Article VIII—In all criminal prosecutions, the accused shall enjoy the right to a speedy and public trial, by an impartial jury of the State and district wherein the crime shall have been committed, which district shall have been previously ascertained by law, and to be informed of the nature and cause of the accusation; to be confronted with the witnesses against him; to have compulsory process for obtaining witnesses in his favor, and to have the Assistance of Counsel for his defence.

Article IX—In Suits at common law, where the value in controversy shall exceed twenty dollars, the right of trial by jury shall be preserved, and no fact tried by a jury, shall be otherwise re-examined in any Court of the United States, than according to the rules of the common law.

Article X—Excessive bail shall not be required, nor excessive fines imposed, nor cruel and unusual punishments inflicted.

Article XI—The enumeration in the Constitution, of certain rights, shall not be construed to deny or disparage others retained by the people.

Article XII—The powers not delegated to the United States by the Constitution, nor prohibited by it to the States, are reserved to the States respectively, or to the people.

Sidenote 18—Moral Development (Wilber 1995):

- **Preconventional**—egocentric, geocentric, biocentric, narcissistic, body bound
- **Conventional**—sociocentric, ethnocentric, culture-bound
- **Postconventional**—worldcentric, universal pluralism, asks "Who am I?" for the first time, reflexive and introspective, hypothetico-deductive, relies on evidence to settle issues

(continued from page 89)

Individual development—Jean Piaget reviewed the development of the individual mind and its parallels to the development of social systems. These parallels by age class include 0 to 2—sensorimotor (archaic, archaic-magic); 2 to 7—preoperational (egocentrism, perspectivism, realism, and reciprocity); 7 to 11—concrete operational thinking; and age 11+—formal operational thinking.

The first imaginary images appear to the mind at 7 months. A child regards his or her own point of view as absolute and then discovers the possibilities of other points of view. Reality is that which is common to all points of view taken together. At 18 months, a child learns to differentiate his or her own feelings from the feelings of others. At 3 years, a child becomes a coherent and stable self, able to use language. Symbols are used, the first being the word "No!" Concepts are grasped, but magic still dominates the 2 to 4-year-olds. Even at 4 to 7 years, children retain some belief that an individual can magically alter an object, but they recognize that their thoughts do not control the world. Thus, "magic," says Wilber (1995), "is transferred to Daddy, God, or some volcano spirit." Rituals and prayers are added to move from magic to magic-mythic.

Carl Jung believed that all the forms and motifs of the world's great mythologies are collectively inherited in the individual psyche of each of us—and Freud and Piaget agreed. Thus mythic membership produces an intensively cohesive social order. In the concrete operational stage, the child begins to enter the world of other minds and can take the role of others, but still is egocentric, sociocentric, and anthropocentric—centered on a role identity in a society of other roles. But the child can grasp the nature of a holon of whole/parts, value hierarchies, and continua of preferences vs. the either-or. With formal operational thinking comes the transformation from role identity to ego identity, from sociocentric to worldcentric—the capacity to distance oneself from egocentric and ethnocentric embeddedness and consider what would be fair to all people, not merely one's own. Freedom from embeddedness in bodily impulses and assigned social roles produces the fully separated, individuated sense of self. Mythic membership gives way. A new world of feelings, dreams, passions, and idealism can develop. This is the first truly ecological mode of awareness—the child can grasp mutual interrelationships, take different perspectives, and coordinate systems. Formal operational thinking allows the child to understand justice, mercy, compassion, reciprocity, equality, conscience, rights, and responsibilities (sidenote 18). Emergence of rationality, however, can produce a massive loss of cultural meaning and social integration and the need for new integration at the global level.

Reason has its own inherent problems and limitations, but Wilber says that is no cause to "board the Regress Express and set the Way Back Machine to medieval or horticultural or foraging" or pre-European settlement conditions. Rather, transpersonal development is called for—increasing interiorization and decreasing narcissism. One is no longer merely buffeted by immediate fluctuations in the environment and relative autonomy—the capacity to stay inwardly focused—increases individuation. This produces internalized action or the capacity to internally plan an action and anticipate its course rather than being merely an automaton. This vision-logic is the stage beyond formal operational thinking; it is dialectical, integrative, creative, synthetic, and integral a-perspectival. Formal operational thinking is simple problem solving; vision-logic produces creative scientists and thinkers. Ecology and relational awareness emerges with formal operational thinking but comes to fruition with vision-logic. Vision-logic integrates the well-differentiated matter, body, and mind. Vision-logic sounds good, but it is not the omega point of personal evolution; it has its downside, primarily dread, the existential malaise. The cure for this angst is transcendence. The transpersonal domain starts with reason, with truth established by evidence (results of experimental methods), and produces claims of higher awareness that embraces love, identity, reality, self, and truth (Wilber 1995).

The transpersonal domain starts with reason, with truth established by evidence, and produces claims of higher awareness that embraces love, identity, reality, self, and truth.

Wilber (1995) says the single greatest task facing modernity and postmodernity is integrating the person, culture, and nature—integrating the interior subjective worlds of *I* and *We* with the exterior objective *Ego* (as worldcentric stance of universal pluralism, altruism, benevolence, and freedom) and the *Eco* (the biosphere). The whole point of rationality and its capacity for multiple perspectives is to put oneself in the shoes of others and find a mutual enrichment and appreciation of difference, a celebration of diversity. Another urgent task of postmodernity (the here and now) is the development and establishment of genuine environmental values—a moral and ethical stance toward nonhuman holons. One of the most obvious difficulties is the biocentrism of the eco-camp with all life forces having equal value and equal worth. Wilber (1995) offers a holarchic alternative:

- All things and events are perfect manifestations of spirit, thus all holons have equal and ultimate value or equal ground-value.
- All holons are whole/parts, and thus have whole-value and intrinsic value (value in and of itself). There are levels of significance,

too—the greater the depth of holons, the more significant for the Kosmos; all have rights to exist, otherwise the whole dissolves.

- As parts, all holons have instrumental values (extrinsic value); the more "partness-value" (the greater the whole of which the holon is part), the more fundamental for the Kosmos.

In other words, it is much better to kill a carrot than a cow even though they are both perfect manifestations of the spirit with equal ground-value, but the cow has more depth (and consciousness).

Agencies, Organizations, and Society

It seems inescapable that public conservation agencies must evolve, develop, and become more democratic, informative, and facilitative to be of use in the 21st century (Danter et al. 2000). Impediments to organization change are various and formidable, internal and external (Bull 1994, French et al. 1994). Most conservation agencies are top-down, command-and-control, hierarchical bureaucracies with centralized techno-structures derived from the early industrial age and excessively inflexible. They are kept that way by internal power structures and external controls of laws, regulations, codified processes, and litigation and lobbying. Internal transformation is challenging enough—to change the policies and culture of a government agency is a complex endeavor. The former Lands Commissioner for the State of Washington offers the following advice (Belcher 2001): Be sure you want the job. Much of this book has been about the need for transformation and transcendence. Transformation does not occur without significant effort and without outside intervention. If we, as a society are to progress toward more effective, more democratic, more collaborative, more local forms of conservation, all the stakeholders—agencies, private and nonprofit organizations, and individuals—must undergo positive, purposeful change.

What is our purpose? What are we about? There seems to be an emerging consensus for conservation; common themes are arising across the globe. For most of us, attachment to family, community, and place helps define us. We wish to form a civil society that strives for attainment of human happiness and achievement of human potential, provides for social justice and equity for the present and future generations, and preserves the capacity of the all-important *land* that is our home, sustenance, and future opportunity.

We cannot leave it to others to preserve our land, our communities, or our sense of well-being. We must do it ourselves, from the bottom up. Our society suffers from the yoke of the top-down. We must "think globally and act locally."

Those who are attached to place emotionally, culturally, economically, and spiritually, must be the ones to discover the path to harmony in the shared ownership of the land. We must learn together and jointly make decisions about how to conserve the land and nature.

Science, Scientists, and Society

In the postmodern world, science and scientists have come under increasing criticism because of their ways of thinking and of participating in the greater society. Maser (1994) listed five roadblocks to legitimate scientific acquisition of new knowledge: lure of grants

Regine Carey leans against a giant yellow cedar. Photo by A. Carey.

(and legislatively appropriated research funds) aimed at predetermined results; attachment to a single hypothesis; scientific methodology that can only reject or fail to reject hypotheses (no formal mechanism for proof); science used to safeguard established dogma; science in denial of human participation in nature. It is obvious that the processes of distributing funds for conservation science (from legislatures through funding agencies and organizations) are driven by a combination of external forces of present and emerging crises and public demand and the political philosophies, prevailing science dogma, and environmental philosophies of those involved in the distribution processes. Funding for conservation science does not necessarily follow any rational, critical examination of gaps in knowledge, and this should be made clear to users of science. Other ways in which scientists and other people involved in conservation think and behave also may squelch development of consensus (Maser et al. 1998):

- Scientists without a spiritual foundation, in a sea of arrogance and increasing intellectual isolation.
- Continuing narrow specialization that produces fragmented worldviews.
- People pointing outside of themselves to the causes of environmental problems.
- Asking science to answer questions about social ideas.
- Ostracizing those with the courage to question the acceptance of normal scientific inquiry.

The scientific community acknowledges many of these, and other, concerns; e.g., focus on contemporary research erases historical contributions of science and leads to science recycling (Graham and Dayton 2002). Still, successful collaborative management requires a base of science information (Wondolleck and Yaffee 2000). Collaborative management must deal with complexity, uncertainty, and change; it must integrate across space and time. Collaborative management must build understanding among stakeholders, coordinate across boundaries, make effective decisions, and develop the capacity to deal with future challenges. It cannot do any of these without good science and technical support. People making decisions about conservation often need quantitative, or at least qualitative, estimates of ecological values. Placing values on the environment depends on the skill and is influenced by the culture of the researcher (Pizzolotto 1994). Value concepts can be influenced by both scientific and social factors, which may be in conflict. Criteria such as naturalness and rarity are almost never referenced to an objective zero value. In most cases, evaluation is done by criteria that distinguish between natural (undisturbed) and highly degraded conditions. Natural is relative (everything is natural) and the idea that man takes part in this naturalness seems largely accepted, especially in Europe with a long history of a natural-cultural mosaic (see fig. 2c).

Social Sciences

Christensen and Donoghue (2001) suggested a research framework for conservation in the Pacific Northwest that recognized that (1) social values are unknown for rural people, communities, and development; (2) traditional concepts of rurality do not reflect today's rural places and people; (3) collaborative management—collaborative stewardship for ecosystem management—is largely undeveloped; and (4) socioeconomic change in rural communities is poorly understood. They quote Gifford Pinchot, the founder of the U.S. Forest Service: "It is the duty of the Forest Service to see to it that … every … resource of the forest is used for the benefit of the people … in the neighborhood … ."

Research on social aspects of conservation has been growing and gaining focus as communities demand more active, meaningful roles in conservation planning (Kruger 2003). Studies of community-forest relations now use a variety of approaches—conventional objective methods, collaborative inquiry, and rapid rural appraisals by using open-ended surveys and focus groups. All the methods are subject to criticism, but what is most lacking is clear definition of purpose—for whose interest, to what end (Sturtevant 2003)? Dialogue, active listening, and triangulation using different sources of data and methods allow analyses that can contradict, complement, and confirm existing knowledge of the community; what is more difficult to address is that some communities lack even the social and human capital to participate; inequality, disaffection, and quiescence may impede participation (see also Carr and Halvorsen 2001) (sidenote 19). Citizen juries offer unique and novel opportunities to engage the public in conservation values (Ward 1999). A small, but socially representative group is provided with time and information to conduct a democratic deliberation about what it is worth to pursue conservation when there is no market value to establish prices. These participants (or their employers) can be financially compensated for the large investment of time required. Some advantages relative to other methods of inquiry are that the participants can

Sidenote 19—Common beliefs that underlie feelings about public forest management activities in Michigan with relative importance to influencing management indicated by percent value (adjusted r^2) (Carr and Halvorsen 2001):

Community/forest linkages:

- Forests are as much a part of a community as streets and buildings: 8 percent
- Forest lands are a community to which humans belong: 6 percent

Forests as ecological systems:

- Forests should be managed like an agricultural crop: 26 percent
- Managing forests for any purpose upsets nature's balance: 25 percent
- Forests are such complex ecosystems they cannot be managed at all: 18 percent

Making management decisions:

- Citizens working together can make the best decisions about how to manage public forests: 9 percent
- How forests are managed is the responsibility of the professional forester: 6 percent

Values that should be protected:

- Forests should be managed to protect their ecological value: 21 percent
- Forests should be managed to protect their recreation value: 17 percent
- Forests should be managed to protect their economic value: 17 percent
- Forests should be managed to protect their spiritual value: 15 percent
- Forests should be managed to protect their commodity value: 13 percent

engage in collaborative learning and become well informed; the deliberative process can become more democratic and legitimate; social dimensions are more likely to be captured; and distributional issues are likely to be addressed more directly. Potential problems include poor representativeness, bandwaggoning, stentorian opinion leadership, tight definition of the agenda by sponsors, providing partial or selected information, and juror preconceptions.

Studies of populations restructuring following immigration and the implications for conservation, economics, and the cultural dimensions of social life are emerging (Nelson 2002, Overdevest 2000). Participatory action research includes a variety of methods but emphasizes education and developing of consciousness in communities through the Aristotelian principle that individual fulfillment can be achieved through participation in improving the quality of life by working with others for the common good (Kruger and Sturtevant 2003). This democratic participation allows people to discuss, formulate, and decide public issues that are important to them and that directly affect their lives. In this research, managers, scientists, and planners take on new roles as facilitators and teachers, guiding public deliberation *from below*. Participatory action research accommodates the present paradigm shift away from the public land management leviathan born of centralization, specialization, rationalism, depersonalization, and industrialism.

Conservation research seems to lack (1) participant-observer anthropological methods, (2) intervention methods in which scientists embed themselves in social processes, and (3) values elicitation based on specific communities and specific places. However, such research is emerging. Presented here is a summary of an anthropological investigation, followed by some intervention methods, and finally, some ideas about values elicitation.

Terre Satterfield (2002) provided a fascinating analysis of identity, knowledge, and emotion in the conflict between loggers and environmentalists over old-growth forests in Oregon. She reported that few environmental controversies have been more dramatic than that contest of political, economic, and scientific forces. Congressman DeFazio of Oregon described it as a "religious war." In the contests of culture and power, culture consists of shared webs of meaning, moral outlooks, and worldviews internalized in the behavior of the members of each culture versus the overarching, multiorigined, and multifaceted cultural resource that individuals draw upon while manipulating it to fit their own ends. Both loggers and environmentalists talk about the joy of being close to nature, about forest science, about being victims of greater economic and political forces, about the implications of the past for the future landscape, and about being emotional activists. In shaping its vision of a new and better world, each group manipulates its references to reflect features of the overall social system perceived to be dominant (a process known as fugitive political conduct of subordinate groups). This is a creative means by which people reconfigure cultural systems. Oppositional dialogues are basic to identify cultural conflicts. Activists concerned with altering the status quo state their grievances and their imagined new and better worlds. They make repeated public statements about who they are and how different they are from their opponents. And they mobilize by staking out identity centered on territory and by invocations to common cause. Satterfield concluded that all battles about the physical environment are battles about place and the ties between place and identity. Both environmentalists and loggers make up communities attached to places, even though mobility and mass communication mean very few communities are integrated, geographically bounded wholes. Rather communities are made up of people in separate places (environmentalists in cities, loggers in rural settings) effectively becoming a single community through the continuous circulation of people, money, goods, and information.

The social identities of loggers and environmentalists were well established. Loggers were natural-resource workers, informed by applied science based on common sense empiricism, and reflecting the conservation ethic of the first Chief of the U.S. Forest Service, Gifford Pinchot (forests are fertile, renewable crops are in need of protection). The central concern of the loggers was the long-term sustainability of communities based on family-wage employment, a spirited logging ethos, and the forests. Environmentalists saw themselves as an ecological resistance movement deeply concerned with spirituality, aesthetics, and biocomplexity, willing to commit their minds and bodies to protecting old growth, and reflecting the land ethic of John Muir and Aldo Leopold. The two groups did not conform to traditional sociopolitical divisions based on class, gender, or political party. Both groups were sensitive to the privilege granted scientific explanations in policy formulations. But neither trusted science; both used it selectively to bolster their arguments.

Loggers were attracted to science that makes common sense (sidenote 20) and knowledge gained through practice. Given the collapse of modern science and its contention that forestry should be a rationalized agricultural process, loggers were left to develop their own identity-based critique of expert knowledge, especially when expert opinion violated common sense. Environmentalists preferred science that acknowledged the mystery and sanctity of the

Sidenote 20—Albert Einstein once said, “Common sense is both the refinement of everyday thinking and the collection of prejudices acquired by the age of eighteen” (Satterfield 2002).

natural world. Environmentalists were especially ambivalent about science because of their uncertainty about exactly where to place an eco-centered self in the field of authoritative knowledge. Satterfield states that an abstract, deeply ambivalent, and anti-applied image of science is entirely consistent with a belief in the need for humans to maintain a humble, unintrusive stance toward nature. Thus, both groups sought to rewrite the criteria for valid knowledge.

Satterfield goes on to recount the history of the exploitation of natural resources in the Pacific Northwest and feelings of betrayal both groups experienced at the hands of federal managers, stating, "The destruction of communities and the depletion of resources have distinguished the political economy of Washington, Oregon, and northern California." In describing the contrast of the environmentalist nostalgia and glorification of past epochs with the loggers' idea of rural living embedded in an ecologically benign lifestyle (with a historical claim to place), Satterfield asks "Under what temporal, social, and even spiritual arrangement do claims of place attachment become legitimate?" Satterfield's anthropological participant-observer research provides considerable understanding to policymakers and stakeholders in conservation debates. Her book certainly provides a basis for mutual understanding and a resource for achieving some common vision. She concludes that the conflict will not be solved, and improved logging practices will not be created if the more imaginative and experientially wise activists on both sides are silenced. In determining values of stakeholders, moral concerns, situational uniqueness, and context specificity of imaginings makes elicitation of values by discussions and surveys problematic. There are two key considerations: (1) Language, power, and creative thought are not captured by value-elicitation processes dominated by economic approaches such as cost:benefit analyses that assume the majority of the public endorses rational, economic expression of the market values of nature and that monetary expressions of value reflect that which is held dear, worthy of protection, and ethically or socially esteemed. Economic approaches privilege some actors and marginalize others. (2) Stakeholder values are not neat and discrete, but contextual. These conclusions lead one to conclude that data collection and analysis by centralized staffs for use by line officers in decisionmaking are likely to be poorly informative; direct participation by stakeholders in deliberations about specific policies and practices in specific contexts and places are more likely to capture the desires of the stakeholders.

Place is a powerful social influence on conservation politics, and place-based inquiry brings to the fore the diverse ways in which values and meanings are articulated and negotiated, but which are typically excluded in conservation decisionmaking (Cheng et al. 2003).

Forest ecology—Perry (1998) identified the major scientific challenges for conservation as understanding (1) the relationship between managed forest structure and ecological function at the stand scale; (2) spatial patterning of stand-level structures that meet biodiversity goals for a given bioregion; and (3) temporal dynamics of stand and landscape structures resulting from natural disturbance, anthropogenic disturbance, and their interactions. He reviewed the major strategies of ecosystem management and their failings and concluded that (1) reserves cannot be large enough to preserve regional biodiversity; we also need managed forest to function to conserve biodiversity; (2) it is a false belief that logging of any kind fits within the range of natural variation; the question is, how far can management depart from natural disturbances before compromising system integrity?; (3) complexity and stability are linked but poorly understood; we need a better understanding of structure, process, and function at local and landscape scales. Conservation research has been focusing on fragments of narrow problems, never mind the major problems facing humanity (sidenote 21). A narrow disjunct focus reflecting disciplinary myopia is not serving us well (Ehrenfeld 2002, Stevens and Montgomery 2002).

Sidenote 21—The world's most important problems, according to Ehrenfeld (2002):
- Materialism
- Deterioration of communities
- Anomie
- Commercialization of formally communal functions (health, charity, communication)
- The growth imperative
- Exploitation of the Third World
- Disintegration of agriculture
- Ignorance of the ecology of diseases, especially epidemic disease
- Loss of important skills and knowledge
- Devastating decline in the moral and cultural-intellectual education of children
- Impoverishment and devaluation of language
- A turn from environmental and human realities to electronic substitutes

A narrow disjunct focus reflecting disciplinary myopia is not serving us well.

Collaborative management—Improved problem solving and leadership are needed to address conservation problems. Interdisciplinary problem solving incorporating problem definition in human-social terms, mapping the social (sidenote 22) and decision processes, analyzing basic beliefs, and clarifying one's own worldview are necessary (Clark 2001) (sidenote 23). But, take these truths to be self-evident (Wondolleck and Yaffee 2000): (1) agencies tend to be biased and ineffective, (2) traditional decisionmaking has been biased and ineffective, and (3) people are frustrated by the adversarial decisionmaking process. Even with massive investments of time, money, and interdisciplinary science, conservation decisionmaking by federal agencies in the Pacific Northwest produced ongoing controversy (Associated Press 2003, Barnard 2003, Dodge 2002, Dombeck and Thomas 2003, McCool and Kruger 2003, Milstein 2002). Conservation scientists (Anderson et al. 1999) have recommended left-brain approaches (a priori agreement on analyses, rules, structure, and order) that are more likely to be perceived as the power politics of science rather than attempts at consensus building. In

Sidenote 22—The social process includes (Clark 2001):
Participants:
- Who is participating?
- Who is demanding to participate?
- Who else should be participating?

Perspectives:
- Demands—What do the stakeholders want?
- Expectations—What are the stakeholder assumptions about the future?
- Identifications—On whose behalf are decisions being made and what are their perspectives?

Situations:
- In what situations do stakeholders interact?
- Where should they interact?

Base values:
- What are the assets and resources of the stakeholders?

Strategies:
- Which ones are being used or are available for use?

Outcomes:
- What are they?
- Who is benefiting?
- Who is being deprived?
- What should the distribution of values be?

actuality, these recommendations are a response to perceived bad faith on the part of some participants in collaborative data analysis. Collaborative learning requires open communication, diverse participation, unrestrained thinking, constructive conflict, democratic structure, multiple sources of knowledge, extended engagement, and facilitation (Schusler et al. 2003). The questions of who is at the table, who they represent, why ethical behavior is presumed, and what happens if consensus cannot be reached need to be emphasized (Overdevest 2000). Setting ground rules for process, interactions, behaviors, facilitation, attendance, and many other issues is essential. But true collaboration is needed.

Collaboration is the pooling of resources by two or more stakeholders to solve problems (Wondolleck and Yaffee 2000) (sidenote 24). But the key to conservation is to have all stakeholders fully represented in the collaboration and to proceed on the local level. Success in collaboration is defined in the perceptions of the participants, although objective and standardized measures of progress are desirable (Rolle 2002) (sidenote 25). As collaborative management matures, increasing emphasis should be put on continuous process improvement and the application of the principles of total quality management and adaptive management. Similarly, considerable experience has been gained with self-directed work teams in industry that can be applied to collaborative management groups (Harper and Harper 1993, Katzenbach and Smith 1993). These sophisticated approaches are becoming increasingly feasible as various stakeholders are becoming more sophisticated and often represented by well-trained and highly educated professionals employed or volunteering in nongovernmental organizations. As the complexity of conservation problems increases, so does the need for collaborative management, and the need for adequate funding of collaborative management. Conservation decisions have profound, sometimes irreversible effects, on local communities (McCool and Kruger 2003). Investment in collaborative learning and collaborative management is becoming increasingly common in the public, nonprofit, and industrial sectors. There seems to be no viable alternative; top-down, command-and-control approaches are inflexible and ineffective (Wondolleck and Yaffee 2000).

Collaborative management has a long history in the Pacific Northwest—over 230 successful public-private cooperatives have been established (Wondolleck and Yaffee 2000). The fifth national park to be designated was Mount Rainier National Park in 1899; its designation, unlike previous parks, arose from a people's campaign, well organized, sustained, and based in large part on a "love of landscape" and Mount Rainier, "the mountain that was god," as a symbol of place (Catton 1996). Collaborative management evolved in response to problems caused by agency policy and land management, business practices, and impasses in conservation owing to conflicts that persist through administrative, legislative, and judicial processes. The consequences of the current dysfunctional modes of decisionmaking have been public alienation and pervasive mistrust. Six of ten Americans feel powerless and disenchanted; less than half express confidence in U.S. institutions. The roots of collaborative management are in the neighborhood and community and are not purely interest driven and are always, to some degree, place driven. A famous Pacific Northwest collaborative management group, the Quincy Library Group, has a strong sense of place; a local focus; shared problems, fears, and sense of crisis; shared goals and interests; a common vision statement; and compatible interests. Another famous Pacific Northwest group, the Applegate Partnership, has a similar character. An emerging overarching conservation objective, for which there seems to be an evolving consensus, is sustainability. Conservation collaborative management recognizes the need to integrate different geographic and temporal scales and the need to deal with complexity, uncertainty, and change. Collaborative management not only acknowledges, but also makes sense of the three principal human communities (place, identity, and interest) and decentralizes decisionmaking, producing a civic environmentalism.

The benefits of collaborative management include effective decisionmaking; improved understanding among agencies, organizations, and the public; cross-boundary coordination; and improved capacity to deal with future challenges (Michaels et al. 2001, Wondolleck and Yaffee 2000, Yaffee and Wondolleck 2000) (sidenote 26). Collaborative management requires processes that include early, frequent, and ongoing involvement; substantive involvement; consensus decisionmaking; inclusive and representative makeup; cooperative, not adversarial attitudes; and flexible, positive attitudes. Collaborative management requires collaborative learning—joint fact finding, inventing options collaboratively, and developing a common understanding with a base of scientific information and information from independent, outside experts and scientists (Wondolleck and Yaffee 2000).

Of course, collaborative management is not a panacea; concerns about collaborative management include accountability, adherence to law, the demands placed on public and private groups, cooption by local economic development interests, and problems in evaluation (Conley and Moote 2003, Overdevest 2000). Increasing emphasis is

Sidenote 23—Clark (2001) cites Lasswell's five tasks of problem orientation:

- Clarify goals or preferred outcomes.
- Describe trends including changes relevant to goals.
- Analyze factors that shape trends, including causes, motives, and policies.
- Make projections about likely future developments under various circumstances.
- Invent, evaluate, and select alternatives to pursue goals.

Sidenote 24—Resources, values, or bases of power can be quite diverse (Clark 2001), e.g. people can give and receive:

- **Power:** support in making decisions in specific contexts
- **Enlightenment**: information
- **Wealth:** opportunity to control resources including money, people, and parcels of nature
- **Well-being:** opportunity for personal safety, health, and comfort
- **Skill:** opportunity to develop talents into operations of all kinds including professional, practical, and artistic skills
- **Affection:** friendship, loyalty, love, and intimacy in interpersonal situations
- **Respect:** recognition in a profession or community
- **Rectitude:** appraisal about responsible and ethical conduct

being placed on evaluating the efficacy and efficiency of conservation efforts worldwide (Bare et al. 2000, Christensen 2003). Collaborative management "takes a lot of care and feeding" (Wondolleck and Yaffee 2000). The basic dilemma is cooperation versus competition. That competition is more rational than cooperation from the point of the individual, and the collective will not do as well under competition as with cooperation, have been recognized since the time of Aristotle. Economics, evolutionary biology, and political science all presume individuals maximize self-interest and undermine cooperation. The prime example is Garrett Hardin's tragedy of the commons. Institutional barriers are numerous as are barriers owing to attitudes and perception. Singleton (2002) evaluated three cases of collaborative watershed planning in the Pacific Northwest. Success was impressive in some areas, but limited by difficulty in resolving core conflicts over equity, distributive effects of conservation planning, competing visions of nature, and goal. But, Singleton states, collaborative environmental policymaking is clearly an idea whose time has come. The rationale for devolution of decisionmaking power is that local people and local governments have clearer understandings of local socioeconomic and cultural circumstances and are better equipped to devise fine-tuned regulatory solutions to environmental problems than those who make top-down centralized decisions. What is needed is local autonomy coupled with broad accountability. The promise of collaborative management is satisfying local needs while conforming to state and federal law.

Sidenote 25—Rolle (2002) suggested that the progress of a collaborative group can be evaluated by its ability to (1) meet its mission and achieve outcomes; (2) be sustained; (3) understand the community; (4) be inclusive and diverse, reflect the community; (5) create a forum for diverse ideas and shared learning; (6) increase community capacity; (7) increase cooperation across organizational, administrative, and jurisdictional boundaries; (8) stimulate innovation, new ways of doing business; and (9) facilitate changes in policy, laws, and programs.

Sidenote 26—Successful collaborative efforts (Wondolleck and Yaffee 2000):

- Build on a sense of community/shared vision
- Create new opportunities for interaction among diverse groups
- Generate effective and enduring processes
- Develop more open, flexible, and holistic mind sets
- Establish responsibility, ownership, and commitment
- Create proactive and entrepreneurial behavior
- Build support and resources from numerous sources

CHAPTER 4

Conservation Revisited

Conservation is the set of attitudes, principles, and practices we adopt individually and collectively to meet people's needs and fulfill people's aspirations from nature while not diminishing the capacity of nature for renewal, for creativity and evolution, to meet the needs of future generations, and to support a present and future diversity of life on Earth. Biologically, diversity is defined in terms of genes, populations, species, and other taxa and levels of organization such as biotic communities and ecosystems. Biodiversity, however, is more than the variety of things in a defined set. Biodiversity is a concept with philosophical, social, economic, and political components because the diversity of life is an irreplaceable asset to humanity and the biosphere. Biodiversity is a blanket term for the natural biological wealth that is the foundation for human well-being. Nature seems a better term. The challenge of nature conservation is integrating diverse worldviews and philosophies to achieve general sustainability of human communities. Conservation of biodiversity (nature) is "… management of human interactions with the variety of life forms and ecosystems so as to maximize the benefits they provide today and maintain their potential to meet future generations' needs and aspirations" (Reid and Miller 1989).

Biodiversity is inseparable from the ecological, evolutionary, and managerial processes of nature that affect biological diversity. These processes include climate change, weather patterns, hydrologic cycles, pollution, photosynthesis, soil generation, nutrient cycling, and maintenance of soil fertility, water cycling, predation, mutualism, competition, parasitism, pest control, silviculture, grazing management, agriculture, animal husbandry, and horticulture. Linkages among processes must be taken into account whether the goal is to obtain products from individual species, services from ecosystems, or to keep ecosystems in a natural state for future generations. Altering ecosystems affects both processes and biodiversity, but with a wide range of ecosystem- and alteration-specific outcomes. Nevertheless, there are guiding principles (Reid and Miller 1989):

- The mix of species making up a community changes constantly even under conditions of environmental stability; thus, conservation of biodiversity should not be aimed at maintaining exact community composition, but at maintaining the overall variety of species while allowing ecosystems to change.
- Biodiversity increases with environmental heterogeneity at multiple scales.
- Spatial heterogeneity influences not only the composition of species within a community but also the interactions among species, including competition, parasitism, and predation.
- Periodic disturbances are important in creating mosaics that foster high species diversity.
- Size and isolation can influence community composition, as can the transition zones between communities.
- Certain species have disproportionate influences on ecosystems; some species are prone to extirpation.

Thus, understanding how complex systems emerge from the interaction of biological entities at all levels with the external environment is critical to understanding ecosystem function; a systems approach is necessary. Biocomplexity, not just biological diversity, is the defining property of ecosystems (Dybas 2001).

Given that current extinction rates are high and accelerating and that human populations are growing, using more resources, and generating more wastes, Pimm et al. (2001) asked, "Can we defy Nature's end?" They answered themselves: the first priority is protecting remaining natural ecosystems. They concluded that saving the remaining diversity is possible. Globally, the greatest harm is impacts on vulnerable diverse areas that contribute relatively little to human economic well-being, such as humid tropical forests that contain two-thirds of all terrestrial species and the Amazon, Congo, and Southeast Asia rivers that contain one-half the freshwater fish species. They also concluded that protecting diversity is economically feasible. But there is no single answer to protecting diversity. The Pimm approach protects biodiversity for its intrinsic values. Protected areas and reserves are not sufficient for either simple species conservation or to maintain the capacity of nature to provide future generations of people, other animals, plants, and fungi with the same opportunities for quality of life and evolution today's species have. The most pressing need today is to train and empower conservation professionals to meet with interested citizens, help them assemble into collaborative learning communities, and to inform and facilitate a process of collaborative management (see also Pinchot Institute for Conservation 2001). Conservation organizations need to modernize and begin using 21st-century methods of organizational and professional management and development (French et al. 1994, Katzenbach and Smith 1993, Rummler and Brache 1995, Senge 1990). Agencies need financial and political support to develop their human capacities. Conservation research and management should be distributed away from centralized authorities and organizations, close to the front lines of on-the-ground management. Certainly, immediate protection of biodiversity is needed in the Third World; hotspots and coldspots of diversity should be identified (Kareiva and Marvier 2003) (sidenote 27). Preservation of hotspots, regions with unusually high concentrations of endemics that have also suffered severe habitat destruction, such as tropical rain forest, oceanic islands, Mediterranean ecosystems in California and South Africa, is the reigning conservation paradigm. Other approaches can be taken in the First World, from reducing consumption and waste to managing the environment intentionally at multiple scales; from local community management of forests to governmental regionwide management and regulation of solid waste, air quality, water quality and supply, transportation networks, and energy supplies. There is a broad consensus that more research is needed on links between biodiversity, ecosystems, ecological services, and people. But there is a crying need for action research (French et al. 1994) that can enable people to come together to solve local problems.

Five years after the Rio conference in 1992 (callout 4), 1.3 billion people lived in absolute poverty, 20 percent of the world population lacked access to safe water, and 840 million people suffered malnutrition. Globalization of economies accelerated and led to accelerated environmental degradation. Citizens in the United States consumed in 1 year what citizens of Africa or India consume in their

Sidenote 27—Kareiva and Marvier (2003) asked what about coldspots (i.e., the Arctic or Serengeti)? The hotspot approach has five significant flaws:

- Hotspots for different taxa do not necessarily coincide, hotspots are often identified by plants lists that are not necessarily indicative of other taxa, and most taxa are unstudied.
- Degree of threat (present and future) is hard to quantify.
- The hotspot approach is reasonable only if the only goal is to protect the largest possible number of species in the smallest possible area.
- Focus on hotspots could allow major ecosystems to degrade.
- Hotspot conservation ignores environmental sustainability.

lifetimes. Problems of poverty, population growth, industrial and social development, depletion of natural resources, and destruction of the environment are closely interrelated and call for political transformation to sustainable development (Brown 2000). A substantial minority in the United States is concerned with intergenerational equity; but we need to make that a majority that is also concerned with intragenerational equity. We cannot pursue conservation without compassion, conscience, and consciousness.

In our ongoing cultural evolution, paradigms shift and, sometimes, new ones emerge. An emerging paradigm is the reflective, living systems paradigm (Elgin and LeDrew 1997). This paradigm includes a growing capacity for self-reflection and an ability to make fresh choices. It has a living system view of wholeness and interconnectedness. Its goal in life is to develop a balanced relationship between inner and outer selves and live in a way that is sustainable and compassionate, with conscious consumption. Conscious consumption is an ever-changing balance of inner and outer, material and spiritual, personal and social. Sense of self grows through conscious, loving, and creative participation in life. It is natural to respect all that exists as integral to the larger body of life. This paradigm bodes well for humanity. Older paradigms do not (Regier 1993).

Callout 4—Rio Declaration on Environment and Development (United Nations 1972)

The United Nations Conference on Environment and Development, having met at Rio de Janeiro from 3 to 14 June 1992, reaffirming the Declaration of the United Nations Conference on the Human Environment, adopted at Stockholm on 16 June 1972, and seeking to build upon it with the goal of establishing a new and equitable global partnership through the creation of new levels of cooperation among states, key sectors of societies and people, working towards international agreements which respect the interests of all and protect the integrity of the global environmental and developmental system, recognizing the integral and interdependent nature of the Earth, our home, proclaims that

- **Principle 1**—Human beings are at the center of concerns for sustainable development. They are entitled to a healthy and productive life in harmony with nature.
- **Principle 2**—States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources pursuant to their own environmental and developmental policies, and the responsibility to ensure that activities within their jurisdiction or control do not cause damage to the environment of other States or of areas beyond the limits of national jurisdiction.
- **Principle 3**—The right to development must be fulfilled so as to equitably meet developmental and environmental needs of present and future generations.
- **Principle 4**—In order to achieve sustainable development, environmental protection shall constitute an integral part of the development process and cannot be considered in isolation from it.
- **Principle 5**—All States and all people shall cooperate in the essential task of eradicating poverty as an indispensable requirement for sustainable development, in order to decrease the disparities in standards of living and better meet the needs of the majority of the people of the world.
- **Principle 6**—The special situation and needs of developing countries, particularly the least developed and those most environmentally vulnerable, shall be given special priority. International actions in the field of environment and development should also address the interests and needs of all countries.
- **Principle 7**—States shall cooperate in a spirit of global partnership to conserve, protect and restore the health and integrity of the Earth's ecosystem. In view of the different contributions to global environmental degradation, States have common but differentiated responsibilities. The developed countries acknowledge the responsibility that they bear in the international pursuit to sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command.
- **Principle 8**—To achieve sustainable development and a higher quality of life for all people, States should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies.
- **Principle 9**—States should cooperate to strengthen endogenous capacity-building for sustainable development by improving scientific understanding through exchanges of scientific and technological knowledge, and by enhancing the development, adaptation, diffusion and transfer of technologies, including new and innovative technologies.
- **Principle 10**—Environmental issues are best handled with participation of all concerned citizens, at the relevant level. At the national level, each individual shall have appropriate access to information concerning the environment that is held by public authorities, including information on hazardous materials and activities in their communities, and the opportunity to participate in decisionmaking processes. States shall facilitate and encourage public awareness and participation by making information widely available. Effective access to judicial and administrative proceedings, including redress and remedy, shall be provided.
- **Principle 11**—States shall enact effective environmental legislation. Environmental standards, management objectives and priorities should reflect the environmental and development context to which they apply. Standards applied by some countries may be inappropriate and of unwarranted economic and social cost to other countries, in particular developing countries.
- **Principle 12**—States should cooperate to promote a supportive and open international economic system that would lead to economic growth and sustainable development in all countries, to better address the problems of environmental degradation. Trade policy measures for environmental purposes should not constitute a means of arbitrary or unjustifiable discrimination or a disguised restriction on international trade. Unilateral actions to deal with environmental challenges outside the jurisdiction of the importing country should be avoided. Environmental measures addressing transboundary or global environmental problems should, as far as possible, be based on an international consensus.

- **Principle 13—**States shall develop national law regarding liability and compensation for the victims of pollution and other environmental damage. States shall also cooperate in an expeditious and more determined manner to develop further international law regarding liability and compensation for adverse effects of environmental damage caused by activities within their jurisdiction or control to areas beyond their jurisdiction.
- **Principle 14—**States should effectively cooperate to discourage or prevent the relocation and transfer to other States of any activities and substances that cause severe environmental degradation or are found to be harmful to human health.
- **Principle 15—**In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.
- **Principle 16—**National authorities should endeavour to promote the internalization of environmental costs and the use of economic instruments, taking into account the approach that the polluter should, in principle, bear the cost of pollution, with due regard to the public interest and without distorting international trade and investment.
- **Principle 17—**Environmental impact assessment, as a national instrument, shall be undertaken for proposed activities that are likely to have a significant adverse impact on the environment and are subject to a decision of a competent national authority.
- **Principle 18—**States shall immediately notify other States of any natural disasters or other emergencies that are likely to produce sudden harmful effects on the environment of those States. Every effort shall be made by the international community to help States so afflicted.
- **Principle 19—**States shall provide prior and timely notification and relevant information to potentially affected States on activities that may have a significant adverse transboundary environmental effect and shall consult with those States at an early stage and in good faith.
- **Principle 20—**Women have a vital role in environmental management and development. Their full participation is therefore essential to achieve sustainable development.
- **Principle 21—**The creativity, ideals and courage of the youth of the world should be mobilized to forge a global partnership in order to achieve sustainable development and ensure a better future for all.
- **Principle 22—**Indigenous people and their communities and other local communities have a vital role in environmental management and development because of their knowledge and traditional practices. States should recognize and duly support their identity, culture, and interests and enable their effective participation in the achievement of sustainable development.
- **Principle 23—**The environment and natural resources of people under oppression, domination, and occupation shall be protected.
- **Principle 24—**Warfare is inherently destructive of sustainable development. States shall therefore respect international law providing protection for the environment in times of armed conflict and cooperate in its further development, as necessary.
- **Principle 25—**Peace, development and environmental protection are interdependent and indivisible.
- **Principle 26—**States shall resolve all their environmental disputes peacefully and by appropriate means in accordance with the Charter of the United Nations.
- **Principle 27—**States and people shall cooperate in good faith and in a spirit of partnership in the fulfillment of the principles embodied in this Declaration and in the further development of international law in the field of sustainable development.

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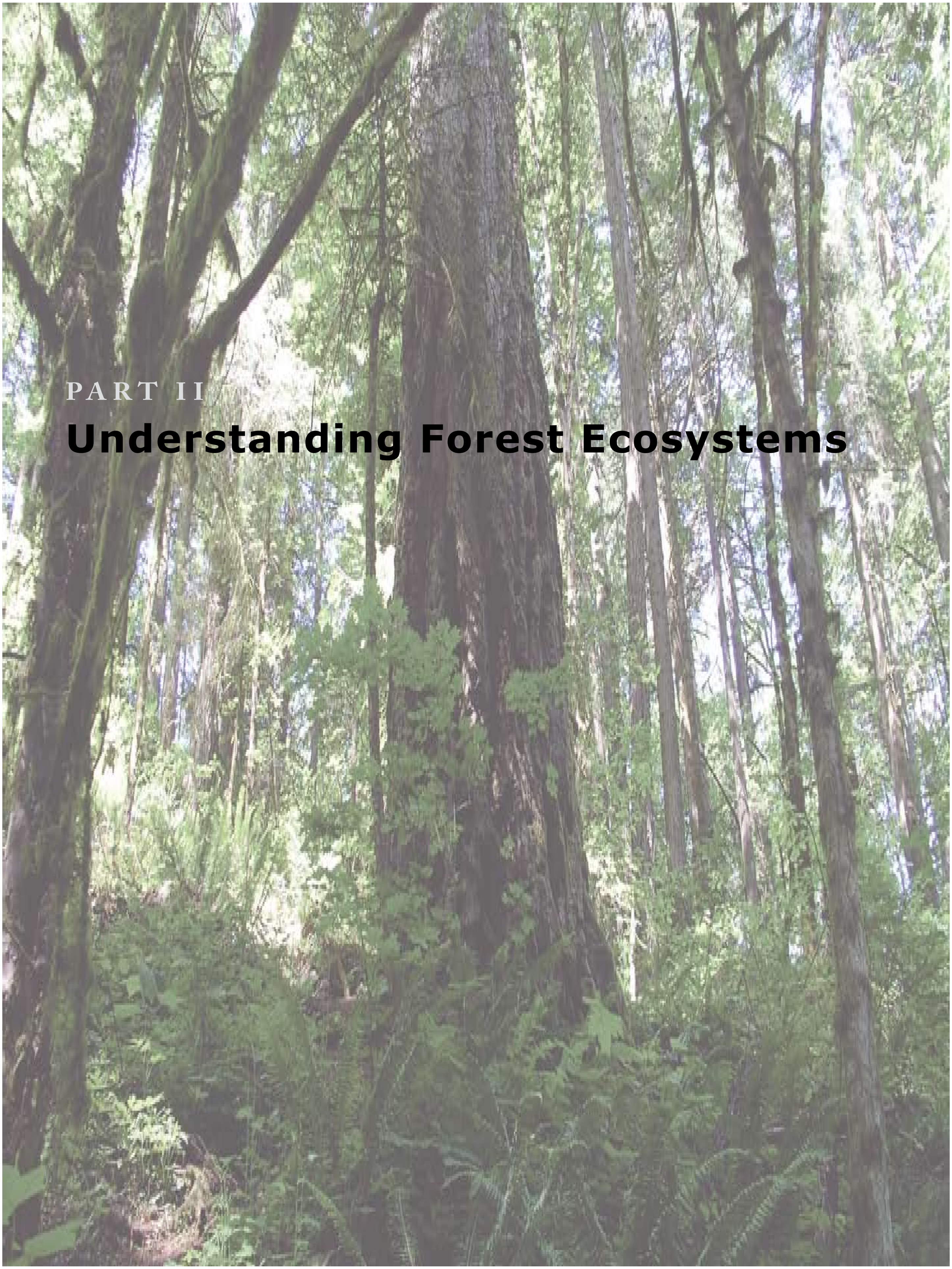


PART II

Understanding Forest Ecosystems

PART II **Key Points**

- Biodiversity is a salient feature of forests and depends upon disturbances at a variety of temporal and spatial scales.
- Temperate forests exhibit common patterns in structure, composition, and development at multiple spatial and temporal scales.
- Resilient forests develop complexity through envelopment of simpler biotic communities by more complex biotic communities over time, not replacement of one community by another.
- Key processes contributing to biocomplexity in forests include disturbances, legacy retention, crown-class differentiation, decadence, canopy stratification, understory development, development of habitat breadth, and niche diversification.
- Management is a human activity designed to meet human goals, including preservation of a natural system, recovery of a threatened species, maintenance of biodiversity, or wood production.
- Management based on ecological processes is more likely to be successful than management based on simply-defined structural conditions.
- Process-based management requires reference conditions, benchmarks, and measurable indicators of change.
- Effective management necessitates considerations of multiple spatial scales and long periods, including consideration of global climate change and human population growth.
- Active, intentional management (AIM) for conservation of nature and sustainable production of economic goods and ecological services is necessary because forests are complex and people desire diverse values from forests. AIM is hard to achieve without collaborative learning.
- Resilient forests are high in species diversity and functional groups, contain diverse ecological interrelationships, have complex physical and biotic structure, have high biomass (living and dead), are spatially heterogeneous, and are internally dynamic.
- Many characteristics of resilient forests depend on regular small disturbances, occasional intermediate disturbances, and rare severe disturbances.
- AIMing for resilient forests rests on using planned disturbances to help achieve resiliency by promoting diversity, spatial heterogeneity, biocomplexity, and accumulation of biomass.

CHAPTER 5

Terms, Concepts, and Theories

Part II of *AIMing for Healthy Forests: Active, Intentional Management for Multiple Values* provides definitions of ecological terms that can facilitate understanding and a discussion of how the science of ecology and the art of conservation are inseparable from philosophy, especially ethics. Chapter 6 examines the ecological foundations of biodiversity that underlie any conservation effort and provides examples of how these work at the landscape scale and at the scale of small forest ecosystems. Chapter 7 begins with a theoretical underpinning for active, intentional management (AIM) based on stochasticity, disturbance, and change. Building on this, the second part of the chapter focuses on structure, pattern, and process of forest ecosystems and how management of ecological processes is essential to AIM. Chapter 8 describes some of the practical and operational aspects of AIM. What then might seem missing is a cookbook of AIM recipes. But a quick review of this publication in its entirety reveals why such a cookbook for a limited region, like the Pacific Northwest, is likely to be misleading and result in unintended consequences.

- The region is ecologically diverse, and understanding local ecosystems is key to successful conservation.

- Active, intentional management must be process based with emphasis on (1) diagnosis of current conditions, (2) prognosis with and without intervention, (3) an accepted-reference condition and establishment of baseline conditions by which to judge progress, (4) use of benchmarks (alternative-management approaches) by which to judge success, and (5) choice of metrics by which to evaluate any current state of the management system.
- Active, intentional management is itself a social process that depends on good faith in collaborative learning and collaborative management. The AIM approach must be fully justified in the eyes of all stakeholders and culturally appropriate. A cookbook by its nature is pedantic, top-down instructions, or, in holarchical terms, a pathological dominator. In any event, no one I know has the knowledge to write a comprehensive cookbook for all occasions.

Terminology

Careful use of technical terms is essential to effective communication and developing common understanding. Misuse, abuse, and loose use of terms underlie much dissension in ecology and misunderstanding among various people interested in forest management and other environmental issues. For example, *habitat* is a badly abused term. It is used here according to its general definition (the place where a member, social group, population, or regional population of a species lives) and more technical definition (the range of biotic communities a species inhabits in a landscape or region).

Thus, a northern spotted owl has its habitat; a pair of spotted owls has certain habitat requirements; the elements of the habitats of spotted owls on the Olympic Peninsula include nest trees, nest groves, roost sites, foraging areas, and so on; and the habitat of northern spotted owls in lowland forests of Oregon and Washington is commonly old-growth forest. Habitat quality is best evaluated by various demographic measures of the owl—tenure of occupancy, longevity of occupants, number of young produced, owl densities, proportion of pairs breeding, and so on (fig. 12). Wildlife-habitat relationship books document the relationships between each vertebrate species in a region and its associations with plant community types, special landscape features, and specific elements of its habitat (Johnson and O'Neil 2001). However, there is no spotted owl dispersal habitat (a place where young owls often die), foraging habitat (foraging areas are but one element of owl habitat), old-growth habitat (it is old-growth forest), wildlife habitat (What is not habitat for some species of wildlife?), or snag habitat (a snag is simply a dead tree); "habitat types" are vague—more precise descriptions of vegetation are warranted for clear communication.

Vegetation can be described in terms of vegetation zones defined by environmental conditions such as temperature, moisture, distance from the ocean, elevation, side of major mountain range, and location within or among physiographic (landform) provinces. For example, the Western Hemlock Zone (Franklin and Dyrness 1973) is a broad lowland climatic zone of western Oregon and Washington that includes a variety of forest types characterized by Douglas-fir, western hemlock, western redcedar, and a variety of other trees. When referring to widespread, broad types of vegetation, zones are useful: Sitka Spruce Zone (along the coasts of Washington and Oregon), Western Hemlock Zone (widespread in the lowlands of western Washington and Oregon), Mixed Conifer-Mixed Evergreen Zone (southwestern Oregon and northern California), and so on.

There are lists of the numerous forest types for North America that are named after dominant trees, but such lists are cumbersome, not available to many people, and increasingly obsolete. Common tree species, however, can be used to identify common types of forest, as they exist in the present; for example, Douglas-fir forest (mostly Douglas-fir with other trees scarce), Douglas-fir/western hemlock forest, silver fir forest, Sitka spruce/western hemlock forest, and so on.

Many forest classifications, however, are based on the notion of climax types—the type of vegetation community that would develop under idealized stable conditions over the long-term; these are often referred to as potential natural vegetation (PNV) types and are expressed in terms of dominant overstory trees and key indicator plant species that would occur (and do occur in old growth) in the understory. They are derived from extensive sampling within vegetation zones and emphasize elevational, topographic, and edaphic (soil) relationships. They have been mapped for large areas (for example, Henderson et al. 1989 for the Olympic Peninsula of Washington and Moir 1989 for Mount Rainier). Potential natural vegetation types are only occasionally referred to here, but they do provide considerable information on the potential biodiversity of a landscape and the quality of growing conditions on a site—often more accurately than the extant vegetation. Easily confused with PNV types are plant community types. Plant communities may be grasslands, shrub lands, savannahs, forests, and other types and are often named after the dominant and key indicator species. They differ from PNV

Figure 12—Two juvenile spotted owls. Photo courtesy of USDA Forest Service.

types in that, like forest types, they describe extant conditions. In this book, descriptors such as Douglas-fir/salal/Oregongrape refer to a plant community type, not a PNV, unless otherwise stated.

Forest or community type is not sufficient to describe a forest in a meaningful ecological way. It is important to include a descriptor of seral stage—where along a continuum of development of biocomplexity the forest lies. A set of seral stages that are useful in describing both natural and managed forests is provided later. However, in referring to natural forests broadly, complex forests more than 225 years or so old are called old growth (fig. 13). Old-growth and complexly structured 80- to 225-year-old forests with legacies from old growth simply are called old, natural forest (Carey et al. 1992). Any natural forest younger than 80 years old is called young forest (Carey and Johnson 1995). When talking about simply structured natural forests, the classification provides specific terms. Any forest resulting from clearcutting or logging of the majority of overstory trees is second growth, whether or not it has been logged once, twice, or more than twice, in keeping with the dictionary definition. However, it is wise to avoid using classifications of stands of trees—the typical forestry classification based on size of tree and wood product quality. Thus, talking about a second-growth Douglas-fir forest in the biomass accumulation stage with implications for forest ecosystem function and biodiversity is more informative than what a forester might call a large-sawlog Douglas-fir stand ready for harvest. For conservation purposes, a stand of trees is only a part of a forest ecosystem and forest ecosystems are elements of landscapes and landscapes are elements of regions.

Theories, Frameworks, and Points of View

The basic and applied sciences of ecology have had a popular impact unlike that of any other science (Worster 1990). Underlying this impact is the hope that this science can offer a great deal more than mere data—that it can serve as a pathway to a kind of moral enlightenment. Ecology provides understanding (what is), and ethics provides relatedness and relationships (what ought to be)—thus there are links between the cognitive-scientific and practical-ethical spheres (Rozzi 1999). Garrett Hardin, in his very influential paper in *Science* magazine (Hardin 1968), stated that lack of technical-scientific solutions to problems of human behavior resulted in the arms race, unrestrained human population growth, and the tragedy of the commons—that individuals will overuse some common resource to

Figure 13—Large fallen trees are a common sight in complex forests of the Pacific Northwest; such large coarse woody debris will provide protection and foraging sites for amphibians, small mammals, and birds for many years to come. Photo by A. Carey.

their own gain and to the destruction of that resource at the expense of the greater community. E.O. Wilson (1999a) reiterated that environmental problems are innately ethical. Paul Ehrlich (2002) recapitulated these ideas—the cutting edge of environmental science has switched from ecological and physical to behavioral with the need to alter the course of cultural evolution. The belief of Adam Smith (about 1776) that some "invisible hand" redirects individuals motivated solely by personal gain to promote the public interest is the underlying basis for our present social adoption of laissez-faire capitalism. But, the tragedy of the commons has belied the concept of the invisible hand for more than a century, as has the history of European and Euro-American exploitation of North, Central, and South America (Wright 1992). The tragedy of the commons is an ecological concept based on the idea that natural selection favors forces of psychological denial—that is, the individual benefits from his ability to deny the truth that society as a whole will suffer

(Hardin 1968, Ornstein and Ehrlich 1989). Thus, observations of unrestrained resource use (mining, overgrazing, pollution, and many other examples) and analogous phenomena in nature suggested to Hardin that there needs to be a normative concept of mutual coercion mutually agreed upon to produce social arrangements, which in turn produce responsibility. In other words, people have to agree on what is right and ethical and develop norms of behavior (and regulations and laws) that positively reinforce (provide rewards), negatively reinforce (provide punishment or threat of punishment), and remove obstacles to people acting and cooperating in ways that are socially responsible.

Many ecological concepts become normative when applied to conservation (Callicott et al. 1999). An example is the tenet that morally gross inequities throughout the world are biophysically unsustainable—perpetuating poverty has deleterious, irreversible impacts on the biosphere and hinders cooperation among parties of different socioeconomic status (Daily and Ehrlich 1996). E.O. Wilson (1998) calls for a new unity of knowledge, incorporating biology, social science, ethics, and environmental policy. Yet, he sees the greatest challenge to ecology as the cracking apart and resynthesis of the assemblages of organisms that occupy ecosystems:

- Accurately and completely describing complex systems.
- Reassembling the descriptions into models that capture the key properties of the entire ensemble.
- Measuring success by the power to predict emergent phenomena when passing from general to more specific levels of organization.

The important question is, Are there general organizing principles that allow an ecosystem to be reconstituted in full without full knowledge of all its component parts (for example, species, genes, molecules, and atoms)? Some of this synthesis will be attempted here and left to the reader to judge its success.

The ways people (including scientists) dwell in the natural world influences the ways they understand, explain, and look at nature. Franklin (1998) says naturalness is the great icon of the environmental community. Angermeier (2000) agrees "most conservationists value naturally evolved biotic elements such as genomes and communities over artificial elements," but states that this judgment is not shared by society at large and is based on intrinsic and instrumental values, including respect for nature; furthermore, naturalness is a continuum. Still, Angermeier posits, naturalness is a more reasonable guide for conservation than ecosystem features such as diversity, productivity, and evolution—the foundations for concepts such as ecological integrity and ecological restoration. All these concepts are explored here.

Barry Commoner formulated four laws of ecology that proved culturally influential but scientifically vague (Partridge 2000) (see Part 1, sidenote 5). Sagoff's antithesis is Nature does not know and Nature does not care (Partridge 2000). Thus, the ways people represent nature (e.g., in science models) constitute scenarios that inspire attitudes, behaviors, and ways of inhabiting nature. The Darwinian metaphor of the tree of life suggests common biological nature and origins that people share with all living species—a kinship, an extension of cultural respect beyond our own species, a biocentrism that values all life. A metaphor of a web of life suggests the instrumental value of biodiversity for human survival requiring an environmental ethic of environmental, economic, and utilitarian interdependence (Rozzi 1999). Thus, in any ecological paradigm or model there are values, assumptions, and worldviews that are often preconscious to the modeler and unexplained to the reader. Look and you will find some here.

Ecology has pursued an irregular course driven by seemingly diametric views of nature based on 2000 years of science, from the use of natural unknowable forces (magic) to biologically based mechanisms (Graham and Dayton 2002, Paine 2002). This course has led to debate that forces ecologists to explore how nature works and then to generate a synthesis—this cycle of thesis, antithesis, synthesis, and new thesis. Ecologists, however, are divided into subdisciplines that tend to focus on contemporary and emerging questions with the concomitant loss of previous synthesis; thus, ecology is a science of déjà vu—revisiting major conflicts (Naeem 2002) (sidenote 28). This process has taken place within the lifespan of contemporary ecologists and produced a cacophony that has postmodern philosophers denying the objectivity of science (Rykiel 2001). Thus, ecology is a mix of theory, empirical observation, worldviews, and ethical beliefs.

Naeem (2002) suggests that no single feature of the Earth's biota is more captivating than its extraordinary taxonomic diversity. He presents an emerging paradigm that is a synthesis of community and ecosystem ecology which, while concentrating on functional versus taxonomic diversity, promises to refocus attention on the broader significance of the Earth's biota. This emerging paradigm is that biodiversity governs ecosystem function versus the old paradigm and central tenet of ecology that biodiversity is primarily an

Sidenote 28—Naeem's (2002) *Déjà vu* conflicts in ecology:

- Does ecosystem or community ecology provide better insights into the working of nature?
- The relative importance of abiotic and biotic factors in governing biotic community composition
- The virtues of phenomenological vs. mechanistic research
- The relationship between biodiversity and stability
- The relative importance of taxonomic vs. functional diversity
- The relative strength of observational vs. experimental approaches

epiphenomenon of ecosystem function and secondarily structured by community processes. Neither is correct in an absolute sense—there are feedbacks between the two and these are explored here as well.

Paine (2002) is a little more circumspect about paradigms than is Naeem (2002). He says ecology has had few paradigm shifts because it is a pluralistic, multiple-causation discipline. Rather, ecology has fads, bandwagons, favored themes, and transient foci of interest that wax, wane, and recover. Bandwagons attract adherents by timeliness, vigor, showmanship, and novelty—no one doubts their reality or importance, but interests wane as limits to advancement increase. Paine says these themes have a common biological heritage—the enormous complexity of natural systems—and share a common trait—multiple causation is commonplace and unavoidable. Still, the faddish nature of ecology results in much recycling of ideas and concepts under new labels. Often progress is made, for example, the evolution of the concept of niches from the Grinnellian (niche as habitat) to the Eltonian (niche as role or occupation) to the Hutchinsonian (niche is the multidimensional space occupied

This decaying snag, which looks like an artist's sculpture, adds not only wildlife value but also aesthetic value to an old-growth forest. Photo by T. Wilson.

by a species in a biotic community as a result of interactions with other species and environmental conditions) (Graham and Dayton 2002). However, progress is hindered by ecological subspecialization that leads to parallel evolution of concepts, erasure of history as contemporary ecologists lose touch with their historical roots, and expansion of the scientific literature beyond the cognitive limits of individuals. Despite the evolution of niche concepts and the utility of the Hutchinsonian niche, the term niche has little agreed-upon meaning across subdisciplines in ecology. There are many areas in the applied ecological sciences where overreductionism, narrow specialization, and emphasis on single causes and linear relationships may be misleading.

This evolution of paradigms in ecology has followed similar upheavals in society and the physical sciences (Barabási 2003, Gleick 1987, Prigogine and Stengers 1984, Worster 1990). Thus, 18th-century beliefs in stability, order, uniformity, closed systems, and predictability have been dispelled. The 19th-century thermodynamic concept that the universe is running down with energy leaking out (entropy) has been replaced with a Darwinian concept of biological systems running up—becoming more organized. And the mid-20th-century emphasis on nonequilibrium in natural systems and the primacy of stochasticity or randomness is being replaced by an appreciation of self-organizing systems that bring order out of chaos. Prigogine won the Noble Prize for his work on nonequilibrium systems and dissipative structures. He said Man's new dialogue with nature should focus on two questions: the relationship between disorder and order (e.g., evolution) and the reversibility versus irreversibility of entropy (the roles of complex, dissipative structures, self-organization, determinism, and chance). Prigogine concludes that the universe is pluralistic and complex; structure disappears and appears; some processes are stochastic, others are probabilistic; basic processes are deterministic and reversible, but natural processes contain essential elements of randomness and irreversibility. Key concepts are complexity, nonlinearity, instability, fluctuation, surprises, and self-organization. These will be themes of management approaches developed here. Thus, we must abandon the hubris of Newton, as described by John T. Desaguliers in 1728 (Prigogine and Stengers 1984):

> Nature compelled, his piercing Mind obeys,
> and gladly shows him all her secret ways;
> 'Gainst Mathematicks she has no defense,
> and yields t' experimental Consequence.

We must learn to live with ambiguity and uncertainty; we will never have perfect predictability; we must let go of simple linear models (e.g., 2 + 2 = 4); and we cannot expect nature to reproduce her riches after we have extensively disturbed a mix of environmental variables, even if we place an area off limits to future human activity.

> Any science that conceives of the world as being governed according to a *universal theoretical plan* reduces its various riches to the drab applications of general laws thereby becomes an instrument of domination. And man … sets himself up as its master (Prigogine and Stengers 1984) [italics added].

We must rely on some natural processes of self-organization to produce adaptive complex systems. Some such natural processes include the tendency to form small tightly bound *hubs* or subsystems loosely connected to one another in networks (Barabási 2003), a theme embedded in Panarchy theory. Simply stated, "The disorderly behavior of simple systems provides a creative process that produces complexity or richly organized patterns that are sometimes stable and sometimes unstable" (Gleick 1987). We can use science and learning in understanding processes and heightening the intentionality of our decisions and actions. Like myths and cosmologies, science's endeavor is to understand the nature of the world, the way it is organized, and humankind's place in it, … the relation of being to becoming … appearance of order out of undifferentiated order (Prigogine and Stengers 1984).

Panarchy Theory

Panarchy theory (Gunderson and Holling 2002) is a decentered view (divorced from any narrow theory or discipline) that rests on the following principles: (1) the universe is composed of systems (interacting groups of things) within larger systems (interacting groups of subsystems), ranging from a microscopic soil microcosm to the global social-economic-biospheric system; (2) change, indeed surprises, are inevitable; and (3) reorganization after catastrophes resulting from change allows adaptation to the new conditions of life. Why is this important? Simon Levin (1999) describes ecosystems as dynamic assemblages of interacting components self-organized into evanescent patterns of interaction on multiple scales of space and time. Their only essential constant is change. Even the balance of nature describes a system far from equilibrium alternating between periods of relative stability and periods of dramatic change.

If this were true, then our challenge would be to avoid oversimplifying our definitions of forest ecosystems, to avoid assuming that a forest will grow into a particular seral stage no matter what has happened or might happen in the future, and to avoid trying to manage for or preserve a particular forest condition as if it were static and unchanging. It would mean ensuring our forests have all the elements that help them to be resilient after minor surprises (acute, or short-term, small to intermediate disturbances), allowing them to adapt to changing environmental conditions (slow change or chronic minor disturbances) without suffering catastrophic destruction, and when they do suffer catastrophic destruction, to recover quickly in a way that maintains the ecological services that we, and all other forms of life, need. Levin (1999) offers the "Eight Commandments of Environmental Management" (sidenote 29). Part II will explain the application of Levin's suggestions in forest conservation.

Sidenote 29—The eight commandments of environmental management (Levin 1999):

- Reduce uncertainty.
- Expect surprises.
- Maintain heterogeneity.
- Sustain modularity.
- Preserve redundancy.
- Tighten feedback loops.
- Build trust.
- Do unto others as you would have them do unto you.

CHAPTER 6

Ecological Foundations of Biodiversity

Forest ecology is about the interactions of organisms with each other and their environment. It follows, then, that forest structure, composition, function, productivity, resilience, and adaptability depend on some minimum amount of diversity of organisms available to the self-organizing system (Bazzaz 2001, Cardinale and Palmer 2002, Holling 1992, Ives et al. 2000, Lindenmayer and Franklin 2002, Loreau et al. 2001, Naeem 2002, Naeem and Li 1997, Tilman 1999, Tilman et al. 1997, Wardle et al. 2000). Diversity accumulates from site-type diversity among small plots within biotic communities to the species diversity that describes a biotic community (α-diversity), differences between communities (β-diversity), total species diversity in landscapes (γ-diversity), and the floras and faunas of regions (Whittaker 1975). Diversity influences ecological processes through a variety of mechanisms and different degrees of organization. Genetic diversity operates at the level of local species populations and metapopulations. Species diversity strongly influences processes at the level of biotic communities and ecosystems. And the diversity of biotic communities strongly influences ecological processes that operate across ecosystems within landscapes. Different processes affect diversity at different scales, thus, a top-down approach also is necessary to fully understand patterns of diversity (Whittaker et al. 2001).

It is sometimes useful to think of diversity as the number and distribution of species in Earth's biosphere, patterns of diversity as the varying forms of biotic communities in space and time, and processes of diversity as the dynamic aspects of communities driven by both endogenous (internal) and exogenous (external) influences (Bridgewater 1988). To make sense of diversity, one must first consider biogeography and what determines the pool of species in a region. The selection of species from the regional pool that are found in any particular landscape depends on the characteristics of that landscape and landscape-level processes. Within landscapes, biotic communities arise with their composition determined by the local environment as well as the character of the landscape and its dynamics. Thus, within regions, biological diversity (genes, species, and communities) differs in space and over time. Patterns measured at small scales, such as within communities, do not necessarily hold at larger scales (among communities within landscapes); nor do processes prevailing at small scales necessarily prevail at larger scales and vice versa. Consequently, understanding patterns of diversity cannot be automatically addressed by scaling locally measured variables to larger areas and longer times or by applying broad patterns or general concepts to specific locations. Furthermore, strong components of stochasticity (randomness) and historical events may be operating at each spatial scale. Nevertheless, before examining what determines the diversity of species and forest communities in forested landscapes and forest-dominated regions, it is pertinent to ask why there are so many species?—a question underlying much of ecology and evolution (Hutchinson 1959).

Why Are There So Many Species?

Early theories related diversity to competition (table 9). The more alike individuals are, the more likely they compete for limiting resources, and the more likely natural selection promotes traits that maximize efficiency of resource exploitation to the extent that individual fitness (reproductive success) benefits. The most intense competition occurs between members of the same species and leads to specializations for a limited set of resources, and, under conditions of isolation, to speciation. The next most intense competition exists between closely related species; such species evolve differences in morphological or other characters to more efficiently exploit different resources; for example, bill size differs within and among species of Darwin's finches, and the different finches specialize on different

Table 9—**Theories of biodiversity**

Theory	Contention
Area	Number of species is a result of sampling effort and environmental heterogeneity.
History	Diversity is a consequence of geologic events, dispersal events, and isolation leading to speciation.
Energy	Resource-rich environments promote diversity; partitioning of energy among species limits richness.
Stress	Benign environments support more species than harsh environments; fewer species can adapt to harsh environments.
Stability	Stable environments support more species; few species are able to adapt to varying environments.
Disturbance	Disturbance promotes diversity by disrupting competitive interaction.
Interactions	Competition, predation, parasitism, and mutualism affect niche partitioning.

Source: Adapted from Whittaker et al. 2001.

sizes of food. Within small homogeneous areas, environmental stability leads to competitive exclusion and reduced numbers of species. As environmental heterogeneity increases within a community, niche differentiation, coadaptations, predation, and mutualisms promote increased complexity and diversity (Cohen and Stephens 1978, Fretwell 1972, Gilpin 1975, Levins 1968, May 1973). If one defines the spaces available for habitation and for interactions among species by using a large variety of environmental variables (including area and timing of use) that have some importance to one or more species, it becomes apparent that a large multivariate space exists within which numerous species can exploit various parts (i.e., define their habitat by adaptation to critical environmental variables) and within which potentially competing species can partition resources through niche differentiation (Carey 1981, Hutchinson 1957, Whittaker et al. 1973). Similarities among coexisting species are least limiting where productivity is high and seasons are uniform, for example, the Tropics (MacArthur 1965). In most environments, disturbances serve to disrupt dynamics of interactions, reduce severity of competition, reduce abundances of dominant species, and promote diversity. Small- and intermediate-scale disturbances produce heterogeneity within communities that produces preinteractive niche differentiation, wherein different niches are available to similar species even before they interact and undergo behavioral or evolutionary change as a response to interactions, such as competition, with other species. Catastrophes

Sidenote 30—The cause-and-effect explanation of population regulation:

- Population regulation does entail demographic density dependence.
- Density dependence is necessary, but not sufficient for population regulation.
- Competition and predation are possible sources of density dependence.
- Environmental heterogeneity is important in predator-prey, host-parasitoid, and host-parasite systems.
- Niche differentiation is important in competition.
- The spatial dynamics of succession and development are important in maintaining mosaics (environmental heterogeneity).
- Finite dispersal, neighborhood interactions, and effects of endogenous pattern formation are also important.

destroy communities and lead to rapidly changing conditions as new communities develop. Proliferation of disturbance-dependent species results in species-rich regional flora and fauna (Bridgewater 1988). Management that homogenizes communities and spreads exotic species can lead to globalization and reduced diversity of native flora. Management that includes introductions of exotic domesticated species and marked changes in landscapes (e.g., planting trees in the Great Plains) can lead to hybridization of species with an overall loss of species diversity (Levin 2002).

Closely related, then, to the questions of why there are so many species and how they coexist are questions about what regulates population densities. A population is regulated if it persists for generations with fluctuations above zero (Hixon et al. 2002). A fundamental tenet of ecology is that population regulation is density dependent with negative feedback; in other words, the propensity to increase in size is high when population size is small and decreases as the population grows large. Extinction occurs when regulatory mechanisms that promote population growth are weaker than disruptive events (disturbances) or stochastic variation. As with diversity, ecologists examining regulation first focused on competition, then moved on to disturbances such as predation, and then to the concept of metapopulations that are demographically open to immigration and emigration and that can persist without density dependence. As in all debates in ecology, the discussion spiraled from alternative simple explanations of population regulation to a greater understanding of the complexity of cause and effect (sidenote 30). The bottom line is that population regulation is a truly community-level phenomenon (Connell and Orias 1964, Hixon et al. 2002, Hutchinson 1978) and, thus, necessarily intertwined with species diversity.

Frank Preston (1969) noted that “every naturalist from Darwin downwards has felt aggravated that a few species are very common and most are rare.” The number of species and number of individuals per species in a functional group or biotic community appear to follow a log-series distribution (Fisher et al. 1943). Indeed, the lognormal distribution has emerged as the distribution underlying commonness and rarity (Preston 1948, 1960, 1962a, 1962b, 1969, 1980, 1981) and many other biological phenomena (Limpert et al. 2001). Sugihara (1980) concluded there is a minimum form of community structure involving hierarchically related niches; that niche apportionment is multidimensional, produces evolutionary ecological considerations, and results in species diversity; and that the end result is lognormal species abundance patterns. The practical import of the lognormal distribution is that with any sample of a large number of species, only a few species can be expected to be abundant; many will be rare (fig. 14). Thus, rarity is not necessarily indicative of poor or degraded environmental conditions, rather it is the rule. However, species do not necessarily retain the same relative abundances through time—environmental change (slow, fast, acute, or chronic) and stochastic (random) events affect different species differently. For example, in an experiment in increasing spatial heterogeneity in the canopy of second-growth forests (Carey et al. 1999d), native plant species diversity increased by 150 percent with concomitant changes in relative abundance (Thysell and Carey 2001a), species of litter invertebrates changed in relative abundance within functional groups at fine scales in response to treatment (Schowalter et al. 2003), the overall diversity and relative abundances of hypogeous and epigeous fungi on the forest floor increased (Carey et al. 2002), the diversity and abundance of winter birds increased (Haveri and Carey 2000), and rarer mammals increased in abundance (Carey 2000b, Carey and Wilson 2001). Many of these changes probably were due to changes in relative abundances and increased abundance of rare species in response to changes in environmental variables, but perhaps with some changes owing to germination of dormant seeds and to immigration (e.g., by ruderal plants and birds from surrounding areas). These changes illustrate that the simple number of species (often referred to as species richness) is inadequate to describe

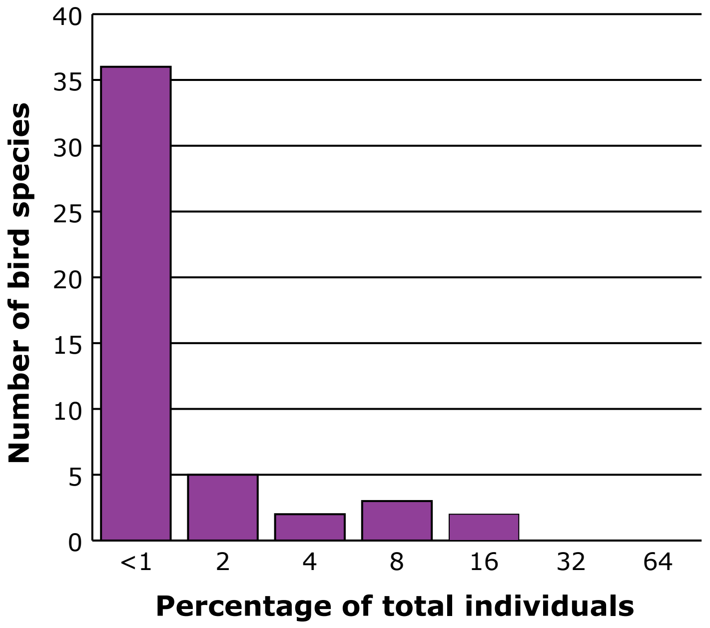


Figure 14—The distribution of occurrence in diurnal forest birds in the Oregon Coast Range (adapted from Carey et al. 1991) approximates a lognormal distribution; lognormal distributions characterize commonness and rarity in many biological phenomena.

the diversity of a community. Other useful measures include the numbers of species each accounting for, say, more than 5 percent of individuals, changes in the rank order of species, and changes in the ranks of individual species on a lognormal scale (Carey et al. 1991, Carey and Johnson 1995). The degree to which individuals are equally apportioned among species is called evenness. Increasing richness and evenness are not necessarily indicative of improving conditions for native diversity—these changes could reflect decreased overall abundance, invasion by exotic species, or replacement of rare or specialized species by common or generalist species. Comparing the structure of a biotic community in a relatively undisturbed natural environment to that in an environment under marked human influence provides a measure of the biotic integrity of the human-dominated environment (Karr 1991, 1993) and may indicate the relative sustainability of alternative management regimes in forests (Carey and Harrington 2001, Carey and Johnson 1995).

Relative rarity also increases with levels in food webs. Species at the tops of food chains—predators (fig. 15A)—are rarer than those they prey upon (fig. 15B) and nonpredators in general, including macroinvertebrate predators in Mollusca (fig. 15C), Annelida, and Arthropoda (Ahlering and Carrel 2001). For example, limited sampling in the Missouri Ozark Mountains found all 3 phyla, 8 classes, 19 orders, and 62 morphospecies with 28 percent of detected species being predatory but only 9 percent of individuals belonging to those species. Rare species are less likely to be detected during sampling

Figure 15—(A) An adult northern spotted owl and (B) a bushy-tailed woodrat. Photos courtesy of USDA Forest Service. (C) Two Burrington jumping slugs. Photo by J. Ziegltrum.

for diversity than common species, and it is difficult to establish the absence of a species. This problem of sampling is confounded when rare species are cryptic, very small, evasive, or inhabiting environments inimical to people—difficult to find even when present. Few scientists have studied stygofauna—inhabitants of caves and ground water—yet these species are numerous: 1,000 protozoa, 3,000 crustacea, 590 arachnids, 106 vertebrates (92 frogs), perhaps a total of 7,000 species (Gibert and Deharveng 2002). Nevertheless, rare species are more subject to local extinction than abundant species. Thus, expectations should be low that any particular rare species would be found in any limited sample of individuals or areas. Care must be taken to ensure the curve of species accumulation with increasing sampling effort has reached an asymptote before estimating total diversity for any particular group of species or narrowly defined community (group of species); it is much easier to detect differences in the distribution of individuals among species, the number of species per a large sample of individuals, the number of species for a specific area sampled, or the structure of the narrowly defined community. This profound characteristic of commonness and rarity of species has obvious important implications for reserve strategies, conservation goals, effectiveness monitoring, and choice of indicators.

Most of the estimated 4 to 112 million extant species have yet to be described and given a name (Wilson 1999a). Perhaps 98 percent of birds are known, 1.5 percent of algae, and less than 1 percent of bacteria. Questions about the effects of human activities on little-studied groups are literally endless. Little is known about the Grylloblattids (cockroach-crickets). These primitive insects, without wings or eyes, were discovered in Canada in 1911 and are known as ice bugs, ice crawlers, and rock crawlers (*Grylloblatta* spp.). They are found almost exclusively on mountains higher than 500 meters in Russia, China, Korea, Japan, and North America; endemism (species found only in one biogeographic area) is high in North America (fig. 16). Their preference for low temperatures (ca 4° c) slows their development—3 years may be required for eggs to hatch and 7 years to reach maturity. There are fewer species (25) in this order-suborder than

Figure 16—A rock crawler on Carpenter Ridge in the Sierra Nevada mountains, California. Photo by A. Wild © 2003.

any other order of insects. They live in environments where arthropod diversity is low. Many live on snowfields and glaciers and feed on other insects frozen on the surface of the snow or ice. One species has been found on glaciers on Mount Rainier, the tallest (about 4,400 meters) volcanic peak in the continental United States, sitting astride the Cascade Range in Washington and another species on the relatively low Mary's Peak, devoid of snowfields and glaciers, just west of Corvallis, Oregon. Studies in British Columbia, however, showed them to be widespread, with an affinity for edges between forests and clearcuts (Huggard and Klenner 2003).

Corliss (2001) asked "Have the Protozoa been overlooked?" in biodiversity calculations. He relates that more than 213,000 protists, including 92,000 protozoa, are important pathogens (causing diseases including malaria, sleeping sickness, leishmaniasis, and many others), help control bacteria, and contribute to nutrient turnover. *Eimeria* spp. are common protozoan intestinal parasites of small mammals in North America. Studies of small mammals easily uncover new species of endoparasites such as *Eimeria* (Fuller and Duszynski 1997, Torbett et al. 1982); new range records of ectoparasites, such as fleas (Main et al. 1979); new species and geographical occurrences of the smallest forms of life-like viruses (Main and Carey 1979, 1980); even new range records of the small mammals themselves (Carey 1978a); and incidentally, new records of rarer organisms such as achlorophyllous mycotrophs (Thysell et al. 1997a). A team of scientists (Memmott et al. 2000) examined the food web of one common plant species in England—scotchbroom—now an introduced pest species of growing importance in Washington (Carey 2002a). They identified 154 taxa in a food web with 370 trophic links: 19 herbivores, 66 parasitoids, 60 predators, 5 omnivores, and 3 pathogens with a total 82 functional groups, 9 orders of insects, plus vertebrates, arachnids, bacteria, and fungi. There is no end to biodiversity. Forest ecologists have just scratched the surface of biological diversity; they rarely consider parasites and pathogens, even though forests play important roles in maintenance of diseases of people, such as Lyme Disease and its tick vectors (Carey et al. 1980a, 1981).

Sidenote 31—Biodiversity according to Blondel (1987):

- Biological systems are temporal as well as spatial; they always reflect a history from glaciation to human land use changes.
- Geologic time and processes (plate tectonics, climate change, and glaciation) join and separate faunas and floras.
- Evolutionary time produces genetic changes in populations through natural selection.
- Ecological time produces changes in communities with ecological succession and community development.
- Evolutionary convergence at the level of communities is hard to distinguish from phylogeny.
- Mechanisms of community organization differ between primeval and human-dominated landscapes because of reduced diversity:
    - Size of any local population not at equilibrium is determined by local resource conditions.
    - Species distributions are broken into a mosaic of local populations which exchange propagules in accordance with local demographic conditions.
    - The prime factor affecting transfer between local populations in the same neighborhood is the specific disturbance regime and the mosaic it produces.
    - Evolutionarily, a metapopulation (the local populations of a mosaic of biotic communities) promotes genetic diversity and polymorphisms in response to disturbance regimes, predation, and competition.

Biogeography

Biogeography refers to the diversity of organisms and the regulation of diversity in heterogeneous and changing environments. It is now well understood that patterns and processes in diversity must be considered in reference to space, time, and *change*—and that these three dimensions are inextricably linked. Neither deterministic (cause-and-effect) nor stochastic (random effects) paradigms are sufficient for understanding biogeography; ecologists need biological realism and multifaceted, interactive approaches to comprehend ecological systems; thus, hierarchy theory is essential to understanding biogeography and biodiversity because it bridges biogeography, ecology, and evolution (Blondel 1987) (sidenote 31).

Regional diversity (regional species pool, biotic communities, and life zones) is determined by long-term global processes and the resulting biogeography. Historically, theories of diversity have not addressed clearly components of general diversity or dealt adequately with geographical scale (Whittaker et al. 2001). Thus, α-, β-, and γ diversities are used ambiguously—the terms local, landscape, and regional diversity are more intuitive. Moreover, inventorying all species is difficult, if not impossible, and knowing how heterogeneity of environmental factors differs with scale is prerequisite to evaluating differences in diversity at local, landscape, and regional scales (Endler 1977). Thus, a top-down approach is important to understanding patterns of diversity (O'Neill et al. 1986). For example, there is a grand cline globally, with low diversity at the poles and high diversity in the Tropics. Plate tectonics, continental uplift, volcanism, glaciation, global climate change, mass extinctions, replacement of higher taxa (e.g., placental mammals by marsupials), and wind and river erosion and deposition have profoundly affected patterns of species occurrences. Historical contingencies operate at every scale. Tausch et al. (1993) refer to the "Legacy of the Quaternary" (0 to 2 million years ago), with its 24 glacial events and interglacials producing spatially and temporally variable climates and instability in plant communities with species composition constantly changing. Others have drawn similar conclusions after examining paleoecological or biochronological sequences (Gagosian 2003, Hallett et al. 2003, Johnson and Mayeux 1992, Millar and Woolfenden 1999, Pielou 1991). They warn against trying to recreate presettlement vegetation—it may not be feasible. Pielou (1991) stated "At no time has there been a return to 'things as they were.'" Furthermore, the future will be different from the past.

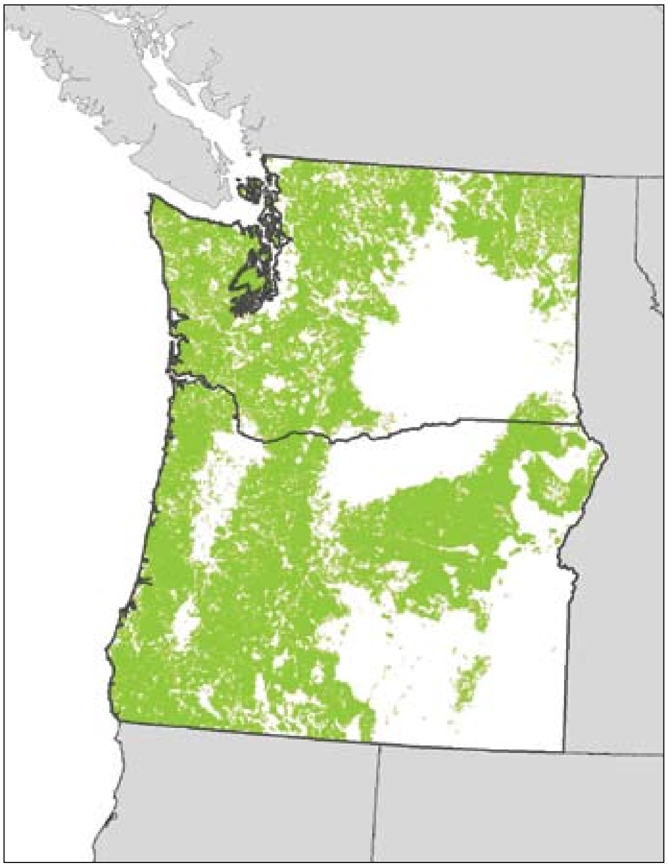
Humans have been an overriding influence on biogeography, from exterminating the largest North American mammals 11,000 years ago to using fire to manage the natural environment; bringing about large-scale vegetation change with grazing and agriculture; purposefully and accidentally introducing novel plants, diseases, insect pests, and vertebrates into vulnerable ecosystems; using persistent toxic chemicals in agriculture, forestry, and manufacturing;

- Humans have played important and diverse roles in determining biogeography.
- A complicated network of interacting factors has determined the present distribution and abundance of species.

polluting air, water, and soil; and changing the global climate (Blondel 1987, Bonnicksen et al. 1999, Diamond 1998, Krech 1999, Palumbi 2001, Pyne 1997, Wright 1992).

The amount of forested area in the United States increased from 1952 to 1963, peaking at 309 million hectares, and then declined to 303 million hectares by 1997—a loss of 6 million hectares, or 2 percent (roughly the size of West Virginia); current projections suggest another 3 percent loss (9 million hectares) in total area, including a 4-percent loss of privately owned forests by 2050 (Alig et al. 2003). Along the Pacific coast, the 92 million hectares of forest existing in 1953 is expected to decline to 84 million hectares in 2050—a 9-percent decline (almost half the size of Washington state); however, private forests will decline from 34 million to 28 million hectares—a decline of 17 percent owing to land use changes (fig. 17). The climate change hypothesis predicts that the geographic range of forests will shrink owing to catastrophes or dieback and will be replaced by grasslands (Loehle 2000). Mote (2003) reports that temperatures and precipitation in the Pacific Northwest in the 20th century increased at rates higher than the global average, with effects on flora and fauna. Global climate change, changes in regional climates, and changes in land use by people have strong effects on species, biotic communities, and even biomes (Hansen et al. 2001). Climate has a strong influence on PNV and natural disturbance regimes.

Figure 17—Forty-eight percent of Oregon and Washington is covered by forest—approximately 20 million hectares or 78,000 square miles. Graphic by D. Olson.



Biogeographic diversity includes endemism and taxonomic distinctiveness, whereas local diversity focuses on numbers of species and distribution of individuals among species. The two are not necessarily positively correlated. For example, the Olympic Peninsula of Washington joined the mainland of North America because of plate tectonics but remained ecologically relatively isolated; thus, the peninsula has both numerous examples of endemism (at high elevations) and high diversity locally (at low elevations) and regionally across the peninsula, owing in part to a dramatic precipitation gradient. For example, tree crowns on the western peninsula may harbor 77 species of epiphytic plants, and tree boles may support 70 epiphytes. The endemic Roosevelt elk influences both forest structure and succession, reducing shrubs and promoting grasses (fig. 18). The magnificence of the elk and the forest caused President Grover Cleveland to set aside 891,000 hectares as the Olympic Forest Reserve in 1897; in 1907, President Teddy Roosevelt created the Mount Olympus National Monument; and in 1938, President Franklin Roosevelt created the Olympic National Park (Sharpe 1956). Islands, on the other hand, may have high endemism but few species (MacArthur and Wilson 1967, Whittaker et al. 2001). The mammalian fauna of the archipelago of southeastern Alaska provides a Pacific Northwest example of high endemism and few species.

Residual historical patterns from geologic history, climate, and physiography (e.g., biogeographic barriers such as mountain ranges, deserts, large rivers, and oceans) explain much of *regional diversity*. Western North America has 95 floristic associations each characterized by a flora, biogeographic range, and bioclimatic conditions. Washington and Oregon comprise 15 physiographic (landform) provinces, each containing multiple vegetation zones (Franklin and Dyrness 1973). Successional and developmental patterns differ significantly among the zones. Multiple types of biotic communities occur within each zone, with a total of almost 400 types. Johnson and O'Neil (2001) linked 541 species of indigenous vertebrates to 85 types of vegetation cross-classified by 26 *forest structural conditions* and 20 shrub- and grassland-structural conditions in Washington and Oregon (table 10).

The area west of the Cascade crest in Washington and Oregon contains nine major physiographic provinces, a dozen vegetation zones, and four major biogeographic barriers (the alpine of the Cascade Mountains on the east, Puget Sound in north-central western Washington, the Pacific Ocean on the west, and the Columbia River separating Washington (north) from Oregon (south). Soils range from serpentine inclusions in the south to uplifted marine sediments, volcanic ash, volcanic basalts, outflows of material from the bursting of glacial dams on Lake Missoula in distant Montana, glacial moraines, glacial outwash plains, colluviums, and alluviums with organic matter practically absent to deep layers of humus, litter, and coarse woody

Figure 18—A bull Roosevelt elk. Photo by A. Carey.

debris (standing dead trees, fallen trees, stumps, and large tree parts), depending on locale and management history.

The area is characterized by wet, mild winters, cool, dry summers, and a long frost-free season. During all seasons, prevailing westerly winds are moist. Climatic diagrams show typical Mediterranean curves, but summer fog provides about 200 millimeters of additional water and extended periods of cloudiness that reduce evaporation. During the 20th century, the region became significantly warmer (by 0.9 °c) and wetter (14 percent wetter), warming at a rate faster than the global average (Mote 2003). The vegetation spans the gamut from Mediterranean types in the Mixed-Conifer/Mixed

Table 10—Examples of wildlife habitat relationships in Oregon and Washington forests

East-side species occurrences and forest types:

Taxon	Mixed conifer	Lodgepole pine	Ponderosa pine	Upland aspen
Amphibians	12	9	13	4
Reptiles	11	12	21	5
Birds	116	83	131	77
Small mammals	43	26	31	24
Bats	11	9	15	5
Carnivores	18	13	14	10
Ungulates	9	8	7	5
All species	220	160	232	130

Source: Sallabanks et al. 2001.

West-side species occurrences and structural stages:

Taxon	Grass/forb	Shrub/seedling	Sapling/pole	Giant trees
Amphibians	19	19	20	28
Reptiles	19	16	16	17
Birds	61	92	98	140
Mammals	66	65	64	78

Source: Olson et al. 2001.

West-side species occurrences and habitat elements:

	Amphibians	Reptiles	Birds	Mammals
Rock/talus	3	10	27	35
Fallen trees	12	5	18	50
Duff/litter	10	4	5	19
Moss	1	0	5	4
Snags	4	0	57	22
Shrubs	1	0	21	11
Live trees	3	0	72	37

Source: Shield et al. 2002.

Evergreen Zone in the south (fig. 19A) to Idaho fescue grasslands and oak woodlands along the Rogue, Umpqua, and Willamette River valleys and the Puget Trough (fig. 19B) to subalpine fir, alpine meadow, and 27 glacial systems on Mount Rainier up 4,400 meters above sea level (fig. 19C) to sand dunes and shore pine at the ocean edge (fig. 19D) to conifer rain forests near sea level on the Olympic Peninsula (fig. 19E) (Daubenmire 1978, Franklin and Dyrness 1973, Peinado et al. 1997).

Figure 19—Vegetation variations of the Pacific Northwest: (A) redwoods of northern California; (B) oak grasslands near Corvallis, Oregon; (C) Mount Rainier, Washington; (D) coastal conifers along the western edge of the Olympic Peninsula; and (E) towering Sitka spruce and western redcedar in the Hoh Rainforest. Photos by A. Carey.

In Pacific North America, there are four major physiognomic groups of forests plants:

- Sclerophylls—367 taxa in oak forests and chaparrals.
- Acicular—187 taxa in upland interior forests of true fir, pine, sequoia, juniper, and some oak groups.
- Temperate—315 taxa in forests of redwood, western redcedar, western hemlock, subalpine fir, and Douglas-fir.
- Boreal—237 taxa.

Not only is the Olympic Peninsula a hotspot of endemism, the entire Pacific Northwest has a number of well-known vertebrate endemics, including Keen's mouse, Douglas' squirrel, Townsend's chipmunk, mountain beaver, red tree vole, and shrew-mole—the latter three genera are unique to the Pacific Northwest. Among birds, the northern spotted owl is a well-known subspecies unique to the Pacific Northwest. There are also more than 62 species of reptiles and amphibians, with more added as their taxonomy is revised and expanded (Leonard et al. 1993, Nussbaum et al. 1983); endemics include Cope's giant salamander, the Oregon slender salamander, Larch mountain salamander and others, including some endemic to the greater Northwest, such as the tailed frog. The transition from the Western Hemlock Zone to the Mixed-Conifer Zone is a zone of speciation for chipmunks and red tree voles.

The first sawmill in Oregon was established in 1829, and there were 173 mills by 1870. Large catastrophic disturbances occurred during the 20th century (e.g., the 1933 Tillamook Burn consumed over 97,000 hectares, and the 1962 Columbus Day Storm blew down 6 billion board feet of timber). Despite widespread logging, natural catastrophes, human-caused fires, and human settlement, western Washington and Oregon are still dominated by forests. Western Oregon is 80 percent forested with 52 percent federal, 41 percent private, and 7 percent state forest. However, of this forested area, 78 percent is less than 120 years old. Western Oregon does have 3.7 million hectares of wilderness (Campbell et al. 2002). Historically, the primary catastrophic disturbance in western Washington and Oregon has been fire. In Douglas-fir/western hemlock, Pacific silver fir, and subalpine forest types, fires have been of high severity but low frequency, and in mixed evergreen, dry Douglas-fir, and red fir forest types, fires have been of moderate severity and frequency (Agee 1998). Additional large-scale-disturbance windstorms (e.g., the 1921 blow in Washington) and smaller scale-disturbance ice storms have been relatively uncommon, and forest grew to ages of 250-, 500-, or 1,000 years or more.

Figure 20—Basalt cliffs line the edge of the Salmon River, Idaho, and provide a stunning backdrop for recreational activities, such as kayaking. Photo by A. Carey.

On the east side of the Cascade Range of Oregon and Washington, massive basalt flows covered with volcanic ash extend to the Salmon River in Idaho where they abut uplifted marine sediments (fig. 20). Mountains to the east and west form a large basin with borders of strong moisture gradients and dissected by long rivers, with the Columbia River predominant. Vegetation is diverse owing to the variety in climate, geology, landforms, hydrology, flora, fauna, and disturbances by fire, insects, pathogens, and water (Hessburg et al. 2000). Differences in physiography, lithology, topography, geomorphic processes, and climate produce broad-scale patterns; environmental gradients, successional and developmental dynamics, and patch-scale disturbances produce meso-scale patterns. Forests dominate to the north and on the slopes and foothills surrounding the basin and have increased in the Blue Mountains, Columbia Plateau, and Upper Snake River with fire suppression. Precipitation has increased markedly (by 38 percent) in the north-central area in the 20th century (Mote 2003).

Hemstrom (2001) emphasized that not only are vegetation patterns a result of such environmental variation and disturbances at multiple scales, but also that vegetative patterns influence the amount, severity, and distribution of disturbances by insects, pathogens, and fire. Numerous bark beetles (Hayes and Daterman 2001) and insect defoliators (Torgersen 2001) have major impacts on the forests. Root diseases are common (Thies 2001) as are dwarf mistletoes (fig. 21), rusts, and stem decays (Parks and Flanagan 2001). Historically, fire tended to occur at higher frequencies and lower severities (but still at scales of more than 10,000 hectares) compared to west-side forests (Agee 1998). Well before the arrival of settlers from the east, less than 3 percent of east-side forest was old growth, and it was in isolated patches (Youngblood 2001) (fig. 22). Thus, it appears that east-side forests exhibited a relatively fine-scale mosaic of different communities and developmental stages (intercommunity mosaic) compared to a relatively fine-scale developmental (intracommunity) mosaic in west-side forests.

Figure 21—Dwarf mistletoe. Photo by A. Carey.

Today, advanced forest succession and associated accumulations of biomass are increasing vulnerability of forests to catastrophic disturbances by insects, diseases, and fires (Tiedemann et al. 2000) (fig. 23). This region has high floristic diversity, with many endemics adapted to disturbance, owing to its complex biophysical environment (Croft 2001). Similarly, many of the indigenous vertebrates are disturbance adapted, benefiting from mosaics, including lynx, wolverine, and fisher (Bull et al. 2001) and a number of birds, especially those dependent on dead trees, including seven species of woodpeckers and nuthatches (Bull and Wales 2001b); seven amphibian species are of conservation concern and sensitive to disturbance (Bull and Wales 2001a).

Current vegetation patterns are a result of the interactions of grazing, timber harvest, tree planting, fire suppression, and lack of active management after planting, and topographic position. Ridge, slope, footslope, plains, and toeslopes all historically supported different communities (late-seral single-layer forest, early-seral-

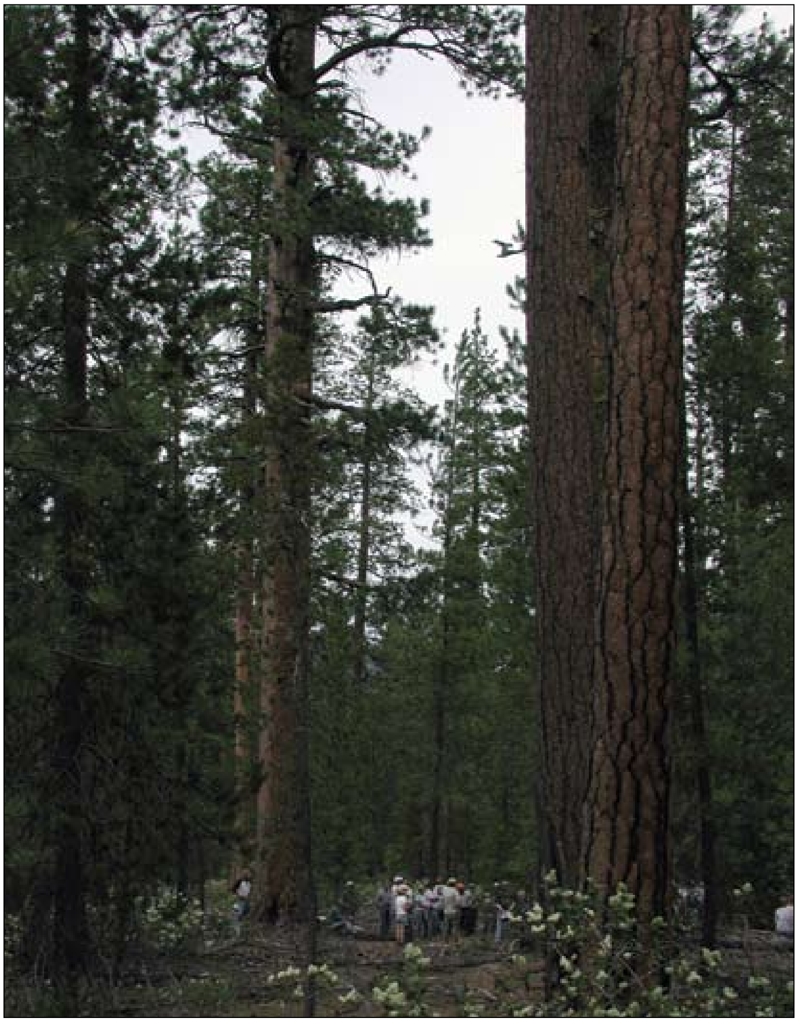


Figure 22—East-side forests: an isolated old-growth patch near Sisters, Oregon. Photo by A. Carey.

midseral forest mosaic, late-seral multilayer forest, late-seral single-layer forest, and midseral broadleaf-tall shrub mosaic, respectively) (Hemstrom 2001). Resource management has produced late-seral multilayer and early-seral mosaics on most sites with increased intertree competition, competition stress, increased susceptibility to insect attack, pathogens, and fire, and a switch from local to broad-scale disturbance patterns that changed not only patterns of plant species but vertebrates as well.

Human and natural disturbances may well have changed some ecosystem processes; for example, loss of a successional mosaic with actinorhizal shrubs (snow brush and bitter-brush) that normally replenish soil nitrogen lost by fire through nitrogen fixation could lead to long-term nitrogen depletion and reduced productivity (Busse 2000). Anthropogenic disturbances have also displaced native biotic community types and reduced productive potential for 17 or more PNV types, especially salt desert shrub, Wyoming big sagebrush/warm basin big sagebrush, mountain big sagebrush/mesic-wet, mountain big sagebrush/mesic-wet with juniper, and wheatgrass grasslands, making it difficult or impossible to restore these ecosystems to historical conditions. Major sources of change include livestock grazing, invasive species, changes in fire regimes, and climate change (Bunting et al. 2002). Hessburg et al. (2000) summarized the salient changes: decline in shrub land, loss of herb land, shift from early- to late-seral species, decline in western white pine in Idaho and Montana, dominance by shade-tolerant conifers in the Great Basin, and loss of patches with old-forest character.

Figure 23—An example of a low-intensity fire in a west-side second-growth forest. Photo courtesy of the USDA Forest Service.

These kinds of changes are common in interior western North America (fig. 24). For example, in the Targhee National Forest in Idaho, logging, grazing, and fire suppression prompted a transition from a fire-driven mosaic of grass, shrub, broadleaf, and mixed-forest community types to a conifer-dominated landscape—aspen declined from 37 percent to 8 percent, and conifer forests increased from 15 percent to 50 percent of the landscape. The problems here are not ones of fragmentation but increasing patch sizes and reduced disturbance frequencies reducing the diversity of communities in the landscape (Gallant et al. 2003).

Thus, at the *landscape scale*, topography, soils, disturbance regimes, tidal dynamics (in coastline landscapes), linked series of

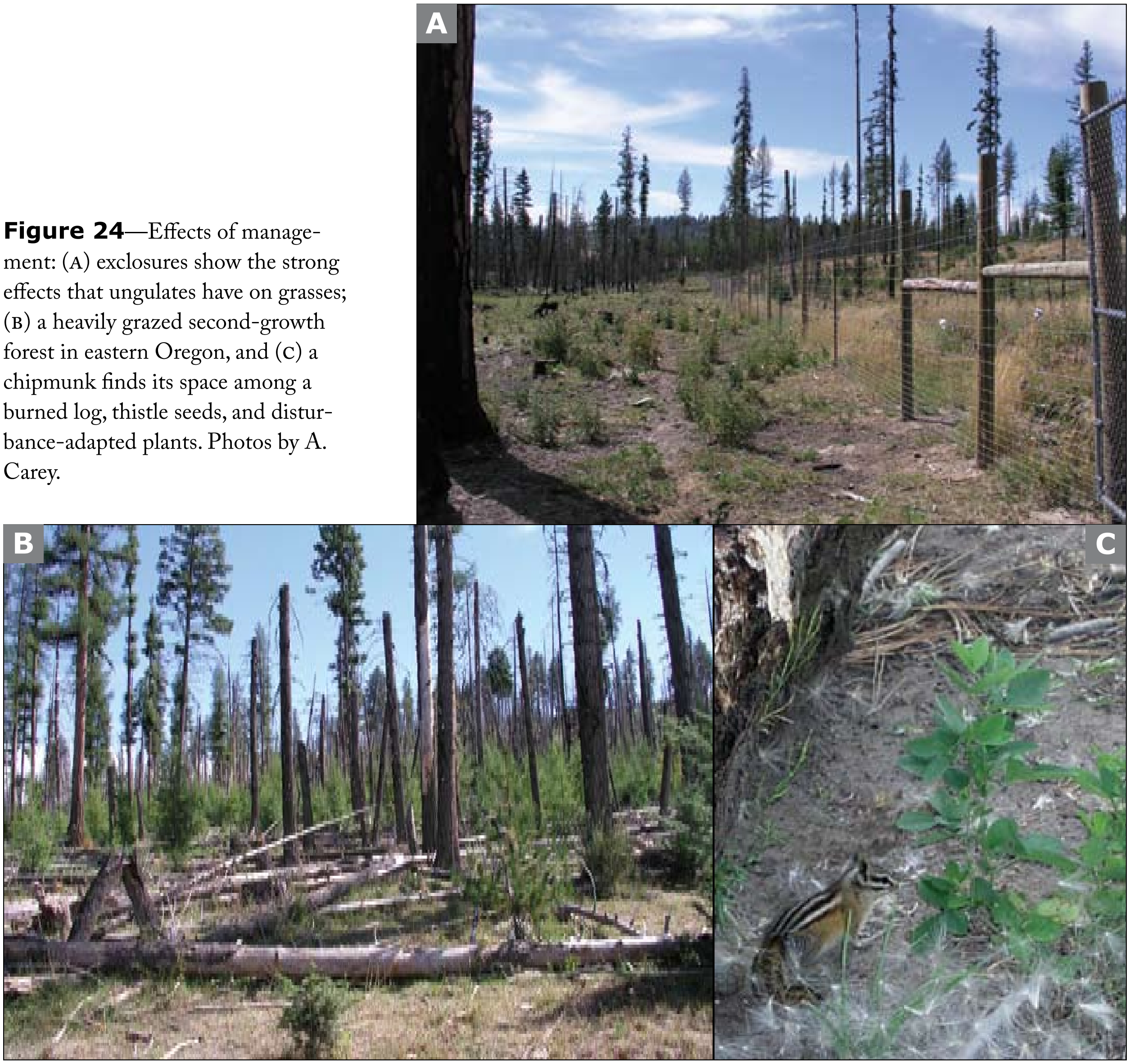


Figure 24—Effects of management: (A) exclosures show the strong effects that ungulates have on grasses; (B) a heavily grazed second-growth forest in eastern Oregon, and (C) a chipmunk finds its space among a burned log, thistle seeds, and disturbance-adapted plants. Photos by A. Carey.

events, management regimes (the nature of the shifting steady-state mosaic of a regulated forest), and cumulative effects of management activities are important. At *local scales*, microenvironmental variation, intermediate disturbances, community dynamics, patch dynamics, and management activities are important. However, Blondel states that "Since processes which produce biological diversities operate differently, and at different rates …along the scales of space, time, and change, many theories … are … more complementary than conflicting" (Whittaker et al. 2001).

Disturbance has long been recognized as a primary underpinning of biological diversity in landscapes.

Landscape Ecology

Diversity in a landscape will result from (1) natural random sampling of the regional species pool (Hubbell 2001) and (2) a variety of deterministic factors and processes operating at various scales including topographic, climatic, and edaphic diversity, history of disturbances (frequency, intensity, spatial extent, duration, and variance in times since disturbance), structural and biological legacies retained after disturbances, distances from sources of colonizers for various species, the vagility (dispersal ability) of those species, and the dynamics of biotic communities (reorganization, succession, development, creative destruction). Disturbance has long been recognized as a primary underpinning of biological diversity in landscapes because it is a major determinant of spatial heterogeneity at multiple scales (Bormann and Likens 1979, Canham et al. 1990, Carey et al. 1999c, Connell and Slatyer 1977, Foster et al. 1998, Franklin et al. 2002, Levin and Paine 1974, Oliver 1981, Petraitis et al. 1989, Pickett 1976, White 1979, Whittaker 1975). Examples of large, infrequent disturbances include the 1938 Northeast hurricane, 1980 eruption of Mount St. Helens, 1993 Tionesta tornado, 1998 Yellowstone fire, and the 1993 Mississippi floods (Foster et al. 1998). The resulting landscape patterns were controlled by interactions among the specific disturbance, the abiotic environment (especially topography), the vegetation at the time of disturbance, and the enduring legacies left by the disturbance. Northern coniferous forests are characterized by infrequent stand-replacing fires driven primarily by climate, strongly influential of plant population structure, genetics, and evolution, and inducing spatial heterogeneity (Turner et al. 2003). Spatial heterogeneity was more important than any other single environmental variable in explaining the abundance of mule deer in California—fine-grained mosaics with abundant edges, irregularly shaped patches, and high fractal dimensions allowed deer to exist within small home ranges

Figure 25—A patchy landscape dominated by clearcuts. Photo courtesy of USDA Forest Service.

(Kie et al. 2002). Heterogeneity among communities in the landscape generally increases the number of species in the landscape. For example, canopy cover gradients promote diversity of larval amphibians and coexistence of spring peepers and wood frogs in forests (Skelly et al. 2002).

Not all disturbances create complexity and heterogeneity, and not all heterogeneity promotes diversity. Traditional clearcutting, for example, produces regeneration sites that are as uniform as possible (fig. 25). When followed by planting (and often herbicide application), a simple monoculture with reduced diversity may result. In Pacific Northwest forests, most forest species are found in old-growth forests, but both managed and natural forests in closed-canopy stages from 30 to 200 years old may have markedly reduced diversity. Landscapes managed under short-rotation timber management may have increased abundances of exotic and ruderal species and markedly decreased diversity of native species (plants, fungi, and animals) (Carey 2003a, 2003b, 2003c; Carey et al. 1999c, 1999d). With short rotations and intentionally simplified stands of timber, whatever complex forest is left in the landscape is highly isolated from other complex forests and will remain so for quite some time (a century or more) even if management for timber stops. Such a landscape suffers from both loss in area of complex forests and fragmentation. For example, clearcuts less than 12 years old in British Columbia are significant barriers to dispersal of red-legged frogs, depending on weather and body mass of the frog. The warmer and drier the clearcut, the less permeable the clearcuts become because of physiological constraints on frog respiration (Chan-McLeod 2003).

Clearcuts may also be hostile environments for California red-backed voles because of lack of moisture, food, and cover (Clarkson and Mills 1994, Hooven and Black 1976, Mills 1995, Tallmon and Mills 1994), and for Douglas' squirrels and northern flying squirrels because of lack of trees. Closed-canopy competitive-exclusion forest communities with their sparse understories are inimical to Townsend's chipmunk, Keen's mouse, Oregon creeping voles, and a variety of other mammals. When rotations are short (say under 40 years), more than 25 percent of the landscape would be maintained in inhospitable conditions for animals of various life histories (Carey et al. 1999d). Thus, the life history of a species, the nature of the ecotones (a transitional zone between two communities containing the characteristic species of each), and the contrasts between juxtaposed communities determines the ecotone's degree of permeability and function as a boundary between communities—in other words, whether a hospitable mosaic is being maintained or whether the habitat of some species is being fragmented (Cadenasso et al. 2003a, 2003b).

Ecotones—loosely referred to as edges or boundaries—influence the flow not only of organisms but also materials and energy through mosaics. It is important to note that this is often a two-way flow—not only can a clearcut or field influence the microclimatic environment (light, temperature, and moisture) of a forest (Chen et al. 1995), but the reverse can happen also (Cadenasso et al. 1997). These edge effects (alteration of environmental conditions by the presence of a boundary or ecotone between two relatively homogeneous and usually contrasting environments) arise whenever areas are partitioned into patches, naturally or anthropogenically. Care must be taken, however, not to treat them as static; they are often rapidly changing in forested landscapes. Edge effects differ with disturbance regimes, time since creation, development of a sidewall of vegetation, successional or developmental state, and topographic position. Ecotones are complex three-dimensonal (at least) zones characterized by both above- and belowground gradients. These gradients exist even in the fine-scale mosaics with openings of 0.0 to 1.0 hectares (York et al. 2003). A tenfold increase in area of opening can produce a 34-percent increase in height growth of seedlings in gaps. Linear discontinuities such as narrow roads may not drastically alter the ecotone between two communities (Cadenasso et al. 1997). Understanding of how ecotonal boundaries influence the functioning of ecological systems is poorly developed (Cadenasso et al. 2003a, 2003b, 1997).

Natural catastrophic disturbances and intentional-management catastrophic disturbances, such as variable-retention timber harvesting, leave and maintain substantial biological legacies for the newly reorganizing forest. In Pacific Northwest landscapes under natural disturbance regimes or managed on long rotations with an emphasis on intracommunity biocomplexity, occasional patches of early-successional communities may add substantial species diversity to the landscape. Variation in species diversity among communities in landscapes is due to the structure, composition, and productivity of the various biotic communities, unless a community type is rare and patches are very small or small and isolated from similar communities—then it might have reduced diversity (Aars and Rolf 1999; Bayne and Hobson 1998; Bender et al. 1998; Boulinier et al. 2001; Brothers and Spingarn 1992; Debinski and Holt 2000; Lindenmayer et al. 1999, 2002; MacArthur 1965; MacArthur and Wilson 1967; McIntyre and Hobbs 1999; Opdam 1991; Robbins 1982; Whitcomb 1977; Whitcomb et al. 1976; Yahner 1985, 1988; and many others).

The effects of island size and distance from the mainland and agricultural-urban woodlot size and distance from other woodlots have been shown to reduce diversity and abundance of numerous species of various life forms. Island biogeography gave rise to conservation biology, which focuses on reserve design (single large versus several small reserves), degree of isolation of forest fragments, and the need for connecting corridors between fragments of isolated forest. However, one size never fits all; even within the narrow group of mammalian predators within a small region, measurement and mitigation of fragmentation must be scaled to species mobility (Gehring and Swihart 2003).

Fragmentation

In recent years, fragmentation has been viewed as the primary threat to diversity. Fragmentation routinely is conflated with (1) destruction of forests; (2) deliberate change in forest type (e.g., conversion of deciduous forest to conifer monocultures); (3) change in seral-stage structure of forested landscapes; (4) change in disturbance regimes of particular landscapes and regions; (5) direct human disturbance of wildlife (such as noise and mechanical impacts of forest management activities), recreational activities (hunting, fishing, birdwatching, hiking, and sightseeing), nature study, and ecological research; (6) effects of roads, which range from habitat loss to barriers to movement, pollution, and killing of wildlife by vehicles; (7) spread of exotic species; and (8) negative effects on soils, hydrology, and aquatic systems. It can be useful to distinguish between the effects of loss of forests to other uses of the land (loss of total area available for habitation by various species and loss of particular types of biotic communities) and fragmentation (isolation) of the remaining forest suitable for habitation by a species or group of species. Fragmentation refers to those effects of long-term (multiple decades to centuries) isolation of a plant community type or seral stage by markedly unlike types; short-term isolation may have no long-lasting effects. Long-term isolation includes effects on dispersal processes; small population sizes (which result in increased probability of genetic inbreeding, reduced fitness, and extirpation by various causes); effects on microclimatic and other physical modifications of isolated patch by its matrix; competition, parasitism, and predation by species well adapted to the matrix and matrix-patch interface; and aggregations of habitat elements of various wide-ranging species at scales mismatched to the species' life histories.

Fragmentation can affect forests in several different ways. For example, old-growth remnants can contribute to much of the species diversity in young forests. The amount of old-growth forest in an agricultural landscape can account for more than 65 percent of the variation in late-seral herb diversity within recently established forests (although, it may still take centuries for all herbs to recolonize and come to some equilibrium in species diversity) (Vellend 2003). In contrast, small remnant patches well separated from one another may reduce the ability of a forest to support local vertebrate populations. For example, the Oregon white oak communities of the Puget Trough of Washington are embedded in a prairie, wetland, and second-growth Douglas-fir matrix. Oak patches are dwindling in size owing to invasion by Douglas-fir and fire exclusion, and in number owing to agricultural, suburban, and urban development. The result is the near and perhaps imminent extirpation of the western gray squirrel in western Washington (Bayrakci et al. 2001, Ryan and Carey 1995). Fragmentation can also lead to scale mismatch. For example, when second-growth Douglas-fir in the competitive exclusion stage fragments old-growth Douglas-fir forest, it may result in an increase in the total area traversed by spotted owls to meet their minimum habitat area requirements at costs substantial enough to produce instability in owl pair membership (Carey et al. 1992).

Logging of old-growth forests in the Pacific Northwest has reduced markedly the total amount of old growth and produced a distribution of old growth characterized by large blocks, donuts (large blocks at mid elevations but with centers at high elevations without forest), and scattered small patches embedded in a landscape of second-growth forest. Although some scattered patches are small enough to suffer climatic influences of adjacent nonforest (shrub-sapling stages), the nonforest usually develops quickly into closed-canopy forests, and the remnant patches of old growth retain their associated flora and fauna (e.g., Neotropical migratory birds, Carey et al. 1991; aquatic amphibians, Bury et al. 1991b; vascular plants, fungi, and small mammals, Carey 1995, Carey and Johnson 1995, Carey et al. 1999b, Corn and Bury 1991a; and invertebrates, Marcot 2004). For these organisms, logging old growth led to habitat loss and habitat degradation but did not lead to effects of fragmentation, although recolonization of logged-over streams by aquatic amphibians did not take place after four to five decades (Bury and Corn 1991, Corn and Bury 1989), and questions remain about the ability of red tree voles to colonize developing second-growth forests (Carey 1999; Corn and Bury 1986, 1988; Gillesberg and Carey 1991).

A recent survey revealed little experimental evidence to support the contention of fragmentation effects (Debinski and Holt 2000). Only 20 experiments were uncovered, 6 in forests and 14 in old fields. Arthropods showed the best fit to the theory. Birds, mammals, early-successional plants, long-lived species, and general predators did not respond as expected. The reasons for lack of fit to theory were edge effects, competitive release, and the spatial scale of the experiment.

Whereas fragmentation is often stated as deleterious to biological diversity, mosaics are thought to increase diversity. Thus, it is important to distinguish between mosaics and fragmentation. Mosaic phenomena belong to two broad subgroups (Whittaker and Levin 1977):

- Intracommunity patterns related to microsite differentiation and species responses to it, such as development of habitat breadth or diversity in vegetation site types—microsites are the places where plants are rooted, and variation in microsite and the species occupying them produces a mosaic differentiated both physically and biologically.
- Intercommunity successional and developmental mosaics for which disturbance is a major determining force.

There is almost universal occurrence of mosaics in natural biotic communities. The diversity of these internal mosaics is a consequence of the evolution in natural communities toward diversity of both species and interspecies relationships. Disturbance disrupts patterns in vegetation communities owing to environmental gradients, producing a mosaic of communities. The disturbance mosaic and the mosaic owing to variation in biotopes (physical landscape elements, or *places of life*; larger physical sites that support biotic communities) result in a variety of more or less stable states in the landscape in the absence of further disturbance.

The pervasive notion that the *matrix* in which forest *fragments* are embedded is hostile to organisms within those fragments is often, even usually, not the case. A landscape considered structurally fragmented may still be functionally *variegated* (diversified) to some species (McIntyre and Hobbs 1999). Several factors are often overlooked when applying principles of island biogeography to old-growth forests in forested landscapes:

- Within such landscapes, the majority of old-growth-associated species are found in most seral stages of forest development (Ruggiero et al. 1991).
- Almost all old-growth-associated species will be found in

younger forests if those forests have significant biological legacies and intracommunity complexity (Carey 1989; Carey et al. 1992, 1999b, 1999c).

- Connectivity in a forested landscape can be achieved by several mechanisms besides corridors (including riparian areas) dedicated to spatial connectivity:

    - Permeable edges—edges between seral stages that do not present barriers to dispersal—also provide spatial connectivity.
    - Maintenance of shifting steady-state mosaics in forests managed under long rotations provides temporal connectivity among patches of old-growth/old-complex forests.
    - The earlier the seral stage—the shorter its duration and the lower its proportion of the landscape under intentional management for biodiversity (Carey et al. 1999c) and the greater the likelihood of maintaining old-growth species, such as the spotted owl (Carey et al. 1992, Carey and Peeler 1995) and northern goshawks (Finn et al. 2002) in the landscape.
    - Various landscape elements, such as areas with potential for deep-seated or rapid-shallow landslides, wetlands, and rock outcrops, maintained in intact forest contribute to a finer scale mosaic than most operational landscape units, providing refugia for organisms of limited vagility and foraging opportunities for organisms of high mobility.
    - Roads provide dispersal corridors, facilitate movement, and increase accessibility of different patch types for many native species.
    - High nest parasitism and predation are often associated with forest edges in agricultural-urban landscapes. However, in forested landscapes, parasitism may be rare in ecotones, and predation may be more prevalent in interiors of biotic communities than in ecotones (Tewksbury et al. 1998).

Allen and Hoekstra (1990) suggested the useful analogy of biotic communities in a landscape as wave interference patterns between processes and organisms interfering with and accommodating each other—a more useful, dynamic, concept than specific black-and-white communities (either habitat or nonhabitat for various species) etched into a map of places in the landscape. The main evidence for fragmentation effects has been from studies of birds in generally nonforested landscapes. In managed forest landscapes, however, a proliferation of songbird fragmentation studies has produced a growing awareness that avian diversity and abundance reflects the quantity of the different biotic communities available rather than the spatial arrangement or *fragmentation* of any one of them (Cushman and McGarigal 2003, Lee et al. 2002, Lichstein et al. 2002, Lindenmayer et al. 2002). Furthermore, the accumulated research does not support the concepts of consolidating clearcutting to reduce edge and landscape heterogeneity. Haila (2002) described the concept of island biogeography as an "intellectual attractor" that is too ambiguous to be useful in terrestrial environments—all natural environments are *fragmented* and that different organisms and ecological systems experience *fragmentation* in variable and even contradictory ways. Thus, any analysis of fragmentation must be context specific given the variety of organisms and multiplicities of temporal and spatial scales. In terrestrial systems, it is impossible to distinguish between disturbance and fragmentation as conventionally defined; distinguishing between fragmentation and a mosaic is a matter of degree and permanence of change in capacity to support a complete biotic community.

Isolation, Connectivity, and Viability

Ecologists have focused on number and overall connectivity of patches of habitat of particular species or of biotic communities supporting assemblages of species as landscape features. Landscape details include the size, shape, and edge permeability of the patches (Buechner 1989). Much discussion relates to the viability of a species metapopulation in a patchy environment in which local populations are subject to periodic extinction. Viability, under these premises, depends on successful dispersal and colonization of vacated or underpopulated patches. Some patches may be dispersal sinks that absorb more dispersers than they produce, effectively removing individuals from the metapopulation.

Four factors influence the movement of animals into sinks: (1) the perimeter-area ratio of the source patch, (2) the size of the sink relative to the size of the source, (3) the distance that dispersers can travel through a sink, and (4) the ease with which individuals move across the edges of the source patch. Sinks are only important to the degree to which they absorb individuals that may have gone on to colonize vacated habitats or individuals that emigrate as a matter of life history from an underpopulated patch and subsequently are unable to return. A sink can be a valuable source of colonists when it is near a source patch, yet does not suffer from the same forces that occasionally bring about extinction of the population in the source patch. Sources that routinely produce surplus animals that immigrate may occasionally suffer abrupt extinctions of their own population (or in the case of overdispersed species, such as the spotted owl, the death of a member of a breeding pair). Defining landscapes simply in terms of sources and sinks is as problematic as defining them in terms of habitat and nonhabitat. Few documented cases exist of strict sinks, but many exist of varying quality of habitat.

Emphasis on patchiness in relation to dispersal and colonization stems from island biogeography (MacArthur and Wilson 1967). A crucial difference between islands and continental systems is the ability of species to move between areas. Island biogeography sought an understanding of the species-area relationship and factors influencing the relationship (e.g., isolation and island elevation) in the context of islands in an inhospitable sea (MacArthur and Wilson 1967). Confusion often results from application of island concepts to forested landscapes (Carey and Harrington 2001). Misapplication of island concepts has contributed to failure to identify factors relevant to diversity at particular scales in continental environments, especially because scale of isolation differs with species life histories (Whittaker et al. 2001). Insularization of terrestrial communities occurs when climate change produces isolated mountaintop communities (Brown 1971) or when land use within a landscape changes dramatically, for example, returning Neotropical migratory birds encounter increasing fragmented forests as agriculture isolates woodlots in the Midwest (Whitcomb et al. 1977).

In western Washington, the western gray squirrel once found habitat in the Oregon white oak-dominated ecotones between prairies, Douglas-fir forest, and wetlands in landscape mosaics maintained by judicious prescribed burning by indigenous peoples to maintain an important source of medicinal plants and carbohydrates such as camas root. Gray squirrels require more than 5 hectares of juxtaposed oak woodland, Douglas-fir forest, and wetlands for habitation (Ryan and Carey 1995); a minimum effective population size in this environment would certainly require more than 50 occupied sites within a small landscape for genetic reasons alone (Soulé and Wilcox 1980). In the last century, fire suppression and fire exclusion have led to invasion and dominance of the oak woodland-prairie-wetland mosaic by Douglas-fir (Thysell and Carey 2001b). Reduced frequency of occurrence, size, and vigor of oak woodlands and motor vehicle traffic along roads near the remaining woodlands now threatens the continued existence of populations of western gray squirrels in western Washington (Ryan and Carey 1995). Even though a substantial area of oak woodlands and oak-fir ecotones remain, they are widely scattered across a landscape dominated by Douglas-fir forest, prairies, and human development. Western gray squirrel populations have crashed (Bayrakci et al. 2001). Although underconnected landscape elements can produce problems in dispersal, colonization, and maintenance of viable populations, excessive connectivity between individual organisms and homogeneity of communities can lead to increased susceptibility to density-dependent catastrophic disturbances, such as disease.

Temporary Isolation

In the western Washington lowlands, isolation by glaciation, postglacial hydrologic events, maintenance of landscape mosaics by indigenes, agriculture, forestry, development of transportation networks, and urbanization resulted in genetically distinct populations of northern flying squirrels in the Black Hills and the Puget Trough lowlands (Wilson 1999b). Timber harvest within the lowlands reduced genetic variability in local populations in the short term, but genetic diversity recovered rapidly because of outbreeding with nearby local populations. The flying squirrel is remarkably well adapted to avoiding inbreeding with its promiscuous mating system and long (relative to body size and population density)-distance movements (1 to 5 kilometers) by males to find mates. Multiple paternities of single litters have been documented (Wilson 1999b). Similarly, in Finland, the Siberian flying squirrel is threatened by past land use changes but now benefits from improved landscape permeability afforded by second-growth forest of low-quality habitat (Reunanen et al. 2000).

Conclusions on fragmentation in other studies of small mammals in the Pacific Northwest are debatable (Carey and Harrington 2001). Studies of Keen's mouse isolated in old-growth forests separated by clearcuts raised concern about effects of fragmentation (Lomolino and Perault 2000). Other studies found California red-backed voles isolated in old growth by clearcuts (Mills 1995). Both concluded there were negative effects of forest fragmentation and called for systems of reserves and corridors. Keen's mouse, however, is common in forests 40 to 90 years old with a western hemlock component (Carey and Harrington 2001, Carey and Johnson 1995, West 1991) and California red-backed voles also are common in young forests (Corn and Bury 1991a, Gilbert and Allwine 1991) (table 11). If isolated by clearcuts, isolation would be relatively short lived. Thus, temporal landscape dynamics, such as shifting steady-state mosaics maintained by regulated forests, are important considerations but rarely considered in landscape-scale studies of the effects of forest management on vertebrates.

Dispersal and Colonization

"Opportunities for movement and habitat diversification provided by the spatial aspect of the environment make possible in a variety of ways coexistence of species that could not otherwise survive together" (Levin 1976). Furthermore, if a landscape is heterogeneous, different combinations of species are likely to be favored in various locations and maintained elsewhere principally by dispersal from more favored regions, and this will act to increase the overall species richness. Dispersal in heterogeneous environments serves to lessen fluctuations in species populations and may increase population persistence by several orders of magnitude (Roff 1974a, 1974b). Dispersal is also important in colonization of newly developed regeneration niches. For example, Schwarz et al. (2003) found that, for seven species of trees at Hubbard Brook Forest in New Hampshire, environmental factors, disturbance, and competition operated within the local patch, but spatial autocorrelation suggested that neighboring patches were important as sources of colonizers consistent with seed-dispersal distance. Elevation was the primary environmental factor, followed by slope angle, and soil chemistry. In Amazonian forests, spatial heterogeneity plays an important role in the coexistence of Neotropical ant species that feed on the same species of plant. Where the food plants are found in high densities, the more fecund species dominate. Where the food plants are well distributed, the species that is the better long-distance flier dominates. A dispersal-fecundity tradeoff allows two genera to treat spatial heterogeneity in patch density as

Table 11—**Relative abundances (percentage of value in old growth) of the western red-backed vole in young, mature, and old-growth forests in the Oregon western Cascades and Coast Range**

	Seral stage		
Province	**Young**	**Mature**	**Old growth**
West Cascades	85	71	100
Coast Range	67	111	100

Source: Adapted from Corn and Bury 1991a and Gilbert and Allwine 1991.

a niche axis, and heterogeneity allows coexistence of the ants in the landscape (Yu et al. 2001).

Movement of organisms through landscapes depends on how they move and their capacity for movement. The wind-dispersed seeds of some plants and the spores of some fungi move long distances through and above the vegetation. The seeds of other plants, the spores of hypogeous fungi, and propagules of lichen move little or depend on dispersal by animals. Invertebrates exhibit huge variety in mechanisms and range in movement, moving from centimeters to kilometers. Migrating birds, waterfowl, many raptors, and bats move across the landscape in the air, well above the vegetation, little influenced by the nature of the biotic communities below, other than the contribution of the communities to the quality of the landscape as migratory corridor or as a habitat (an arrangement of patches suitable for foraging, roosting, nesting, and other essential behaviors). Other birds, in their daily activity, may confine their movements to particular strata of vegetation or show various degrees of willingness to move between landscape elements of markedly different natures. Terrestrial amphibians, reptiles, and some small mammals move through litter on the ground for relatively short distances of less than 5 to 50 meters on a daily basis (e.g., shrews and some salamanders) but farther when dispersing. Other mammals move on the surface of the forest floor from 50 to 500 meters daily (e.g., mice and chipmunks) to more than 1 kilometer (deer and elk). Squirrels (from the family Sciuridae) move daily from 100 meters to more than 1 kilometer through forest canopies (Carey 1991, 2000a).

Characteristics of the landscape that influence animal movement include environmental grain (the size of the patches within biotic communities and landscapes), sharpness of edges, nature of boundaries, connectivity, and interface permeability. Success of transit among landscape elements depends on the relative habitat quality of the various landscape elements (Basquill and Bondrup-Nielsen 1999). Adjacent elements each with high quality as habitat present few barriers to movement; the boundaries, edges, and ecotones between them have high permeability. Permeability can be measured by a species' willingness to cross the boundary. Permeability is also influenced by (1) motive to move, (2) the characteristics of the habitat of origin, (3) the characteristics of the patch of destination, and (4) the characteristics of the ecotone. A dispersing animal may be more willing to cross an unfamiliar or inhospitable environment than a foraging animal. An animal leaving a saturated or poor-quality habitat may move more willingly into a less populated or higher quality habitat.

Habitat selection itself is density dependent (Greene and Stamps 2001). Animals generally adapted to exploiting forests, for example, Neotropical migratory birds (fig. 26), may show minor effects on abundance but not distribution, in landscapes dominated by forests over 40 years old, even if the oldest forests are isolated by younger forests in the landscape. In other words, young forests are slightly poorer quality habitat for Neotropical migrants and markedly poorer for year-round resident birds, but both groups persist in the young growth, and their abundances are unaffected in the old forest (Carey et al. 1991, Haveri and Carey 2000). In Quebec landscapes where forests were fragmented by agriculture and urbanization, nonmigratory movements of breeding Neotropical migratory birds were affected by landscape composition and configuration. Other effects of fragmentation beyond habitat loss and limitation of movements among patches of habitat may include nest parasitism and predation (Belisle et al. 2001), especially in nonforested landscapes.

Linear features of the landscape, such as trails, roads, roadsides, fencerows, streams, and poorly vegetated ridgetops may variously facilitate or impede movement depending on the species. Roads and roadsides provide corridors for dispersal and enable gene flow in small mammals in fragmented forests in Australia (Bennett 1990). However, it can be difficult to distinguish a travel corridor from a linear habitat. For example, white-footed mice in the United States prefer structurally complex fencerows over their *natural* habitats of intermediate to simple structure (Merriam and Lanoue 1990).

Figure 26—A western tanager is a common spring and summer visitor to the Pacific Northwest. Photo courtesy of USDA Forest Service.

Passerine birds in Poland used shrub corridors to make greater use of a pine-meadow-lake mosaic than a mosaic without shrub corridors (Dmowski and Kozakiewicz 1990). Simulation models suggest that any corridor is better than none, high-quality corridors can increase metapopulation size, and populations in isolated patches of habitat, even if connected by low-quality corridors, are most vulnerable to extinction (Henein and Merriam 1990). In Great Britain, the European red squirrel has an effective dispersal distance of less than 1.5 kilometers between patches of forest separated by fields. Deforestation resulted in genetic isolation. Corridors that linked patches of forest and patches that were less than 1.5 kilometers apart allowed the squirrels to disperse by using patches as stepping stones. Limited reforestation allowed northern genes to leapfrog through hundreds of forest fragments and hundreds of kilometers in 20 years (Hale et al. 2001). This increased connectivity in the landscape, however, is raising fears of epidemic spread of the parapox virus that is deadly to squirrels. In Italy, extensive forest and forested corridors are allowing the spread of introduced eastern gray squirrels, which are threatening the continued existence of the native European red squirrel; the fear is that forested corridors will lead the eastern gray squirrel to France (Lurz et al. 2001).

Landscape Epidemiology

Concerns about settlers contracting zoonotic diseases (diseases of wild animals transmissible to people) in the former Soviet Union led to the development of landscape epidemiology (Pavlovsky 1966), a long-forgotten precursor to today's landscape ecology that evolved primarily from island biogeography (MacArthur and Wilson 1967). Pavlovsky died at the age of 81 in 1965. He developed his theory of the natural nidality (sensu site, nest, or niche) of pathogen persistence in 1939. Pavlovsky showed that the presence of organisms pathogenic to humans or their domestic animals could be predicted from the characteristics of the landscape. Investigation of the landscape-biotic community-pathogen complex relationship could be used to identify modifications of the landscape to break the transmission of pathogens among wild animals or changes in human use of the landscape that would reduce the risk of exposure of people and domestic animals to the pathogens. Pavlovsky implemented successful landscape management programs by using a hierarchical approach starting with biogeographic regions and scaling down to landscapes and biotic communities within landscapes. Efficacy entailed understanding the community ecology of the pathogen as well as the autecologies of the hosts and vectors of the pathogen. In the United States, landscape epidemiology has been used in research on rabies ecology and control in the Mid-Atlantic States (Carey 1982, 1985a; Carey et al. 1978), the ecology of Colorado tick fever in Rocky Mountain National Park in Colorado (Carey 1978c, Carey et al. 1980b, McLean et al. 1993), and Lyme disease in New England (Carey et al. 1980a, 1981). Studies of host-parasite systems, more than perhaps any other systems, mandate a consideration of variety in spatial scale—from landscapes of tissues within an organism (Carey and McLean 1978) to landscapes of biotic communities that support the parasite, vector, and hosts (Carey 1979; Carey et al. 1978, 1980b) and to regional (Carey 1982) and global (Carey and McLean 1983) variations in the ecology of a pathogenic organism. Epidemiology also reinforces the idea of being careful about what one wishes for—Hunter (1999) stated the goal of conservation biology was to preserve all species down to the lowest microbe; many would disagree with the values (and outcomes) implicit in that goal.

Landscape-epidemiological approaches incorporating spatial analysis in nested hierarchies of scale are now providing better understanding of diseases and parasites of wild plants, including trees. In Arizona, mistletoes that infect mesquite trees are spread by the Phainopepla, a bird that consumes its fruits and defecates its seeds. The pattern of infections and spread, however, is influenced by different factors at different scales (within tree, within the neighborhood of the tree, and across the landscape) that reflect interactions of the three species and the external environment (Aukema 2003b). Many diseases of trees are influenced by the structure and composition of biotic communities and landscapes. Basic epidemiology predicts that large numbers of susceptible hosts in contact with one another invite an epidemic—the larger the numbers, the greater the spatial extent of dense populations of susceptible individuals, and the greater the adjacencies of similar populations, the greater the epidemic catastrophe. For example, root diseases are important natural disturbance agents affecting all tree species in all forest ecosystems in eastern Oregon and Washington (Thies 2001). Shifts in tree species composition following fire exclusion (to species vulnerable to root rot), partial cutting, and management that retained high densities of trees have led to increased root disease. In fact, fire exclusion, introduced diseases, and management that produced high tree densities have led to a widespread decline in forest health (Tiedemann et al. 2000). Dense monocultures of variants ill-adapted to environmental conditions (offsite plantings) are well-known for their low vigor and susceptibility to needle diseases (Kavanagh et al. 2000) and root diseases (Filip 1999). The emergence of Swiss needle cast as a serious problem in coastal Douglas-fir illustrates these basic principles of epidemiology (Filip et al. 2000). Defoliating insects can produce major disturbances; these include spruce budworm, Douglas-fir tussock moth, Pandora moth, and larch casebearer, and others, maybe two dozen species overall (Torgersen 2001). Risks of outbreaks of these insects increase with low tree species diversity and high densities of susceptible trees.

It is also well known that introduction of novel diseases and insect pests can produce catastrophes; for example, chestnut blight, white pine blister rust, and numerous others. These introduced diseases may have surprisingly widespread effects even in the absence of dense, spatially extensive populations of susceptible individuals. For example, a disease complex is causing a decline in Pacific madrone. The primary pathogen is *Nattrassia mangiferae*, which causes cankers and shoot blight. Infected trees are stressed and become vulnerable to *Fusicoccum aesculi*, the secondary pathogen that causes branch dieback. All ages and all sizes of madrone are affected (interestingly, the complex can also cause skin disease in people and other animals). The primary pathogen was probably introduced into California with Persian walnut trees in the 1960s. The low resistance of madrone, severe weather stressing madrones, and fire suppression (fire destroys the disease inoculum) have allowed the disease to spread rapidly despite the scattered, patchy nature of madrone distribution (Elliott et al. 2002). Houston (1992) explicated a simple model for dieback and decline diseases:

Healthy trees + Stress = Altered tree tissues → Dieback

Altered tree tissues + More stress = Further alteration of tree tissues → Continued dieback.

A more complex theory emphasizes S, E, P, and B:

- S—simplified forest structure creates a predisposition to dieback;
- E—edaphically extensive sites to which the species is not well-adapted, including shallow soils poorly buffered from climatic extremes, increases probability of stress;
- P—periodically recurring perturbations owing to weather and climate instability produce stress; and
- B—biotic agents provide the coup de grace (Mueller-Dombois 1992).

Interactions between diseases, insect outbreaks, and other disturbances are widely recognized (Bebi et al. 2003, Hayes and Daterman 2001). For example, the White River National Forest had widespread fires in 1879 and a spruce beetle outbreak in the 1940s. Forests that burned in 1879 were less affected by the beetle outbreak in the 1940s. However, neighboring stands dominated by Engelmann spruce and elevation influenced the susceptibility of forests to insect infestation. Forests affected by the beetles showed no higher susceptibility to subsequent fire. The authors concluded that large, infrequent disturbances (fire, beetles) are often the dominant factors structuring an ecosystem and produce lasting ecological legacies. Subsequent ecological processes are strongly influenced by climatic and topographic factors and the contingencies of spatial arrangement of survivors, timing of availability of propagules, and barriers to spread of disturbance.

Landscape Mosaics

Mosaics can be variously hostile to biodiversity, supportive of biodiversity, inimical to particular species, or scaled such that they are supportive of all the indigenous flora and fauna. When landscapes are degraded by disturbances or lack of disturbances (natural or anthropogenic), effects of insularization owing to habitat loss are rarely distinguishable from direct effects of habitat loss or degradation without consideration of a variety of life-history characteristics of the organisms of interest. Spotted owls in the Western Hemlock Zone of southwestern Oregon occupied increasingly large areas as old-growth forests were harvested and replaced by early-seral stages (Carey et al. 1990). Eventually, owls were no longer able to track their prey base and their social structure began to break down (Carey et al. 1992). Although owls foraged in forests other than old growth, these foraging areas were either widely scattered or only intermittently suitable for foraging (Carey and Peeler 1995). In the Mixed Conifer Zone, more varied prey with a greater total biomass allowed owls to occupy smaller ranges and to use less old forest than in the Western Hemlock Zone just to the North. Isolation of blocks of old forest by intervening large clearcuts, however, was equivalent to the loss of an entire prey species in terms of energy expended to access sufficient amounts of old forest (Carey and Peeler 1995). Nevertheless, the grain (scale of patches) in the landscapes was small enough that dispersal and recolonization processes remained successful. Thus, the effects of timber harvesting on spotted owls were habitat loss and degradation of the landscape as a whole as a context for spotted owl habitat. It is not clear if there were negative effects owing to insularization. Spotted owls foraged in isolated patches. There was no evidence of either impediments to recolonization of vacated habitat or genetic isolation, either by barriers to movement or isolation by distance. Long-term genetic effects would be unlikely, given current population sizes and landscapes gradually improving in habitat quality. Markedly reduced metapopulation size and reduced reproductive attainment owing to pair instability, however, increases the probability of local extinctions that, theoretically, could cascade into regional extinctions.

As with spotted owls, landscape use greatly affects Tengmalm's owl in Finland, a small woodland owl that preys on voles whose abundance varies over 3- to 4-year cycles (Korpimaki 1988). Agricultural lands are its preferred foraging areas when voles are numerous. Spruce forest is preferred when voles are low in abundance on agricultural lands. Pine plantations are avoided. Of 104 territories studied for 10 years, more were occupied in only 1 year or in 5 or more years than would be expected by chance. Twenty-nine areas of the landscape were never occupied. Owls in good territories benefited from vole peaks by foraging over farmlands and shifting to alternate prey in woodlands during the low phase of the vole cycle. These more structurally complex portions of the landscape provided opportunities for prey switching. Poor territories supported breeding pairs only in peak vole years. Nearly all females shifted territories between successive breeding attempts, moving to more experienced males who could track local prey populations, rather than just moving to territories in better structured portions of the landscape. Males did not change territories.

Because predators are especially challenged by variable landscapes, theoretical ecologists have begun to model the dynamics of predators in patchy environments. They have developed models of predator distribution based on relative prey abundance (Bernstein et al. 1991). These models assume intake rate maximization, predator learning, nonnegligible prey handling time, and mutual interference between predators. Independent variables include travel costs between patches and the structure of the environment. When travel costs are small, prey depletion is slow, interference is moderate, predators conform to an ideal free distribution, and prey mortality is density dependent. As travel costs increase, the rate-maximization predator becomes more sedentary, and the population settles out at distributions far from the ideal free distribution. Prey mortality approaches density independence and later negative density dependence. In semicontinuous environments, with prey density correlated between neighboring patches, the slower the rate of spatial variation in prey (i.e., the coarser the environmental grain), the poorer the adjustment to the ideal free distribution, on account of the predator's need for learning. When the sample of the landscape within the reach of the individual predator is unrepresentative of the average prey density in the landscape (grain is coarse relative to the range of the predator), predators cannot learn the global distribution of foraging opportunities and fail to optimize intake. Predators shift ranges whenever the gain rate in the current patch is lower than the expected mean gain rate for the landscape as a whole. Well-informed predators should treat the world as though it were discontinuous (patchy) by aggregating only in patches with prey density above a certain threshold. As the cost of shifting foraging areas goes up, it still pays predators in very poor patches to move. Nevertheless, for patches above a certain threshold, cost of migration offsets potential gains of moving and predators do not migrate. Above that threshold, predators are distributed at random across patches with inverse density dependence between intermediate and good patches. If the cost of migration is very high, predators do not move even from poor patches, and predator mortality becomes inversely density-dependent across patches. These model simulations do not address, but do illustrate, that patch quality defined in terms of absolute prey abundance is of paramount importance in maintaining healthy predator populations even though relative differences between patch types may remain high (Carey and Peeler 1995).

Southwestern Oregon has suffered some of the most severe effects of timber harvesting on landscape composition in the Pacific Northwest (Carey et al. 1992, Carey and Peeler 1995). Patches of old-growth forest often were isolated from one another, with intervening expanses of early seral stages. However, studies of terrestrial amphibians (Corn and Bury 1991b), forest birds (Carey et al. 1991), and small mammal communities (Corn and Bury 1991a) revealed no fragmentation effects. Similarly, salamanders occupied even small patches of old growth in coastal British Columbia, suggesting such patches retain value as habitat (Dupuis and Bunnell 1999). Species of terrestrial salamanders in southwestern Washington respond differently to timber harvests but generally remain present in stands after thinning (Grialou et al. 2000). The reasons for lack of fragmentation effects are two: few species have distributions confined to old growth (Carey 1989), and forests develop rapidly after timber harvests, thus the duration of absolute isolation is too short for untoward genetic effects or stochastic demographic processes that may lead to extinction. The effects of continued isolation of old-growth fragments by clearcuts and competitive exclusion stages are unknown but would be expected to have negative impacts on a number of species, especially some of those that are poor dispersers and that have low reproductive potential (Carey 1989). Aquatic amphibians do show effects of isolation. Timber harvesting across small water courses in southwestern Oregon evidently led to extinction of local populations; these sites remained uncolonized decades later (Bury et al. 1991b, Corn and Bury 1989). The reasons for lack of colonization, however, are unclear—Did the streams remain unsuitable for habitation? Were there no nearby (relative to ability) sources of colonizers? Was the forest surrounding the streams inhospitable to dispersers (of low permeability)? Were the streams below the reaches studied even less hospitable (less permeable to dispersers) than the reaches themselves?

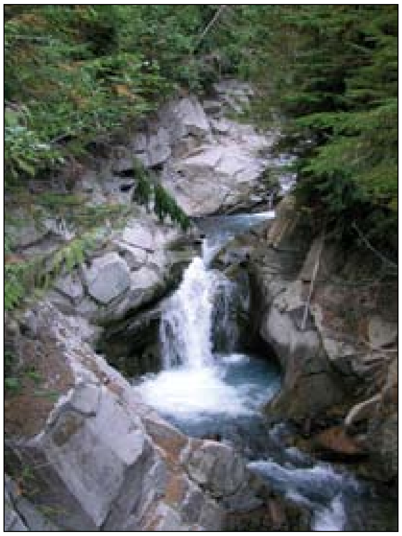


Figure 27—A cascading watercourse through a basalt streambed. Photo by A. Carey.

Landform Variability

Landform sets the stage for the ecological theatre—the diversity of biotic communities in a landscape—and the evolutionary play (Hutchinson 1965). Variability in landform includes differences in elevation, aspect, slope, and lithology, for example, basalt versus marine sediments. These factors influence many other environmental variables, such as solar radiation (including photosynthetically active radiation), temperature regime, wind, precipitation, soil moisture, substrate texture, mass soil movements, and erosion, on a finer scale than the influence of overall climate. Topography and geology locally, as well as regionally, determine degree of dissection by watercourses, presence of wetlands, cliffs, rock outcrops, and talus, soil-site characteristics, and abundance of fine sediments in streams. Together, these determine the types of, and variation in, potential natural vegetation and availability of niches of highly specialized animals. For example, a substrate of marine sediments is more easily eroded than one of basalt (fig. 27). Streams running through marine sediments or glacial outwash are more likely to have large woody debris incorporated in their structure, and pools formed by large woody debris are likely to accumulate sediments (figs. 28A, C) following large upstream disturbances, reducing interstices between rocks that are important to larval giant salamanders; these streams are also less likely to have the smooth rocks needed by tailed frogs (Wilkins and Peterson 2000). Still, these streams may provide reaches suitable for spawning by Pacific salmon (fig. 28B).

Natural disturbance history, anthropogenic disturbances such as accidental fire, purposeful fire, grazing, timber management, and zoning (transportation corridors, cities, towns, suburbs, agricultural lands, rangelands, managed forests, parks, natural areas, and wilderness) determine the actual diversity within, and particular nature of, biotic communities in the landscape. The interplay between landscape character and biodiversity has led to the conclusion that environmental variation would be a good surrogate for directly measuring organismal diversity (Faith and Walker 1996). For example, in western Washington, Bosakowski (1997) found more bird species (78 species) in a landscape managed as an industrial forest than Manuwal and Huff (1987) found in natural forests more than 40 to 500 years old (46 species). This, however, is a comparison of apples and oranges—a sample of a landscape with all its inherent variability compared with a sample of narrowly defined forest conditions. The landscape still lacked species dependent on old growth, the seral stage that was in shortest supply. This example does illustrate problems inherent in reducing measurement of biodiversity to a single

Figure 28—(A) and (B) coarse woody debris creates pools along a stream; (C) sediment deposition along a stream favored by chum salmon (note the dead chum salmon). Photos by A. Carey.

(or a few) indexes—too much information is lost; effects of variability at different scales and effects of variability within types are lumped into coarse categories of landscape units (either physical or biotic, usually not both); information on entire ecosystems and species groups is lost, including effects of isolation on particular types of landscape units.

Landform Analysis, Communities, Habitats, and Niches

The ecosystem concept and ecosystem management have been challenged on the basis that ecosystems cannot be precisely defined and that ecosystem size differs with the size of the organism, life form, or process of interest. This challenge is only defensible for strict, narrow views of the world. Definition of ecosystems and scales of ecosystem management must include, of course, an appreciation of the various spatial scales at which various organisms operate—from viruses to spotted owls (Carey and Curtis 1996; Carey et al. 1978, 1980a, 1980b, 1992, 1999b). A hierarchy of scales is also necessary. Landscape analysis allows scaling of variation in geomorphic features and of the biotic communities that result from the interaction of landform and historical and contemporary disturbance regimes. Scaling is commonly used in watershed analyses, supported by systems ecologists (Odum 1971), community ecologists (Whittaker et al. 1973), population biologists (Hutchinson 1978), landscape ecologists (O'Neill et al. 1986), and empirical data from the Pacific Northwest (Carey and Peeler 1995). Scaling is essential to ecosystem and landscape analysis and management. Scaling can be related to various life forms and life histories.

A useful hierarchy begins with units homogeneous in aspect, slope, slope position, elevation, soil, geomorphology, rainfall zone, and other characteristics that make up landscapes and are the *places* where plants and animals settle. These are biotopes—*places of life* (Hutchinson 1978) and can be described in terms of their potential natural vegetation. For example, Henderson et al. (1989) mapped the 64 forested plant associations of the Olympic National Forest on this basis. Note that Hutchinson (1978) describes biotopes as being homogeneously diverse—in other words, they can be broken down into successively more homogeneous subparts and scaled up into larger units that may also be homogeneously diverse such as a shifting, steady-state, mosaic landscape. Yet, in the rugged topography of the Pacific Northwest, a natural ecological scaling, which is also operationally appropriate, presents itself with the variation in

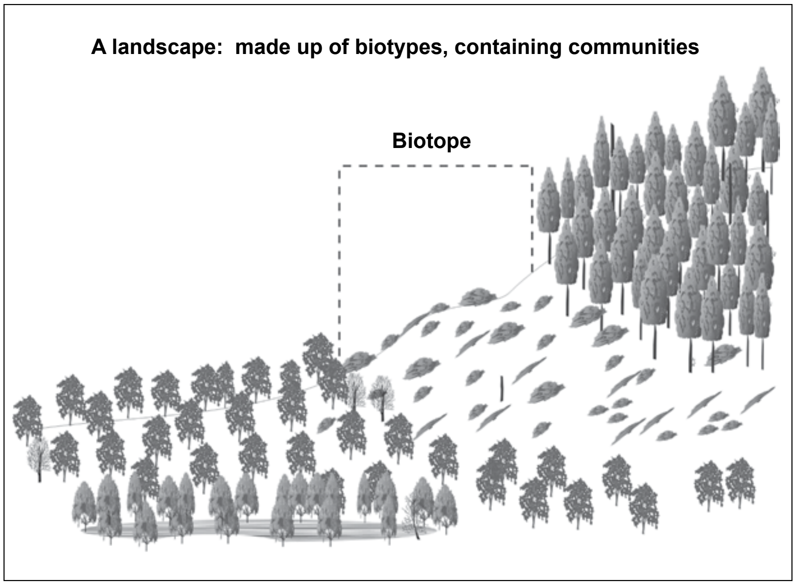


Figure 29—A schema for precise terminology—a landscape is made up of relatively homogeneous units of landform. These units are biotopes, or "places of life." Biotopes illustrated here are a wetland, a lowland, a toe of a slope, and a mid-slope. Biotopes are occupied by biotic communities, which are often characterized by their dominant vegetation and seral stage. This landscape is composed of forest communities that differ in species composition and seral stage. The range of biotic communities a species can inhabit is called its habitat. Quality of habitat can be inferred by plotting the density of the species across the array of biotic communities. Thus, habitat is defined by each species' use. Only part of each biotic community may be suitable to a species because of specific environmental requirements or because of interactions with other species. The part of the community used by species is called a niche. The niche is determined by both the ability of a species to exploit the resources in the community and other species that might compete for those resources, prey upon the species, or parasitize the species. Both habitats and niches can be described by multiple environmental variables. These variables describe potential habitat and niches (the complete multivariate space available) and realized habitats and niches (the space actually used) (adapted from Carey 1981, Whittaker et al. 1973). These concepts are of paramount importance in modeling landscapes and in landscape management. Few species are confined to a single biotic community, and species interactions may be influenced by the overall character of the landscape or just by adjacent communities that differ in species composition.

landform (Carey and Peeler 1995); the task may be more difficult in a Midwestern prairie or a lowland tropical rain forest. The species occupying and invading the biotope interact to form biotic communities that together with the physical aspects of the biotope are ecosystems (fig. 29). Because *biotope* has received poor acceptance in the lexicon of North American ecology, hereafter, *landscape unit* is used interchangeably with biotope, depending on context.

The ecosystem is the basic functional unit of ecology (Begon et al. 1986; Hutchinson 1978; Odum 1963, 1971; O'Neill et al. 1986; Whittaker et al. 1973) and is defined as "an ecological community together with its environment, functioning as a unit" (Pickett 2000). Odum (1971) used small forests (e.g., on a hillside) as examples of ecosystems; Bormann and Likens (1979) defined them as small, "watertight" watersheds of 10 to 50 hectares. This scale seems appropriate for Pacific Northwest terrestrial biotic communities as well (Carey and Peeler 1995, Carey et al. 1999d). However, Odum (1971) pointed out that aquatic systems must be defined at a larger scale, such as a drainage basin. A tenfold larger scale (100 to 500 hectares) seems appropriate for smaller streams and rivers. Watersheds in the Pacific Northwest run in the thousands of hectares (say 5,000 to 20,000 hectares for state of Washington designated Watershed Administrative Units). In reality, three attributes are important in defining landscape units: structure (the spatial relationships among the distinctive ecosystems composing the landscape), function (interactions among the ecosystems), and change (the alteration of the structure and function of the ecological mosaic through time) (Turner 1989). Landscapes are aggregations of ecosystems. Each successive level of aggregation can be considered a building block for serving larger ecological functions and larger conservation goals. The ecosystem is the fundamental building block but cannot be understood or effectively managed without considering intracommunity heterogeneity and landscape and regional contexts. Landscapes sum into physiographic provinces that have characteristic vegetation zones or life zones and eventually into biomes and, finally, the biosphere.

The basic operational unit in forestry is the stand—a more or less homogeneous group of trees. Stand identification rests on the age and species composition of the dominant trees and, as a result, can vary markedly from less than 5 hectares to thousands of hectares. Thus, stands may be perceived as having greater homogeneity than their associated biotic communities. Thus, using traditional forestry criteria may result in an excessively coarse scale for identification and delineation of ecosystems. Traditionally, botany has focused on a very small scale—much less than 0.5 hectare. Miller et al. (2002) examined spatial patterning of ground-layer species in old-growth northern hardwood forests by using 0.25-square-meter plots in grids of 1,860-square-meter grids. Ground-layer species were autocorrelated (clumped) at less than 2.5 to 21 meters depending on tree sapling density—randomly distributed at high sapling densities but clumped at low densities. The smallest scale autocorrelations resulted from vegetative reproduction and larger scale patterns from dispersal within a patchy environment. Microtopography and coarse woody debris were important to the maintenance of plant diversity within the biotic community, and the authors emphasized the need for within-community microhabitats or patchiness, suggesting a much larger scale would be relevant to plant communities. Busing and White (1993) looked at the effects of area on old-growth eastern hemlock-hardwood forest attributes by using 0.1-hectare subplots within 1.0-hectare plots. They found canopy gaps were generally less than 0.05 hectares, but that tree density, basal area, mass, leaf mass, and large tree density suggested a grain or patch size of about 0.2 hectare (one tree occupying 0.05 hectare). Canopy openings covered 13 percent of the area with most less than 200 square meters, but a multiple tree fall gap was more than 1000 square meters. Beckage and Clark (2003) also found that spatial heterogeneity in deciduous forests was important in providing unique regeneration niches that maintained a diversity of trees; York et al. (2003) found the same in Sierra Nevada conifer forests with experimental gaps of 0.1 to 1.0 hectare. However, the size, intensity, and spatial distribution of compositional patches were not affected solely by gap size but also by microtopography, seed dispersal distances, vegetative reproduction, and species interactions. Their results suggest a scale much larger than 1 hectare would be appropriate, especially because within-community heterogeneity is so important. As Kint et al. (2003) concluded, tree distribution and patterning ("positioning") determines different light regimes and regeneration patterns; the mixture of tree species also helps to determine light regimes and litter composition as well; and vertical and horizontal differentiation resulting from positioning, mixtures of tree species, age distributions, and competition determines spatial variation in microclimate, food supply, and structural complexity that provides for a variety of animals and plants. So, studies of forest plants suggest that communities range in size from tens to hundreds of hectares or more but have substantial heterogeneity at the scale of 0.2 to 0.5 hectare or less. This is very similar to the scale of variation in tree canopies, understory vascular plants, fungi, and use of patches by arboreal rodents in old-growth conifer forests in southwestern Oregon (Carey et al. 1999b).

Well, what about animals? Morris (1987) examined the question of scale in relationship to individual animals and populations. He suggested that both individuals and populations respond in one of two general ways. "Fine-grained species" [actually species responsive to fine environmental grain] use subsets of the mosaics within biotic communities in direct proportion to the abundance of the subsets; coarse-grained species select some communities over others. The possible scales that could be considered include the species' geographic range, the spatial scale at which population density varies, temporal scales of generation time, migration and dispersal distances, territory or home-range sizes, and the space and time of daily activities. He suggests distinguishing between two aspects of habitat. Macrohabitat would be the minimum area corresponding to that within which an average individual performs all of its biological functions during typical activity cycle (essentially the original definition of home range). Microhabitat would be defined by the physiochemical variables that influence allocation of time and energy within the macrohabitat/home range. This approach, however, is excessively individual-of-species specific; considering the responses of species populations is much more informative (Maguire 1973). Describing habitat in terms of the range of biotic communities used, the relative value of those communities as measured by some population response, the necessity for specific habitat elements, and the role of within-community heterogeneity in promoting coexistence of species, is much more informative for species adapted to fine-grained mosaics (biotic communities) and species responsive to coarse-grained landscapes. Using a population approach will help converge on a common scale related to the natural scale of biotic communities and will result in much smaller units than forestry criteria, say covering 10 to 200 hectares. This is also the mappable scale of aspect (the direction a hillside faces) in topographically well-dissected, mountainous landscapes (Carey and Peeler 1995). Biotic communities of this size are just large enough to support populations of vertebrates of low mobility: terrestrial and aquatic salamanders (Bury and Corn 1988a, 1988b; Bury et al. 1991a, 1991b); passerine birds (Carey et al. 1991, Huff et al. 1989, Huff and Raley 1991); forest-floor small mammals (Carey and Johnson 1995); and arboreal rodents (Carey 1991, 1995). This scale is amenable to examining niche complementarity and its effect on ecosystem function and source-sink dynamics for many species (Bond and Chase 2002). However, a small area (less than 10 hectares) may not withstand the climatic and biologic influences of an adjacent ecological community of markedly different character (Chen et al. 1992). Indeed, no ecosystem stands alone—all are influenced by, and receive organisms from, the other ecosystems in the landscape. A 10-hectare area is too small to support even an individual spotted owl; a spotted owl might forage over 140 hectares in a night (Carey 1993; Carey et al. 1990, 1992). Much larger areas may be too small to contain an aquatic ecosystem large enough to support a fish community (Odum 1971). Thus, 10- to 200-hectare biotopes along with the plant, fungal, and animal communities they support and the water and energy they receive are good fundamental terrestrial building blocks. This scale is appropriate for examination of biodiversity and ecosystem function. At this scale, management can be used to set back, maintain, or accelerate the process of forest development, promote simplicity or complexity in the forest community, and provide for either paucity or diversity of ecologic services, recreational experiences, and economic goods. Thus, the lay of the land and the condition of the ecosystem provides the actual size of the ecosystem management unit. Natural drainage patterns, operational restrictions imposed for streamside zones and other fragile-soil areas, and the economics of tracking and managing small isolated parcels of land also influence management unit boundaries and the resultant character of the landscape.

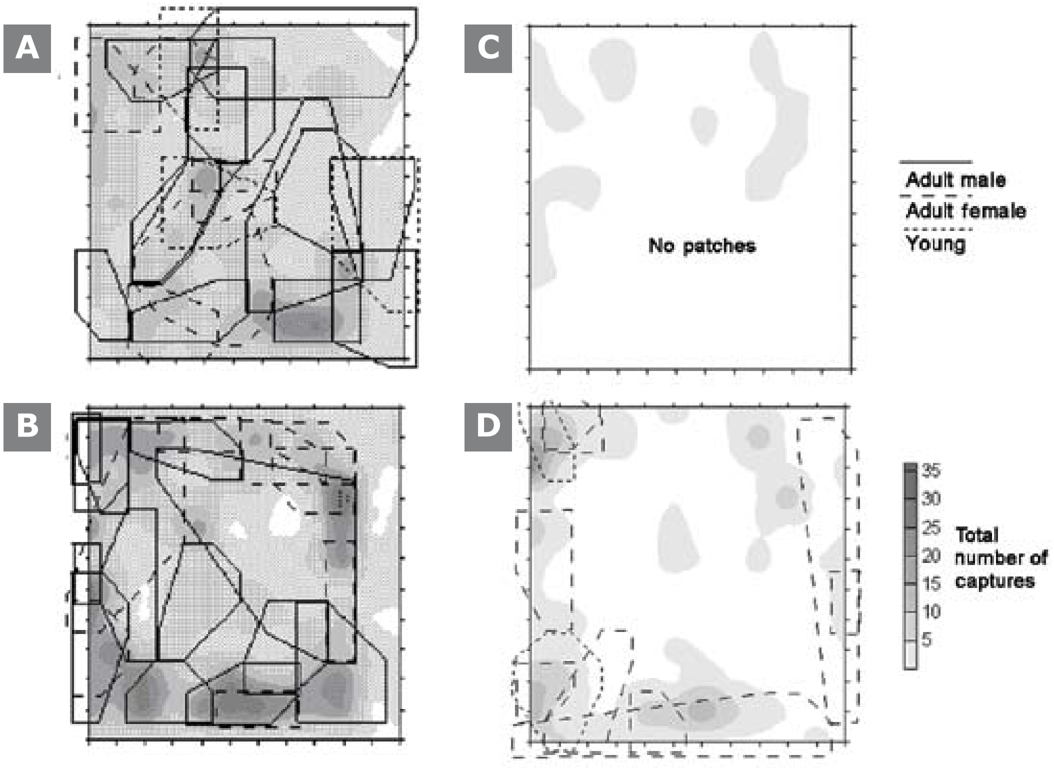
Streams are divided into classes (orders) based on their size and position in the watershed. The contributions of streams and streamsides to biodiversity differ markedly (Hawkins et al. 1983). Small streams and wetlands usually contain detritus-based communities supporting amphibians as top predators; many of these amphibians occupy upland communities as adults (Leonard et al. 1993). Larger streams usually contain photosynthesis- and detritus-based communities supporting fish as top predators. Additionally, streamside biotic communities include species unique to the riparian zone, including some amphibians (Olympic torrent salamander), birds (American dipper), and small mammals (water shrew). Other species, such as Roosevelt elk, prefer riparian communities over upland communities (Raedeke 1988, Woodward et al. 1994). Riparian forests also provide corridors that direct, facilitate, and impede movements of both small and large vertebrates. A minimum landscape unit for aquatic communities is the small watershed.

For the second-level operational building block, the life histories of animals of medium mobility in a terrestrial landscape provide guidance; for example, a pair or two or three of spotted owls, a resident fish stock, populations of screech owls, blacktail deer, and Roosevelt elk, or multiple populations of northern flying squirrels. Managerially, the scale includes the ability to manage for water quality, maintain ecological services in the face of small catastrophic disturbances (wildfires, windstorms, and timber harvests), produce a sustained yield of wood products, and support a small timber mill (only a part of a timber-dependent human community). This is the scale of watersheds; watersheds are naturally discrete landform units (Bormann and Likens 1979, Odum 1971). One or more watersheds constitute a landscape. Small watersheds in the state of Washington are 6,000 to 20,000 hectares. Small landscapes aggregate into larger units that can provide for a population of spotted owls, several populations of the largest mammal—Roosevelt elk, multiple fish stocks, metapopulations of amphibians, small mammals, and small birds, and a base for local economies. At larger scales, focus is on connectivity and permeability: river systems, ecological corridors (for gene flow through dispersal and for migration), and even highway systems. Large landscapes are 200,000 to 400,000 hectares.

Ecological theory explains simply patterns of abundances of a wide variety of plants, arthropods, and vertebrates by three factors (Brown 1984): (1) each species is limited by a combination of physical and biotic variables that define multidimensional habitats and niches; (2) spatial variation is somewhat stochastic but usually autocorrelated; and (3) closely related, ecologically similar species differ in no more than a few niche dimensions. The factors that regulate the distribution and abundance of a species, however, may vary with season (Fretwell 1972). Populations living in seasonal environments are exposed to regular changes in resource quality and abundance. Within a given space and time, individual animals are faced with choices about which areas or biotic community to inhabit. This habitat selection is part of the foundation on which the structure of small mammal communities lies (Rosenzweig 1989). Even resource partitioning is mainly achieved by habitat selection. At the large scale, the selection is among biotic communities and is called habitat. At a fine scale (*microhabitat*), selection occurs within a biotic community. Habitat preferences change more readily than resource preferences and are highly density dependent (resource preferences are only weakly density dependent). Thus, habitat preferences are most easily measured when a species is rare and are likely to decay at high densities (overall high resource levels). Habitat selection assumes (Fagen 1988) (1) animals move freely to preferred habitats, (2) animals prefer the available habitat offering the highest per capita resource availability, (3) resource availability is highly predictable, (4) moving between habitats costs little, (5) moving within each habitat costs the same as moving between habitats, and (6) individual reproductive success within each habitat decreases as population density increases. The fundamental niche of species is the set of environmental conditions and resources that permit a population to persist when not limited by competition or predation; this niche can be described evolutionarily as the environment in which mean fitness is 1 or more and outside of which mean fitness is less than 1. Natural selection operates principally as a conservative force to improve fitness within the fundamental niche (Holt and Gaines 1992).

In summary, landscapes are composed of biotopes occupied by biotic communities. The array of communities a species inhabits defines its habitat in that landscape. Within a biotic community, a species makes use of only a part of the available space; this use is dependent on interactions with other species and the space actually occupied is the niche (Carey 1981, Hutchinson 1978, Whittaker et al. 1973). For example, in the Montane Zone of the Rocky Mountains, Richardson's ground squirrel is confined by its colonial social behavior and habit of denning in burrows to areas of deep, friable soil such as meadows and aspen groves; thus deep soil determines its habitat. The golden-mantled ground squirrel has a much broader habitat; it is capable of inhabiting most of the biotic communities in the montane landscape. However, the golden-mantled ground squirrel can be excluded from communities on deep soils by the aggressive Richardson ground squirrel. In those areas, rock outcrops and the Richardson ground squirrel defines the niche of the golden-mantled ground squirrel. The least chipmunk has even a broader habitat spanning several zones; but its occurrence in any particular area depends on physical aspects of the habitat that allow it to avoid confrontation with other more aggressive chipmunks and ground squirrels (Carey 1978b, 1981; Heller 1971). In the Pacific Northwest, the northern flying squirrel occupies a wide range of biotic communities. Its abundance, however, varies markedly across those communities in response to various habitat elements that provide food, cover, and shelter. The squirrel can be extirpated from communities that are low-quality habitat by predation by long-tailed weasels. Even in high-quality habitat, its population density can be reduced sharply by predation by spotted owls (Carey et al. 1992). Within communities that provide poor-quality and those that provide high-quality habitat, the flying squirrel still only uses a fraction of the available space (fig. 30). In southwestern Oregon, use seems to be conditioned by coarse woody debris and interactions with truffles at the fine scale (microhabitat) and diversity of vegetation site types at a slightly large scale (habitat breadth) (Carey et al. 1999b) (table 12). In western Washington, factors determining the niche of the flying squirrel seem more related to the presence of mast-producing hardwoods in addition to vegetation complexity, abundance of cavity trees, competition primarily with chipmunks, and predation by owls and weasels (Carey 1995, 2000a, 2000b; Carey and Harrington 2001).

Figure 30—Habitat is defined by the use of a species. Use is often measured as density (number of animals per hectare), and density is often determined by the use of space. Good habitat for both (A) northern flying squirrels and (B) Townsend's chipmunks was provided by old growth, and bad habitat for both (C) flying squirrels and (D) chipmunks was provided by second growth (adapted from Carey et al. 1999b). Shading reflects the numbers of captures of the squirrels and the lines represent short-duration foraging patches (flying squirrels) and home ranges (chipmunks). Note there are unused portions for each species in both stands.



Communities and Ecosystems

Biotic communities comprise the species occupying a particular biotope (site in a landscape) that, together with that site, form a local ecosystem that supports those local species populations. Much debate has taken place over whether or not biotic communities are real assemblages of interacting species or haphazard assemblages of species whose composition reflects historical contingencies and random sampling from a regional species pool. The latter reductionist view reflects narrow focus and lack of consideration of interactions taking place at various levels of biological, spatial, and temporal

Table 12—Population response of northern flying squirrels to environmental variables in Oregon[a]

Response measure	Scale	Dependent variable(s)	Independent variable(s)[b]	Variance explained[c]
Potential habitat (Total habitat space sampled)	Points in a landscape	▪ Variance in vegetation structure	▪ Crown-class differentiation (25%), decadence (16%), canopy stratification (11%), understory development (10%)	63%
		▪ Composition	▪ Position on a moisture gradient (24%)	24%
Realized habitat	Points in a landscape	▪ Presence-absence of squirrels	▪ Decadence (0.8) + canopy stratification (0.6) + crown-class differentiation (0.3) + understory development (0.3)	60%
Habitat quality	Among communities	▪ Abundance	▪ Decadence (17%) + habitat breadth (21%)	50%
Carrying capacity	Among communities	▪ Maximum abundance over time	▪ Decadence (45%) + habitat breadth (25%) – position on the moisture gradient (16%)	70%

[a] The entire area sampled was described by the structure and composition of the vegetation; structure could be reduced to four independent variables, and composition to one independent variable. Flying squirrels occupied only a part of the available space, and this part was described well by the four structural variables. Variance in abundance across the biotic communities, however, was best explained by decadence (fallen trees and snags) and by complexity of the vegetation community (habitat breadth). The maximum attainable densities of squirrels were best predicted by decadence, habitat breadth, and position on a moisture gradient indicating that rich mesic communities supported higher populations than communities on dry sites or very wet sites.

[b] Different types of statistical analysis were used depending on the nature of the dependent variable. The values in parentheses represent the relative contribution (or importance, which could be negative or positive) of each independent variable in explaining the variance in the dependent variable. These values may or may not sum to the values in the variance explained column or to 100 percent because the exact statistical meanings of these values varies with the analytical method.

[c] The total percentage of variance explained by the statistical procedure.

Source: Adapted from Carey et al. 1999b.

organization. Such a view is most likely to be held by one who focuses on large, immobile organisms, such as tropical trees, that are species rich, diverse in dispersal ability, and adapted to environmental homogeneity (Hubbell 2001). The former view is more likely to be held by ecologists who must consider competitive, mutualistic, host-parasite, predator-prey, and complex food web relationships of species of markedly varying mobility and dispersal capability coexisting in spatially and temporally heterogeneous landscapes and biotopes (Tilman and Kareiva 1997).

Many of the contentious issues in ecology carry over into the applied ecology of forest ecosystem management and conservation of biodiversity. The concept of biodiversity, at its basic level, is a community concept. The same can be said of functional groups, guilds, niche, ecosystem, ecological succession, forest development, biotic integrity, resilience, stability, and forest health. The contemporary question boils down to: Are assemblages of species in place and time (1) simply an accident of history built upon by random immigrations and extinctions versus (2) a result of a self-organizing adaptive system, conditioned by history and drawing from regional species pools, but forming assemblages consisting of tightly connected nodes of species loosely connected into a larger system of tightly connected nodes (Barabási and Bonabeau 2003, Dunne et al. 2002), all within an evolving holarchic system that develops in biocomplexity until some major external force causes catastrophic collapse, followed by reorganization? In other words, is the basic unit of ecology, the ecosystem, a site inhabited by a chaotic or random assemblage of species or an organized, ecological, system? To many ecological modelers, statistical ecologists, and mathematicians, arrangements in space and time do seem poorly predictable, unstable, and chaotic. To naturalists, often imbued with a tolerance of ambiguity born of experiential appreciation of natural wonder, the patterns and organization in nature are manifest—familiar and predictable but often accompanied by delightful or fearful surprises. In the stochastic view, there is no logical need for conservation. In the systems view, conservation is required to maintain keystone species, keystone complexes, and a species pool that provides for redundancy in functional groups, which facilitates system adaptability and change through time.

In the stochastic view, there is no logical need for conservation.

* * *

In the systems view, conservation is required to maintain keystone species, keystone complexes, and a species pool that provides for redundancy in functional groups, which facilitates system adaptability and change through time.

Another major ambiguity in defining, discussing, and studying biotic communities is that limiting consideration to a subset of species on a site (or among sites) requires decisions that are somewhat arbitrary. Examples of arbitrarily defined biotic communities include mosses, lichens, herbs, achlorophyllous mycotrophic plants, shrubs, trees, hypogeous ectomycorrhizal fungi, epigeous mycorrhizal fungi,

Sidenote 32—Growth form (also referred to as growth habit or life form)—how plant species are put together and shaped, such as forbs, grasses, lichens, shrubs, trees, vines, etc. (Grime 1977).

litter arthropods, forest-floor mollusks, forest-floor salamanders, Neotropical migratory birds, forest-floor small mammals, arboreal rodents, and bats. Certainly, these groups of species that are more-or-less similar in some aspects of their phylogenies, physiognomies, physiologies, and ecologies are more comprehensible than the totality of species, more likely to exhibit apparent niche differences (resource partitioning, differences in trophic relationships) that allow explication of system function, and more likely to be keyed to a recognizable subset of elements of forest ecosystem structure or composition—but they are not independent of interactions with other species or groups of species, even species at different trophic levels, of markedly different sizes, and with various life histories.

Certain aspects of community-level diversity are axiomatic. Species diversity within biotic communities generally increases with the spatial extent (area) of the community, history of intermediate disturbances, time since last major disturbance up to some asymptote, and heterogeneity. Diversity within a specific community can vary markedly with time since catastrophic disturbance, with high diversity as the disturbed site is colonized by exploiters and low diversity when a few species dominate the system (as in the competitive exclusion stage of forest development). Diversity increases with differentiation (e.g., crown-class differentiation, or development of dominance, codominance, subordinance, and suppression among trees and species of trees, and differentiation among microsites owing to effects of dominant plants on light, moisture, microclimate, and soil chemistry) arising from interactions (competition, predation, mutualism) that modulate species fluctuation in species abundances. Diversity also increases with development of spatial complexity arising from accumulation of biomass and small-scale disturbances but decreases (at least for vertebrates and vascular plants) in the absence of disturbance as the ecosystem maintains a relatively stable quasi-climax state. With succession (replacement of one relatively discrete biotic community by another) and development (envelopment) of communities over time in forest-dominated systems, the trend is toward increased biomass, a system shift from production to maintenance of biomass, vertical stratification by increasing diversity of growth forms (sidenote 32), complexity in arrangement of physical and biological structures in space, diversity in species composition, increases in niche complementarity, selection for competitive ability, and tightening and slowing of nutrient cycling, as products of community self-organization and self-regulation (Carey et al. 1999b, Franklin et al. 2002, Margalef 1968, Odum 1969, Pickett 1976, Whittaker 1972).

Note, the difference between *succession*—replacement of a grass community by a shrub community by a tree community or replacement of a deciduous tree community by a conifer-dominated community—and *development*. Development is a process by which ecosystems (the abiotic and biotic circumstances of a site) expand in multivariate dimensions with each expansion *enveloping*, not displacing, the preceding condition. A young second-growth Douglas-fir forest can develop from the competitive exclusion stage, in which the firs each attempt to capture as much of the multidimensional growing space as possible to the exclusion of weaker firs and other members of the community, to diverse communities undergoing development of habitat breadth (vegetation-microsite type diversity) and preinteractive niche diversification (these concepts will be discussed in detail later). Although, many of the firs maintain their positions of dominance for centuries, most of the originally scarce species increase in abundance, and new species are recruited. Thus, species diversity is not an unchanging property of a community. Species extinctions, speciation, and invasions occur at multiple scales simultaneously.

Biological diversity decreases in systems exploited by humans. In exploited ecosystems, community succession and development are often truncated, the maturity and complexity of ecosystems are reduced, and fewer species and life forms produce the bulk of the biomass. Management often deliberately simplifies biotic communities and sometimes even the physical variability of the ecosystem. Even the structure of the soil may be simplified with a concomitant decrease in the diversity of soil organisms. Weeds and pests increase rapidly and disperse easily. Strong exploitation of very mature ecosystems may produce a total collapse of a rich organization (Margalef 1968). The root causes of loss of biodiversity are often stated to be destruction and fragmentation of natural plant communities, although pollution, invasion by exotic species, overharvesting of resources, and disease can be important (Wilson 1999a). Conversion of forest, wetlands, and grasslands to farmland, suburban, urban, and industrialized areas in eastern North America resulted in some extinctions, multiple widespread extirpations, and reduced vertebrate populations and led to the Federal Aid to Restoration of Wildlife and Fish Acts in 1937 and 1950 (Allen 1954). Nevertheless, the same patterns of exploitation and loss of biological diversity continued in western North America (Lee 1993).

Diseases, such as chestnut blight, Dutch elm disease, white-pine blister rust, and many others have had profound effects on composition and structure of forest communities. The effects of epidemic disease and reduced biodiversity may be acute in the short term but still produce chronic results. For example, chestnut blight, fire exclusion, agricultural clearing, clearcutting for timber harvest, and purposeful increases in deer populations disrupted a dynamic equilibrium among upland oaks to the extent that white oak, once supreme among oaks prior to the arrival of Europeans in eastern North America, is in dramatic decline (Abrams 2003). The most dramatic example is a drop from composing 33 percent of all oaks to 9 percent in eastern West Virginia. Such compounded perturbations have produced similar ecological surprises in a variety of systems (Paine et al. 1998). Shifts to some alternative relatively stable state of lowered diversity in response to slow change or chronic stress may occur dramatically and rapidly (Holling 1986, Scheffer et al. 2001).

Self-Organizing Systems

What is this idea of self-organizing systems? R.H. Whittaker (1969) described organization as the means by which functioning complexity is maintained through time. Salient organizing principles include competitive interplay (leading to niche structure) and adaptive diversification (leading to complex food webs). Thus, diversity increases during development, and overall diversity in tree-species-rich broadleaf forest tends to be higher than in evergreen conifer forests dominated by a few tree species. Diversity of vascular plants tends to decrease with decreasing environmental stability and increasingly extreme conditions that might interfere with development of greater organization and complexity. The diversity of a community, then, is a form of complexity, of organized differentiation, and expresses the kind of organization—competitive interplay, role differentiation, and diverse interactions—tending to modulate community fluctuation. Microsite variation alone is insufficient to provide for even the diversity of tree species; interactions among dominants and subordinates and among species are key (Fox 1977). Positive interactions (mutualisms and facilitation) play a critical role in ecological communities by reducing physical and biotic stresses and by contributing to development (or even creating new biotic communities) on which many species depend (Mulder et al. 2001, Stachowicz 2001). Simply by growing, many species alter their local environment by shading, blocking the wind, intercepting precipitation, and altering soil chemistry by their litter and exudates. Mutualists, such as ectomycorrhizal fungi on the roots of conifers and rumen bacteria and protozoa in the four-chambered stomachs of deer and elk, are essential to nutrient transfer and trophic facilitation. Some species are ecosystem engineers, and modify the environment by their activities (e.g., American beaver and the big-time excavator of trees, the pileated woodpecker). Less obvious engineers are wood-boring insects and decay-causing fungi. These species provide critical habitat elements for numerous species including refuge (protective cover and protected nest sites) from physical stress, predation, and competition. Diversity within functional groups like ectomycorrhizal fungi and bryophytes is thought to help maintain an ecosystem through environmental change and under environmental stress.

When self-organizing forces for evolution of diversity interact with the technological capacity of postindustrial socioeconomic-environmental systems, a predicament arises. A system of accelerating growth and increasing complexity stretches ever tighter the means of organization while producing social and environmental problems ever more difficult and beyond realistic prospects of solution, increasing tensions and frustrations of people who must maintain the organization and try to deal with problems, and producing increasing numbers of people who scorn the system and its complexities without a rational sense of the limitations on alternatives (Whittaker 1969). Thus, Holling (2001) incorporates social, economic, and environmental levels in the hierarchies of Panarchy theory to examine how we might move toward sustainability, which he defines as the capacity to create, test, and maintain adaptive complexity while maintaining development—the process of creating, testing, and maintaining opportunity. He defines self-organization as the development of complex adaptive systems in which multiple outcomes are possible and dependent on accidents of history. Diversity and the individuality of components, localized interactions among components, and an autonomous process that uses the outcomes of those local interactions to select a subset of those components for enhancement are characteristic of complex, adaptive systems. Thus, he states, if sustainability means anything, it has to do with the small set of critical self-organized variables and the transformations that can occur in them during the evolutionary process of societal development. Thus, Holling (2001) suggested a dozen truisms (sidenote 33). Panarchy theory describes how a healthy sociological system can invent and experiment, benefiting from inventions that create opportunity while it is kept safe from those that destabilize. Panarchy theory is discussed more in depth later, but now let's return to some fundamentals of biological diversity.

Sidenote 33—Current understanding of Panarchy theory (Holling 2001):

- Multiple stable states are common.
- An adaptive cycle is the fundamental unit of dynamic change.
- Not all adaptive cycles are the same; some are maladaptive.
- Sustainability requires both change and persistence.
- Self-organization shapes long-term changes.
- There are three types of learning—incremental, lurching, and transforming.
- The world is lumpy.
- Functional diversity builds resilience.
- Tractability comes from the rule of hand ($x>3$).
- Emergent behavior emerges from an integrated system.
- Management must take surprise and unpredictability into consideration.
- Adaptive management outperforms optimization for stable targets.

Formation of Biotic Communities

Various theories provide different perspectives on how species populations assemble into biotic communities (Belyea and Lancaster

1999, Gotelli 1999). Trait-environment theory posits that certain traits of individual species allow those species to occur together in specific biotic communities. Island biogeography theory asserts that assembly incorporates competition and stochastic colonization processes. Contingent ecology relates that assembly is conditioned by the specifics of the locality and its history. Deterministic ecology claims that community assembly conforms to some general principles. Fundamental principles that apply widely in community formation are called assembly rules. These rules constrain the behavior of the assembly process and arise from various processes occurring within the community. The same rule may apply to communities that differ historically and may lead to similar or to divergent trajectories, depending on a number of variables, including regional species pool, specifics of the locality, and specifics of history. As far as we can tell, dispersal constraints, environmental constraints, and internal dynamics of populations within communities interact to select species that not only can coexist but also interact to increase biomass and to produce nonrandom spatial distributions of species. Dispersal constraints determine the pool of potential colonists and result from species-specific traits, storage effects, landscape ecology, and history. Environmental constraints restrict species establishment and mediate interactions among residents and successful colonists. Environmental changes can lead to changes in communities. Assembly rules are general and mechanistic and operate within the situation-specific constraints imposed by colonization sequence and environment. An example of a rule is the proportion of total resources consumed increases as each additional species invades. Internally, species compete for the same resources within, but not between, functional groups. This rule suggests that a common pattern should be that invading species are likely drawn from different functional groups until each group is represented, before the pattern repeats itself. As resource use increases within a functional group, interspecific competition increases, and species overdisperse to minimize niche overlap. Rules operate within and across trophic levels and whole systems through resource dynamics and spatial dynamics to select sets of coexisting species. The interaction of an assembly rule operating at one level of community organization (e.g., within a functional group) with a rule operating at another level of organization (e.g., across trophic levels) may lead to patterns of community structure that could not be predicted from either rule working independently. This phenomenon can be viewed as an emergent property of self-organization as well as evidence of a chaotic system.

A.S. Watt (1947), in his presidential address to the British Ecological Society, emphasized a patchwork mechanism of community assembly. Aggregates of individuals and species form different kinds of patches—these patches form a mosaic that constitutes the community; thus, recognition of patchiness is fundamental. Patches (or phases) are dynamically related to each other, and when this dynamic produces orderly change, there is persistence in the community pattern. Much later, Ives et al. (2000) argued that complex communities composed of modular subcommunities lead to community stability and species richness. Departures from the inherent tendency to orderliness may be caused by fortuitous (stochastic) obstacles to the normal sequence of events, with the final community structure resulting from causes of order and causes of disorder (Watt 1947; note the similarity to the self-organizing system that produces order out of chaos). Watt emphasized relationships among components of ecosystems in space and time, saying these relationships constituted the primary means of maintaining the integrity of the community. Thereby, he argued for communities defined as homogeneously diverse dynamic assemblages with a recognizable pattern just as Hutchinson (1978) did 30 years later. Watt described the community as a space-time mosaic, wherein each patch is dependent on its neighbors and develops under conditions partly imposed by them. Watt (1947) provided examples from diverse biotic communities—bogs, bracken-grass heaths, beech-birch woods, tropical forests, and others. He emphasized process over structure—the thing that persists is the process and its manifestation in space-time patterns. Emphasis on process over structure is essential for effective management and conservation of naturalistic ecosystems (Carey 2003a, 2003c; Carey et al. 1999b) and is a theme of this book. Like Holling (1969) 20 years later in his adaptive cycle and Bormann and Likens (1979) 30 years later in their studies of the dynamics of northeastern forests, Watt (1947) talked about a cycle of change with an upgrade phase that accumulates biomass and develops habitat potential and downgrades that can come about through insects, diseases, and physical disturbances. Time and again, throughout the brief history of ecology, the same phenomena become repeatedly recognized for their importance and are renamed and reincorporated into ecological theories that provide us with a broader and deeper understanding of how nature works. Patchiness provides a diversified (spatially heterogeneous) environment providing diverse regeneration niches for plants and fundamental niches of animals among the various patches. Dynamic processes and environmental heterogeneity within the community are important determinants of biological diversity (Huston 1979).

Chesson (2000) provided yet another, different, perspective on community organization by asking what mechanisms maintain species diversity. How do species coexist? Coexistence mechanisms function in two ways: (1) equalizing—minimizing the average difference in fitness among species and (2) stabilizing—increasing negative *intraspecific* interactions over negative *interspecific* interactions. Stabilizing mechanisms are essential for coexistence and include resource partitioning, frequency-dependent predation, and mechanisms that depend on fluctuations (variability) in population densities and in environmental factors in space and time. Complementarity in resource use leads to higher net primary production, a broader base for diversity (Hooper 1998). Complementarity or partitioning of resources by plants comes about through difference in rooting that affects access to water and nutrients, difference in architecture that helps fill aboveground space more efficiently, differences in phenology that allow different species to harness the same resources, but at different times of the year, and differences in physiology that lead to differences in type of nitrogen used or sources for phosphorous. Some species aid the growth of other species through provision of resources or amelioration of harsh environments in a process of facilitation. For example, some species fix nitrogen in a form available to other species, whereas some shade the soil and conserve moisture and alter the microclimate, providing niches for other species. Finally, the interplay of behavioral, biological, chemical, physical, and social interactions that affect, sustain, or are modified by living organisms in the community brings about biocomplexity.

Biocomplexity arises as temporal, conceptual, and spatial boundaries are breached and the system exhibits emergent, or unexpected, properties—in other words, the whole of system behavior is greater than the sum of the parts (Michener et al. 2001). For example, in Arizona, with large crown fires in the absence of elk, there is a positive relationship between severity of fire and regeneration of aspen via asexual reproduction; sprouting is 10 times greater at high fire intensities than intermediate intensities; there is virtually no regeneration without fire. Elk selectively browsed aspen ramets after high-severity fires, two times more than after intermediate-severity fires, thus largely negating the increased regeneration.

Fire and elk had different effects on arthropods (53 taxa in 11 orders and 21 families). Fire alone had no effect, but fires of intermediate severity, followed by elk browsing, increased arthropod diversity by 30 percent and abundance by 40 percent. Severe fire followed by browsing reduced diversity by 69 percent and abundance by 72 percent. The interaction of fire and elk produced four types of arthropod assemblage within the community mosaic, overall a marked increase in diversity. Thus, scaling up from populations to community-level interactions revealed unexpected outcomes; greater complexity (in time, space, and multiple factors) produced reversal of effects, unexpected outcomes, or emergent properties (Bailey and Whitham 2002).

Ecosystem Structure

Structure is another term frequently used in forest ecology and conservation that means different things to different people. According to the dictionary, a structure is something made up of a number of parts put together in a particular way. Chad Oliver (Oliver and Larson 1990) uses structure to refer to his stages of stand development (stand initiation, savanna, stem exclusion, understory reinitiation, and old growth) and talks about structure-based management in which landscapes are intentionally managed to contain a variety of structures (stages of stand development). Structure is also defined as the way parts are put together; for example, forest ecologists will select a number of variables to measure to describe the structure of a particular forest or to compare the structures of forests of different histories. With this meaning, Spies (1998) suggested that forest structure is both a product and a driver of ecosystem processes and biological diversity. Franklin et al. (2002) described the structural development of natural forest ecosystems and its implications for forest management and conservation.

Important components of structure include live trees of various sizes, vertical foliage distribution, horizontal variation in canopy density, and coarse woody debris. Note that limiting structure to these types of variables is just seeing trees for the forest—trees do provide physical structure but not all structure (table 13) (figs. 31A–E). The structure of narrowly defined biotic communities can be described in terms of species richness, evenness, and ranking of species (Carey 1991, 1995; Carey and Harrington 2001; Carey and Johnson 1995; Carey and Wilson 2001). Populations of a species are often described in terms of age structure and its implications for future growth of that population. Closely related to the concepts of structure are architecture and growth form.

Architecture is sometimes used to refer to how tree growth (how the bole, branches, bark, and foliage are put together) differs among species. Tree architecture can influence environmental conditions such as light and precipitation penetration through the tree crown, and it may provide diverse sites for occupancy by a variety

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Table 13—Key structural attributes of Pacific Northwest old-growth forests identified before and after systematic study in western Washington and Oregon

Before study	After study
▪ Large live trees	▪ Diverse tree sizes
	▪ Diverse tree species
▪ Large standing dead trees	▪ Abundant live and dead trees with cavities
▪ Large fallen dead trees	▪ Dead organic biomass is high, but composition and abundance differ among forest types
▪ Horizontal heterogeneity	▪ Horizontal patchiness
	▪ Diverse patch types
▪ Multilayered canopy	▪ Canopy gaps
	▪ Variable foliage height diversity
	▪ Biocomplexity

Source: Adapted from Carey et al. 1999a and Franklin et al. 1981.

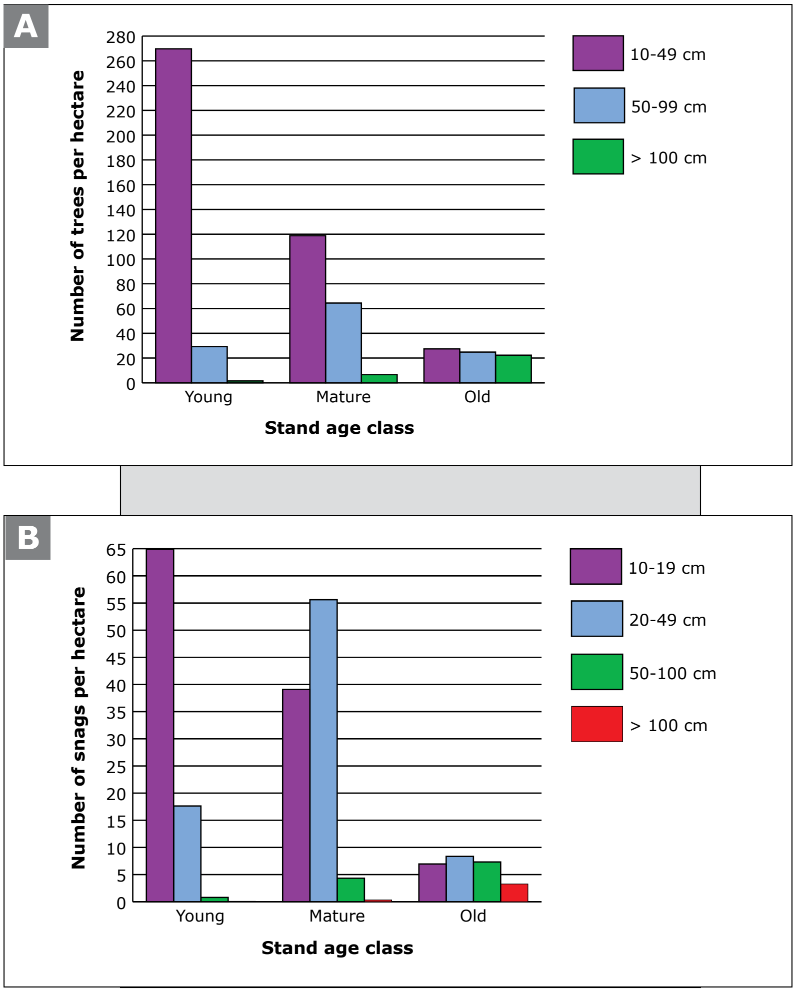
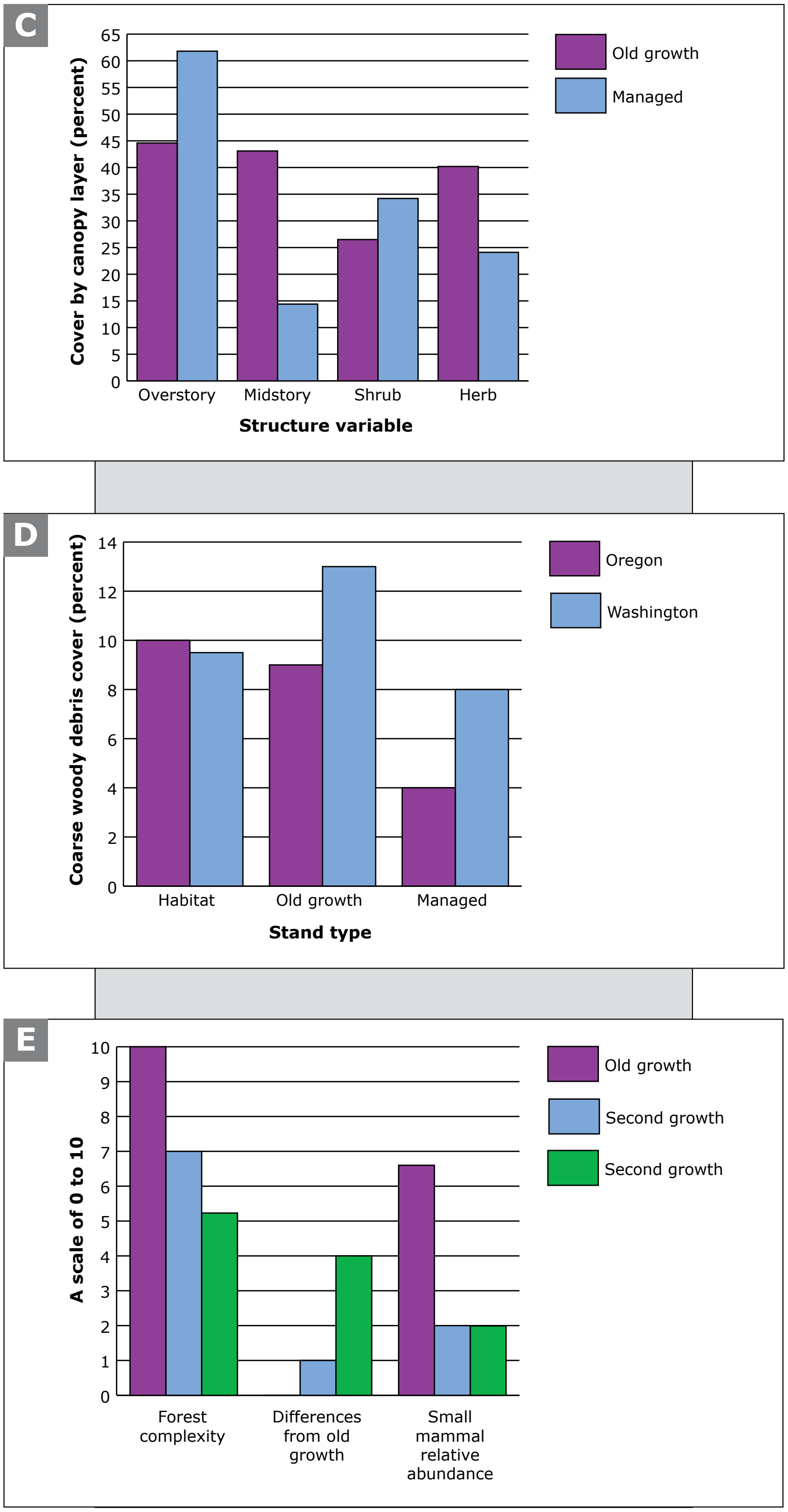


Figure 31—(A) Number of trees per hectare by diameter at breast height (DBH) in young, mature, and old stands of the southern Oregon Coast Range. (B) Number of snags per hectare by DBH in young, mature, and old stands of southern Oregon Coast Range (adapted from Carey et al. 1991). (C) Foliage-height profiles (percentage of cover by canopy layer) in managed and old-growth forests. (D) Coarse woody debris cover in northern flying squirrel habitat and in Oregon and Washington old growth and managed forests (adapted from Carey et al. 1999b). (E) Biocomplexity in old-growth and two samples of second-growth forests on the Olympic Peninsula (standardized to 10 for old growth); the degree to which complexity of small mammal communities differs from those in old growth and overall relative abundance of small mammals (adapted from Carey and Harrington 2001).


C
Cover by canopy layer (percent)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
Overstory
Midstory
Shrub
Herb
Structure variable
Old growth
Managed
D
Coarse woody debris cover (percent)
0
2
4
6
8
10
12
14
Habitat
Old growth
Managed
Stand type
Oregon
Washington
E
A scale of 0 to 10
0
1
2
3
4
5
6
7
8
9
10
Forest complexity
Differences from old growth
Small mammal relative abundance
Old growth
Second growth
Second growth

(continued from page 185)

organisms from spiders in furrows in rugose bark to lichens, mosses, and liverworts on branches. Architecture is also used to refer to how forest canopies are put together and how variation in canopy architecture might influence ecosystem processes and biological diversity (Carey 1994).

Growth form is a more general concept about how plant species are put together and differ from other species, for example, forbs, grasses, lichens, shrubs, and trees (USDA National Resources Conservation Service 2004) (table 14). Growth form has obvious implications for ecosystem structure. Small-scale architecture—e.g., how twigs and leaves or needles are put together—influences plant physiology and tolerance for a range of environmental conditions, such as light, temperature, and moisture. Growth form also affects a plant's competition strategy (Grime 1977) (table 15). However, architecture and growth-form concepts illustrate that structure and especially function are often not independent of species composition. Species composition affects various ecosystem functions in multiple ways in and beyond contribution to structure, for example, production of chemical leachates, nitrogen fixation, support of mycorrhizal activity, phenology of fruit and seed production (food for animals),

Table 14—**Growth forms and definitions**

Growth form	Definition
Forb/herb	▪ Vascular plant without significant woody tissue above or at the ground; forbs and herbs may be annual, biennial, or perennial, but always lack significant thickening by secondary woody growth and have perennating buds borne at or below the ground surface
Graminoid	▪ Grass or grasslike plant, including grasses (Poaceae), sedges (Cyperaceae), rushes (Juncaceae), arrow-grasses (Juncaginaceae), and quillworts (*Isoetes*)
Lichenous	▪ Organism generally recognized as a single "plant" that consists of a fungus and an alga or cyanobacterium living in symbiotic association; often attached to solid objects such as rocks or living or dead wood rather than soil
Nonvascular	▪ Non-vascular, terrestrial green plant, including mosses, hornworts, and liverworts; always herbaceous, often attached to solid objects such as rocks or living or dead wood rather than soil
Shrub	▪ Perennial, multistemmed woody plant that is usually less than 4 to 5 meters in height; shrubs typically have several stems arising from or near the ground, but may be taller than 5 meters or single-stemmed under certain environmental conditions
Subshrub	▪ Low-growing shrub usually under 0.5 meter tall, never exceeding 1 meter tall at maturity
Tree	▪ Perennial, woody plant with a single stem (trunk), normally more than 4 to 5 meters in height; under certain environmental conditions, some tree species may develop a multistemmed or short growth form (less than 4 meters in height)
Vine	▪ Twining/climbing plant with relatively long stems, which can be woody or herbaceous

Source: USDA National Resources Conservation Service 2004.

digestibility of foliage, production of toxins (e.g., phenols) in foliage, resistance or propensity to disease, insect attack, and decay, and many other phenomena that markedly influence species interactions. For example, Douglas-fir is relatively decay resistant after injury and provides decayed wood for excavation by woodpeckers usually only after death of a major part of the tree; long-lasting fallen Douglas-fir provide regeneration niches for various plants and an important habitat element for numerous animals. Grand fir commonly experiences heart rot while alive and provides dens for American marten after the tree falls. Ponderosa pine and western redcedar may undergo substantial heart rot to the extent of producing a hollow, live tree useful for denning by American black bears and squirrels and roosting by Vaux's swifts and pileated woodpeckers. Unfortunately, many forest ecologists and wildlife biologists bend the third meaning of *structure* (an organ or part of an organism; something constructed)

Table 15—Plant characteristics of the three primary competition strategies

Plant characteristic	Competitive	Stress tolerant	Ruderal
Shoot morphology	▪ High dense canopy; extensive lateral spread above- and below-ground	▪ Extremely wide range of growth patterns	▪ Small stature; limited lateral spread
Leaf form	▪ Robust, often mesomorphic	▪ Small, leathery, or needle	▪ Various, often mesomorphic
Litter	▪ Copious, often persistent	▪ Sparse, sometimes persistent	▪ Sparse, not usually persistent
Maximum potential growth rate	▪ Rapid	▪ Slow	▪ Rapid
Growth form	▪ Perennial herbs, shrubs, and trees	▪ Lichens, perennial herbs, shrubs, and trees (often very long lived)	▪ Annual herbs
Leaf longevity	▪ Relatively short	▪ Long	▪ Short
Leaf phenology	▪ Well-defined peaks of leaf production coinciding with period(s) of maximum potential productivity	▪ Evergreens with various patterns of leaf production	▪ Short periods of leaf production in period of high potential productivity
Flowering phenology	▪ Flowers produced after (or, more rarely, before) periods of maximum potential productivity	▪ No general relationship between time of flowering and season	▪ Flowers produced at the end of temporarily favorable period
Proportion of annual production to seeds	▪ Small	▪ Small	▪ Large

Source: Grime 1977.

to refer to individual elements of the ecosystem, for example, referring to a snag (standing dead tree) as a structure or providing the various structures (in the sense of the elements of the habitat) that a species needs. Thus, one forest ecologist may discuss structure-based management and mean the management for a limited number of stages of stand development in a landscape, another may be referring to managing tree species composition and tree growth to replicate some idealized stage of structural development of forest ecosystems, and a third may be discussing how to provide the individual components of a forest thought to be important to either individual species or a variety of species of wildlife. Again, such emphasis on structure without careful consideration of processes may not at all produce the desired outcomes. Stand structural stages based on tree size class and diameter at breast height (d.b.h.) do not address most aspects of biocomplexity. Idealized stages of structural development based on tree sizes do not necessarily correlate well with ecosystem function because they do not address composition and internal dynamics, or if they do, they do so superficially. Ecological correlates of ecosystem function in natural old-growth forests with all its biocomplexity do not have the same correlation with function in a simplified, managed forest. For example, d.b.h. and variance in d.b.h. can discriminate among managed young, naturally young, naturally mature, and naturally old forests, and thus would be correlated with the functions of old forest, such as providing habitat for spotted owls. Yet, these old, natural forests are complex—spatially heterogeneous, structurally diverse, biologically diverse, and dynamic. Plantations can be managed to produce large trees and even trees of two age classes and thus, trees of large d.b.h. and high variance in d.b.h. Yet these forests are often simple in structure despite having two canopy layers—dominated by a few species and reasonably static—continuing to accumulate biomass in trees, but failing to partition biomass among growth forms, produce structure through decadence, and maintain a dynamic, spatially heterogeneous environment. There is a great and inexorable tendency to reduce ecosystem management to the provision of a limited set of static elements—trees of large d.b.h., snags of large d.b.h., logs of large d.b.h.—without understanding that processes *are* functions. These elements set as goals are actually intermediate products of complex processes; the dynamics of the system are more important than a few simple elements. An example of the latter is the importance of intermediate disturbances to the maintenance of biological diversity in forest ecosystems (the Intermediate Disturbance Hypothesis).

Ecological correlates of ecosystem function in natural old-growth forests with all its biocomplexity do not have the same correlation with function in a simplified, managed forest.

Forest Structuring Processes

Once a forest has been established, there are four basic internal processes that develop structure over time: crown-class differentiation, decadence, canopy stratification, and understory development (Carey et al. 1999b). Nevertheless, conditions immediately prior to and during establishment (type of catastrophic disturbance, extent of disturbance, duration and repetition of disturbance, degree of legacy retention, landscape context) influence how the forest develops. As complexity of structure develops, overall habitat space increases—a process of development of habitat breadth. The increase in dimensions of the community allows for *preinteractive* niche diversification. In the 500- to 1,000-year continuum of development of natural, old-growth forests, numerous structural stages may occur (Franklin et al. 2002). In managed forests, however, some processes may be eliminated, others truncated, and some accelerated; complexity may be restricted or enhanced; thus, a variety of *states* of development can be identified but these do not constitute a continuum—that is, they are not necessarily inevitable, inexorable, sequential, or even conducive to continuing development of complexity (tables 16, 17, and 18).

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The dynamics of the system are more important than a few simple elements.

Table 16—**Stages of forest development based on ecological processes**[a]

Generic model	Timber/wildlife (duration in years)	Natural development	Active management	Simple	Complex
Stand initiation	▪ Grass-forb (2 to 5) ▪ Shrub (3 to 10) ▪ Open sapling-pole (8 to 20)	▪ Disturbance and legacy creation ▪ Cohort establishment	▪ Ecosystem reorganization	✓	✓
Stem exclusion	▪ Closed sapling-pole-sawtimber (40 to 100)	▪ Canopy closure ▪ Competitive exclusion ▪ Biomass accumulation	▪ Canopy closure ▪ Competitive exclusion ▪ Biomass accumulation	✓ ✓ ✓	✓
Understory reinitiation	▪ Large sawtimber (10 to 100)	▪ Maturation ▪ Vertical diversification	▪ Understory reinitiation ▪ Canopy stratification ▪ Niche diversification	✓ ✓	✓ ✓ ✓
Old growth	▪ Old growth (200 to 700) ▪ Climax (700+)	▪ Horizontal diversification ▪ Pioneer cohort loss	▪ Natural old growth ▪ Natural climax		✓ ✓

[a] Stages used in a generic model of forest development contrasted with structure-based timber classes used in a wildlife habitat relationship model, a model of Douglas-fir forest development under natural conditions, and a model for active ecosystem management.

Source: Adapted from Carey and others 1999b, Brown 1985, Franklin and others 2001, Oliver 1981, Oliver and Larson 1996.

Table 17—**Potential stages of development in managed, second-growth Douglas-fir forests with approximate correspondence to stages of stand development and structural conditions**

Stage of development	Management and subsequent ecological processes
Ecosystem reorganization:	▪ Removal of a majority of overstory trees with minor to major retention of biological components (future legacies) is followed by planting or seeding of trees, colonization by vagile forest species and by native and exotic invasive nonforest species, and succession from bare ground to grass-forb-herb communities to shrub-tree communities to a tree-dominated community. ▪ Referents: Stand initiation; 6 conditions (as identified by Johnson and O'Neil 2001)—grass/forb-open to sapling/pole-moderate
Simple	▪ Clearcutting variants, site preparation, planting, vegetation control, and stocking control produce an even-aged monoculture or a forest dominated by a few tree species with one species dominant.
Complex	▪ Variable-retention harvest systems with 5 to 30 percent retention of legacies, depending on area size and context; reduced and variable site preparation; planting with natural regeneration expected to establish multiple species of trees; planting or seeding to restore lost native plant diversity if necessary; limited vegetation control to ensure full stocking and vegetative diversity; precommercial thinning to promote multiple tree and shrub species and forestall competitive exclusion of numerous species.
Competitive exclusion:	▪ No management beyond ensuring full stocking, selecting desired species, and controlling competitors. ▪ Referents: Stem exclusion; sapling/pole-closed, small tree-single story-closed, medium tree-single story-closed, large tree-single story-closed
Simple	▪ Trees fully occupy the site and compete intensely with one another and other plants for light, water, nutrients, and space by growing tall quickly, eventually overtopping and suppressing shorter life forms, and slower growing species and conspecifics. ▪ Self-thinning produces even spacing and, sometimes, reduced intertree competition; failure to self-thin leads to loss of crown depth and spindly trees; competitive exclusion may extend to a majority of vascular plants, invertebrates, and wildlife.
Complex	▪ As above, except legacies from the preceding stand (from fallen trees to stumps to patches of intact forest) provide refugia within the forest for a wide variety of species; refugia maintain some spatial heterogeneity and species diversity; suppressed trees may provide substrate for cavity-excavating wildlife and foraging for saprophytic insects and insectivorous birds and mammals.
Biomass accumulation:	▪ Management includes conventional thinning to moderately high relative densities, selection for desirable timber species, and removal of decadent, defective, and competing trees. ▪ Referents: None; sapling/pole-moderate, small tree-single story-moderate, medium tree-single story-moderate, large tree-single story-moderate
Simple	▪ Trees fully occupy the site with moderate intertree competition; even-aged codominants grow and accumulate wood biomass rapidly while providing limited resources to other life forms.
Complex	▪ Low to moderate diversity and biomass of common plant species are maintained; growth of dominant trees contributes to maintenance of homogeneity; legacies maintain some heterogeneity and diversity.

Stage of development	**Management and subsequent ecological processes**
Understory reinitiation:	▪ Silvicultural thinning, self-thinning, and natural growth and mortality promote dominance by some trees, death of other trees, and release of plants in the understory from overstory competition. ▪ Referents: Understory reinitiation; sapling/pole-open, small tree-single story-open, medium tree-single story-open, perhaps large tree-single story-open, depending on stand history.
Simple	▪ A uniform canopy of evenly spaced trees leads to uniform understory conditions with dominance by a few species such as a shade-tolerant conifer or native clonal species such as salal and swordfern.
Complex	▪ Variable-density thinning produces canopy heterogeneity that leads to variable light and moisture regimes in the understory, which, together with legacies, produce an understory of patches of diverse composition, but generally low in stature. ▪ When necessary, due to previous management or competitive exclusion, underplanting augments the understory with key deciduous and conifer species.
Understory development:	▪ Thinning or other mortality reduces competition among trees, increases growth of trees, and releases understory from competition; understory develops in stature, abundance, and species diversity. ▪ Referents: None; six small to medium tree-multistory conditions, depending on legacies and decadence.
Simple	▪ A homogeneous overstory with moderate to low crown closure produces an understory that is botanically diverse but still dominated by a few species and lacking a distinctive patchy pattern; layers may develop, but lack of legacies precludes a fully developed, complex biotic community.
Complex	▪ Variable-density thinning produces canopy heterogeneity with high to moderate to low crown closure by dominants and codominants; heterogeneity produces crown class differentiation, including ingrowth by hardwoods and shade-tolerant conifers. Variable understory environmental conditions produce understory patches of differing composition. ▪ Cavity-tree creation and coarse woody debris augmentation during thinning and legacies from the preceding forest further compound the heterogeneity. ▪ The resulting complex structure provides a diversity of niches for species within various life forms, including fungi, mosses, lichens, achlorophyllous mycotrophs, grasses, forbs, evergreen shrubs, deciduous shrubs, deciduous trees, and shade-tolerant conifers.
Niche diversification	▪ Additional variable-density thinning or group selection may further contribute to developing high biocomplexity, including species diversity, structural diversity (live, dead, and fallen trees of various sizes; patchy understory; patchy midstory; canopy gaps; and gaps filled by shade-tolerant trees growing into the overstory), and vertical and horizontal spatial heterogeneity, but the forest still has not developed the giant structures characteristic of old-growth forests. ▪ When needed, cavity-tree creation and coarse woody debris augmentation during thinning maintain the decadence process. ▪ Referents: None; six medium to large tree-multistory conditions, depending on numerous variables.

Stage of development	Management and subsequent ecological processes
Gap dynamics	▪ Managed forests more than 125 years old with high niche diversification and trees and tree-based structures of giant size, including legacies and the current dominant cohort. ▪ Either passively managed for late-seral forest values along streams, on mass-wasting areas, in watersheds, or in reserves, on long rotations in shifting steady-state mosaic landscapes, or with group selection for uneven-age management. ▪ Referents: Old growth (but not natural); giant tree-multistory, depending on numerous variables

Source: Adapted from Carey and Curtis 1996, Johnson and O'Neil 2001, and Oliver 1981.

(continued from page 191)

Legacy retention—After a catastrophe destroys much or all of a forest canopy, the ecosystem reorganizes and begins to develop anew. The degree of retention of biological legacies from the preceding forest has profound influence on the site and the organisms available to the new ecosystem (Franklin et al. 2002, 2000). Legacy retention can range from a few live trees to a mixture of trees, shrubs, coarse woody debris, and intact forest floor to entire patches of intact forest. The more legacies retained, the more a forest-influenced environment is maintained and the greater the mycorrhizal networks, species and sizes of trees, degree of spatial heterogeneity, and available species pools. Some important legacies include seeds or seedlings of multiple species of conifers and hardwoods, ectomycorrhizal fungi, large coarse woody debris, large live trees with epiphytic mosses and lichens, and large dead trees. Legacies can provide fuel for future or ongoing disturbance—e.g., from the falling of damaged and dead trees owing to decay or wind or fires in the accumulated fuel. Legacies and the size and shape of the forest that was destroyed determine how distant any particular point in the reorganizing ecosystem is from sources of organisms that might colonize or recolonize a newly developing forest. The landscape context (biotic communities and seral stages) of the reorganizing ecosystem determines which other species are available to recolonize a new forest. If a full complement of species is available, four basic processes—crown-class differentiation, decadence, understory development, and canopy stratification—determine how forests initially develop structurally in the Pacific Northwest and many forests elsewhere (Carey et al. 1999b). Each of these processes can be jumpstarted by legacies and hastened by active management and intermediate-scale disturbances. As basic structuring processes interact, two subsequent (higher order) processes—development of habitat breadth (Carey et al. 1999b) and preinteractive niche diversification (Hutchinson 1978)—increase the diversity, composition, and structural complexity of the biotic community.

Crown-class differentiation—After trees have fully occupied the site, a tree canopy forms. Initially, the canopy may be dense and uniform, but over time, some trees must become dominant and others codominant, subordinate, or suppressed for development to proceed. Crown-class differentiation is important to producing large trees, trees with large branches and deep crowns, canopy heterogeneity and rugosity, small dead and dying trees, and a variety of other crown and canopy characteristics that develop habitat space for a variety of forest organisms. Differentiation can come about through (1) retention of coarse woody debris and other elements that cause patchy regeneration such as advance regeneration and larger trees of different sizes, (2) establishment of multiple species of trees (each with different growth rates), (3) self-thinning, (4) small- and intermediate-scale natural disturbances (including lightning, fire, windstorms, ice storms, insect infestations, and infections by pathogens), and (5) management (e.g., precommercial thinning, commercial thinning, and fertilization). Dense stocking, reliance on self-thinning, and tardy, light, evenly spaced thinning, however, can forestall differentiation, decrease biocomplexity, and lead to instability (Wilson and Oliver 2000). Elements and events that produce spatial heterogeneity can hasten the development of a complex community. Although crown-class differentiation can take place at small scales (one to a few trees), it affects the entire stand at larger scales (say 40 to 400 hectares or more). Intermediate-scale heterogeneity (0.1 to 0.5 hectare), however, is necessary for development of biocomplexity. Intermediate-scale legacy retention, natural disturbances, and management promote not only crown-class differentiation but also the higher level processes leading to habitat breadth and niche diversification.

Decadence—Decadence is a complex process essential to biodiversity. Decadent trees (live trees with wounds or active decay, standing dead trees, and fallen, decaying trees) can be retained during harvest operations. They can develop naturally as a result of self-thinning, suppression, disease, insect attack, damage by falling trees, and weather-related events (lightning, windstorms, ice storms, and snowstorms). Or they can be created by intentional wounding, topping, infecting, or killing. Decadent trees have essential roles in providing substrate for (1) a large variety of cavity-, hollow-, and

Table 18—**Characteristics of stages of development in managed forests without (simple) and with (complex) legacy retention, spatial heterogeneity in the canopy, and maintenance of decadence processes**

Stage	Biomass allocations	Decadence	Spatial complexity	Niche divergence[a]	Resistance to change[b]
Ecosystem reorganization:					
Simple	Trees, herbs, shrubs	None	Some	Some	Low
Complex	Trees, shrubs, herbs	Much in legacies	Much	Much	Low
Competitive exclusion:					
Simple	Trees	Small trees, deciduous trees	Some	None	High
Complex	Trees	Legacy logs and snags, small trees	Some	Some	High
Biomass accumulation:					
Simple	Trees	Well-decayed small trees	Some	Some	High
Complex	Trees	Large legacy structures; small trees	Some	Some	High
Understory reinitiation:					
Simple	Trees, shrubs	Possible insect/disease mortality	Some	Some	Moderate
Complex	Trees, shrubs	Various[d]	Much	Much	Moderate
Understory development:					
Simple	Trees, shrubs, herbs	Possible insect or disease mortality	Some	Some	Moderate
Complex	Various[c]	Various[d]	Much[e]	Much	Moderate
Niche Diversification					
	Various[c]	Various[d]	Much[e]	Much	Dynamic[f]
Gap dynamics					
	Various[c]	Various[d]	Much[e]	Much	Dynamic[f]

[a] Niche divergence refers to preinteractive niche diversification in which a variety of ecological niches are provided by disturbance, thus reducing competition and promoting complexity.

[b] Resistance to change indicates stages in which management intervention is particularly important to foster continuing development.

[c] Conifers of different species and age cohorts, deciduous trees and shrubs, evergreen shrubs, ferns, forbs, lichens, and bryophytes arrayed in patches that differ in composition and structure.

[d] Large legacy live trees with decadence, snags, fallen trees, litter, and deep humus; created cavity trees and snags; felled trees, insect/disease mortality.

[e] Varying in vertical, horizontal, and temporal dimensions.

[f] These stages have internal dynamics of change in patches over space in time; still, they are highly resistant to disturbance.

Source: Adapted from Carey and Curtis 1996, Johnson and O'Neil 2001, and Oliver 1981.

crevice-nesting wildlife; (2) pecking and tearing foraging by insectivorous birds; (3) physical partitioning of the forest floor that reduces competition between deer and elk and among small mammals; (4) cover for small mammals and salamanders; (5) support of invertebrate communities that are prey for insectivorous arthropods, birds, small mammals, and amphibians; (6) foraging sites for mycophagous small mammals; (7) travel ways; (8) entryways to subnivean environments; and (9) rooting and nutrient sources for a variety of plants and fungi (see Bunnell et al. 1999, Harmon et al. 1986, and Johnson and O'Neil 2001 for reviews). Typically, forest management for wildlife emphasizes only one or two elements of decadence: large, dead, moderately decayed conifers and large, fallen, moderately decayed conifers. The former are the trees most commonly used by cavity-excavating birds, and the latter provide important shelter for terrestrial amphibians and certain small mammals. However, to focus on these structures without considering the entire process of decadence and how the process differs with seral stage is a mistake. For example, a conifer with a broken top may continue to grow, develop a new top or "basket" top, develop top rot and provide perch, roost, and nest sites for hawks, owls, eagles, ospreys, woodpeckers, squirrels, bats, and various of other wildlife over a long period before it dies and thence long after. In younger conifer forests, deciduous trees such as red alder, willow, and aspen provide valuable cavity trees despite their relatively small size (Bunnell et al. 1999, Carey et al. 1997). For example, red-breasted sapsuckers will nest in small decadent willows (20 centimeter d.b.h.) in second-growth forests but use only large snags averaging 113 centimeter d.b.h. in old-growth forests. Sapsuckers (and other woodpeckers of the family Picidae) are often double keystone species in keystone species complexes. For example, in Rocky Mountain forests, red-naped sapsuckers excavate cavities in fungus-infected aspens that are required as nest sites by two species of swallows and drill sap wells into willows that provide nourishment for themselves, hummingbirds, orange-crowned warblers, chipmunks, and an array of other sap feeders (Daily et al. 1993). Thus, additional emphasis is warranted on providing numerous live deciduous trees, subject to eventual suppression or infection with top rot, early in forest development, and both conifers and hardwoods with cavities or other evidence of top rot, late in forest development, to provide various sizes of cavity trees (relatively small deciduous trees and relatively large conifers). Pileated woodpeckers play a cavity-creation keystone role in Pacific Northwest forests (Aubry and Raley 2002) and, actually, throughout many forests in North America. These large birds are capable of excavating nest cavities, entrances to hollow trees, and entrances to insect galleries in the interior of large, moderately decayed trees that later are used by a wide variety of birds and mammals.

Understory development—Seeds and plants retained on site germinate, regrow if damaged, or continue to grow as light, water, and nutrients become available through canopy gaps. Canopy closure can extirpate many of the retained species and, if long enough, even eliminate seeds from the soil seed bank. In the absence of full canopy closure (limited stocking, disturbance, or management action such as precommercial thinning) and with crown-class differentiation, gap formation, or commercial thinning, the understory develops in stature and composition. With sufficient light, the understory increases in foliage volume and fruit production, providing invertebrate and vertebrate animals with a variety of food and cover. For example, foliage of deciduous shrubs, such as oceanspray provides forage for larval moths (Lepidoptera) that are important food to insectivorous birds and mammals (Muir et al. 2002). Vine and bigleaf maple seeds and hazelnuts are especially valuable to squirrels in coniferous forests, where their staple foods are produced sporadically (conifer seed) or are of low nutritive value (truffles) (Carey et al. 1999b, 2002).

Canopy stratification—As canopy dominants attain full stature, subordinates die, and disturbances cause gaps through the death of canopy dominants and codominants, and canopy dominants lose control of the light regime. Increased light to the understory, along with retention or recruitment of shade-tolerant conifers and hardwoods, and continued gap formation through natural mortality or silvicultural thinning, allows various strata of vegetation—low herbs, short shrubs, tall shrubs, and a midstory of deciduous and coniferous trees—to develop. Control of the internal light regime now rests with the midstory and tall-shrub shade tolerants, and diversity in the interior environment of the forest increases. Increased botanical diversity may be accompanied by horizontal and vertical heterogeneity in composition and foliage volume. Thus, a large variety of trophic relationships develop, and the overall habitat space begins to differentiate into diverse niches that support an enhanced variety of plants and wildlife.

Development of habitat breadth—With legacy retention and following a long period of gap development or management such as variable-density thinning, the forest develops patchy overstory, midstory, shrub, and herb layers. The result is a fine-scale mosaic of 0.1- to 0.5-hectare patches of 10 to 30 vegetation site types with each type composed of a different mix of species that differ in growth form. For example, one patch may have an understory of moss with a dense midstory of shade-tolerant conifers under a relatively open overstory; another patch may exhibit a continuous column of foliage from different plants from the forest floor to the overstory. Note that the resulting structure is quite different than the development of ladder fuels in interior ponderosa pine forests where flammable Douglas-fir provides ladders for ground fires to reach canopies. The patchy structure resulting from development of habitat breadth includes less flammable species in the understory than in the overstory and provides biological and physical gaps in both understory and overstory that impede the spread of potentially catastrophic disturbances such as fire and disease. Thus, intermediate-scale heterogeneity has proven beneficial for wet to moist coastal forests (Carey et al. 1999b) and moist to dry interior forests (Graham et al. 1999, Harrod et al. 1999, Reynolds et al. 1992). The process of developing habitat breadth (the full range of small-scale vegetation site types, or patches, characteristic of old, natural forests in the region) seems essential to the maintenance of biodiversity in two obvious ways. First there is an overall increase in habitat space—the volume of space the forest occupies, the overall surface area of plants within that volume, and the architectural niches formed by the variety of growth forms. Second, the diversity of plant life and growth forms provides a variety of substrates and foods (foliage, seeds, fruits, nuts, and carbohydrates in root exudates) for use by other plants, fungi, invertebrate animals, and wildlife at a scale suitable for exploitation by organisms of low to moderate mobility, resulting in niche diversification.

Preinteractive niche diversification—When legacies have been retained or large structures (large live trees, dead trees, and fallen trees) have developed and the four basic stage-setting processes have gone on to produce habitat breadth, the phenomenon of preinteractive niche diversification (Hutchinson 1978) may take place. Simply put, the forest has developed sufficient variety in structure, diversity in plant composition, and patchiness (and patch types) such that many species that typically would compete in simpler environments can coexist, even in large numbers. For example, resident cavity-using birds overlap in space and resource use in young, simple forests, and occupancy of these forests by some of these species may be variable or sporadic. In old, complex forests, all are present and in greater abundance than in young forest; each tends to forage on different substrates (e.g., bole and branch sizes) and, thus, more separately in fine-scale space. Similarly, a variety of decaying plants (wood and foliage) produces various sizes of saprophytic invertebrates, each primarily consumed by a different insectivorous mammal (e.g., shrew, Soricidae) with appropriate-size mouth parts. Diversity in foliage cover provides hunting perches for spotted owls and protective cover for their prey. A simple forest may provide the owl with one species of prey, but a complex forest provides several species of prey (Carey et al. 1992). Thus, a complex forest provides a more stable resource for the owl and less predator pressure on any single prey species. Niche diversification operates at various trophic levels, providing for diverse forest-floor invertebrate fauna, fungi, and vascular plants; diverse insectivorous, mycophagous, granivorous, and herbivorous mammals; and diverse predators at the top of food webs (Carey 2003a).

Ecosystem Development and Community Succession

Diversity begets diversity. However, if the diverse communities are all simply structured, have high contrast, or are arrayed in too coarse or too fine a grain, species diversity could decrease. Change begets diversity. However, if change is too frequent, too severe, or too simplifying, diversity could decrease. Static conditions are thought to reduce diversity, but a dynamic equilibrium such as a shifting, steady-state mosaic (at either the ecosystem or landscape scales or both) may maintain high diversity. Diversity within communities generally increases as the ecosystem increases in biocomplexity but can decrease over time in stages where stability is high and dynamics are low (Whittaker 1965). Diversity in landscapes generally increases with the number of disparate community types in the landscape but can decrease in landscapes where disparate community types have been deliberately simplified by management for commodity production. Few communities, however, are fixed in space and time. Most undergo development and many undergo succession. Most are eventually affected by some kind or some suite of disturbances, natural, anthropogenic, or both. How can one go about sorting out all these diverse influences at the larger scales on diversity? Modeling provides the most tractable approach. Of course models are only as good as their underlying concepts are sufficient to the purpose of the model and the degree to which the incorporated databases reflect reality.

Wildlife-Habitat-Relationships Models

Considerable effort has gone into compiling databases that relate species occurrences to community types, stages of community development, and various elements of landscapes (e.g., caves, cliffs, and talus slopes) and elements of biotic communities (e.g., snags, coarse woody debris, and deciduous tress). For vertebrates, these databases are known as Wildlife Habitat Relationship (WHR) models. Similarly, considerable effort has gone into plant community and forest type classifications. The WHR databases have several weaknesses; for example, (1) they assume static conditions, (2) they do not incorporate measures of resistance to change or susceptibility or probability of disturbance, (3) they generally do not project future trends, even in the absence of disturbance, and (4) their models of forest development are derived from models of timber growth and yield in even-aged stands of trees that serve their intended purpose well but are too tree-focused for modeling diversity (e.g., they lack information on biocomplexity). Timber models were not developed to account for the diverse elements of wildlife habitat; therefore, they serve WHR purposes poorly, unless augmented by numerous other habitat variables. Thus, the most current WHR database for Oregon and Washington (Johnson and O'Neil 2001) cross-tabulates forest–dwelling species by 20 *forest structural conditions*, 9 *habitat types*, and almost 100 *habitat elements* and subcategories. Structural conditions include grass/forb—open, grass/forb—closed, shrub/seedling—open, shrub/seedling—closed, sapling/pole—open, sapling/pole—moderate, sapling/pole—closed, small tree—single story—open, and so on, up to large tree—multistory—closed and giant tree—multistory. Habitat types range from west-side lowland conifer-hardwood forest to upland aspen forest. Categories of forest habitat elements include down wood, litter, duff, shrub layer, moss, flowers, lichens, forbs, fungi, underground plant parts, ferns, herbaceous layer, snags, tree size, mistletoe brooms, dead parts of live trees, hollow trees, tree cavities (fig. 32), bark, legacy trees, large branches, fruits, seeds, nuts, and edges. Numerous other habitat elements, ecological and abiotic, are tabulated. The cross-tabulated WHR models are data-rich and useful but cumbersome. Their complexity exceeds the cognitive limits of people engaging in discussions of field conditions or in collaborative management. Still, with careful incorporation into simulation models, they allow exploration of the consequences of alternative conservation scenarios and estimations of vertebrate diversity at multiple scales, at least (Carey et al. 1999d). However, they generally do not incorporate spatial interactions among communities. Analysis of spatial relationships in landscapes as it relates to species persistence and maintenance of biodiversity is in its infancy. Less complex, but still holistic models of forest development are more tractable and can be quite useful for heuristic modeling exercises and designing silvicultural prescriptions. Of course, the more reductionist the model, the less predictive ability it may have in the real world.

Forest Development Models

The simplest tree-focused model of forest development has four stages that follow either a natural or human-created large-scale disturbance: stand initiation, stem exclusion, understory development, and old growth (Oliver 1981). This model has proven too reductionist for modeling WHR in simulations of Pacific Northwest landscapes (Carey et al. 1999d). Carey and Curtis (1996), building on Bormann and Likens (1979), went beyond stand-structure classes to a set of eight developmental stages based on the processes taking place within the forest ecosystem that influence the development of the

Figure 32—(A) A northern flying squirrel and (B) a deer mouse peer out of natural tree cavities. Photo A by W. Colgan III; Photo B by A. Carey.

greater biotic (plant, fungal, and animal) community. Franklin et al. (2002) followed with an expanded classification of natural stand development (still focused on trees), nominally based on structure, but in actuality incorporating processes (e.g., canopy closure and biomass accumulation) and a large body of literature, including work on how stand development differs in managed and natural forests. Naturally developing forests may go through as many as eight major sequential stand conditions, differing in duration from less than 10 to more than 500 years. However, management can truncate the sere of forest development, eliminate entire stages, speed up or slow down transition between stages, and produce stand conditions not found in natural forests (Carey et al. 1999c, 1999d). Development may be limited to as little as 40 years in Douglas-fir forests, yet complex forests may require 70 years or more to develop, and forests producing a full array of values may require rotations of 125 to 250 years or longer (Carey and Curtis 1996). Thus, modeling active management and its effects on forest development requires a different type of classification—a nonsequential classification that can be subdivided into decadal periods. Furthermore, management for biocomplexity and emergent properties requires that models incorporate more than just the development of the tree community. Carey et al. (1999c), for example, modeled the Carey-Curtis 8 stages of biotic community development with 25 total substages. Field tests of the Carey-Curtis classification in formal experiments, retrospective comparisons of forests managed for various objectives, and in retrospective comparisons of managed and natural forests, suggested it was necessary to revise and expand the classification to account for the great diversity of conditions being produced in managed forests in the Pacific Northwest (see table 17). This new classification incorporates seven stages, five of which are cross-classified as simple or complex in structure and composition. The stages differ in how resources (light, water, nutrients, and space) are being allocated to plants, degree of decadence, spatial complexity, niche divergence, and resistance to change (see table 18). The latter is an important consideration in management because it indicates stages in which a relatively stable-state alternative to late-seral forest is likely to develop in the absence of external disturbance. If such a state does develop and persist for a relatively long time, it may prove very difficult to alter its trajectory to development of a complex, biologically diverse forest (Carey 2003a). In timber management, development often is limited to simple subsets of two stages, ecosystem reorganization and either competitive exclusion or biomass accumulation, with cycles (rotations) of 40 to 70 years, with few or with a variety of silvicultural manipulations (see tables 17, 19). In management for biodiversity, emphasis is on the complex subsets of ecosystem reorganization, understory reinitiation, understory development, and niche diversification with rotations of 130 years or more or, with the addition of gap dynamics, on very long rotations (say 350 years or more). A variety of silvicultural manipulations are used, as well as direct wildlife habitat improvements (see tables 17, 19). Despite the complexity of this classification, it, like any classification, is an artificial construct and is best applied when augmented with site-specific knowledge of environmental conditions (climate, weather, microclimate, and natural disturbance regimes), site fertility and productivity, plant community development, and special landscape elements (e.g., wetlands, riparian zones, talus slopes, and cliffs).

Reserve Design

Conservation biologists have taken a markedly different approach than wildlife biologists using WHR models to compare alternative landscape management scenarios. Conservation biologists have focused on reserve design—how to protect as many of the desired communities in the landscape as possible and setting aside areas in hope that managed forests might develop into forests similar to naturally old forests, despite differences in type of catastrophic disturbance, legacy retention, and probable future natural disturbance regimes. They hope future natural disturbance regimes will provide the change necessary to maintain high diversity. Which approach is better: designating reserves or managing change? Is maintaining biodiversity compatible with production of commodities and active management of the land? Is a concept of general sustainability, incorporating environmental, social, and economic sustainability practical? Are reserves necessary? A case study, the Washington Forest Landscape Management Project examined the question and provides some insight.

Washington Forest Landscape Management Project

Exploitation of forests in the Pacific Northwest over the last 150 years repeated the history of eastern North America. Small areas of natural forest were reserved, and the remaining forests were freely exploited. Commercially valuable forests were harvested and replaced with naturally regenerated second-growth forests in degraded watersheds. Mounting degradation led to regulatory emphasis on reforestation, efficient production of wood, and economic stability (sustained yield), without thorough consideration of cumulative impacts at watershed and higher spatial scales. As harvests of old growth proceeded and landscapes became increasingly dominated by early-seral stages, first the spotted owl, then the marbled murrelet, and later, numerous salmonids were designated as threatened with extinction. Public concerns led to restrictions on forest management. Conservation focus switched from stands of timber to landscapes and from wood production to conservation of fish, water, and wildlife and to general sustainability. A presidential initiative to resolve the social conflict produced the 1993 Northwest Forest Plan for management of federal lands. The plan was an effort by disciplinarily diverse academicians, scientists, and managers to address environmental, economic, and social concerns. The plan emphasized late-successional reserves, an aquatic conservation strategy,

Table 19—**Effects of silviculture on ecosystem complexity**

Silvicultural treatment	More complexity	Less complexity
Regeneration harvest:		
▪ Legacy-retention harvest	✓	
▪ Clearcutting		✓
Planting:		
▪ With natural regeneration	✓	
▪ Without natural regeneration		✓
Weeding:		
▪ Retains some hardwoods and shrubs	✓	
▪ Removes hardwoods and shrubs		✓
Precommercial thinning:		
▪ Clumped multispecies retention	✓	
▪ Systematic single species retention		✓
Commercial thinning:		
▪ Variable density plus[a]	✓	
▪ Systematic minus[b]		✓

[a] Variable-density thinning with mixed-closed, moderately open, and open canopies on a 0.1- to 0.5-hectare scale designed to enhance woody plant diversity, maintain deciduous trees, promote recruitment of shade-tolerant trees with underplanting and augmentation of cavity trees and coarse woody debris when necessary.

[b] Light to moderate thinning with even spacing to favor one species.

Source: Adapted from Carey 2003a and Carey et al. 1999b.

monitoring threatened species, and identification, inventory, and management of numerous rare and cryptic species (Staebler 1994). In 2002, the plan was judged a failure in need of overhaul by Chief Bosworth of the USDA Forest Service because timber production projected under the plan was reduced by 75 percent in practice (to 5 percent of the preplan harvests) because of litigation over species sensitive to timber harvest (Dodge 2002, Milstein 2002). Almost 50 percent of the planned timber harvests were to have come from unreserved old growth, and those harvests met especially strong public opposition.

What went wrong with the Northwest Forest Plan? The plan failed to address the debate about what constitutes sustainability—a debate arising from cultural differences among the three major cultural streams in perceptions, values, and beliefs (see Part I) (Ray 1996). However, there are lessons learned from implementation of the Northwest Forest Plan and recent research that suggest better ways of managing landscapes. Indeed, the plan stressed adaptive management. Recapitulation of the federal research response to the forest management crisis in the 1980s and the application of new knowledge in a congressionally mandated modeling study of cross-ownership landscape management provide some insights.

Research Response to the Old-Growth Crisis

By 1980, much of the public was dismayed at the continuing harvest of old-growth forests. Old-growth forests are 250 to 1,000 years old; many are described as cathedral-like, with boles meters in diameter sweeping upwards to canopies almost 100 meters tall. People find these forests awe-inspiring and spiritual. Scientists postulated that old-growth forests were ecologically unique (Franklin et al. 1981) and that numerous species of wildlife depended on old-growth forests (Meslow et al. 1981), particularly the spotted owl (Forsman et al. 1984). Others perceived these forests as warehouses of highly valuable timber that would decay if not harvested and that were essential to the economic and social stability of timber-dependent communities. The onus was placed on Forest Service Research to determine quantitatively the uniqueness of old-growth forest, how much remained, the extent to which wildlife was dependent on it, the species that were dependent on it, the elements of old growth those species were dependent upon, the amounts and distribution of old growth that should be retained to meet conservation objectives, and the degree to which old-growth values could be achieved in managed forests. The USDA Forest Service implemented a coordinated program of research that included replicated, geographically stratified studies of plant, reptile, amphibian, bird, and mammal communities in old-growth (over 250 years), mature (100 to 200 years), and young (40 to 80 years) natural forests, and the research findings have been published (Carey and Spies 1991, Ruggiero et al. 1991). Later, it implemented a separate program of research on the northern spotted owl that included geographically stratified studies of its prey base, habitat use, and demography (Carey et al. 1992, 1999b). Finally, additional studies compared naturally old forests to managed forests (Carey 1995, 2000b; Carey and Harrington 2001; Carey and Johnson 1995; Carey et al. 1999b). The results were used to design treatments to restore lost biodiversity to managed stands (Carey et al. 1999d) and management systems (biodiversity pathways) for small landscapes (Carey et al. 1999c).

Natural Forests

Compared to forests around the world, Pacific Northwest old-growth forests are special—the trees are large and long lived, the vegetation structure is complex, decaying organic biomass is high, and fungal and small mammal communities are especially diverse (Carey 1998b). Old-growth forests are heterogeneous as a set, however; members of this set developed on specific sites that differed in topographic and biogeographic positions, period of development (250 to 750 years), climatic regime, and disturbance regime. Once lost, it is unlikely the old growth could be reproduced either through natural succession or through intentional management simply because the physical conditions of its development are not subject to unvaried natural repetition or to human control. Furthermore, the complete species composition of old growth has not been, and currently cannot be, fully determined; thus, indisputable demonstration of successful re-creation is impossible. Nevertheless, few species of plants and vertebrates are unique to old growth (Carey 1989, Ruggiero et al. 1991).

The spotted owl, among all vertebrates studied, seemed most dependent on old growth given the composition of the landscapes of the 1980s (Carey et al. 1992, Carey and Peeler 1995, Forsman et al. 1984). Other species were associated with particular elements of old growth (see table 13) or undisturbed headwater streams most likely to be found in old growth. Numerous species were most abundant in old growth but were found in other seral stages as well.

Often, abundances were associated with one or more attributes of old growth that were less abundant in younger or managed forests (Carey 1989). Thus, old growth functions differently than many younger forests in that its biocomplexity allows greater biomass and diversity in a number of narrowly defined biotic communities (Carey et al. 1999b, Ruggiero et al. 1991). Many younger natural forests with biological legacies from preceding old-growth forests, however, support vertebrate communities with greater biomass than those in many old-growth forests (Carey 1995, Carey and Johnson 1995, Carey et al. 1999b, Ruggiero et al. 1991), despite smaller average tree sizes. Other young forests support complete biotic communities and even provide habitat for spotted owls (Carey and Peeler 1995). Thus, it became apparent that management cannot indisputably re-create old growth, that any such re-created old growth could be regarded as anthropogenic and not wild or natural in any case, and that attempts to harvest old growth would be contentious and lead to litigation. But, it is not at all clear that forests equivalent to old growth will develop from second growth on those same sites if simply left alone to organize and grow themselves—they lack legacies, equivalent landscape and regional contexts, and similar climate regimes. Improved knowledge of old growth and its importance to people suggested that old growth might best be reserved for its ecological, scientific, and spiritual values (Carey 1998a, 1998b).

Old-Growth Versus Managed Forests

Whereas as many naturally young forests support biotic communities similar to those found in old growth (Ruggiero et al. 1991), many managed forests are depauperate in structure, species, and ecological function (Carey 1995, 1998b, 2000b; Carey and Harrington 2001; Carey et al. 1996b, 1999b). First, many (but not all) managed forests developed without legacies from the preceding forest; these legacies include coarse woody debris, live trees with their mycorrhizal and epiphytic associates, and soil seed banks holding numerous native species of plants and animals. Second, most managed forests were regenerated as dense monocultures that further reduced native diversity through competitive exclusion but allowed exotic species to persist, at least in soil seed banks (Carey et al. 1999b, Halpern et al. 1999, Thysell and Carey 2001a). In intensively managed forests, brush control, precommercial thinning, herbicides, and commercial thinning all are used as tools to reduce diversity. Indeed, stands maintained in the competitive exclusion stage may be more deleterious in terms of biodiversity and landscape function than the small areas of clearcutting that would occur with long rotations (Carey et al. 1999c). Legacies and often spatially variable, multispecies regeneration in natural stands allow key ecosystem structuring processes to proceed at accelerated rates compared to second-growth forests. These processes include crown-class differentiation, decadence, canopy stratification, and understory development and set the stage for higher level processes that lead to biocomplexity: development of habitat breadth and preinteractive niche diversification (Carey et al. 1999b). Understanding processes underlying forest ecosystem development and the structure of trophic hierarchies allows formulation of management systems to develop or restore biocomplexity to second-growth forests (Carey et al. 1999b, 1999c, 1999d). Both comparative ecological studies (e.g., Carey 1995, 1998b, 2000b; Carey and Harrington 2001; Carey and Johnson 1995; Carey et al. 1999b; Carey and Peeler 1995) and formal experiments (Carey 2001, Carey et al. 1996b, Carey and Wilson 2001, Thysell and Carey 2001a) demonstrate that it is erroneous to assume that forested landscapes are dichotomous (diverse old natural forests versus depauperate young forests), that landscape elements (e.g., early seral stages) are unchanging through time, and that second-growth forests will develop essential characteristics of old-growth forests without management intervention.

Modeling Landscape Alternatives

Increasing restrictions on forest management with continuing controversy after the Northwest Forest Plan had negative economic impacts on rural communities and impeded watershed restoration efforts. As lists of species likely affected by timber harvests and other management activities grew, and complexity of management for multiple individual species increased, public officials in the state of Washington wondered if there was not a better way of pursuing economic, social, and environmental sustainability. They requested a study to determine if holistic, cross-ownership, management could lead to better solutions than landscape zoning and single-species conservation plans; an interdisciplinary team of scientists and technical specialists was assembled from the Washington Department of Natural Resources, Washington Department of Wildlife, University of Washington, Oregon State University, and the Pacific Northwest Research Station of the USDA Forest Service (Carey et al. 1999c).

Pragmatic evaluation of management alternatives requires that computer simulations be grounded in reality; thus, the team chose a real landscape in western Washington for which detailed data on stand conditions, tree growth and yield, streams, wildlife-habitat relationships, transportation networks, unstable slopes, operational costs, distance to timber markets, and market values were available. Because alternatives were to be pertinent to diverse landowners, from industrial forests to state-managed school trust lands to tribal lands, they calculated net present value of extracted wood products and sustainable decadal revenues over the long term (300 years). Tradeoffs between economic and environmental values would be manifest; however, many values produced would accrue to society in general, not to the individual landowner or trust. Thus, public subsidies or other benefits might be required as incentives to private landowners. Total landscape management would include non-reserved federal lands and would have to be acceptable to the public at large. Thus, these five ecological indices were used to evaluate alternative silvicultural systems and landscape management scenarios (Carey et al. 1999c):

- Ability of the landscape to support wide-ranging old-growth species, based on estimates of the area of late-seral forest required to support one pair of spotted owls, the only threatened species with documented habitat requirements.
- Capacity to support vertebrate diversity based on published accounts of the habitat requirements of 130 species, evaluated as percentage of maximum possible capacity.
- Forest-floor function, defined as the biotic integrity of the forest-floor small mammal community (the top of the forest-floor food web), based on published equations predicting species abundances, and providing part of the prey base for generalist vertebrate predators (weasels, coyotes, bobcats, owls, and hawks).
- Ecological productivity, defined as the biomass (kilograms per hectare) of three species of squirrels and as representing the system's production of fungal sporocarps, fleshy fruits, and seeds of trees (consumed by squirrels) and capacity to support medium-sized predators (weasels, owls, and hawks that consume squirrels).
- Production of deer and elk, based on published models, and taken to represent the system's capacity to support large predators (wolves and mountain lions), subsistence hunting by indigenous peoples, and sport hunting.

Given metrics for comparing results, the next choices were on constraints on management. The team decided that all alternatives should produce a *regulated* forest that produced a relatively even flow of outputs on a decadal basis. Because the existing landscape had imbalanced age classes (primarily 50-year-old stands) as a result of rapid harvesting of old growth, achieving regulation required up to 100 years. Minimal protection of streams was required by state regulations at the time of the simulations, and this protection was commonly deemed unsatisfactory; new regulations would be forthcoming. Federal land managers had adopted requirements of watershed analyses and wide interim buffers around streams, from which management was excluded; this exclusion, however, became more or less institutionalized. Thus, the state and federal approaches provided two extremes, with the state regulations deemed marginal at the outset. Applying the new federal approach to the landscape produced surprising results—34 percent of the landscape was withdrawn from management, and significant parts of the remaining landscape, especially in headwater areas, were so isolated and overdispersed as to become economically infeasible to manage. Similar results were obtained as federal managers began implementing the new guidelines. The team reviewed federal riparian constraints and found, to its surprise, that they were based as much on an upland wildlife and dispersal corridor strategy as on an aquatic conservation strategy. Furthermore, there were few empirical data to support the corridor strategy, the interim guidelines precluded restoration efforts in riparian areas (riparian areas in the landscape to be modeled were highly degraded and devoid of conifers, essential sources of coarse woody debris for instream structure), and the constraints provided relatively little protection to headwater streams, seeps, and mass-wasting areas. The team sought alternatives. First, they shifted emphasis from large streams and rivers to small streams; the impacts on the entire landscape remained large, and the same suite of problems persisted. Finally, they adopted as a third alternative (to the state and federal alternatives), precluding mechanical operations on streambanks and adjacent to headwater seeps and streams; allowing thinning and other restoration efforts in narrow riparian buffers, but not clearcutting; and allowing thinning, but not clearcutting, on mass-wasting areas. The total area in the landscape constrained by this approach was less than 15 percent and did not isolate patches of upland forest.

Next, the team chose three classes of alternative landscape management scenarios: (1) protection, but no manipulation; (2) maximizing net present value of timber commensurate with existing state of Washington forest practices rules; and (3) management for biodiversity, defined as species, biotic communities, and ecosystems, and the ecological services and economic goods they provide. For maximizing timber production, the team used input from industrial forest managers about the feasibility and reasonableness of silvicultural practices and empirical growth-and-yield models. Numerous simulations were done, but the final alternative was clearcutting, site preparation, natural regeneration, precommercial thinning at 15 years, clearcutting at 40 years, and existing minimum state riparian management guidelines. Alternative silvicultural regimes for conserving biodiversity were developed, too. The final alternative included clearcutting with legacy retention, no site preparation, planting of Douglas-fir and natural regeneration of other conifers and hardwoods, regulation of spacing and maintenance of tree species diversity with precommercial thinning at 15 years, and variable-density thinning to induce spatial heterogeneity, maintain tree species diversity, recruit coarse woody debris, and remove wood products at 30-, 50-, and 70 years with final harvest by clearcutting with legacy retention alternating between 70 and 130 years. Rotation ages were deliberately calculated to balance timber revenues with ecological outputs. The new riparian/mass-wasting area management was superior to other riparian management alternatives.

Results of the final simulations were surprising to the team and forest managers. Simply protecting second-growth forest caused the landscape to go through waves of forest development. Initially a substantial ecological crunch occurred because of degraded watersheds and oversimplified stands; a long time (200 years) was required for these stands to achieve an old-growth-like condition (under a possibly unwarranted assumption that time alone would indeed produce naturally complex, old forests). Timber management with minimum constraints produced a landscape inhospitable to over 20 vertebrate species and allowed no recovery of degraded streams; its sustainability was uncertain, but net present value was maximal. Timber management with riparian reserves drawn from federal guidelines, produced relatively narrow, well-separated strips of late-seral forest in the long term, unlikely to function fully as late-seral forest because of their continued adjacency to clearcut and young forests; clearcutting was intensified in the available uplands owing to removal of streamside and adjacent small patches from forest management. Biodiversity management, as it was designed to do, produced significant ecological benefits (see Part 1, table 5), including supporting a pair of spotted owls and producing numbers of deer and elk comparable to the timber management regime.

But, surprisingly, costs were relatively low—only a 15-percent loss in net present value compared to maximizing net present value of timber extraction. Assuming (as occurred) increased riparian protection would be mandatory and eliminating costs of improved riparian/mass-wasting management from comparisons, biodiversity management resulted in only a 6-percent decrease in net present value. Other economic values increased: decadal revenues increased by 150 percent, forest-based employment quadrupled, and the wood products manufacturing sector diversified and relied more heavily on high-quality wood products and value-added manufacturing (Lippke et al. 1996). Initially, the team included a constraint of 30 percent of the landscape in late-seral forest to support one pair of spotted owls; the final shifting steady-state mosaic maintained more than 50 percent of the landscape in late-seral stages, and less than 15 percent of the landscape was in clearcuts in any decade, resulting in a landscape fully permeable to dispersing late-seral species.

Implications

Conservation biologists once argued the relative merits of single, large reserves versus multiple small reserves, the need for conserving genetic diversity, and the need to restrict active management. Forest managers focused on plantation management, transportation networks, and watershed restoration. Now it is becoming recognized by both that active management for biodiversity is needed to restore degraded ecosystems and to produce fully-functional forests outside of reserves. Reserves play important social and ecological roles, but they alone cannot conserve biodiversity. Research and experience have shown that reserve systems can become self-fulfilling prophecies of highly isolated diverse forests separated by depauperate second-growth forests and developed areas and that conventional timber management can oversimplify forest stands to the detriment of stand and landscape function. As human populations grow and increasing demands are placed on our environment, highly intentional systems management (Carey et al. 1999c) and total landscape management will be necessary to conserve the biodiversity of natural-cultural mosaics and the ecological services and economic goods it provides. Shifting, steady-state mosaics of complex forest ecosystems should promote system resilience (Holling 2001). But, the question remains, what kind of management can promote biocomplexity and what evidence for such management exists. A second case study illustrates some of the possibilities—The Forest Ecosystem Study.

The Forest Ecosystem Study

In the latter part of the 20th century, it was time to move beyond biodiversity reserves into *actively* managing forests to conserve biodiversity, including communities and ecosystems and the economic goods and ecologic services they provide (di Castri and Younes 1990, Entwistle and Dunstone 2000). People were demanding both environmental and economic sustainability (Folke et al. 1996, Goodland 1995, Reid and Miller 1989). In the Pacific Northwestern United States, for example, forests are expected to perpetually provide commodities; revenues for landowners, schools, and roads; economic support to local communities; habitat for all forest wildlife and plants; recreational and spiritual experiences; and clean air and water (Carey et al. 1999c, Carey and Wilson 2001). Timber management, however, had simplified forests (Carey et al. 1999b, 1999c; Franklin 1993a, 1993b) and contributed to invasion by exotic species (Halpern et al. 1999, Hobbs and Humphries 1995, Thysell and Carey 2001a), imbalanced biotic communities (Carey 2000b, Carey and Harrington 2001, Haveri and Carey 2000, Wilson and Carey 2000), low prey biomass for vertebrate predators (Carey et al. 1992), and poorly functioning food webs (Carey et al. 1996b, 2002; Colgan et al. 1999). High-quality timber was becoming scarce and low-quality timber overabundant. Environmental degradation and nonsustainable harvests had led to restrictions on harvesting natural forests and disruption of local, regional, and even global timber markets.

In the Pacific Northwest, natural forests and contemporary managed forests differed in structure, composition, and function (Carey 1995, Carey and Harrington 2001, Carey and Johnson 1995, Carey et al. 1999b). Juxtaposed diverse ecosystem elements in natural forests contributed to emergent properties associated with biocomplexity. The scale of variation in arrangement that contributed to synergy was on the order of 0.1 to 0.5 hectare, or 80 to 100 meters (Canham et al. 1990, Carey et al. 1999b). Biotic legacies from preceding forest, propagules from adjacent stands, forest developmental processes, and development of spatial heterogeneity all contributed to compositional diversity and habitat breadth (diversity of vegetation site types). Stand tending for timber, however, purposefully reduced complexity and diversity at the local, landscape, and even regional scales (Carey 2000b, Carey and Harrington 2001). Consequently, population densities of a vertebrate species in managed forests varied in complex ways that reflected not only the abundance of its habitat elements, but also abundances of other ecosystem elements that determined the overall mix of vertebrate species and the degree of species interactions with one another. Biotic integrity (the structure of a narrowly defined community as measured by species relative abundances within the community compared to that in old growth), nevertheless, varied more or less predictably in response to complexity of vegetation structure and absence of various compositional elements because biocomplexity is prerequisite to preinteractive niche diversification, community diversity, and ecosystem resilience (Carey et al. 1999b, Hutchinson 1978, Tilman 1996). Intentional management, nevertheless, should be able to promote biocomplexity (Carey et al. 1999b, 1999c). Retention of legacies of individual live trees, dead trees, coarse woody debris, or even patches of forest can be used with even-age management systems to jump-start ecosystem development processes. Such variable-retention harvest systems transcend traditional silvicultural conventions such as clearcutting (Franklin et al. 1997). Thinning inevitably influences all forest developmental processes, including decadence and development of habitat breadth. Variable-density thinning with underplanting offers to restore tree species diversity and accelerate understory development and canopy stratification. Retaining decadent trees, wounding trees, inoculating trees with top-rot fungi, and creating cavities in trees should promote decadence essential to ecosystem development (Carey et al. 1999b, Franklin et al. 1987). Variable-density thinning creates canopy mosaics in second-growth stands and could promote vegetative heterogeneity similar to that in old growth (Carey and Johnson 1995, Carey et al. 1999b). By removing subordinate and codominant trees, variable-density thinning produces small patches such that light, water, nutrients, and space become available spatially in various amounts to other vegetation. Effects, however, extend beyond the borders of the altered patches of canopy because of low sun angles in the Pacific Northwest. Thus, fine-scale heterogeneity creates an even more diverse mosaic of environmental conditions and potentially numerous patch types in the understory (Canham et al. 1990). Maps of canopy cover and understory plant associations revealed natural mosaics of 0.1- to 0.5-hectare patches with a 2:1 ratio of closed to open canopy promote biocomplexity (Carey et al. 1999b) (fig. 33). Yet, no one had intentionally created such a mosaic experimentally or even managerially.

Experimental Design

In 1991, the Forest Ecosystem Study was established as an experiment to test the efficacy of various techniques for active management of forest to promote biocomplexity (Carey et al. 1999d). The study was located southeast of Olympia, Washington, in the Puget Trough, a low-lying (120 to 165 meters), flat to rolling plain (Carey et al. 1999d). Forests in the Puget Trough had been harvested by extensive clearcutting that provided relatively homogeneous forest without confounding effects of adjacency of natural forest. As with many soils in western Washington, the soils were coarse-textured gravelly-sandy loams formed as a result of glacial recession and glacial outwash. Annual precipitation was 800 to 900 millimeters with only 10 to 15 percent during summer. Vegetation was temperate coniferous forest—the Douglas-fir-oceanspray association of the Western Hemlock Zone.

The study incorporated four approximately 100-hectare *blocks* of forest; four 13-hectare *plots* were delineated in each block (a total of 16 plots). Each plot was subdivided into 64 (0.16-hectare) *cells* by an 8 × 8 grid with 40 meters between grid points and a 40-meter buffer around the grid. This grid provided a template for treatments and sampling (figs. 33, 34). Two blocks had been clearcut around 1927 and later—more than 10 years prior to the study—conventionally thinned twice to a final residual density of 225 trees per hectare

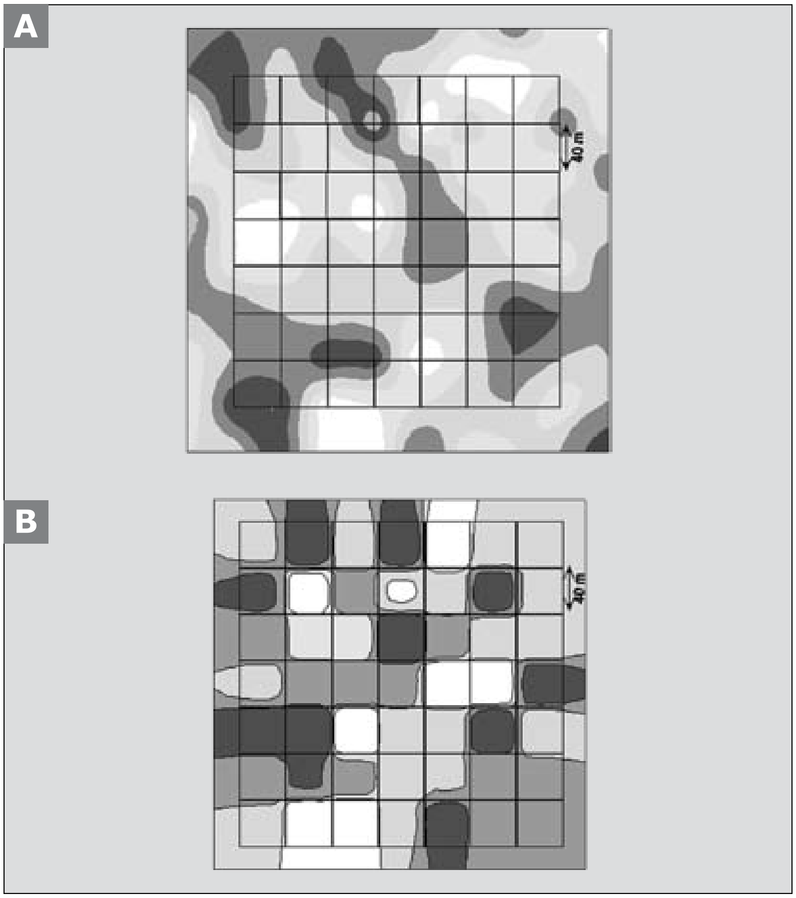


Figure 33—Recreating spatial heterogeneity characteristic of old forests in second-growth forest canopies with variable-density thinning: (A) densities of trees more than 50 centimeters in diameter at 1.5 meters aboveground in a 280-year-old Douglas-fir forest—shading (light to dark) represents densities from 3 to 45 trees per hectare, based on 225 sampling points (from Carey et al. 1999b); (B) relative densities of Douglas-fir more than 20 centimeters in diameter at 1.5 meters following variable-density thinning of a 56-year-old second-growth stand; shading (light to dark) represents relative density classes of less than 3.25, 3.25 to 4.75, 4.75 to 6.75, and greater than 6.75 (adapted from Carey et al. 1999c).

(approximately 7 meters between trees). Few trees (less than one per hectare) were retained from the preceding old-growth forest, and dead trees were removed. Canopy trees were 51 to 54 centimeters in diameter at 1.5 meters aboveground; cover of coarse woody debris was 2 to 3 percent; cover of understory vascular plants was 88 percent, dominated by the evergreen shrub, salal, the evergreen swordfern, and brackenfern. Shade-tolerant conifers were rare. These plots were called as *timber plots*. Two other blocks had been clearcut around 1937, with 2.7 live trees per hectare and 3.5 dead trees per hectare retained from the preceding old growth. Woody debris included old decaying fallen trees (7 to 8 percent cover), stumps of old trees (48 per hectare), and abundant (3 percent cover) small trees killed by suppression or root rot. Understory cover was patchy and 34 percent, dominated by salal. Canopy trees were 600 per hectare and 34 centimeters in diameter at 1.5 meter. Few shade-tolerant conifers were present. These plots were called *legacy plots*.

Experimental treatments included variable-density thinning to induce heterogeneity into tree canopies, underplanting with red alder, western white pine, grand fir, and western redcedar to restore lost tree species diversity, and decadence management for cavity

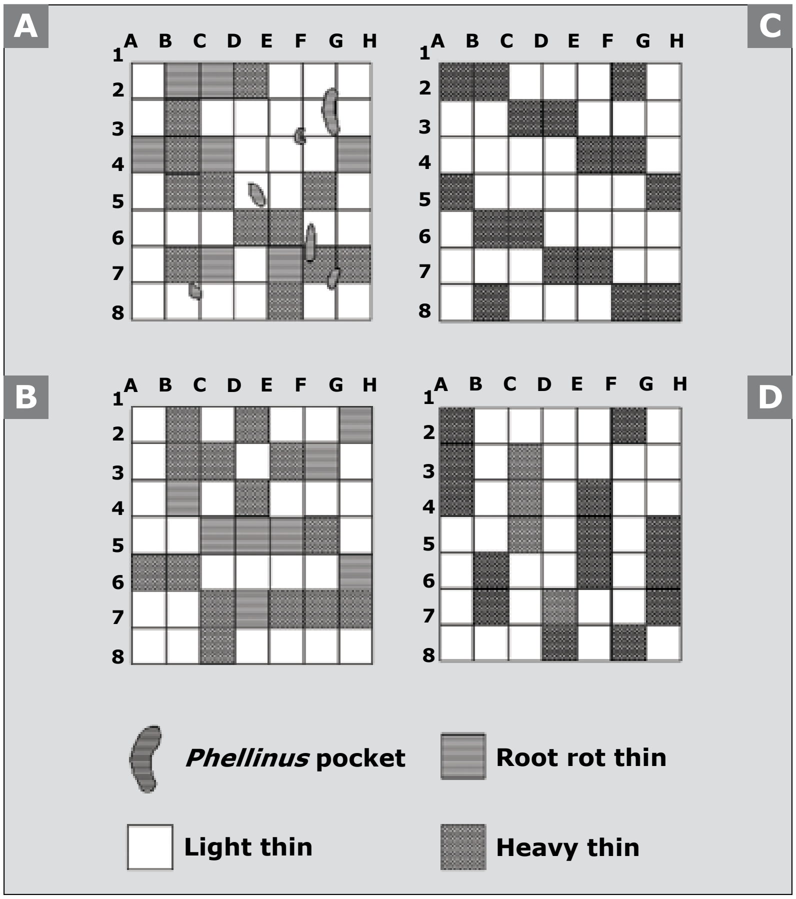


Figure 34—Actual and potential applications of variable-density thinning: (A) Star 101—shows random assignment of subtreatments with actual root rot pockets, (B) Farley 302—shows random assignments of subtreatments with simulated root rot pockets, and (C & D) systematic assignment of light (LT) and heavy thins (HT) (as possible operational applications) in a 2:1 ratio of LT to HT (Carey et al. 1999c).

trees to accelerate ecosystem development. Sampling grids were surveyed, and baseline data were collected in 1991 and 1992. Then, plots were treated by the landowner (Fort Lewis Military Reservation) and contractors with one of four randomly assigned treatments in spring, 1993: control; variable-density thinning with underplanting; dens for squirrels; and variable-density thinning combined with dens. In the first 5 years, supplementary dens had minor effects on flying squirrels (Carey 2002b). Relative density (RD) was used to determine how much to thin; RD is an index to intertree competition in even-aged evenly spaced stands of trees (Curtis 1982). For Douglas-fir, RD ranges from 0 to a biological maximum of 14; excessive crown restriction occurs with RD >7. Conventionally thinned timber plots had RD = 6.5 (biomass accumulation stage) and unthinned legacy plots had RD = 7.2 (emerging from competitive exclusion to biomass accumulation). An implementation team of research and management foresters randomly assigned RDs of 2, 4, and 6 to the cells and RD = 6 to the buffer of each variable-density thinning plot to achieve a 2:1 ratio of light (residual RD >4.75) to heavy thinning (RD <4.75) and a mean residual RD of 4.7 to 4.8. Plots treated with variable-density thinning were called *mosaic plots*.

Response variables were chosen from two perspectives. The first set of variables was drawn from the keystone complex symbolic of Pacific Northwest old growth (forests over 250 years old): northern spotted owl-northern flying squirrel-ectomycorrhizal fungi-Douglas-fir (Carey 2000a). The spotted owl is the flagship species for old growth and has been designated a threatened species by both federal and state governments. The flying squirrel is the primary prey of the owl. Hypogeous ectomycorrhizal fungal sporocarps are the primary food of the squirrel; the squirrels disperse the spores and associated micro-organisms (Li et al. 1986) throughout the forest. Mycorrhizal fungi enhance the ability of Douglas-fir to absorb water and nutrients from the soil and receive carbohydrates in return. The fungi move photosynthetic carbohydrates from trees to the mycorrhizosphere, providing support for a vast array of microbes, insects, nematodes, bacteria, and other soil organisms (Ingham and Molina 1991). Aboveground, the food web expands laterally to include other raptors and mustelids; three species of squirrels; forest-floor small mammals; seeds, fruits, and fungal sporocarps; and various trees and shrubs. Thus, the complex provides a framework that is both functional and heuristic in evaluating forest ecosystem development in response to heterogeneity induced into canopies and to forest management generally (Carey et al. 1999c). The spotted owl and other predators, however, respond to ecosystems at the landscape scale (Carey et al. 1992) and cannot be used to evaluate management at small scales. Thus, research focused on the abundances of three squirrels—the northern flying squirrel (fig. 35A), the Douglas' squirrel (fig. 35B), and Townsend's chipmunk—and compared their abundances to the simultaneously high abundances of all three species in complex old forest. The diets of the three species overlap, but the flying squirrel is a truffle specialist, the Douglas' squirrel a conifer seed specialist, and Townsend's chipmunk is a fruit generalist, feeding on seeds of conifers, seeds and nuts of deciduous trees, berries of shrubs, and truffles, but relegated to areas of high shrub cover in summer and hibernating belowground in winter. Thus, the combined biomass of these three species is a measure of ecological productivity—the reproductive fruits of the forest ecosystem and the capacity of the ecosystem to support diverse vertebrate predator assemblages (Carey et al. 1999c).

The second set of variables focused on forest-floor function, because it is the foundation for sustainability of forest ecosystems (Carey et al. 1996b). Mechanical operations, killing trees, and altering microclimate affect forest-floor function. A basic feature of most forest soils is dominance of biological activity by fungi, particularly ectomycorrhizal fungi. Variables included degree of dominance by fungi as measured by biomass ratios for total fungi to total bacteria, active fungi to active bacteria, and fungal-feeding nematodes to bacteria-feeding nematodes; biomass of predatory nematodes; and biomass and diversity of sporocarps of ectomycorrhizal Ascomycetes, Basidiomycetes, and Zygomycetes (hereafter referred to as truffles); diversity of epigeous fungi; and the coverage of fungal mats (*Piloderma* sp., *Hysterangium* sp., *Gautieria* sp.) (Carey et al. 1996b, Ingham and Molina 1991). Consideration of forest-floor function

Figure 35—(A) A northern flying squirrel consumes a truffle. Photo by W. Colgan III. (B) A Douglas' squirrel postures to defend its food source. Photo courtesy of American Mammal Society.

was extended hierarchically to litter invertebrates, abundance and diversity of vascular plants, and the integrity of the forest-floor small mammal community. This community, dominated by shrews, is particularly diverse in Pacific Northwest forests compared to the rest of the world (Carey and Harrington 2001, Carey and Johnson 1995). Because disruption of soil by mechanical operations and simplification of forest ecosystems by timber management can promote invasion by exotics (Halpern et al. 1999), exotic species were recorded and their tenure in the system tracted. Finally, resident birds play important roles in Pacific Northwest forests in regulating insect populations by insectivory and in decadence processes by excavating cavities in trees (Manuwal and Huff 1987). These birds are particularly sensitive to the simplifying effects of timber management on decadence and seed diversity. Thus, the diversity and abundance of birds in winter was measured (Carey 2003a).

Soil Food Webs and Forest-Floor Character

Both timber and legacy plots had fungal-dominated soils in terms of total-biomass and active-biomass ratios. Total fungal biomass in legacy plots, however, was almost three times greater than in timber plots. Fungal mats covered 66 percent of legacy plots compared to 25 percent of timber plots. Abundances of fungal-feeding nematodes were similar. Bacteria-feeding nematodes in timber plots were 1.5 times more abundant than in legacy plots. Predatory nematodes were most abundant in timber pots. Variable-density thinning had no effect on total biomass ratios but *increased* the dominance of fungi over bacteria in both timber mosaics and legacy mosaics. Total fungal biomass remained unchanged in timber mosaics but decreased in legacy mosaics. Fungal feeding nematodes decreased in timber mosaics but increased in legacy mosaics. Bacterial feeding nematodes and predatory nematodes increased with degree of disturbance within both types of mosaics. Truffle standing crop biomass averaged 0.5 kilogram per hectare but varied markedly (0 to 1.8 kilograms per hectare) seasonally in both timber and legacy plots. Of 28 species of truffles found in untreated forest, 19 species were in timber plots, with 7 of those species only in timber plots, and 21 species were in legacy plots, with 9 of them only in legacy plots. *Rhizopogon* was the dominant genus, with a relative frequency of 40 to 47 percent. *Gautieria* and *Leucogaster* were more frequent in legacy plots than in timber plots, and *Melanogaster* and *Hysterangium* were more frequent in timber plots. Truffle production was reduced in mosaics (from a frequency of 18 percent in control plots to 13 percent in variable-density thinning plots) in the short term with heavily thinned cells most reduced (to 10 percent). Truffle diversity increased to 48 species (versus 28 species in controls) and productivity quickly recovered. *Gautieria* and *Hysterangium* decreased in abundance in mosaics, but *Melanogaster* increased in species diversity and biomass. A total of 64 mushroom species were found prior to treatment, 37 (19 mycorrhizal) in legacy plots and 44 (15 mycorrhizal) in timber plots. Richness of ectomycorrhizal mushrooms was consistently highest in the legacy plots. After variable-density thinning, 108 mushroom species were found in legacy mosaics (versus 89 species in controls), and 78 species were found in timber mosaics (versus 65 in controls). Contrary to expectations, variable-density thinning did not significantly reduce the amounts of large coarse woody debris through mechanical destruction but did add small coarse woody debris in the form of logging slash and unmerchantable stems. Additional large coarse woody debris has been recruited in the form of diffuse root-rot mortality. The forest floor microclimate (temperature and moisture) increased in heterogeneity—mosaics maintained the array of moisture and temperature regimes that controls had but also developed some warm, some moist and warm, and some dry patches. Variable-density thinning produced increased patterning in litter invertebrate communities; all functional groups were maintained, but species dominating the functional groups now differ spatially in response to the induced heterogeneity that includes differences in new litter, added coarse woody debris, increased vascular plant cover, and soil disturbance as well as changes in light and moisture (Schowalter et al. 2003).

Understory Plants

Legacy plots had 27 to 40 species of understory plants compared to 49 to 87 species in the timber plots. Of 91 species found in timber plots, 51 species were not found in legacy stands, and 18 were nonnative species (1 tall shrub, 2 low shrubs, 13 herbs, and 2 grasses). Of 47 species in legacy stands, four were not found in thinned stands, including the old-growth associate Pacific yew, and one was nonnative. Community structure differed with management history, with timber plots dominated by aggressive clonal native shrubs and ferns. Timber plots had greater cover for total understory (88 percent versus 34 percent), tall shrubs (12 percent versus 5 percent), salal (25 percent versus 13 percent), swordfern (16 percent versus 3 percent), and brackenfern (9 percent versus 2 percent). Mosaics initially had reduced understory cover and increased importance of 20 native and 11 exotic species. Two native species decreased in importance. Three years later, understory recovered, species richness increased by 150 percent, only four exotic species persisted in importance, and eight natives increased and seven natives decreased in importance. Underplanting has established root-rot-resistant trees in root-rot pockets that will restore canopy cover and increase the resilience of the forest and, in other heavily thinned areas, increase resistance to spread of root rot. Shade-tolerant trees are now established in patches throughout the plots and have the potential, with continued growth, to begin influencing understory patterning.

Small Mammals

Timber plots had 1.5 times the numbers and 1.7 times the biomass of small mammals of legacy plots, presumably because of their greater abundance and diversity of vascular plants. Keen's mouse, a dominant species in natural forests, was rare in both forests. The Oregon creeping vole was inordinately abundant in timber (3rd ranked) compared to legacy plots (7th ranked) and natural stands. The montane shrew was also inordinately abundant in timber plots (2nd ranked). Neither management produced communities typical of natural forests. After variable-density thinning, deer mice, Oregon creeping voles, and vagrant shrews increased in abundance in mosaics. No species decreased in abundance.

Squirrels

Northern flying squirrels were twice as abundant in legacy as in timber plots (1.0 per hectare versus 0.5 per hectare). Townsend's chipmunks were the opposite (0.2 per hectare versus 0.8 per hectare). Douglas' squirrels were low in abundance in both (0.1 per hectare). Flying squirrels decreased in abundance in legacy mosaics immediately following variable-density thinning (concomitantly with a decline in truffle production) but recovered within 5 years (along with truffle production). Chipmunks increased sharply in legacy mosaics following variable-density thinning and remained high. Douglas' squirrels did not respond to variable-density thinning in the short term. It remains to be seen if flying squirrels and Douglas' squirrels will increase over time as tree diversity increases and as trees increase photosynthetic activity and allocate additional carbon to seeds and ectomycorrhizal associates. California hazel and bigleaf maple are present and may begin producing high-quality nuts and seeds for the squirrels in response to the more open canopy and available light.

Wintering Birds

Species richness was higher in timber (16 species) than in legacy plots (12 species). Richness was unchanged in timber mosaics, ranging from 14 to 22 species 3 to 5 years after variable-density thinning. Richness varied annually but was consistently higher in legacy mosaics than in legacy controls in post variable-density thinning years 3 to 5 (12 to 16 species versus 10 to 16 species in controls). The proportion of stand area used increased in mosaics for two of eight abundant species (winter wren and song sparrow). No species used legacy controls more than thinned or mosaic stands. Cavity-excavating birds (Picidae) were present but low in abundance in all stands.

Implications

All stands maintained fungal-dominated soils, despite continued disturbance in the timber mosaics—three significant removals of subordinate and codominant trees over 20 years by commercial thinning. Mechanical disturbance associated with thinning, however, appeared to destroy near-surface fungal mats and promote *Melanogaster* over *Hysterangium* and *Gautieria*; the latter are more important foods to mycophagists. Induced heterogeneity nevertheless increased total sporocarp diversity. Sporocarp diversity rivaled that in old-growth forests around the region. Impacts of variable-density thinning on truffle production were brief. There is no clear, general effect of management on production of the sporocarps of hypogeous ectomycorrhizal fungi across the region other than effects on fungal mats (Carey et al. 2002). Retaining unthinned patches in mosaics might help conserve fungal mats.

Conventional thinning had produced rich understories dominated by clonal native species with numerous exotic species present in the timber plots. Legacy management had produced depauperate understories. Canopy mosaics markedly increased diversity and abundance of native species in both but only ephemerally increased exotics. With underplanting, variable-density thinning is leading to increased spatial heterogeneity. Achlorophyllous mycotrophic plants were reduced in abundance in areas of dense understory; retaining small unthinned patches in mosaics would help conserve these species.

Both conventional thinning and legacy management had produced imbalanced small mammal communities, with some species common in natural forests low in abundance. Inducing heterogeneity had immediate positive impacts on forest-floor mammals, but restoration of shade-tolerant midstories and development of midstory deciduous trees (e.g., bigleaf maple) will be required to restore biotic integrity. Chipmunks increased markedly in legacy mosaics with only brief declines in flying squirrels. Flying squirrels remained rare in previously thinned stands, perhaps owing to dense homogeneous understories that promoted excessively high and uniform chipmunk abundance. Similarly, variable-density thinning had positive effects on the winter birds and increased the overall habitat quality in mosaics. Bird communities, however, continued to have low abundances of cavity-excavating birds. Promoting deciduous trees (e.g., red alder) early in stand development provides

A variety of trees—both living and dead—along with steep terrain and fog creates dramatic scenery in Olympic National Forest, near Forks, Washington. Photo by T. Wilson.

short-lived trees for cavity excavation in the short term; decadence management may prove essential to maintaining cavity-excavating birds in managed forest.

In summary, this experiment has demonstrated that active, intentional management has potential in restoring and maintaining biological diversity in second-growth forests and in increasing the resilience of such forests to such disturbance agents as wind (larger more wind-firm trees), disease (resistance to spread of root rot), and insects (increased diversity and abundance of overwintering birds) without increasing potential for wildfire (forest floors remained moist; indeed, increased plant cover in the understory should generally produce moister and cooler conditions in the future). Increased diversity in the squirrel community and increased cover on the forest floor should reduce the potential for repetition of past severe predation by long-tailed weasels that decimated flying squirrel populations from time to time. Increased diversity of trees and shrubs bearing hard mast and increased production of hard mast should result in increased numbers and lower fluctuations in squirrel populations (all three species) as well. Inducing heterogeneity into homogeneous, closed canopies has positive effects on diverse biotic communities and ecosystem function as habitat even in the short term (5 years) in forests managed with conventional thinning for timber production and with legacy retention only. The rapidity of the growth of shade-tolerant trees in the understory will determine the rate at which heterogeneity continues to increase, and only time will tell if reduced elements of diversity (e.g., cavity trees, certain small mammals, and certain birds) will be restored; deciduous trees and shrubs are now well establish in the understory.

Stochasticity, Disturbance, and Change

Resolving fear of environmental stochasticity (randomness), uncertainty, unpredictability, and change is aided by systems theory and an understanding of chaos theory and self-organizing systems. Bertalanffy proposed a self-integration (self-organization) model of hierarchical order with four related concepts of change (Regier 1993): (1) progressive integration, or complexity, with parts dependent on the whole; (2) progressive differentiation, or parts becoming more specialized; (3) progressive mechanization, or limiting parts to a single function; and (4) progressive centralization, or certain parts dominate the system. This theory applies to organisms, societies, and ecosystems. Natural historians take self-organization as self-evident—their practical insights flow from comparative empiricism that is a synthesis of both perception and analytical understanding. Academic ecology, however, often consists of abstractions that are mobilized as "band-wagon" paradigms that may not be very pragmatic but may provide fruitful avenues of research to develop fundamental principles.

Empirical observation asserts that biotic communities develop and succeed one another on stages set by environmental variables–geographic location, landform, site characteristics, precipitation, and temperature (Clements 1936). Colonization by pioneers that grow rapidly and withstand physical extremes resets the stage for species replacement through competition. Biomass accumulates, internal regulation of biochemical and physical processes increases, variability is reduced, and a more-or-less stable climax condition results: equilibrium centered, with major disturbance exogenous. It is clear that there are communities that do this, for example, old-growth forests in the Pacific Northwest (Holling 1986). However, many biotic communities, including those in the Pacific Northwest, are subject to regular and irregular, minor and major, endogenous and exogenous disturbances at frequencies often in some way related to the lifespan of their longest lived or most persistent species, such that these species are adapted to the disturbance. For example, the foliage of fire-adapted species is significantly more combustible than related species in communities not subject to frequent fires.

Theoretically, most species can be described on a continuum from *r*-strategists (opportunists selected for maximizing returns in unpredictable-unstable environments) to *K*-strategists (equilibrium species selected for efficiency of foraging in predictable-somewhat stable environments) (MacArthur and Wilson 1967). *K* is the symbol for equilibrium carrying capacity in population models, and *r* is the intrinsic rate of increase in populations. *K*-strategists tend to be larger in size and have lower reproductive potential, longer lifespans, less dispersal ability, and more competitive ability than *r*-selected species. Ecosystems also have strategies for development; in other words, they are self-organizing but regulated by physical, chemical, and biological processes (Odum 1969). The *r* and *K* concepts can be used to describe ecosystem functions, for example, exploitation and conservation (Holling 1986) (table 20). Early-seral stages emphasize exploitive processes (binding nutrients, rapid accumulation of biomass, and modification of the environment). Later-seral stages emphasize increased organization through trophic and competitive interactions (cooperation and coadaptation) that reduce variability and, if uninterrupted long enough, reduce diversity.

Table 20—**Pianka's (1970) correlates of *r*- and *K*-selection**[a]

Feature	*r*-selection	*K*-selection
Climate	Variable and/or unpredictable	Fairly constant and/or predictable
Mortality	Often catastrophic, nondirected, density-independent	More directed, density dependent
Survivorship	Often Type III Deevey survivorship curves	Usually Type I or II Deevey survivorship curves
Population size	Variable in time, nonequilibrium	Fairly constant, equilibrium
Intra- and inter-specific competition	Variable, often lax	Usually keen
Relative abundance	Often does not fit broken stick model	Usually fits broken stick model
Favored by selection	▪ Rapid developement ▪ High r_{max} ▪ Early reproduction ▪ Small body size ▪ Semelparity	▪ Slow development, greater competitive ability ▪ Lower resource thresholds ▪ Delayed reproduction ▪ Small body size ▪ Iteroparity
Length of life	Short	Long
Leads to…	Productivity	Efficiency

[a] The theory of r- and K-selection for life history evolution dominated demographic thinking in the 1960s and 1970s, became archaic in the 1980s, and now has arisen anew to incorporate density-dependent population regulation, resource availability, environmental fluctuation, and predation risk.

Source: Reznick et al. 2002

Hierarchy Theory

Forces of change operate at different scales. Within a given multivariate space, regions of stability expand, contract, and disappear over time in response to changes in slow variables (such as tree growth, fuel accumulation, and increasing herbivore populations). Abrupt change occurs because multiple stable states emerge as slow variables change. Jumps between stability domains may be triggered by exogenous disturbances. External events may lead to highly repetitive consequences by reinitiating ecosystem development. Variability, then, produces diversity as a consequence of cyclic shifting of competitive advantages among species within and among different scales. Thus, change is an internal property of each system, gradual for long periods followed by inevitable jump events.

Hierarchy theory provides useful stability and resilience concepts:

- There can be more than one stability region; multiple equilibria are possible.

- Behavior is discontinuous when elements of a system move from one stability domain to another because they become attracted.
- Precise kind of equilibrium (steady state or stable oscillation) is less important than the fact of equilibrium.
- Parameters of the system that define the existence, shape, and size of stability domains depend on a balance of forces that may shift in patterns of variability in space and time; managerially reduced variability is likely to lead to smaller stability regions whose contraction can lead to sharp changes.

Stability emphasizes equilibrium, low variability, and resistance to and absorption of change. Resilience emphasizes the boundaries of stability domains and events far from equilibrium, high variability, and adaptation to change (the school of linear interactions, however, treats resilience in an opposite fashion—how fast the variables return toward their equilibrium following a perturbation). Holling (2001) developed this theory further into Panarachy.

Panarchy Theory

Ecology has always been concerned with stability—whether natural systems have developed sufficient resilience or stability to absorb increasing human populations and demands for food, fiber, and aesthetic needs (Holling 1969). The concept of a global biochemical homeostasis—that life keeps the atmosphere optimal for the contemporary biosphere—provides a global rationale for rehabilitation, protection of ecosystems, and land-use management (Holling 1986). Global homeostasis prompts questions: How do ecosystems absorb, buffer, or generate change? Why are we surprised when causes, behaviors, and results sharply differ from what we expected? In answer to the latter, our expectations develop from interactions of the metaphors we use to provide understanding and our perceptions of memorable events, both of which are incomplete. Three influential metaphors are (1) nature as equilibrium, (2) nature engineered with multiple equilibria, and (3) nature evolving.

Equilibrium emphasizes constancy in time, spatial homogeneity, linear causation, and images of a benign nature wherein management mistakes can be made, but recovery is assured, for example, the traditional production forestry paradigm (Barrett 1962, Smith 1962). Multiple equilibria suggest a more dynamic system, with spatial heterogeneity and nonlinear causation. Two different beliefs arise from multiple equilibria: (1) landscapes are fixed or we have sufficient knowledge to keep them fixed, and (2) key features are maintained by variability itself and by maintaining the configuration (structure) of a system. In other words, structure-based management can maintain multiple equilibria. This is the unspoken underlying paradigm for conservation biology with its reserves and management for the range in natural variation (e.g., Hunter 1999).

Evolutionary change suggests generative, competitive, and behavioral processes maintain the characteristics of the system. When variability changes, parameter values shift, landscapes change, stability domains shift, key variables become more homogeneous, and perturbation can no longer be absorbed. When control is internal and self-regulated, organizational change may occur. When control is external *and* continuing control requires ever-increasing vigilance, pathologies may develop. Thus, progressive evolution requires not only function but also organization (food webs and trophic relations). The complexity of systems emerges not from random assemblage of numerous controlling processes but from self-organizing systems and a small set of critical processes that create and maintain the self-organization (Holling 2001). Diversity and individuality of components, localized interactions among components, and an independent process that uses the outcomes of local interactions to select components for enhancement are characteristics of complex, adaptive systems. Pragmatic sustainability has to do with the set of critical self-organized variables and their transformation during system development. There is simplicity behind complexity that can be understood and communicated lucidly. This is known as adequate integrative theory—as simple as possible, but not simple; dynamic and prescriptive, but not static and descriptive; embracing uncertainty and unpredictability (Holling 2001). This paradigm underlies intentional systems management for conservation of biodiversity, where biodiversity includes the variety of taxa (genes, species, populations), organization (communities, ecosystems, life zones, biomes), processes (evolutionary, ecological, managerial), and products (goods, services, experiences) (Carey et al. 1999c).

Hierarchies and adaptive cycles comprise the basis of socioecological systems across scales (Holling 2001). Panarchy is the hierarchical structure in which socioecological systems are interlinked in never-ending adaptive cycles of growth, accumulation, restructuring, and renewal. Panarchy theory is a model of complex system behavior that describes how a healthy system can invent and experiment, benefiting from invention that produces opportunities, while being safeguarded from those that destabilize because of their nature or excessive exuberance. Space-time hierarchies are semiautonomous rather than top-down authoritative structures. Their levels are formed from the interaction of elements with shared speed and spatial attributes. Each level operates at its own pace, and each communicates a small set of information to the next higher, slower, and coarser level. Slower and larger levels set the conditions within which faster and smaller ones function. Thus, the forest moderates the climate for individual trees. The levels of a dynamic hierarchy serve two functions: (1) conserve and stabilize conditions for the faster and smaller levels and (2) generate and test innovations by experiments occurring within a level. Examples of hierarchies in space and time are (1) breeze, thunderstorm, front, long wave, El Niño, and climate change; and (2) needle, crown, patch, stand, forest, and landscape. A time-population size hierarchy is individual, small group, contract, policy, law, constitution, and culture. Another is fad, values, and traditions.

The adaptive cycle (fig. 36) transforms hierarchies from fixed, static structures to dynamic, adaptive entities whose levels are sensitive to small disturbances at the transition from reorganization to rapid growth. Three properties shape the adaptive cycle and the future state of a system: (1) inherent potential that is available for change; this potential determines the possible range of future options and can be considered the wealth of the system; (2) internal controllability or the degree of connectedness between internal variables and processes; the degree of flexibility of the system; and the degree to which it can control its own destiny; and (3) adaptive capacity or resilience, a measure of vulnerability to unexpected, unpredictable shocks. Wealth, connectedness, and adaptive capacity are general properties from the scale of a cell to the biosphere. In the adaptive cycle, the trajectory alternates between long periods of slow accumulation and transformation of resources (from exploitation to conservation, r to K) with shorter periods that create opportunities for innovation (from release to reorganization, Ω to α) (fig. 36).

Ecosystem dynamics consist of not only the two functions (exploitation and conservation) that determine succession and development but also creative destruction functions that result from increasing strength of connections in maturing ecosystems that can result in abrupt change. Conservation leads to wealth and becomes an accident waiting to happen—a buildup of stored energy that either is dissipated by local internal disturbance leading to increased complexity or released by wind, fire, disease, or insect outbreaks. When timing is set by the slowest variable (e.g., growth of a dominant Douglas-fir cohort), forces of change can lead to intense, widespread mortality (e.g., catastrophic fire or epidemic disease).

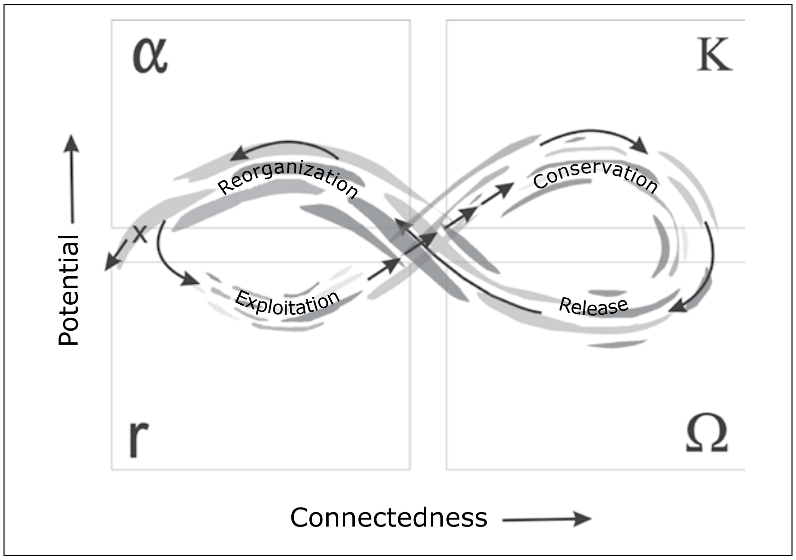


Figure 36—The adaptive cycle of self-organizing systems (adapted from Holling 1986, 2001). Ecosystems may have four primary functions (*r*, exploitation; *K*, conservation; Ω, release; *α*, reorganization), here arrayed in a two-dimensional space of stored resources potentially available (e.g., accumulated biomass, Y-axis) and connectedness (sensitivity to perturbation, X-axis). As plants exploit a newly cleared forest, the ecosystem moves rapidly to accumulation of biomass (conservation), and the stored potential of the system becomes great and connectedness is high. High connectedness increases susceptibility to perturbation. Minor perturbations release some of the stored potential for niche diversification and reorganization of the system into a more complex, less connected structure with high potential. Catastrophes can release most or all of the potential and return the system to exploitation. With legacies, exploitation (*r*) can move rapidly to conservation (*K*); without legacies, exploitation may last longer with low connectedness and low potential.

Individuals constituting slow variables eventually senesce and die, but their impacts are local and not synchronous. When timing is set by the fastest variable, changes are less intense, and spatial impacts, although synchronous over large areas, are patchier. These functions are called creative destruction even though organisms are destroyed, because their success in competition, appropriation of resources, and accumulation of biomass results in a release of tightly held resources promulgating the fourth function, creative renewal (e.g., ecosystem reorganization). Rapid cycling produces patchy ecosystems; slow cycling can produce waves across space (e.g., spruce budworm outbreaks). Things can go awry, however, during renewal. Savannahs can become dominated by woody shrubs because of loss of capacity for water retention. Burning can shift forest vegetation to bogs and eventually peat lands. Clearing tropical forests can produce scrub savannahs. The degree of resilience of a system is determined by the balance between the processes of mobilization (freeing resources for other uses) and retention (e.g., of biological legacies, including coarse woody debris and living plants).

It has long been argued that more species and more interactions confer more stability to biotic communities. The argument is that the more pathways available for movement of energy and nutrients, the less the effect of removing one pathway. Although May (1973) showed that increasing the diversity of randomly connected networks actually decreased stability, ecosystems are not randomly connected (Holling 1986, May 1973). Ecosystems have a hierarchical structure in space, time, and speed of variables. Thus, the relevant measures of species diversity, which is one measure of complexity, should not involve all species but only those contributing to physical structure and dynamics. The most significant measure of complexity concerns the degree of connectedness within ecosystems. Extensive land clearing to produce monocultures produces high connectedness through pest loads and little resistance. In other words, the pattern of connectedness and the resultant balance between stability and resilience are a consequence of the pattern of external variability the system has experienced. In the Tropics, consistent temperature and precipitation produce highly stable forests of low resilience, sensitive to disturbance by humans, and characterized by high species diversity. Temperate systems have high climatic variability, low stability, and high resilience, resistant to disturbance by humans. Hierarchical systems are not static in kinds or strengths of connection that determine resilience. Succession introduces connectedness. Overconnectedness produces discontinuous change, increases variability, and leads to resilience. Underconnectedness leads to collapse of resilience, especially during the destabilized part of the cycle, especially if mobilization is not balanced by retention. Forest ecosystem development disrupts overconnectedness through fine-scale patchiness and promotion of tree species diversity and balances mobilization by intermediate and fine-scale disturbances with biomass accumulation in dominant trees, retention of coarse woody debris on the forest floor, and accumulating slowly decaying organic matter into the soil (Carey et al. 1999b). Thus, adaptive cycles embrace opposites—growth and stability versus change and variety (Holling 2001). The spatial and temporal patterns generated by the four major ecosystem functions (exploitation, conservation, creative destruction, renewal) determine the qualitative structure of the ecosystem. The resultant architecture of the ecosystem provides a variety of niches occupied by different species.

General sustainability suggests a complexity that can overwhelm understanding. At best, efforts to manage ecosystems are experiments testing a general hypothesis of stability and resilience. Management to reduce variability represents an equilibrium-centered view of constant nature. It achieves short-term objectives, but eventually the system evolves into a qualitatively different system—the biophysical environment becomes more fragile and more dependent on vigilance and error-free management. Reduced variability produces reduced resiliency and spatial homogenization produces increased connectedness; the result is surprises. The implications for management are (1) ecosystems have a natural rhythm of change; restricting temporally and homogenizing spatially produces surprises (e.g., Swiss needle cast); (2) developing predictive tools should have a lower priority than designing systems that are flexible enough to undergo renewal after unexpected events. Holling (2001) summarized the current understanding of panarchies (see sidenote 33). It appears that spatial contagion and biotic legacies generate self-organized patterns over scales in space and time (Carey et al. 1999b, 1999c).

CHAPTER 7

From Ecology to Forest Management

How does one move from understanding various ecological processes underlying biological diversity and ecological resilience to pragmatic methods for managing second-growth forests for economic, ecologic, and social values? How does one actively and intentionally manage for multiple values? The problems seem enormous: forestry seems to lack an adequate scientific basis (Perry 1998), and ecology seems to lack an accepted theoretical framework derived from first principles (Belovsky et al. 2004) (sidenote 34). Furthermore, predicting system behavior is difficult because it depends on numerous variables and their interactions (20 components provide countless potential interactions) and causes and effects are difficult to demonstrate, yet emergence of new structure and function seems essential (Schneider and Kay 1994). The solution to conserving nature may be to stop managing for fixed idealized states, to begin appreciating that complex systems emerge from the interaction of biological entities with each other and the environment, and to change our focus from biodiversity to biocomplexity, the defining property of all ecosystems (Dale et al. 2000, Dybas 2001, Holling 1992, Schneider and Kay 1994) (sidenotes 35, 36). Finally, we must recognize that temperate zone forests in the Northern and Southern Hemispheres (one-fourth of the world's forests), are mosaics shaped by fire (fig. 37), wind, herbivory, other natural disturbances, and, increasingly, human activities including fire suppression, logging, grazing, and fossil fuel consumption (Frelich 2002).

In forest ecology, three fundamental practices for managing second-growth forests for multiple values are (1) retention and protection of biological legacies during and after harvests of timber (sidenote 37); (2) long rotation times between major harvests (sidenote 38); and, in the interim, (3) active creation of biocomplexity in managed forests (Carey 2003a, Franklin et al. 2002) (sidenote 39). Legacy retention addresses problems of dispersal-limited species like lichens, and jumpstarts the development of biocomplexity during reorganization. A significant amount of time is required for forests to accumulate biomass and develop a complex structure at multiple scales. Active creation of biocomplexity with a variety of manipulations prevents competitive exclusion and a persistent state of low diversity and limited function.

In fire-adapted forests, management of fuels and diseases with mechanical treatments, grazing, and prescribed fire is also fundamental but complex (Tiedemann and Woodard 2002, Wright and Agee 2004). All AIM practices include management of disturbances of varying intensity and frequency. All species have evolved in the presence of disturbance and, in a sense, are matched to recurrent patterns of disturbance (Frelich 2002, Paine et al. 1998, Tausch et al. 1993). In this context, full intentionality must be brought to the patterns of disturbance that should be induced and that will occur spontaneously as well as to operations, including consideration of

Sidenote 34—Ten fundamental problems in ecology (Belovsky et al. 2004):

- Ecology is faddish—issues come and go without resolution.
- Ecologists exhibit poor scholarship, ignoring the past literature (and literature from allied fields).
- Integration of empirical and theoretical ecology is inadequate.
- Integration of natural history and experimentation is inadequate.
- There is implicit belief in single causes despite evidence for multiple causation.
- Application of equilibrial and disequilibrial perspectives are often misguided.
- Ecological studies are inadequate in replication in space and time.
- Data collection lacks rigor, which hinders comparison of studies.
- Forces driving studies are often methods or statistics, not questions.
- Basic ecology is often conducted as distinct from applied ecology.

Figure 37—Natural regeneration begins to show itself among the snags left by a large-scale fire in the Wallowa-Whitman National Forest in northeast Oregon. Photo by T. Wilson.

purposes, risks, experience, and engineering and geological methodology in the design and management of logging systems and transportation systems. Situations in which risks of environmental damage owing to logging and transportation systems cannot be reduced to an acceptable level (a background disturbance level) will preclude AIM with silviculture. In addition, AIM for biocomplexity may entail restoring lost diversity (planting, underplanting, and seeding) and removing exotic species. In western Washington, common exotics with potential to seriously modify forests include English ivy, English holly, and, along roads and in clearings, scotchbroom. Costs and economic returns of various AIM techniques are often cited as reasons for doing some and not doing others; but poor (partial) AIM is unlikely to hit the target (fig. 38).

Given the potential for purposeful manipulation of ecological processes and unintentional interference with other ecological processes throughout the life of a forest, understanding variability in how temperate and boreal forests develop is necessary for developing pragmatic management systems and avoiding unintended consequences (Frelich 2002). Variation is a genuine property of ecological systems that includes variation in space and in time *in processes* that generate the patterns we observe (Benedetti-Cecchi 2003). This conception of variation is much different than the range in natural variation *in patterns* that has attracted so much attention; those patterns are the result of multiple processes and stochastic events. Although there is a lack of coherent theory linking variation in processes to variation in responses of organisms and systems (patterns), one must grasp and use the processes by which biotic communities organize themselves and understand how the relative influence of each process varies from place to place and time to time with changes in the biophysical environment, including disturbance regime and regional species pool. Thus, key questions are: How much variance is found in the relative importance of basic processes? What are the adaptations in pragmatic management that must follow as one moves from one physiographic province to another or from one forest type to another within the same physiographic province? What are the relationships among the processes that produce complex forest structure and biological diversity and that lead to healthy, resilient ecosystems? To what degree can forest development be guided managerially? To what degree will unhindered and unaided self-organization of forest ecosystems, after destruction of forests by logging, grazing, agricultural clearing, and fire exclusion, produce the materials and services we value for ourselves and for other forms of life?

Sidenote 35—Guidelines for ecosystem management (Schneider and Kay 1994):

- Maintain a hierarchical perspective with careful attention to scale and extent.
- Examine the spatial, temporal, thermodynamic, and informational aspects (dynamics).
- Recognize that system behavior is emergent and catastrophic—dynamic with a degree of unpredictability and with phases of rapid change.
- Accept that ecosystem self-organization unfolds like a symphony—one needs to understand the rules of composition.
- Accept that living systems are self-organizing and will look after themselves—the challenge is to learn to work with these self-organizing processes to meet our needs while preserving the integrity of the system.
- Accept that one must not destroy, but rather must maintain the biodiversity needed for the regeneration processes.

Figure 38—A marksmanship analogy: that's the point of intentionality—AIM carefully, or not at all. In a marksmanship analogy, it is not sufficient to chamber a cartridge and pull the trigger. Target identification, a clear field of view, a safe backdrop, knowledge of ballistics and trajectory, estimation of distance and wind, matching of rifle and cartridge to purpose, careful matching of stock to cheek and shoulder, alignment of rear sight with front sight, careful breathing, and gently squeezing the trigger, are all necessary for high marksmanship. The marksmen-practitioners will be familiar with all the details of technique. Other practitioners and observers are essential to spotting and target identification (interdisciplinary /collaborative management teams), safety (range officer/regulatory agencies), and choosing experts and sharpshooters to support and withdrawing support from the "plinkers" shooting beer cans in a quarry (all stakeholders). Graphic by A. Wilson; photo by A. Carey.

Structure, Pattern, and Process

Much literature exists on the structure of forests, the composition of forest communities, the processes influencing their development, and the patterns of biotic communities imposed on the landscapes by natural and anthropogenic disturbance regimes, particularly for western North America (sidenote 40). A large reading list could also be constructed just on disturbance and resulting patterns in and of biotic communities (Frelich 2002, Korpilahti and Kuuluvainen 2002, Pickett and White 1985b). Much of the disturbance literature addresses landscape dynamics, fragmentation, and design of reserves and corridors. There is also extensive literature available on silvics (Burns and Honkala 1990a, 1990b) and silvicultural systems and techniques (Barrett 1962, Burns 1983, Curtis et al. 1998, Kohm and Franklin 1997, Nyland 2001, Smith 1962), especially for timber management.

Synthesis

A major impediment to achieving synthesis and consensus on how to address the challenge of conservation of nature in managed forest ecosystems lies in deeply rooted ecological philosophies related to concepts of equilibria, stability, succession, development, and alternative stable states. Frelich (2002) suggested many "false" arguments ensue over these concepts as a result of narrow perspectives on the part of the antagonists. He posited that questions of scale and differences in spatiotemporal perspective underlie arguments over these concepts. For example, stability is a function of the length of time of observation and size of area observed. He suggested that interactions of neighborhoods, cumulative disturbance severities, and degree of dominance by late-seral species produce four categories of landscape dynamics that affect stability in species composition and in age structure over time and space and how and whether succession or development takes place (table 21).

Neighborhoods are small groups of trees (10 to 20 meters across) that exist within larger forest communities at the scale of tree-fall gaps, spot fires, and root-rot pockets—a scale of about 50 square meters or about 100 neighborhoods per 0.5 hectare; a 0.5-hectare area, then, may have over 50 patches of significant disturbance (gaps owing to the death of more than two trees). Differentiation of patches also reflects differences in soil and substrates, climatic variation owing to elevation, patterns of invasion by tree species, and positive neighborhood effects when two species or species groups grow together. These complex effects can produce distinctive patches of understory-midstory vegetation at the scale of 0.1 to 0.5 hectare (Carey et al. 1999b). Frelich (2002) suggested that if some relative stability in age structure is to be maintained, the minimum area occupied by a forest community should be 50 times the patch size—or more than 5 to 25 hectares, sizes coincidently and commonly dictated by complex topography (Carey and Peeler 1995). The minimum landscape required to absorb infrequent severe disturbances of less than 2,000 hectares might be 15,000 hectares or more, with no single disturbance occupying more than 20 percent of the area in a 250-year period for temperate deciduous-conifer forests. Induced disturbance regimes (say variable-retention harvesting of 25-hectare biotic communities on variable rotations averaging 100 years) also requires landscapes of 15,000 hectares or more to maintain a shifting-steady-state mosaic on a decadal basis (Carey et al. 1999c). Frelich (2002) referred to "punctuation times" for disturbances that maintain quasi-equilibria in age structure and composition in large landscapes; disturbances of 0.1 to 0.5 hectare can take place on the scale of decades, 10 to 100 hectares on the order of 0.5 to 10 centuries, and 1,000–10,000 hectares on the order of millennia (fig. 39).

Neighborhood effects are widespread and important forces operating in forests. In general, neighborhood effects are the ways in

Sidenote 36—Guidelines for landscape management (Dale et al. 2000):

- Examine impacts of local decisions in a regional context.
- Plan for the long term and the unexpected.
- Preserve rare landscape elements and their associated species.
- Avoid uses that deplete natural resources.
- Retain large contiguous or connected areas of complex forest.
- Minimize the introduction and spread of exotic species.
- Avoid or compensate for the effect of human development on ecological processes.
- Implement management compatible with the natural potential.

Sidenote 37—Biological legacies are diverse:

- Large, old, live conifers with their unique architecture and epiphytic plants, decay organisms, and ectomycorrhizal fungal associates
- Large, old, live deciduous trees with their unique architecture, epiphytic associates, decay organisms, and mycorrhizal symbionts
- Large, dead, standing trees and their associates and inhabitants
- Large, fallen trees on the ground and in streams with their associated biotic communities
- Intact patches of forest floor with their associated flora, fauna, seedbanks, and advance regeneration
- Intact patches of forest, including trees, epiphytes, understory, litter, humus, soil seedbanks, and soil food webs
- The biotic communities associated with intact headwater seeps, streams, and other wetlands
- The biotic communities associated with various intact physical landscape elements such as rock outcrops, talus slopes, balds, and special soil types

which trees alter their immediate surroundings. A more formal definition is:

> Any process mediated by canopy trees that affects the replacement probability by the same or other species at the time of canopy mortality. Neighborhood effects are defined in relation to dominant tree species or groups of species. Positive neighborhood effects (analogous to feedback effects) are processes that promote self-replacement; negative effects are processes that deter self-replacement (unless no other species are available); and neutral effects are processes that neither favor nor disfavor self-replacement (Frelich 2002).

For example, as the canopy of a Douglas-fir-dominated forest grows and closes, death of a Douglas-fir favors replacement by shade-tolerant species such as western hemlock, if seeds or seedlings are present—a negative neighborhood effect for Douglas-fir. But death of a large, dominant western hemlock also favors western hemlock—a positive neighborhood effect for hemlock. There are two types of neighborhood effects: (1) overstory-understory effects, positive or negative, that influence the species composition of seedlings and saplings by shading, litter character, stump sprouting, and seed rain; and (2) disturbance-activated effects, operating mainly in forests perpetuated by intense fire, where seedlings are killed along with canopy trees and new regeneration is due to serotinous seed rain (jack pine, lodgepole pine) or sprouting from underground

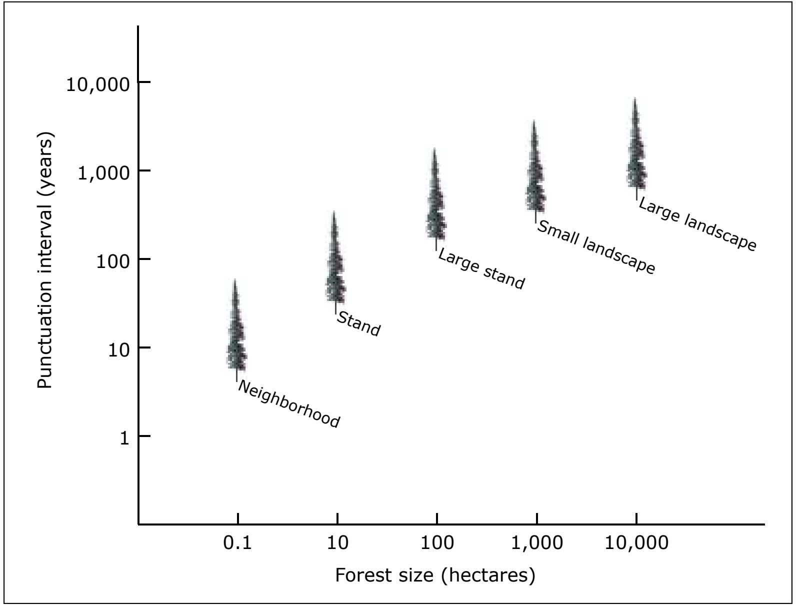


Figure 39—Frequency of disturbance events that disrupt age structure for a variety of forest sizes in Upper Michigan's hemlock-hardwood forest (adapted from Frelich 2002).

root stocks (aspen). Disturbance effects, however, will also result from species adaptations to colonization and dispersal. In the Pacific Northwest, disturbance gaps may be colonized by wind-blown western hemlock seeds (from kilometers away) and bird-transported

Table 21—Four categories of landscape dynamics in temperate evergreen-deciduous forests with reference to correspondence in some forest types of western North America

Category A—Positive neighborhood effects and low-severity disturbance:

- Adjacent stands differ in composition owing to species interactions.
- Low- to moderate-severity disturbances produce different-aged patches at the neighborhood, stand, and landscape scales.
- Stability of age structure is low in the neighborhood, moderate in stands, and high in landscapes.
- Composition stability is high in neighborhoods, stands, and landscapes.
- High-severity disturbance is rare and destabilizes composition.
- Landscape consists of a matrix of late-succcessonal species, all-aged neighborhoods, and stands with a few stand-size inclusions of even-aged early-seral species.
- Examples: western hemlock-sitka spruce in Washington, British Columbia, and Alaska and hemlock-hardwoods in eastern North America

Category B—Positive neighborhood effects and high-severity disturbance:

- Patches on uniform soils owing to species interactions.
- Low- to moderate-severity disturbance plays a minor role.
- High-severity disturbance is common and stabilizes composition in the neighborhood, stand, and landscape.
- Stable age structure is rare in neighborhoods and stands but may occur on large landscapes.
- Successional episodes proceed during periods without crown fire.
- Landscape is a matrix of large complex-shaped stands of even-aged early-seral species with a few small stand-size inclusions of uneven-aged late-seral species.
- Examples: lodgepole pine in Yellowstone National Park and Alberta, Canada, and near-boreal jack pine

Category C—No or negative neighborhood effects and low-severity disturbance:

- Patches of different composition and different age caused by tree-fall gaps and other small disturbances.
- Composition stability is low among neighborhoods, moderate to high in stands and landscapes.
- Severe disturbance is rare and destabilizes composition in neighborhoods, stands, and landscapes.
- Successional episodes are initiated by moderate- to high-severity disturbance.
- Landscape matrix is a fine-grained (neighborhood-scale) mosaic of late-seral species with stand-scale inclusions of even-aged early-seral species.
- Examples: red spruce, white spruce, and paper birch in the Northeastern United States; spruce, fir, birch, and cedar in Minnesota; and Douglas-fir, western hemlock, and western redcedar in the Pacific Northwest

Category D—No or negative neighborhood effects and moderate- to high-severity disturbance:

- Patches of different composition caused by any disturbance.
- Disturbance perpetuates instability of species composition; compositional stability is low among neighborhoods and stands, but differs in landscape.
- Stability of age structure is low among neighborhoods and stands but may be high in landscapes
- Successional episodes initiated by disturbance of any severity.
- Landscape matrix of large complex even-aged stands of mixed early- and mid-seral species with stand-scale inclusions of older forests.
- Examples: white pine, red maple, and northern red oak forests in eastern North America and Oregon white oak-fir-wetlands mosaics in the Puget Trough in Washington

Source: Frelich 2002.

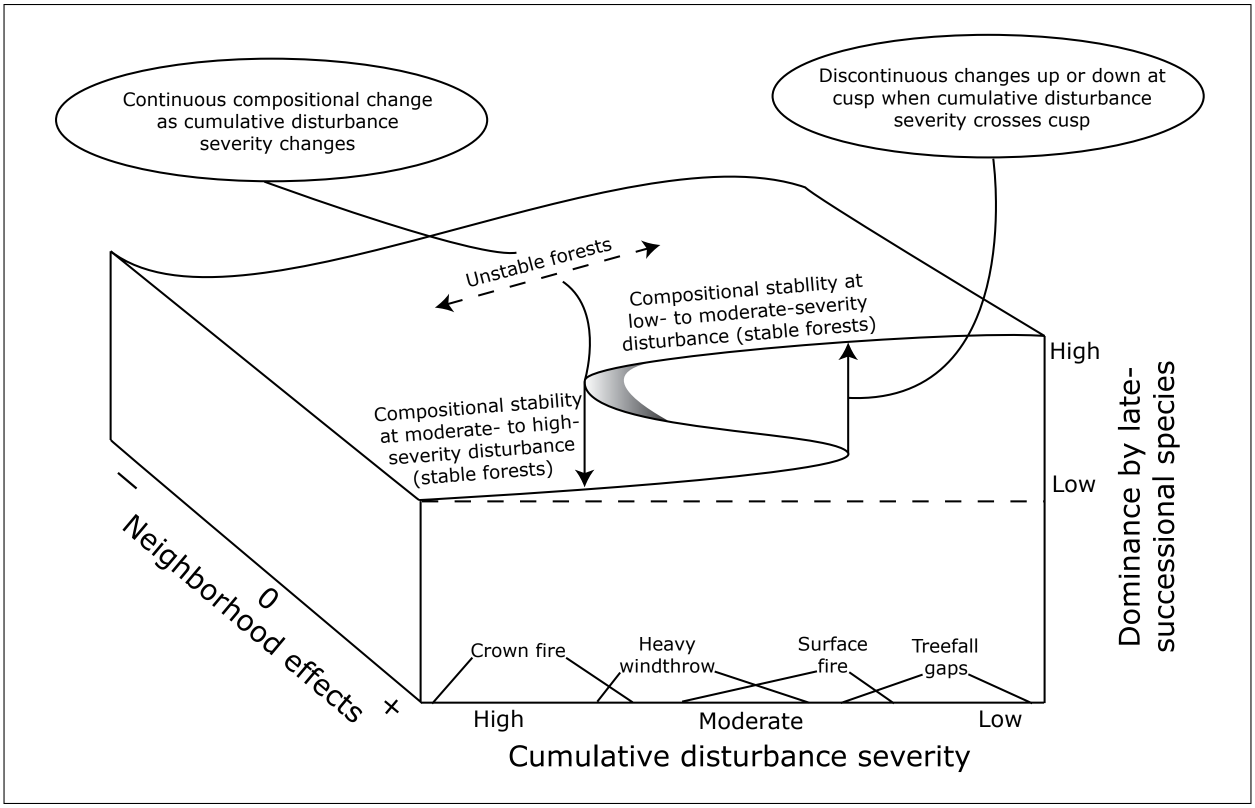
Sidenote 38—What is a long rotation?

- Certainly one that meets or exceeds the culmination of mean annual increment of tree diameter growth—say a minimum of 100 years in Douglas-fir forests.
- It differs with forest type, type of land ownership and associated goals—for example, for Douglas-fir forests, 100 years (industrial forest), 100 to 150 years (state trust lands), and 150 to 350 years (federal multiple-use lands), and a maximum that is indeterminate (late-successional reserves).
- Not a goal with uneven-age management or when no final harvest is planned.

Pacific madrone seeds as well. Conifers and hardwoods often have contrasting neighborhood effects, favoring their own reproduction and reducing the success of the other. Neighborhood affects nutrient availability, light characteristics, duff and coarse woody debris characteristics, and differential biota (such as mycorrhizae) in the forest floor in conifer and hardwood forests. Combined with disturbance regimes, neighborhood effects influence stabilities at the neighborhood, stand, and landscape levels. Landscape categories A and C may produce shifting-steady mosaics. Category A produces a self-perpetuating quasi-climax similar to those described by Clements (1936). Category B produces nonclimax forests of jack pine, red pine, or lodgepole pine. Category C may produce development of complex forests with development reset by infrequent severe disturbance—Douglas-fir can persist in the canopy in significant numbers for over 750 years. This longevity is particularly striking in the context of global climate change wherein most forests in the United States developed during interglacial periods that allowed maximum periods of development of a particular forest type of only 1,000 to 5,000 years (Frelich 2002). Category D resembles the individualistic successional model with no stable endpoint. Rather than focus on succession, Frelich (2002) suggested thinking of vegetation growth stages that integrate development (structural changes) and successional (compositional) changes over time; the concept of envelopment over time, mentioned earlier, may be more appropriate. Ecosystem development stages (see table 17) incorporate concepts of alternative stable states and developmental processes that may avoid or skip particular stages, and the possibility of regression to earlier stages in the absence of disturbance. In any case, severe disturbance always initiates a new sequence of development (envelopment) but not always a new successional sequence. Frelich (2002) proposed a cusp-catastrophe model (fig. 40) that also allows alternative stable states, regression, jumps, and surprises, with possibilities for instability and hysteresis, and that predicts development as a consequence of the interaction neighborhood effects, cumulative disturbance severity, and degree of dominance by late-seral species.

To further clarify differences among succession, development, and envelopment, *succession* is defined as "a directional change in species composition over time, where one species group replaces another" (Frelich 2002). Changes in composition of lesser magnitude than complete replacement are called "fluctuations"—changes in the relative proportions of two or more species. Thus, development sometimes is accompanied by succession, but often it is not. At least five models of succession are extant (Frelich 2002). The cyclic model is A → B → C … → A, and has been attributed to Watt (1947). An example is an aspen forest giving way to red maple giving way to northern hardwoods-hemlock forest followed by fire resulting in a new aspen forest. If this model is true and inexorable, as some argue, then managers can let nature take its course or harvest to emulate the principal regional disturbance and let nature take its course. The convergent model is one with one endpoint from different beginnings A → C and B → C and has been attributed to Clements (1936). For example, Douglas-fir being replaced by western hemlock and red alder being replaced by western hemlock. If this is true—that succession proceeds to a single climax state no matter what starting conditions are—then managers can let nature take its course, and it does not matter what is done in active management, old growth develops anyway. A less common model is the divergent model in which A can go to either B or C depending on feedback mechanisms that magnify initially minor differences (e.g., differences in soil) and perpetuate the divergence. For example, postfire aspen may go to pine, oak, or maple forest. This model calls for careful consideration of initial conditions, context, site qualities, and desired future condition in formulating how to nudge the system onto the desired trajectory. The parallel model says A–disturbance→ A and B–disturbance→ B as is common in boreal forests of North America.

Figure 40—General form of the cusp-catastrophe model, showing how changing disturbance severity affects the composition of stands dominated by species with negative, neutral, and positive neighborhood effects (Frelich 2002).



Managers can let nature take its course or "cut and run." Finally, a Gleasonian individualistic model recognizes multiple pathways of succession and emphasizes continuous change without necessarily a stable endpoint. Such complexity calls for careful AIM to achieve explicit, diverse goals. Our collective empirical experience in deforestation and oversimplified monocultures and near monocultures obviates the first four models even in the long term, given past and present human activities of fire exclusion, logging, grazing, introduction of exotic forest pests and diseases, and global climate change. But the larger question is really whether in most forest management situations are we more often faced with succession or are we more often faced with development (Frelich 2002)? And, again, development is as, or more, often envelopment than it is succession. Envelopment entails adding niche dimensions and species but not necessarily loss of species. Concepts of development through envelopment always recognize that disturbance regimes are complex, interactions abound, and spatial context is important, including both landscape permeability to dispersal and larger scale neighborhood effects of sources of colonizers and ameliorators of environmental conditions. Here again, good AIM is required.

Problems

The problem we face is not so much lack of information but a means to separate the wheat from the chaff (knowledge from ideology), a universally acceptable way of synthesizing and integrating this information to produce some basic principles to guide conservation activities (sidenote 41), and institutions capable of collaborative AIM in the present and future. Traditional ecosystem science emphasizing energy and material flows and population biology emphasizing genetic and species diversity have yet to be reconciled for conservation purposes. As with many environmental problems, social and psychological factors impede progress as much as disciplinary tunnel vision within the sciences (Dietrich 1992, Harris 1996, Kesey 1982). For example, temperaments with an "internal locus of control" prefer taking action to achieve objectives (AIM for multiple values); those with an external locus of control prefer to let things happen (let nature take its course). Field trips for empirical assessments of assumptions, experiential group learning and, especially, formal feedback from experienced professionals can provide "reality checks" (Carey et al. 1999a). Professional experience and inherent biophysical variability argues against both cookbook approaches and leaving things to chance and for thoughtful application of principles. Thus, in the context of conservation of nature and the goods and services it provides, the accumulated research does provide useful information—not so much on absolute species diversity as on forest dynamics and expansion of niche space as prerequisites to high relative diversity. Complexity of niche space contributes to ecosystem resiliency and to trophic pathways supporting plant, fungal, invertebrate, and vertebrate communities, including keystone species, keystone complexes, and prey and predator complexes characteristic of old-growth Douglas-fir forests (Carey et al. 1999b, 1999c). Theories about complexity and expansion of niche space provide a substantial basis for ecological forestry and the production of a variety of goods, services, and values (Carey et al. 1999b). But, niche theory and theories of community development do not necessarily answer all pertinent questions about conservation of rare species, cryptic species about whom little is known, total species diversity, or genetic diversity. The ecological sciences offer little in the way of assurances about human behavior in resource management—fidelity, trustworthiness, scholarship, and degree of intentionality.

The accumulated research does provide useful information—not so much on absolute species diversity as on forest dynamics and expansion of niche space as prerequisites to high relative diversity.

Biological and Functional Diversity

Much research on biodiversity has focused on sessile species and the roles of disturbance, equilibrium, and competition (Connell 1978, Connell et al. 1987, Connell and Slatyer 1977, Pickett 1980, Pickett and White 1985a, Platt and Connell 2003, Roberts and Gilliam 1995). Concern about lichens, bryophytes, vascular plants, fungi, and invertebrates resulted in severe restrictions on forest management on federal lands in the Pacific Northwest, despite the general consensus that disturbance underlies biodiversity (Levin and Paine 1974, Paine et al. 1998, Petraitis et al. 1989, Pickett 1976, White 1979, White and Jentsch 2001) (sidenotes 42, 43). One definition of *disturbance* is "any rapid release or reallocation of community resources"—tree fall, silviculture, and hurricanes can all increase diversity (Sheil and Burslem 2003). Of course, silviculture has been used most commonly to decrease diversity, as is common in plantation monocultures where any species other than the crop tree species are discouraged by maintaining high tree densities, mechanical destruction, and chemical applications (Carey 1998b). Another definition of disturbance is "a relatively discrete event in time that disrupts the ecosystem, community, or population structure and changes the resources, substrate availability, or physical environment" (White and Pickett

Sidenote 39—Creating biocomplexity in Pacific Northwest forest ecosystems includes:

- Maintaining extant species diversity.
- Restoring lost species diversity.
- Ensuring a minor deciduous component in coniferous forest ecosystems.
- Maintaining deciduous forest, meadow, and grassland ecosystems historically present in predominately coniferous forest landscapes.
- Promoting spatial heterogeneity that produces a diverse array of vegetation site types (habitat breadth).
- Promoting a diversity of foliage height profiles among the site types.
- Promoting structural diversity in tree sizes and conditions (live, decadent, dead, standing, and fallen).
- When historically common, maintaining a proportion of the landscapes in forest ecosystems of the type that resulted from catastrophic disturbances such as fire or wind.
- Protecting and promoting the growth of large trees on areas prone to mass wasting or erosion, including areas of colluvium, shallow rapid landslide potential, and deep-seated landslide potential.
- Protecting wetlands.
- Promoting a shifting steady-state mosaic of various complex stages of forest development within the landscape.
- Promoting all this heterogeneity and patchiness on a scale of 0.2 to 0.5 hectare within ecosystems and 10 to 200 hectares among ecosystems within the landscape.

1985) (sidenote 44). Disturbances localized in space and time produce patterns of heterogeneity by renewing limiting resources and permitting their use by species that are not among the dominant species (Levin and Paine 1974). Disturbances comprise continua of minor to major events and changes, endogenous and exogenous to the community, from tree fall to volcanism and from succession to climate change (White 1979). Because of disturbances, forests are structurally dynamic. Dynamic structure produces dynamic environments (chemicals, temperature, moisture, airflow, radiation, and species mix) within the community. The spatial and temporal heterogeneity that results provides the setting for evolution of life history traits adapted to persistence in heterogeneous landscapes (sidenote 45). Science suggests (1) most forests are subject to small-scale local disturbance and occasional larger disturbances, (2) many other processes unrelated to disturbance also interfere with the competitive exclusion that reduces diversity, but (3) there is widespread occurrence of forests of low diversity near younger, richer forests (Sheil and Burslem 2003).

In the late 20th century, research on vertebrate diversity emphasized island biogeographic theory, metapopulations and demographic stochasticity, dispersal and colonization processes, and, in terrestrial systems, mountaintops and forest fragmentation (Brown 1971, Gotelli 1999, MacArthur and Wilson 1967, May 1975, Simberloff and Abele 1976, Whitcomb et al. 1976). These studies assumed more-or-less static ecosystems and landscapes. More recent research emphasizes stochasticity in every process, chaos theory and Panarchy theory (dynamic systems), and neutral theories, for example, random sampling of regional species pools (Hubbell 2001). Perhaps the only generally accepted principle from that time is that there is no reason to believe that every biotope-patch-ecosystem in the landscape should be populated by every species in the regional species pool capable of living in the environment of that patch. Island biogeographic theory informs conservation biology, wherein management attempts to create systems of self-maintaining islands (reserves) and connecting corridors. An emerging generalization in conservation biology is that high levels of environmental stochasticity increase the likelihood of population extinctions. Coexistence theory, however, suggests there are circumstances in which environmental stochasticity increases the chance of persistence, depending on the interactions of life history traits and environmental variability (Higgins et al. 2000). Principles from conservation biology were used to design late-successional reserves on federal lands in the Pacific Northwest in order to provide at least temporary refuge for species not known to inhabit simplified second-growth forests. A sole focus on preserving species populations, subspecies, and species through the creation of reserves, however, is inappropriate even if the ecological qualities of reserves could be maintained in perpetuity (Franklin 1993b). Conservation, however, must move beyond reserve strategies because it is fundamentally impossible to deal with more than a small fraction of even the known species on a species-by-species basis, most species are unknown, and, in reality, biotic communities set aside in reserves will change.

Old forests that have been set aside are not in static equilibrium; they are in a more-or-less dynamic equilibrium undergoing slow change and eventually heading toward catastrophic change, according to Panarchy theory (Gunderson and Holling 2002) and history. Without major disturbance in old-growth Douglas-fir forests, Douglas-fir eventually (on the scale of centuries) will be replaced by western hemlock, Pacific silver fir, or other shade-tolerant species (fig. 41). The new biotic community, dominated by shade-tolerant species and no longer being disrupted by the death and falling of large dominants, may become more simply structured and less compositionally diverse than the immediately preceding developmental stages. The same holds true for other forest types (Bormann and Likens 1979). For example, in the absence of intermediate disturbance, a mix of subalpine fir and Engelmann spruce will be replaced by spruce (Oosting and Reed 1952, Parish et al. 1999). Mixed-oak forests may follow any one of three developmental pathways, but all end in dominance by white oak—timing may be variable, disturbances may change successional dynamics, and exact species composition may determine the occurrence of species-specific waves of mortality (Goebel and Hix 1997).

Disturbances localized in space and time produce patterns of heterogeneity by renewing limiting resources and permitting their use by species that are not among the dominant species.

In many forests, internal dynamics and endogenous disturbances maintain diversity (and resilience) over long periods. Sugar maple replaces yellow birch and is replaced by American beech—but falling of isolated large beech allows yellow birch to reestablish and a shifting mosaic to form within the community (Forcier 1975). Gap-phase replacement, with a mosaic of patches containing varying proportions and densities of saplings and seedlings, characterized Minnesota maple-basswood forests (Bray 1956) in a process similar to

Figure 41—Western hemlock saplings grow from a nurse log. Photo by T. Wilson.

that observed in plant communities in England (Watt 1947). Fox (1977) compared virgin forests in Michigan, Tennessee, Pennsylvania, Florida, and Wyoming and concluded that forests maintaining a compositional equilibrium did so through a dynamic equilibrium of patch types, changing in time and space. His results did not support the hypothesis that mosaics of spatially fixed microsites that favored one species over another would provide for species coexistence in perpetuity (Freyer and Ledig 1972). Ziegler (2002) reported similar results in her study of New York Adirondack forests and review of studies in Michigan, Pennsylvania, and New York. Nevertheless, fine-scale (within biotope) environmental heterogeneity certainly has the potential to contribute to biological diversity (Frelich 2002). Fox (1977) proposed three hypotheses about how autogenic (self-organizing) biotic heterogeneity is sufficient and important to species diversity: (1) forest tree species dynamics are the result of interactions between dominant and subordinate trees at the scale of one to a few large canopy trees; for example, a dominant plant can provide a microhabitat for a younger or smaller plant; (2) processes leading to interactions, especially those regulating density and species composition, all operate on very local scales (except seed dispersal); and (3) local regulation of species composition occurs because dominant trees interact directly with smaller plants through root and mycorrhizal grafting thereby uniquely altering the mortality and growth of various species of seedlings and saplings that are nearby. Thus, the important scale of heterogeneity was one to six or so canopy trees, or about 0.2 hectare. A duality of scales of patchiness was found in old-growth hemlock-hardwood forests maintaining a dynamic compositional equilibrium in the absence of major exogenous disturbances in the Smoky Mountains of Tennessee (Busing and White 1993). Observed canopy gaps (averaging 0.01 hectare) and physical structure (biomass, basal area) varied with these gaps; but spatial variation in composition occurred at 0.5 to 1.0 hectare reflecting the interaction of canopy gaps, microhabitat, patterns of seed dispersal, vegetative regeneration, and species interactions. These authors noted that the potential for high spatial variability of compositional parameters has long been recognized and that 0.5 hectare is the minimum area for evaluating change in physical parameters, and about 1 hectare is the minimum for compositional parameters (as both relate to trees, only).

Succession to a climax community can result in lowered diversity (at least of vascular plants and vertebrates) and lowered biocomplexity as species are lost through succession (Whittaker 1975) and even the abundance of fallen trees and standing decadent trees

Sidenote 40—References on forest ecology and management:

- Allen et al. 2001
- Bergeron 2000
- Bobiec 2002
- Bobiec et al. 2000
- Bormann and Likens 1979
- Busing and White 1993
- Canham et al. 1990
- Carey 2003a
- Carey et al. 1999a, 1999b
- Clements 1916, 1936
- Connell and Slatyer 1977
- Cooper 1960
- Dale et al. 1986
- Denslow 1980
- Donnegan and Rebertus 1999
- Forcier 1975
- Foster et al. 1996
- Fox 1977
- Franklin and Waring 1980
- Franklin et al. 1987
- Franklin et al. 2002
- Frelich 2002
- Goebel and Hix 1997
- Grime 1977
- Halpern 1988, 1989
- Halpern and Franklin 1990
- Harrod et al. 1999
- Holling 1992
- Huff 1988
- Jones 1945
- Kimmins 1996
- Massman 1982
- Odum 1969, 1971
- Oliver 1981
- Oliver and Larson 1996
- Oosting and Reed 1952
- Parish et al. 1999
- Peet and Christensen 1987
- Peltzer et al. 2000
- Perry 1994, 1998
- Perry et al. 1989
- Pickett 1976
- Poage and Tappeiner 2002
- Roberts and Gilliam 1995
- Ryan et al. 1997
- Shugart 1984
- Shugart and West 1980
- Stewart 1986

decreases (Bormann and Likens 1979, Carey 1983). For example, northern hardwood forests over 200 years old in West Virginia had less structural complexity (e.g., a lack of cavity trees and lack of understory) than 80- to 100-year-old second growth nearby. Similarly, Scheller and Mladenoff (2002) found understory diversity was lower in old-growth northern hardwood forests in Wisconsin and Michigan than in even-aged second growth which, in turn, had less diverse understories than uneven-aged second growth. Differences in species composition in the understory were the result of sunlight and coarse woody debris; each age class had its own characteristic combination of understory composition, diversity, and spatial patterning. Large- and small-scale disturbances, such as hurricanes and blowdowns, respectively, promoted various aspects of understory regeneration in Southeastern hardwood forests, such as seed germination, growth of seedlings and established plants, and fruit and seed production (Kwit and Platt 2003). Mid-altitude forests on Mount Rainier that have not had a major disturbance in close to a millennium have the appearance of a much younger forest in biomass accumulation stage—most of the original dominants have fallen, and even the fallen trees are well-decayed and indistinguishable from the forest floor. Not much is known about the effect of quasi-climax stages on micro-organisms, nonvascular plants (lichens, bryophytes), fungi, and invertebrates. For example, the Quinault Research Natural Area on the Olympic Peninsula of Washington, is over 500 years old (middle-aged old growth) and dominated by very large western hemlock and Sitka spruce and large, fallen trees (fig. 42). During a 3-year study, it supported neither flying squirrels nor spotted owls (Carey 1995). It did, of course, support a great diversity of other organisms, including ferns, lichens, mosses, and liverworts (and, most likely, a high diversity of organisms in the forest floor).

In any case, it is likely the old growth of today eventually will be affected by catastrophic disturbance. The eruption of Mount St. Helens in 1980 destroyed old-growth forests set aside for spotted owls (Ruediger 1985) (fig. 43), recapitulating an earlier eruption in 1480 (Agee and Krusemark 2001). Volcanism and other geologic processes (such as those associated with glaciation and glacial recession) have shaped the landscapes in Washington and Oregon not only through basaltic lava flows, creation of pumice fields, lahars, and massive eruptions, but also long-distance ash deposition and large-scale flooding. An earthquake that caused substantial tree fall may have set the stage for a massive fire in 1700 near Mount Hood, and a sunspot minima may have led to global cooling, drought, and lightning that led to a large fire event in 1493 (Agee and Krusemark

- Swedish National Board of Forestry 1990
- Tappeiner et al. 1997
- Van Pelt and Franklin 2000
- White 1985
- Whittaker 1956, 1960, 1965, 1975
- Whittaker and Levin 1977
- Winter et al. 2002a, 2002b

Sidenote 41—Some basic principles of forest conservation:

- Protect highly valued rare, fragile, and threatened ecosystems.
- Maintain healthy forests across landscapes and regions, and especially near where people live and work.
- Manage forest for multiple values by maintaining legacies, by using long rotations (time between major harvests), and actively managing for biocomplexity.
- Encourage people to experience the forests and to learn about their functions and values.

Sidenote 42—The Intermediate Disturbance Hypothesis (Connell 1978)—"the highest diversity of tropical rain forest trees should occur either at an intermediate stage in succession [development] after a large disturbance or with smaller disturbances that are neither very frequent nor infrequent; either represents an open non-equilibrium."

2001). Windstorms in 1921 and 1962 destroyed large areas of forest in western Washington and Oregon (Henderson et al. 1989). At the same time, the introduced white-pine blister rust changed the nature of Cascade old-growth forests, adding numerous large snags but decimating various species of pine. Ponderosa pine now infiltrated by Douglas-fir has increasing vulnerability to catastrophic destruction (Harrod et al. 1999).

Most old growth in the Pacific Northwest developed after catastrophic fires 300 to 600 years ago. "Natural fire rotations" appeared to be 465 years for Mount Rainier and 347 years for Mount Hood (Agee and Krusemark 2001). Fires were more frequent in the Oregon Coast Ranges in the 19th and 20th centuries (Juday 1977, Wimberly and Spies 2001). In some areas, fires reduced the prevalence of western hemlock, a species poorly adapted to fire. These fires have been attributed to the end of the Little Ice Age but were concurrent with the arrival of settlers from the Eastern United States. Both settlers and Native Americans used fire to maintain grasslands, promote grazing, and clear forest. As disturbance regimes change, patterns of forest development that follow future catastrophic disturbances may differ from the patterns of the past—the climate, natural and anthropogenic disturbance regimes, regional and local species pools, and regional and landscape environmental contexts already differ from the past.

Natural disturbances, timber harvest, and land use changes have produced an uneven distribution of old growth with large intervening areas dominated by developed areas and managerially simplified competitive-exclusion stages of second-growth forest. Landscapes dominated by competitive-exclusion stages (through their negative

Sidenote 43—If disturbance underlies biodiversity, why is there such an emphasis on reserves and restricting management even in second growth? Three likely explanations:

- Many see old-growth species as "*K*-selected" species, adapted to stable conditions which are increasingly rare and thus in need of protection when they exist, as defined by the presence of such a species.
- A perverse adaptation of the precautionary principle (Principle 15 of United Nations 1972) by which any uncertainty precludes human action and proponents of action must demonstrate efficacy of action.
- Deep distrust among ecological disciplines, managers, regulators, and conservation groups based on the history of exploitation of natural resources in the United States. Jack Ward Thomas (2002), former leader of the Forest Ecosystem Management Assessment Team that provided the basis for the Northwest Forest Plan and former Chief of the USDA Forest Service, provides a review.

Figure 42—Regine Carey stands between large, fallen trees on the 600-hectare Quinault Research Natural Area, an undisturbed old-growth forest of the Olympic Peninsula. Photo by A. Carey.

effects on dispersal and colonization processes) may prove more detrimental to nature conservation than either (1) large areas of forests destroyed by catastrophe but contain substantial embedded legacies or (2) dispersed clearcuts in landscapes of forests actively managed on long rotations in which complex stages of forest development predominate and landscape permeability is maintained (Carey et al. 1999c). Managerially simplified stands with exacerbated competitive exclusion and biomass accumulation *work against interactions* of environmental factors and the functional ecologies of species that are the foundation for maintenance of plant species diversity, not only in temperate forests but also in boreal forests (Messier et al. 1999) and diversity in plant communities in general (Grime 1977). Even productivity declines, often quickly, when biomass accumulates rapidly and a syndrome of changes leads to reduced carbon assimilation (Ryan et al. 1997).

Plants require energy, water, and mineral nutrients for growth; natural environments, however, differ in orders of magnitude in the availability of these resources. For example, light varies 100-fold from the canopy to the rain-forest floor; precipitation varies 500-fold from deserts to tropical rain forest; and nitrogen ranges almost 300-fold from the poles to the tropical rain forest (Chapin et al. 1987). The functional ecology of plants can be represented by a three-sided triangle of interaction wherein the sides represent the importance of competition, disturbance, and environmental stress in determining the strategy a plant species (or even a life history stage) takes. Grime (1977) labels these strategies as *C* (high competitive ability in stable environments), *S* (high stress tolerance with reduction in vegetative and reproductive vigor), and *R* (short lifespan and high seed production in severely disturbed environments) (fig. 44) (see table 15). In plants, *R* stands for ruderal; in animals, *r* is the symbol of a measure of reproductive ability. Animal ecologists use *K*, the symbol for carrying capacity, to represent strategies that emphasize long life, low reproduction, and survival in stable environments and r to represent short life, high reproduction, and adaptation to volatile environments (Hutchinson 1978, Reznick et al. 2002) (fig. 45) (see table 20). Grime's triangle, however, allows subdivision of a 3-D space to describe various life histories, and he recognizes that conditions on a biotope change through time as plants modify the environment. Species in a dynamic community exhibit a multiplicity of strategies—this multiplicity is one basis for ecosystem resilience. In forest communities, architectural adaptations allow seedlings of different species to grow under different environmental conditions (Messier et al. 1999). In other words, complex, dynamic ecosystems

Figure 43—Between 1980 and 1986, Mount St. Helens had several small steam and ash eruptions as a series of dome building eruptions built the 1,000-foot tall lava dome in the crater. This photo shows a dome-shattering explosive eruption that occurred in the fall of 1982. Photo by P. Frenzen.

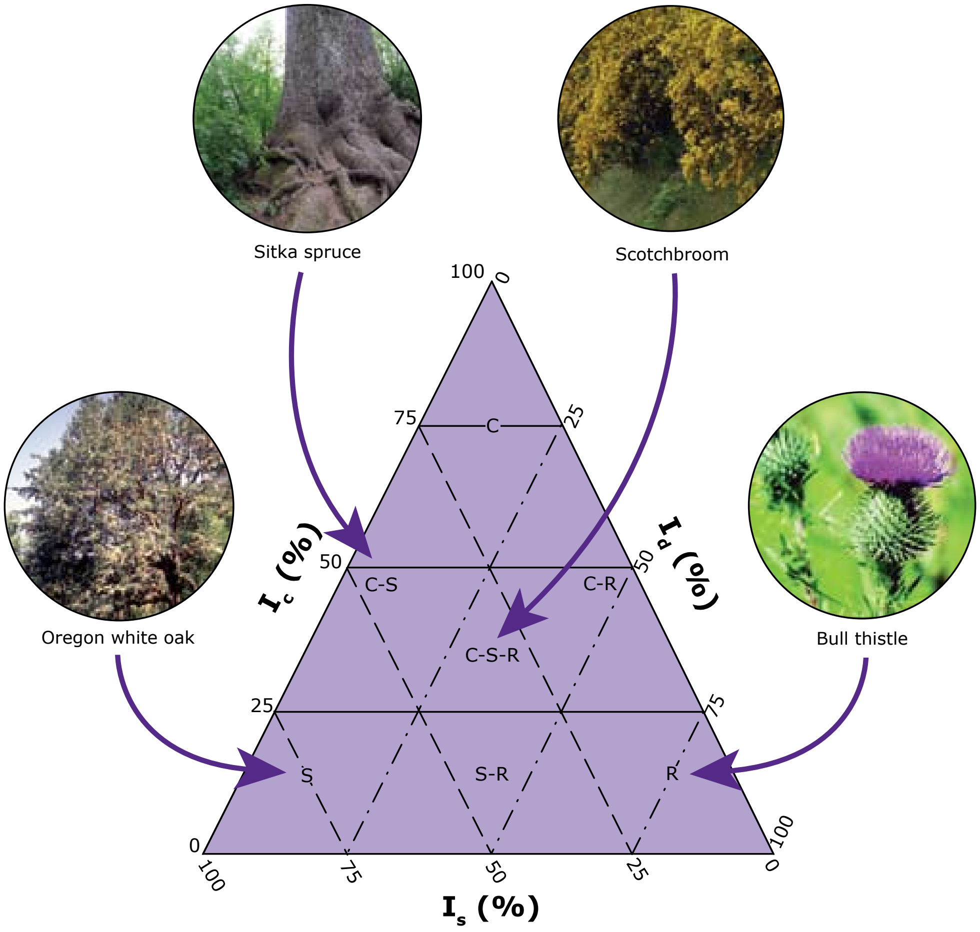


Figure 44—Model describing the various equilibria between competition, stress, and disturbance in vegetation and the location of primary and secondary strategies. I_c—relative importance of competition (———), I_s—relative importance of stress (-----), and I_d—relative importance of disturbance (— • —). Ruderal (*R*), competitive (*C*), and stress-tolerant (*S*) strategies along the *r*–*K* continuum (adapted from Grime 1977). Graphic by A. Wilson; oak photo courtesy of USDA Forest Service; thistle photo courtesy of USDI Bureau of Land Management; Sitka spruce photo by T. Wilson; scotchbroom photo by A. Carey.

make room for a diversity of species within the various functional groups. Adaptations include steep leaf angles (to minimize photoinhibition by allowing more light to penetrate to lower leaves), horizontal leaves (to shade competitors), and allocation of carbon to leaves versus stems and branches. Lower relative growth rates and higher allocation to roots is more characteristic of late-seral forest (species that emphasize maintenance of accumulated biomass) than early-seral forest species (species scrambling to compete for ephemerally available resources). Allocating carbon to foliage and stem growth helps in competition for light; allocating carbon to fine roots enhances competitive ability for nutrients. In conifers, pines are less efficient at intercepting light (0.16 STAR [shoot silhouette to needle surface] ratio) than firs (0.28). With diminishing light and increasing shade tolerance, lateral branch growth is favored over height growth, number of whorls and interwhorl branches is decreased, live-crown ratio is decreased, and horizontal display of needles and branches is increased (fig. 46). Thus, crown architecture must achieve some balance in a complex system by performing conflicting tasks such as enhancing photosynthesis, adapting

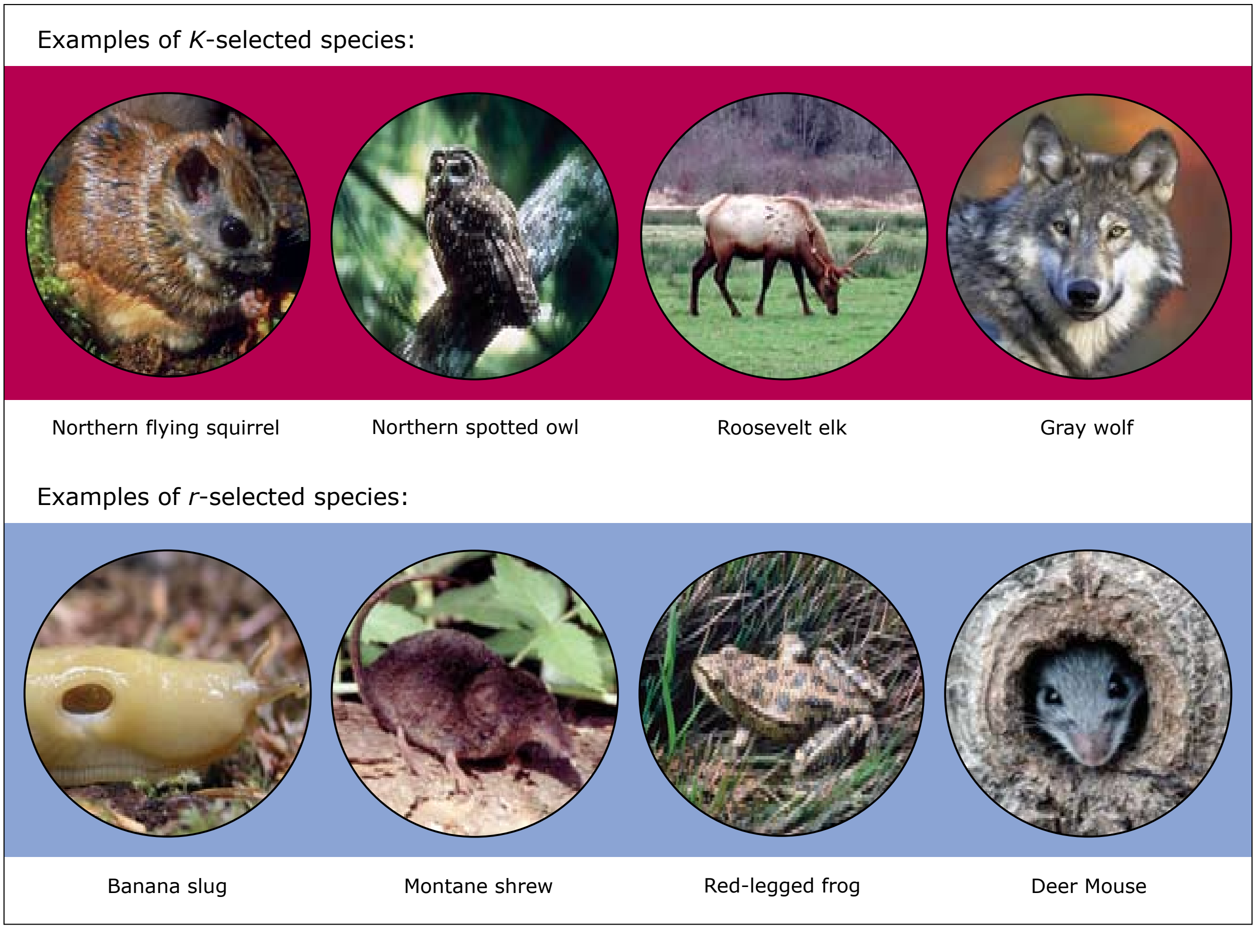


Figure 45—Examples of *K*- and *r*-selected species. Graphic by A. Wilson; flying squirrel photo by W. Colgan III; banana slug photo by T. Wilson; owl and shrew photos courtesy of USDA Forest Service; elk and mouse photos by A. Carey; red-legged frog photo by M. Jennings, U.S. Fish and Wildlife Service; wolf photo by G. Kramer, U.S. Fish and Wildlife Service.

for survival in the winter, and allowing light to penetrate to deeper layers—one result is the conical crown of many conifers (Messier et al. 1999). As trees grow, their requirements for sunlight change. The tuliptree requires 12 percent full sunlight at 1-meter tall but 25 percent full sunlight when 10 meters tall. Some conifers produce one kind of needles when growing in the shade and must produce new, different needles for growing in sunlight. Shade-tolerant trees like western hemlock and some firs and spruces can grow for extended periods in a shaded understory, awaiting release by large falling trees causing gaps, severe windstorms toppling the overstory trees, and outbreaks of defoliating insects (Messier et al. 1999). Thus, species diversity in forests is dependent upon large and small gaps and functional relationships among size of canopy opening, nature of above- and belowground environments, and the response of the seedlings and saplings of various species. Natural thinning (self-thinning) and even intentional (managerial) thinning may produce deaths of individual trees that may be relatively inconspicuous but collectively determine much of the structure, development, and dynamics of forest ecosystems (Peet and Christensen 1987, Thysell and Carey 2001a).

Sidenote 44—Order and disorder—"To many ecologists, natural disturbances are key ecosystem processes rather than ecological disasters that require human repair" so said prominent ecologists in the public debate over removal of damaged trees after natural disturbance and subsequent attempts at restoration (Lindenmayer et al. 2004). This quotation is an especially telling statement of worldviews and a policy opinion. It is telling because these leading scientists lumped all disturbances into one group rather than distinguishing among small, intermediate, and catastrophic disturbances or between autogenic (endogenous disturbances that are normal and regular parts of ecosystem development) and exogenous forces that may be either part of a disturbance regime characterizing a region over a long term or rare geologic or weather events. The quotation, however, is prefaced to refer to "Recent large-scale natural disturbances including wildfires that burn [millions of hectares]."

What are the pertinent definitions of the key words according to the Oxford English Dictionary?

- Disturbance: an outbreak of disorder … interference with the … due course … of any … process.
- Disaster: anything that befalls of a ruinous or distressing nature … a sudden …. calamity.
- Catastrophe: an event producing a subversion of the order or system of things … a sudden and violent change in the physical order of things … affecting the earth's surface and the living beings upon it….

Shugart (1984), however, emphasized that the individual attributes and population dynamics of species as they relate to competition, although important, interact with processes of facilitation and small-scale (0.1 to 0.2 hectare) gap formation, compared to even smaller gaps (0.04 to 0.08 hectare) in tropical forests. Thus, temperate forests demonstrate a regularity of pattern indicative of a multiplicity of plant-environment and plant-plant interactions; Shugart (1984) thus joined Odum (1969) in stressing self-organizing phenomena.

In summary, research has provided useful and important insights about the processes of plant community development in forest ecosystems, mechanisms leading to and maintaining biological diversity, and the ramifications of large-scale anthropogenic and natural disturbances for landscape function. As a practical matter, individual studies and individual syntheses generally are narrowly focused. This narrow focus, at times, has resulted in emphasizing reductionism at the expense of holism (Barbour 1996). Narrow, intradisciplinary foci have led to unnecessary polarization of worldviews among scientists and among conservationists, including false dichotomies of management by preservation versus intensive management for commodities and maximum economic return on investment (sidenote 46). Such dichotomies cloud the view of the bigger, long-term picture of conservation of nature. Maintaining these dichotomies, however, is a choice, not inevitability. We have the potential collectively to develop the holistic, integrated worldviews that are needed for effective conservation. It seems that an emphasis on ecological processes and system dynamics underlying forest development and maintenance of biodiversity offers more promise than a focus on specific structural elements, particular endpoints of structural development, particular patterns of a limited set of idealized "structural stages," rare species, absolute species diversity, or leaving recovery of ecosystem and landscape function to time and chance alone.

Processes Underlying Forest Development

> Ironically, it is the history of environmental fluctuations, natural disturbance processes, and subtle, often indirect, human impacts that shape the characteristic structure, composition, and ecosystem processes of old growth (Foster et al. 1996).

Ecologists have been arguing about the nature of virgin forests since 1924 (Jones 1945). Jones's review documented common ages of dominants around 300 years old in beech forests in Europe, 350 years in pine forests of Asia, 350 years in hemlock forests of eastern North America, and with the oldest and largest trees (750+ years for several species) in California, Oregon, and Washington. Coastal British Columbia trees, however, rival those in other parts of the Pacific Northwest. Northern coniferous forests seemed smaller in stature (of course, we now know the oldest trees may be quite small evergreens in xeric parklands and woodlands). He noted that there were many types of structure in virgin forests: even-aged, single-storied, uniformly closed-canopy forest; two or more ages in either separate stories or separate groups; all ages present, intimately intermingled, with irregular open canopies; all ages in a mosaic of even-aged groups; and all ages present with a regular, uniform canopy and a storied structure. The most common structure seemed to be dominance by old stems, but with a wide range of ages, and two to three canopy gaps per hectare. Fire seemed of supreme importance in the origination of natural forests but "tempest," fire, root-rot, heart rot, insect attack, and disease produced various phases of senescence, or large amounts of decadence. Climatic changes brought about "re-adjustment" of dominant species. But in all cases, the forests were in dynamic equilibrium with individuals dying and being replaced by individuals of other species with compensatory changes taking place elsewhere; in other words, the shifting-steady-state mosaics later described by Fox (1977), Bormann and Likens (1979), Shugart and West (1980), Pickett (1980), Oliver (1981), and Franklin et al. (2002). Not too bad for the turn of the century. A more recent review of old growth in temperate and boreal forests of Europe (Nilsson et al. 2003) found that the older canopy trees were 200 to 300 years old even in forests without significant harvests for over 2,000 years. Large (more than 70 centimeters) d.b.h. trees numbered 10 to 20 per hectare (40 to 60 square meters basal area per hectare) depending on forest type and site, with 10 percent of all standing trees dead, and with snags composing 30 percent of dead tree volume. These deciduous and mixed deciduous-conifer old-growth forests were judged to be similar to those in the Eastern United States. But the authors found that old growth in the Pacific Northwest had older, larger trees, fewer trees per hectare, but with greater basal area and total volume of trees and with a larger proportion (30 percent) of standing trees dead (fig. 47).

Development of forest ecosystems from reorganization through old growth is an interacting complex of processes (some of which counteract one another) that lead to characteristic trophic structure (food webs) and material cycles (Beckage et al. 2000, Bergeron

Thus, there are disturbances, localized or widespread, mild or intense, acute or chronic; and there are catastrophes—acute, intense, and widespread. Some disturbances are ecosystem processes (endogenous to the ecosystem) and some are exogenous forces destructive of the established system, its processes, and its biological diversity. Human reaction to disturbances differ with the intensity, acuteness, and distance from the observer. Policies on how to deal with disturbances are by definition based on human worldviews and human values, not "objective" science; they are often formulated hastily during and immediately after major disturbances. The scientists propose "… to formulate salvage harvest policies before major disturbances … exemption of [certain] large areas … [and] good planning should guide the timing and intensity of salvage harvesting."

Figure 46—A western hemlock's unique lateral branching allows it to survive in the shadow of larger conifers. Photo by A. Carey.

Sidenote 45—Generalities from studies of disturbance (White and Jentsch 2001):

- Disturbance is a primary cause of spatial heterogeneity and influences competition, environment, and substrate and resource availability.
- Disturbance is crucial to biotic diversity and an important evolutionary force that produces both complementarity and redundancy in biota that promote ecosystem stability.
- Disturbances shape communities to be resilient in the face of disturbance through functional redundancy.
- Humans are a major source of minor and major environmental disturbances and influence the rate and intensity of natural disturbances, often to the detriment of biological diversity.
- Disturbances differ with topography, climate, and soil development.
- Disturbances differ with feedback and interactions—disturbance can promote further disturbance.
- Disturbances differ in heterogeneity, patch size, intensity and severity, and legacies.
- Disturbances differ in space and time.
- Systems respond to disturbance in three ways: threshold responses, scale-independent responses, and continuous responses.
- Species and communities differ in their responses to different disturbances.

2000, Odum 1969). Development after catastrophic destruction and reorganization usually (1) is an orderly process that is reasonably directional and therefore predictable, (2) results from modification of the physical environment by the community, and (3) culminates in a stabilized ecosystem in which biomass and symbiotic function constitute a strategy of homeostasis, but not necessarily a classic old-growth condition (see table 17). The reorganization phase itself is highly variable in nature and length—in the Pacific Northwest regeneration of trees in sufficient number to create a forest can take 30, 50, or more years after a catastrophic fire (Huff 1995, Poage and Tappeiner 2002, Winter et al. 2002a), and spatial heterogeneity can be very high owing to legacies and differences in seed sources.

In late-seral forests, shifting-steady-state mosaics (dynamic patches) (Pickett and White 1985b) provide for a degree of dynamic equilibrium through gradual changes in space and time both within forest ecosystems and across forested landscapes. Various exogenous disturbances and environmental heterogeneity within the biotope interact with a variety of ecological processes to promote biocomplexity within the ecosystem. Without disturbances (exogenous and endogenous), the development of biocomplexity will be truncated. Biocomplexity within the biotic community develops as patches begin to differ in character, rate of change, and type of change over time more than would be expected on a uniform site without successive disturbances. Thus, forest development in lowland, carefully cultured plantations is likely to be quite different than in upland heterogeneous sites subject to various minor and intermediate exogenous disturbances but little intensive culture.

It is essential to effective management to realize that the catastrophic destruction and the legacies it generates set the stage for the development to follow. Different disturbance regimes set different stages (Frelich 2002). The effects of timber harvesting and other human activities may be quite different from those of most natural disturbances in the case of clearcutting and somewhat similar in the case of partial cutting (sidenote 47). In numerous locales in North America, including the Capitol Forest of Washington (*Capital Forest: The Forest That Came Back*, Felt 1975), unregulated timber harvesting led to deforestation and erosion. In both western Oregon and Washington in the 20th century, forests destroyed by wildfire reburned; for example, the forest destroyed by the Tillamook Fire of 1933 burned again in 1939, 1945, and 1951, probably as a result of human activity (Agee 1991). Potential for reburns can be high in early succession to Douglas-fir on moist sites, but once crowns close, potential for fire decreases. Forests may then develop for another 200 to 500 years with their character conditioned by a specific catastrophic disturbance and the legacies it left. If the forests go undisturbed for 700 to 1,000 years, Douglas-fir will be lost, and Pacific silver fir and western hemlock will be the primary seed sources of a new postfire regeneration. In more mesic sites in the Oregon Cascades, partial burns after canopy closure may occur every several decades or centuries; forest development follows a different course, with a mixed dominance of Douglas-fir and other species maintained. And in dry sites in southwestern Oregon, partial burns are common; true firs and hemlock may be rare and multiple age classes of Douglas-fir and hardwoods such as madrone or tanoak may be common. Thus, the importance of biological legacies and disturbance regimes and their contributions to reforestation has been recognized since Clements' work on forests in 1916, the Hubbard Brook forest experiments of the 1960s, and reforestation of the area around Mount St. Helens in the 1980s (Franklin and MacMahon 2000, Franklin et al. 2002).

The most important ecological insight from studies of natural boreal, montane, and temperate coniferous forests and tropical forests is that forest ecosystems are highly varied and dynamic in

Sidenote 46—False dichotomies—A major wildfire in southwestern Oregon ignited a firestorm of countervailing philosophies among prominent scientists that precluded intentional analysis and planning (Lindenmayer et al. 2004, Sessions et al. 2003, Thomas 2002). Should the forests have been managed to reduce fuels before the fire? Should damaged timber be salvaged for its economic value and jobs? Should damaged timber be salvaged to underwrite restoration efforts? Does salvage cause damage rather than speed recovery? Should nature be allowed to take its course? Should the reorganizing forest be managed to speed recovery of late-seral forest conditions? These questions are less about science and more about value and purpose. The most pertinent questions are why, where, when, how, how much, in what manner, for what specific purpose, at what risk, with what uncertainty, for what collective result?

Figure 47—Old-growth trees on the Olympic Peninsula—some living, some dead. Photo by T. Wilson.

Sidenote 47—Second-growth forests may differ markedly from one another, even in the same region. Influences to a forest include:

- Site characteristics—elevation, slope, aspect, homogeneity of topography, soils, site fertility, wetlands, rock outcrops, and many other physical features, including site modification by fire or erosion
- Amount of legacies retained from the previous forest
- Time since reorganization
- History of disturbance and management after reorganization
- Amount and scale of spatial heterogeneity
- Stage of forest development
- Species and life-form diversity
- Resilience and potential for development following disturbance
- Health, presence and effects of common forest diseases and pests
- Overall biocomplexity

structure and composition and in the patterns they form on landscapes (Foster et al. 1996). All ecosystems studied have exhibited some responses to past human activity. The rate of change in disturbance processes and associated ecosystem attributes was greatest in the historical (not contemporary) period, and many present-day old-growth forests comprise anomalous or unique assemblages relative to those of their historical counterparts. Another way of saying this is that those old-growth forests that survived when the majority were destroyed may have been unusual in their character, their location, or both. Old-growth forests today represent adaptations to past environments, including human activities, and are not necessarily as well-adapted to future environmental conditions—but might well be highly adaptive, owing to their biodiversity. Old-growth forests in the Pacific Northwest at best represent less than 6,000 years of existence in a time of continuing climate change (Brubaker 1991). Thus, their adaptiveness probably is not a result of tight coevolution of species over the long term in a stable environment but rather successful self-organization that allowed accumulation of biomass and biocomplexity. Across North America, human activities on regional to local scales with various direct and indirect impacts on ecosystems, altered climate and cloud and precipitation chemistry, eliminated native species (e.g., passenger pigeons, deer, elk, moose, and beaver—all of which influence some forest processes), introduced exotic species, including pathogens (e.g., chestnut blight, Dutch elm disease, beech bark disease, hemlock wooly adelgids, white pine blister rust), and changed fire regimes. Thus, to be effective, strategies for the preservation, management, and restoration of old growth or for the conservation of nature in general must be based on acceptance and anticipation of change (Foster et al. 1996). Comparisons of natural forest and second-growth forests deliberately shaped by silviculture have repeatedly illustrated that conventional silviculture does not mimic natural disturbances, promote the same developmental processes that occur naturally, or produce resilient ecosystems with high capacity for adapting to change (Bergeron et al. 1999, Carey 2003a, Price et al. 1998). Not only is a new forestry needed, but managers must look beyond stands and landscapes to the region and to the globe if planning is to be reasoned.

Exogenous Disturbances

Earth is first and foremost a “fire planet” in which an oxygen-rich atmosphere and carbon-based living organisms

> regularly conspire to create conditions that make combustion and widespread conflagration a recurrent, indeed inevitable fact of life (Cronon in Pyne 1997: ix).

When people think of forest fires, they usually think of wild (unplanned and unmanaged) fire. But, the history of human use of fire is long and astounding. Fire has been used purposefully, indiscriminately, commonly, and frequently. Much of the Earth's biological diversity has resulted from the presence of people and their use of fire. Fire also provided the means by which people claimed nature, rendered it habitable, and refashioned it into pastoral and agricultural landscapes worldwide (Pyne 1997). Human use of fire over the ages purposefully shaped the subsequent biotic communities in North America, from the southeastern pine parklands to the interior prairies of Kentucky to the prairies and oak woodlands and savannas of western Washington (Pyne 1997, Thysell and Carey 2001b, Tveten and Fonda 1999). But conversion of forest to grazing and agricultural purposes was not the only use or cause of forest fires. The interaction of geologic events, climate change, natural forest fire regimes, indigenes' purposeful use of fire, accidental and malicious use of fire by indigenes and settlers from the Eastern United States, fires resulting from careless logging practices, fires resulting from the construction and operation of railroads, forest management and fire exclusion, and arson reshaped many forested landscapes and their biotic communities, particularly in the inland Northwest, but even in the Pacific Northwest (Pyne 1997).

To be effective, strategies for the preservation, management, and restoration of old growth or for the conservation of nature in general must be based on acceptance and anticipation of change.

Long before settlers from Europe arrived, indigenous peoples managed landscapes and maintained particular biotic communities across North and Central America with deliberate use of fire (Krech 1999, Pyne 1997, Wright 1992). Settlers from the Eastern United States found the landscapes managed by indigenous peoples in the Pacific Northwest (Oregon's Willamette Valley and Washington's Puget Trough) particularly attractive. The first U.S. settlers in Washington usurped, for their own agricultural purposes, the prairie, woodland, and wetland mosaics managed with fire by the Nisqually people in the Puget Trough. The nearby Skokomish people of the eastern Olympic Peninsula maintained shrub parklands dominated by Douglas-fir for winter grazing by Roosevelt elk and perhaps for berries (fig. 48) and basket material; there is evidence (prairies up to 1,200 hectares) that people on the west side of the peninsula did likewise. Coastal indigenes also intensively managed estuaries for root and tuber production (Deur 2002, Turner and Cocksedge 2001). Yakama people (and perhaps the Cowlitz,

Figure 48—Red and blue huckleberry can be found growing side by side on the Olympic Peninsula. Photo by T. Wilson.

Nisqually, and Puyallup) burned subalpine forest on Mount Rainier to push back the forest and maintain parklands for their berries and support of deer, elk, and mountain goats. The Calapooya people of the interior valleys of western Oregon used fire to maintain prairies and oak woodlands and to shape the adjacent conifer upland forests of the Coast and Cascade Ranges, perhaps again for grazing by wild ungulates, oak woodlands, and parkland berry fields. Numerous plants that once thrived in the managed natural-cultural mosaics of the Pacific Northwest Amerindian cultures are now threatened by the subsequent introduction of exotic plants and the continuing land use changes of an ever-growing U.S. population (Carey 2002a, Thomas and Carey 1996, Thysell and Carey 2001b). Farther south in the Sierra Nevada, the Nisenan community managed the forest with fire for 2,000 years (along with lightning-ignited fires in drought years) for hunting grounds and cordage until they were decimated by introduced malaria and dislocated and persecuted by gold miners in the mid-19th century (Stephens and Collins 2004). Subsequent mining, grazing, logging, and, finally, fire suppression produced markedly different fire regimes and forest conditions. Now conservationists debate about desirable future conditions for these forests, with increasing doubt about natural variation concepts based on historical ecology.

Of all the temperate and tropical forests of North and Central America, it is likely that the low- to mid-elevation old-growth forests of the Pacific Northwest are among the least affected by indigenous peoples (Pyne 1997). Northwestern coastal forests with high annual rainfall in fall, winter, and spring are relatively fire-resistant, and the trees grow too large to be razed by stone-age people or even preindustrial iron-age people. In any case, dry summers and lack of domesticated grains and root vegetables limited opportunities for farming; indeed, it appeared carbohydrates may have been more limiting to Pacific Northwest indigenes than protein or fat, given abundant, salmon, deer, and elk and the considerable time they spent harvesting and drying berries, camas roots, and tubers of wetland plants. Much of the temperate forests of the Eastern United States and forests in Central America had been changed into croplands, woodlands, and savannas well before the arrival of European settlers. Fires, however, were rare in northern New England, where windstorms, small and large, were major stimuli of natural change (Ziegler 2002). Fire-return intervals were 1,000 years or more in the Adirondack Mountains of New York. The spruce-beech-fir-hemlock-birch forests of northeastern Maine were in a climax stage in the early 19th century with evidence of a natural fire-return interval of 800 to 1,150 years (tree lifespans less than 300 years) (Lorimer 1977). But just to the south, fires were common in western Maryland old-growth oak forests from 1615 to 1958—42 fires with a return interval of 8 years (Shumway et al. 2001). Catastrophic fire-return intervals in the Pacific Northwest were long as well but variable. For example, fire frequency in mountain hemlock forests of southwestern British Columbia, as well as in much of the Pacific Northwest, varied continuously over the last 11,000 years, linked to climate change via large-scale atmospheric patterns (Hallett et al. 2003). There has been continuous climate change in North America since the last major ice age (Pielou 1991), even the last 2 million years (Tausch et al. 1993). Catastrophic fire-returns intervals have been as short as 150 to 300 years in wet mountain hemlock forests, and 230 to 240 years in the Oregon Coast Range and in southeastern British Columbia montane spruce forests, and as long as 1,200 to 2,400 years in coastal British Columbia mountain hemlock and western hemlock forests (Hallett et al. 2003). About 20 percent of very wet hypermaritime forests and very wet maritime forests of Vancouver Island, British Columbia, have gone more than 6,000 years (up to 12,000 years) without fire; forest on terraces have gone 4,400 years without fire, forest on hills have gone 740 years without fire, but all forest on south-facing hills all burned within the last 1,000 years (Gavin et al. 2003). These almost fire-free forests are marked by ubiquitous gaps and tree replacement rates of 35 to 390 years. Otherwise, fire is nearly universal in western North America, but marked by heterogeneity in regimes and heterogeneity internal to individual fires (Lertzman et al. 1998, Wimberly 2002) (fig. 49). There is substantial variability in fire intensity even in the absence of underlying ecological or physical patterns (Wright and Agee 2004). Even modest temporal variability in fire frequency can induce significant variation in forest age structure over time. Openings caused by fires differ from a low of 0.03 to 0.3 hectare in southwestern ponderosa pine forests to 0.8 to 2.7 hectares in red fir/Douglas-fir forests to more than 3,200 hectares in Oregon mountain hemlock and to more than 10,000 hectares in conifer forests in Idaho, Washington, Oregon, and Alaska (Agee 1998). Fire severity ranges from high in subalpine fir, Pacific silver fir, western hemlock, and Douglas-fir forests; to moderate in mixed-conifer/mixed-evergreen, dry Douglas-fir, and red fir forests, and low in mixed-conifer, ponderosa pine, and oak-woodland forests. In other words, fire severity is highest where it is wettest and coolest, fires are infrequent, and extreme weather sets the stage. And fires are lowest where it is warmest and driest and vegetation is adapted to frequent fires; but the extent and severity of forest fires is not necessarily well correlated. Thus, fire regimes can be characterized as low-severity/nonlethal, mixed-severity/moderately lethal, and high-severity/lethal. For example, in unlogged ponderosa pine-Douglas-fir forest in the Colorado Front Range, evidence was found of light fires in 1534, 1686, 1700, 1775, 1841, and 1963 and moderate-intensity fires in 1587, 1631, 1723, and 1851. The historical landscape was less densely forested than today; forests had low densities of trees, open canopies (10 to 30 percent canopy cover), and openings over 15 to 25 percent of the landscape; some dominant trees persisted for 500 to 600 years. However, at higher elevations in Colorado (2,100 to 3,000 meters in Rocky Mountain National Park), crown fires were part of the natural disturbance regime (Ehle and Baker 2003). Of 103 historical disturbance events, 97 percent were due to fire and 7 percent of those were high-severity fires (70 percent were low-severity fires). At least one crown fire occurred within 300 years in seven of the nine plots studied. Crown fires produced dense even-aged stands that, because of subsequent surface fires, developed into less dense uneven-aged stands after 200 to 300 years. Thus, the fire ecology of high-elevation ponderosa pine forests in Colorado is somewhat different than that in the lower elevation Front Range and those in the Southwest. Historical fire produced a mosaic landscape in Colorado just as it did in the Oregon Coast

Figure 49—A forest fire in Montana's Bitterroot Valley during the 2000 fire season. Photo by J. McColgan, Alaska Fire Service, Bureau of Land Management.

Ranges (Wimberly and Spies 2001) despite differences in intensity and frequency. But logging, grazing of livestock, fire suppression, and urban encroachment have produced young second-growth forests that are densely stocked and that have excessive fuel loads resulting in unusually severe fires and widespread insect epidemics (Kaufmann et al. 2003) (fig. 50). In the 58-million-hectare interior Columbia River basin (46 percent forested), physiographic diversity, the interaction of three major air masses, and summer drought produces at least 22 forest types with fire-return intervals ranging from 6 to 419 years (with a mean of 51 years) (McKenzie et al. 2000b). In addition to seasonal and annual droughts, fires were correlated with multiyear climatic signals, such as the Pacific decadal oscillation, until the 20th century when wet-weather decades, logging, fire suppression, and perhaps changes in burning practices of Native Americans, reduced fire frequencies (Hessl et al. 2004, Wright and Agee 2004). Spatial patterning in ponderosa pine forests in the Columbia basin differs with site—cool, dry grass and warm mesic sites have smaller clumps and higher densities of trees than hot, dry, shrub lands that exhibit strong clumping historically with limited seedling establishment (Harrod et al. 1999, Wright and Agee 2004). Larger openings between clumps of trees may produce increased fuels for fire, which when low in intensity, may favor seedling establishment.

Figure 50—The effects of pine bark beetle on a forest near Fort Collins, Colorado. Photo by A. Carey.

Historically, these forests had patch sizes of 0.09 hectare (with a range of 0.0005 hectare in mesic sites to 0.2 hectare in xeric sites) similar to 0.06 to 0.13 hectare in the Southwest and 0.02 to 0.29 hectare in eastern Oregon. The density of residual large trees (greater than 50 centimeters d.b.h.) was highly variable, 5 to 9 trees per 0.5-hectare plot (a maximum of 19 trees per hectare), whereas fire exclusion, grazing, and timber management have produced more homogeneous stands with 50 trees per hectare, highly vulnerable to bark beetle attack and crown fires. Presettlement forests were at low risk to crown fire and bark beetle attack, suggesting a relatively fine-scale pattern of 0.1 to 0.3 hectare would be an appropriate grain size for managed ponderosa pine mosaics. Land use changes and management practices have affected these forests as profoundly as those in Colorado (Harrod et al. 1999, Tiedemann et al. 2000). There is no such thing as a forest free of fire, and when management has excluded fire then the option of "letting nature take its course" no longer constitutes a sustainable conservation strategy (Agee 2002). Climate, environment, and people interact to produce both disturbance regimes and forests of varying character.

The lack of upland forest destruction by indigenes and long fire-return intervals do not mean that Pacific Northwest forests developed free of human influence. Significant variation in the climate of the United States was due to human activities in Europe and Asia. Eurasians had destroyed their own forests relatively rapidly 5,000 to 8,000 years before the present, beginning with slash-and-burn agriculture, then irrigation of rice fields, followed by development of iron technology, use of charcoal for fuel, harvests of timber for ship building, and urban development—even to the point of affecting climate through agricultural production and loss of forests (Ruddiman 2003). This period of Eurasian deforestation and induced climate change coincided with the establishment of "modern" forest types in the Pacific Northwest (Brubaker 1991). Germans invaded Slavic countries to get wood in 1,000–1,100 AD (Farrell et al. 2000). Great Britain denuded Ireland of trees for naval purposes; reforestation is beginning only now. Even European boreal forests were destroyed (Berglund 1991). Of course, boreal forests are fire-adapted forests, with decadal surface fires and crown fires by the century, depending on degree of drought, dry lightning, and wind, even without human use of fire (Pyne 1997). Thus, boreal forests are more easily burned than Pacific Northwest forests. The only extant temperate forest in Europe that has a natural stand structure is the Białowieza Primeval Forest (primarily a *Tilio-Carpinetum* mesic forest) in Poland (Bobiec 2002). As in most old-growth temperate forests, this forest shows an irregular distribution of legacy (or pioneer cohort) trees; large amounts of coarse woody debris (87 to 160 cubic meters per hectare) and decadence (25 percent of total aboveground biomass); spatial heterogeneity or patchiness; complex avian and mammal communities; relictual invertebrates, fungi, and epiphytic flora; and evidence of successive disturbance by fire, storms, and insect outbreaks. The destruction of European forests had ramifications for Pacific Northwest forests by stemming glaciation (sidenote 48) and, when bubonic plague decimated European populations, it led to reduced carbon dioxide emissions, reforestation, carbon sequestration, and to the Little Ice Age (1300–1900 AD)—the climatic period in which the contemporary Pacific Northwest old growth developed. Undoubtedly there were differences in Pacific Northwest climate, disturbance regime, and the subsequent development of structure and composition of these forests from what would have occurred if deforestation followed by plague had not occurred in Europe. For example, palynological review of 5,000 years of disturbance and vegetation change revealed only two major fires, but a rise in western hemlock pollen began 1,000 years ago in the vicinity of the Queets River on the western Olympic Peninsula, in response to a cooling climate during the Little Ice Age (Greenwald and Brubaker 2001). The history of direct and indirect interactions of people, prevailing climate regimes, continuous climate change, and rare geologic and weather events suggest landscape patterns of the past are not of particular value in designing landscapes of the future. The profound impacts of land use change and forest management of the last century suggest that, even if climate was predictably cyclic and modern people could be removed from a region, it is unlikely we could re-create the biotic communities of the past (Carey 2003a, 2003c; Tiedemann et al. 2000).

What is known for certain is (1) climate will change; (2) human populations and their impacts on local, regional, and global environments will increase for the indefinite and foreseeable future; and (3) burgeoning populations and environmental degradation in developing countries (as happened in Europe historically) will have significant social, economic, and environmental impacts not only in the Pacific Northwest, but also around the globe. The Pacific Northwest is downwind of China. Already we receive substantial deposits of Gobi Desert dust. China's rapid economic development portends huge increases in burning of fossil fuels; there will be environmental ramifications in the Pacific Northwest. Furthermore, low- to mid-elevation forests of the Pacific Northwest are subject to infrequent, unpredictable catastrophic fires, major windstorms, earthquakes,

Sidenote 48—"We are an Ice Age creation but a fire creature" (Pyne 1997).

tsunamis (Everham and Brokaw 1996, Henderson et al. 1989, Sinton and Jones 2002, Stathers et al. 1994), and volcanoes (Franklin and MacMahon 2000). Climatically based disturbance regimes will change. Biological disturbances are becoming of increasing importance. From 1920 to 1989, spruce beetles killed most of the spruce on 850,000 hectares in south-central Alaska; in the 1990s, spruce beetles killed spruce on another 800,000 hectares (Ross et al. 2001) (fig. 51). Interior Northwest forests now seem particularly vulnerable to catastrophic loss owing to interactions of insect pests, disease, and fire as a result of complex historical contingencies including land use changes, drought, fire exclusion, grazing, introduction of exotic species, and homogenizing timber management. In other regions of North and Central America, fire, hurricanes, and tornados regularly cause catastrophic destruction of forest. Continent-wide, the threat of forest destruction (or at least substantial modification) from introduction of exotic diseases and insect pests and spread of existing ones, such as Swiss needle cast, sudden oak death fungus, Asian longhorned beetles, European pine shoot beetles, and emerald ash borers, is not only real but a major event is probable. Hemlock wooly adelgids are causing severe problems in the 11 eastern states comprising the range of eastern hemlock. The worst recorded outbreak of southern pine beetles affected 4.9 million hectares in 2001 and 5.7 million hectares in 2002 (USDA Forest Service 2003). Mountain pine beetles have shown a dramatic increase from 344,000 to 647,000 hectares affected in 2002. Spruce beetles have increased in Arizona, Colorado, Montana, Utah, and Wyoming. Unregulated logging continues in underdeveloped countries, as does conversion of native forests to plantations of exotic species and forest land to agricultural uses. Thus, in our domestic policy, it may be beneficial to emphasize conservation and general sustainability. In our foreign policy, it may be beneficial to emphasize sustainable development and social justice. But, in the least, we must manage our forests such as to maximize their capacity to adapt to an ever-changing environment and allow us to move toward a self-sustaining future.

Figure 51—Adult spruce beetle. Photo by D. McComb, USDA Forest Service. Spruce beetle damage. Photo by W. Ciesla, Forest Health Management International. An adult spruce beetle with eggs. Photo by E. Holsten, USDA Forest Service.

Endogenous Disturbance

After catastrophic disturbance, the developmental endpoint in Pacific Northwest Douglas-fir forests is the "pioneer cohort loss stage" at 800 to 1300 years. Strong spatial patterning (horizontally and vertically) is characteristic of these forests (Franklin et al. 2002). This patterning occurs despite apparent marked differences in degree of stocking in the early stages of forest development (Poage and Tappeiner 2002; Winter et al. 2002a, 2002b). Some of this patterning is the result of occasional (say decadal to multidecadal) small- to intermediate-scale exogenous disturbances such as fires, thunderstorms, rainstorms, windstorms, ice storms, snowstorms, disease epidemics, and widespread insect outbreaks. But significant patterning is a result of various endogenous processes including density-dependent mortality owing to competition (suppression of subordinate trees by dominant trees), endemic disease spread, and insect attack; density-independent accidents and tree fall; symbioses and local biotic interactions; local flooding and mass-wasting (landslide) events; and other local environmental changes. Tree death from heart and root rots is common (Carey et al. 1996b, Hennon 1995, Holah et al. 1993, Huff 1995, Parks and Shaw 1996, Thies 1999, Thies and Sturrock 1995). Root rots can become epidemic in the first 50 years of forest development, reducing stem density, creating gaps, and promoting understory development (Thysell and Carey 2000). However, competition is the major cause of death in most conifer forests under 100 to 150 years old (Carey et al. 1999b, 1999d; Franklin et al. 1987). Heart rots play multiple ecological roles in forests from providing a substrate for excavation of cavities by woodpeckers (fig. 52), to hollow trees for bears and Vaux's swifts, to weakening boles, contributing to bole breakage, tree fall, and gap formation. Bole breakage is a leading cause of death of trees in older forests. Snapping of boles and standing death constitute more than 75 percent of gapmakers in the Pacific Northwest; uprooting accounts for 21 percent (Lertzman et al. 1996). Mechanical damage by falling trees to other trees accounts for 15 percent of mortality in old forests (Franklin et al. 1987). In interior (Idaho and Montana) western hemlock forests, rots can become excessive in 100 to 120 years; in British Columbia, decadence in western hemlock prevails at 225 years. In old-growth hemlock-spruce forests, more than 30 percent of the gross volume of wood is affected by rot; 50 percent of the wood volume in old western redcedar trees is rotten; 80 percent of old-growth Douglas-firs have heart rot (Hennon 1995). Heart rot fungi infects vigorous Douglas-fir at an early age (say 50 years) through small twigs and eventually leads to tree death more than 150 to 170 years later contributing to loss of the pioneer cohort of Douglas-fir and their replacement by shade-tolerant species beginning at 300 to 400 years in the life of the forest. Canopy trees dying while standing, boles breaking, and uprooting are common causes in many forests of North and Central America, producing a spatial-temporal mosaic of patches in different stages of recovery following the disturbance created by the falling tree (Putz et al. 1983). As a result of this variety of noncatastrophic exogenous and small- to intermediate-scale endogenous disturbances, a variety of canopy patterns can form, ranging from continuous closed canopy punctuated at 40 to 150 meters by 1- to 2-meter-wide low-density gaps (20 percent open) to 2- to 6-meter-wide, low-density gaps (40

Figure 52—The importance of heart rot—a pair of pilated woodpeckers nest in an excavated tree cavity. Photo courtesy of USDA Forest Service.

percent open) in young forests to 2- to 30-meter-wide gaps (more than 60 percent open) 40 to 110 meters apart in old forest (Bradshaw and Spies 1992). In southwestern Oregon, 50 percent of old forest had less than 50 percent canopy closure, indicating a gap; these gaps were 70 to 80 meters apart (Carey et al. 1999b). In coastal British Columbia, as forests age, canopies become more open and more heterogeneous (Frazer et al. 1998, Hedberg and Blackwell 1998); 56 percent of old forest area is affected by canopy openings, with 30 percent of the area actually in gaps (Lertzman et al. 1996). Gaps are generally less than 0.1 to 0.2 hectare (Carey et al. 1999b, Spies and Franklin 1989, Spies et al. 1990). Additional patterning is caused by topoedaphic features, especially wetlands and small streams (Carey 1988). The influence of canopy changes on microclimate varies with gap size, season, and degree of understory and midstory development (Benton 1998, Gray et al. 2002). Variation can be extreme in large gaps, with hot dry conditions at the northern end (greatest exposure to sun) and cool, moist conditions at the southern end, which may remain shaded by the adjacent trees. Research has shown that experimentally induced fine-scale canopy heterogeneity can result in a patchy understory microclimate that maintains the range of conditions in untreated stands while adding to the diversity of patches available (fig. 53). This phenomenon is not only prerequisite to development of habitat breadth (Carey et al. 1999b) but also may increase the ability of second-growth forests to support year-round resident wildlife (Haveri and Carey 2000).

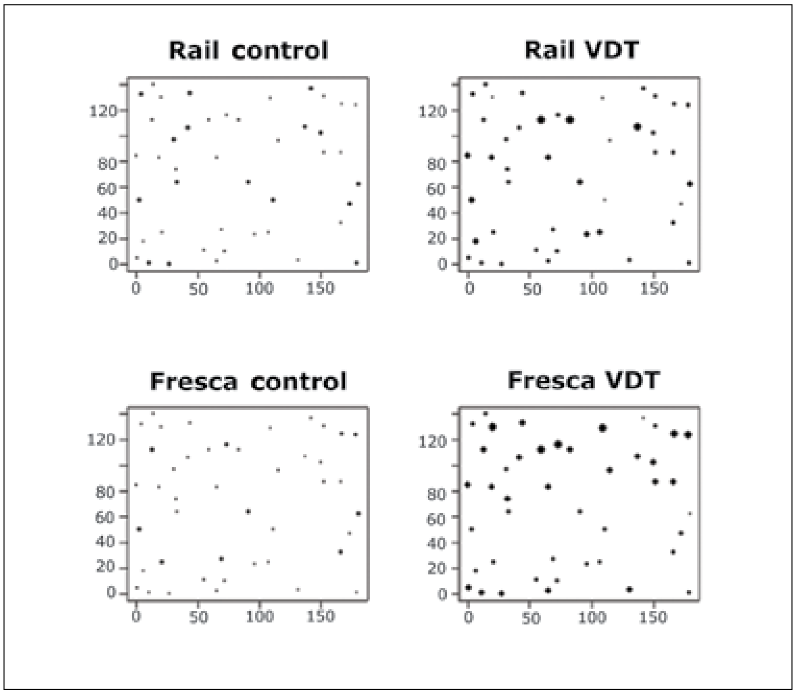


Figure 53—Distributions of maximum air temperature on June 7, 2002, (cool day), in four study plots on the Olympic Peninsula. Relative temperature value at each point is indicated by the size of the circle. Axes numbers indicate meter location on plot. Control plots are on left, and plots treated with variable-density thinning (VDT) are on right (Aukema 2003a).

Sidenote 49—Lessons from the 1998 Yellowstone National Park (YNP) fire (Turner et al. 2003):

- Many northern coniferous forests, like some in YNP, are characterized by natural stand-replacing fires that are infrequent (return intervals of 100 to 500 years), but severe.
- Climate is the primary driver of stand-replacing fire regimes, with variation in fuels less important.
- Catastrophic disturbance influences plant population structure, genetics, and evolution.
- Spatial heterogeneity resulting from catastrophic fire is the rule, not the exception.
- Fires and fire regimes are not all the same, thus wildfire management must be site specific.

Spatial complexity also characterizes forests in regions with chronic low- to moderate-intensity disturbance regimes incorporating wildfire, such as ponderosa pine forests, mixed-conifer forests, and southeastern longleaf pine, flooding in Neotropical riverine forests, or wind, such as the *Nothofagus* forests of Tierra del Fuego (Franklin et al. 2002) (sidenote 49). Complexity is the major factor determining mammalian diversity in South American forests, as a consequence of preinteractive niche diversification (August 1983, Grelle 2003, Mares et al. 1986). Spatial heterogeneity makes construction of models predictive of fire frequency in the interior Columbia basin difficult; large amounts of data at fine resolution are required (McKenzie et al. 2000b). In the absence of human activity, small- to intermediate-scale disturbances result from the interaction of weather, other agents of disturbance, and forest structure and composition that are consequences of past small- to large-scale disturbances: drought creating stress leading to defoliator insect outbreaks; a dry-lightning storm igniting fires (table 22); a wind event causing blowdown; weather patterns leading to periodic intense grazing by grasshoppers, microtine rodents, rabbits, hares, deer, elk, moose, and bison (Frelich 2002).

The frequent and recurring nature of small- and intermediate-scale disturbances and their interactions with the ecosystem suggests they could be considered integral to the system rather than forces exogenous to but impinging on the system. For example, the 2-year spruce budworm exhibits a 32- to 45-year periodicity in defoliating spruce and fir resulting in growth reduction and understory release in high-elevation and high-latitude spruce-fir forests (Parish and Antos 2002). Frequent low-intensity fires on the east

Table 22—Interactions of climate, fire frequency, and fire intensity produce different types of forests

Frequency of light surface fires (in years)	Frequency of intense (crown and severe surface) fires (in years)			
	25–100	100–500	500–1,000	>1,000
<25	Jack pine barrens Aspen parkland		Ponderosa pine Southern pine	Bur oak savanna Giant sequoia
25–100		Red/white oak White/red pine		
>100	NW boreal forest Jack pine/spruce Spruce/fir/birch	NE boreal forest Spruce peatlands Lodgepole pine Interior Douglas-fir	Coastal Douglas-fir Western hemlock Sitka spruce	Sugar maple/basswood Sugar maple/hemlock

Source: Frelich 2002.

slopes of the central Washington Cascades exhibit negative feedback through fuel reduction (Wright and Agee 2004). In the boreal forests of eastern Canada, the spruce budworm may kill balsam fir in the canopy and release seedlings in the understory, controlling canopy turnover in the absence of fire. When human activities have promoted overly dense, stressed stands of trees, buildup of fuels for forest fire, and overly simplified forests, what would have been small- to intermediate-scale more-or-less endogenous disturbance can become individually magnified or jointly cascade into catastrophic destruction of the forest. Various management techniques can be used to reduce the risk of catastrophes. Small-scale timber harvests (patch cuts, partial cuts, and thinnings) can be useful in forests subject to small- and intermediate-scale disturbances. They can also be used where moisture stress is high to promote advance regeneration under the shelter of a partial canopy while maintaining forage for wildlife and decreasing potential for frost damage and erosion (Kneeshaw et al. 2002). Prescribed fire is useful in maintaining biotic integrity and promoting resilience in fire-adapted forests. Under certain circumstances, grazing also becomes a use that can contribute to resilience.

Most forests maintain mosaics in their late-seral stages with a grain size in the range of about 0.1 to 1.0 hectare, probably with a central tendency of 0.2 to 0.5 hectare.

Forests subject to frequent light to moderate disturbances form mosaics. Patches in these mosaics are often mistaken for independent stands of trees, whereas in reality, they constitute a late-seral-stage mosaic (Franklin et al. 2002). Despite variety in disturbance regimes, most forests maintain mosaics in their late-seral stages with a grain size in the range of about 0.1 to 1.0 hectare, probably with a central tendency of 0.2 to 0.5 hectare. For example, White (1985) found establishment of ponderosa pine was infrequent in Arizona, maybe requiring 40 years, with stems aggregated in groups of 3 to 44 trees, 0.02 to 0.29 hectare; ages within groups were variable, with the most homogeneous having a range of 33 years and the least with a range of 268 years. In that area, it appeared seedlings established after the death of one to two large trees in a small area of intensive fire in an otherwise low-intensity fire area. Cooper (1960) reported similar aggregations in southwestern ponderosa pine but with a narrower range of ages within them. In the markedly different old-growth Douglas-fir forests of southwestern Oregon, the grain of mosaics was still 0.2 to 0.5 hectare including in Western Hemlock Zone forests and Mixed-Conifer/Mixed Evergreen Zone forests (Carey et al. 1999b). This scale of patchiness is widespread (Canham et al. 1990).

In general, forest development following catastrophes consists of gradual change and envelopment that result in diversity, complexity

Sidenote 50—Windthrown versus clearcut—what is the difference after 70 years (Price et al. 1998)? Wind left behind legacies that led to heterogeneity when compared to clearcutting:

- Coarse woody debris—0.09 cubic meter per square meter versus 0.04 cubic meter per square meter
- Gaps—17- by 90-meter transect versus 2- by 90-meter transect
- Veteran trees larger than 60-centimeter diameter at breast height (d.b.h.)—11 versus 4
- Snags larger than 20-centimeter d.b.h.—20 versus 5
- Range in live tree d.b.h.—127 centimeters versus 80 centimeters
- Arboreal macrolichens—15 taxa versus 10 taxa
- Percentage of fallen trees larger than 70 centimeters—20 percent versus 0 percent

of structure and processes, and production of large structures, some of which persist through subsequent intermediate and catastrophic disturbances and assist in recovery of the ecosystem (sidenote 50). For example, populations of most vascular plants quickly recover to original levels even after clearcutting and burning, although on severely burned sites, some species may experience local extinction (Halpern and Spies 1995) and grasses and annual forbs (including exotic species) may be more common, and perennial ferns and shrubs less common, than after wildfire, owing to soil disturbance (Peltzer et al. 2000). But as the tree canopy closes and light, water, and nutrients are funneled into producing wood, plant diversity may be suppressed for over 20 years (Halpern and Spies 1995, Long 1977), and abundance and diversity may remain low for 60 years or more (Thysell and Carey 2000). Even the seeds of native plants may disappear from the soil seed bank (Halpern et al. 1999, Lezberg et al. 1999, McKenzie et al. 2000a). Biomass accumulates rapidly across a chronosequence of 3 to 9, 30 to 40, 65 to 100, and over 200 years in various forest types in coastal Pacific Northwest forests, for example, 3.5, 232, 463, and 687 megagrams per hectare (Mg/ha) (1 megagram = 1,000,000 grams) in wet western hemlock forest and 0.6, 143, 423, and 586 Mg/ha in dry Douglas-fir (Hedberg and Blackwell 1998). Tree density and biomass accumulation, however, has high local variation, even in 140-year-old coastal Oregon spruce-hemlock forests, for example 462 to 750 Mg/ha (with 144 to 155 Mg/ha in coarse woody debris) (Acker et al. 2000). Coastal Oregon forests may store up to 1,127 megagrams of carbon per hectare (Mg C/ha), coastal Washington forests, 307 Mg C/ha less. Similarly, Oregon Cascade Range forests store 75 Mg C/ha more than Washington Cascade forests. Overall, Pacific Northwest forests store 338 Mg C/ha—the highest of any forests in the world; 1 percent is in understory vegetation, 6 percent in the forest floor, 10 percent in woody debris, 15 to 32 percent in the soil, and 53 to 67 percent is in trees. Eastern Oregon forests, however, store only 195 Mg C/ha (Smithwick et al. 2002). Coarse woody debris can be especially variable in space and time (Carey and Harrington 2001, Carey and Johnson 1995, Carey et al. 1999b, Wells and Trofymow 1998). Coarse woody debris cover can vary fivefold (5 to 24 percent, averaging 13 percent) in old growth and threefold (5 to 16 percent, averaging 8 percent) in second growth on the Olympic Peninsula versus 10 ± 2 percent cover in old growth and 4 ± 1 percent in second growth in the Oregon Coast Ranges—a twofold difference in second growth between regions (sidenote 51). On southern Vancouver Island, coarse woody debris ranged from 17 to 38 Mg/ha (55 to 149 square meters per hectare) in Douglas-fir forest to 65 to 199 Mg/ha (307 to 636 square meters per hectare) in western hemlock-western redcedar forest—a two- to threefold variation within forest type and fivefold variation between forest types (Wells and Trofymow 1998). After reorganization, alternative stable states are possible, especially in managerially simplified forest—for example, the competitive-exclusion and the biomass-accumulation stages; development beyond these stages may require significant exogenous disturbance. Silvicultural treatments that foster spatial and temporal diversity of resources and environments can be effective in maintaining not only plant species (Carey and Johnson 1995; Carey et al. 1999b, 1994; Halpern and Spies 1995; Thomas and Carey 1994; Thysell and Carey 2001a) but also structural elements and animal communities. Without successive exogenous disturbances, change may be slow or rapid depending on the stage that was set, the legacies that were retained, the environmental heterogeneity inherent to the biotope, and internal disturbances such as root diseases and tree fall. The net result of successful community development is symbiosis, nutrient conservation, stability (not necessarily equilibrium), and decreased entropy.

Accumulation of biomass is fundamental to forest ecosystem development (Bormann and Likens 1979)—it provides resistance to change with minor disturbance and sets the stage for reorganization conditioned by legacy retention with catastrophic disturbance. This accumulation of biomass occurs in the form of various living plants, their exudates and litter fall, and dead and decaying plants and plant parts, down to carbon in the soil food webs (table 23).

Forest development, throughout temperate forests, incorporates multiple other processes that are variously dynamic and stochastic, but also many that are predictable and probable (Bobiec et al. 2000, Bormann and Likens 1979, Franklin et al. 2002, Odum 1969) (sidenote 52). The most deterministic process, however, is accumulation of biomass; less deterministic are the entry of decay into living trees and development of rich epiphytic communities (especially in the absence of legacy retention during clearcutting). Forests with rare catastrophic disturbances but with chronic intermediate and small-scale disturbances are characterized by spatial heterogeneity, especially horizontal patchiness that develops over time. Note, however, that even these processes of generating structural complexity in the forest are a subset of broader ecological processes such as fundamental physical and chemical processes that contribute to soil development and govern nutrient availability and cycling, belowground microbial and fungal processes, dispersal, colonization, competition, facilitation, symbiosis, development of habitat breadth, preinteractive niche diversification, postinteractive niche partitioning, and development of emergent properties. The natural time scale of forest development is long, perhaps 100 to 250 years in eastern deciduous forests (Bormann and Likens 1979, Carey 1983, Oliver and Larson 1996), 250 to 750 years in Pacific Northwest forests—the life expectancy of adult Douglas-fir—and longer in other forests, for example, more than 1,000 years in coastal redwood forests in California and western redcedar forests on Vancouver Island in British Columbia (Franklin et al. 2002, Oliver and Larson 1996). But hundreds or more generations of salamanders, warblers, shrews, mice, squirrels, weasels, and spotted owls occur during the life of a long-lived Douglas-fir or redwood tree.

The ecosystem strategy of homeostasis through maximum support of complex biomass structure conflicts with management goals of maximizing yield of wood products (Odum 1969) and, especially, maximization of net present value from timber production (Carey et al. 1999c). Silviculture, however, can be used either as a means of maximizing return on investment or as a means of optimizing public and private values, including product and biotic-community diversification, with gradual change managed by small- and intermediate-scale disturbances on a time scale of about 150 years. Thus, silviculture can contribute to simplification or to diversification of the ecosystem. With active management, the development of a complex biomass structure is not inexorable; management with low intentionality can impede or preclude development of diverse ecosystems (Carey 1995, 1998b; Carey et al. 1999b, 1999c). However, management of forest ecosystems can accelerate forest development (Carey et al. 1996a).

Table 23—Accumulation of biomass is directly related to the elements of forest structure and their spatial patterning

Individual structures	▪ Live trees
	▪ Large-diameter trees
	▪ Large-diameter branches
	▪ Lower canopy tree community
	▪ Ground community
	▪ Standing dead trees (snags)
	▪ Large woody debris (logs)
	▪ Root wads and soil pits
	▪ Soil organic layers
Spatial patterns	▪ Vertical distribution of foliage/canopy
	▪ Horizontal distribution of various elements
	▪ Gaps and antigaps

Source: Franklin et al. 2002.

Sidenote 51—Coarse woody debris (CWD)—How much is enough? How many snags and fallen trees of various sizes and decay classes are necessary to maintain full ecosystem function? The question has been of intense interest for more than 50 years (Elton 1966, Hamilton and Cook 1940). A national symposium on snags was held in 1983 (Davis et al. 1983) and one on dead wood in 1999—for which the proceedings neared 1,000 pages (Laudenslayer et al. 2002). Coarse woody debris more than 10 centimeters in diameter is difficult to measure because it is not uniformly distributed in forests; rather it tends to be complexly distributed in randomly scattered clumps as a result of gap formation and individual large fallen trees of various species. In other words, multiple processes produce CWD. Trying to measure CWD with a few small plots almost guarantees underestimates owing to many plots with 0 values—for example, Rose et al. (2001, table 1 [in Johnson and O'Neil 2001]) reported very low levels of CWD in Pacific Northwest conifer forests compared to studies that used more intensive sampling. Line intercept methods are preferred but are time consuming. There is no consensus on what measure to use: percentage cover, volume, or biomass. Even when CWD is precisely measured, it is difficult to know how to apply empirical data on the abundance of a structure element of the forest to management recommendations. The responses of keystone species or keystone complexes to CWD can be useful. For example, analyzing space use by flying squirrels suggests that a 10-percent cover of large CWD

Accumulation of biomass, living and dead, *and in different life forms*, contributes to niche diversification, an expansion of the niche space within the ecosystem—the preinteractive niche differentiation (Hutchinson 1957, 1978). This expansion may result in synergism through symbiosis and other mutualisms. Other endogenous processes, such as top rot in living trees, also are integral to autogenic development of ecosystems and may require managerial stimulus in managed second-growth forests. Thus, hypothetically, it is possible to conserve biodiversity in managed forests through planned management disturbances and gradual change that expands various dimensions of the ecosystem (sidenote 53). Management can maintain dynamic shifting steady-state mosaics at both the level of the ecosystem and the level of the landscape within narrower bounds than produced over time by natural disturbance regimes. Over time, then, conservation of biodiversity and adaptive ecological innovation in response to regional and global change would be achieved intentionally even despite (possibly aided by) frequent uncontrollable intermediate disturbances (e.g., disease outbreaks, small-scale fires, and windstorms) and rare catastrophes (large-scale windstorms, fires, and volcanic eruptions). Simple maintenance of a shifting steady-state mosaic, however, may not be adequate to meet all the goals of conservation. Ecological forestry must rest on processes underlying development of structure and composition in complex forests (Carey et al. 1999b, 1999c; Franklin et al. 2002; Oliver and Larson 1996). Beyond legacy retention, reorganization of biotic resources, colonization, and establishment of a new forest community after catastrophic disturbance, there are four structural processes and two compositional processes that constitute the necessary minimum subset of processes that must be considered in designing ecological forest management (Carey et al. 1999b). These are crown-class differentiation, decadence, understory development, canopy stratification, development of habitat breadth, and niche diversification.

Crown-Class Differentiation

Crown-class differentiation is the achievement of dominance (full growing space) by some trees, codominance by others, and subordinance of yet other trees (table 24). It also includes differentiation in branches within crowns that occurs as a result of the differentiation in crown class among trees. In a densely stocked plantation, trees compete with one another through rapid height growth; the one that overtops its neighbors wins, and, thus, there is a tendency toward

provides sufficient foraging area for truffles of ectomycorrhizal fungi for near complete use of an area of forest in the Pacific Northwest (Carey et al. 1999b). In moist forests in Washington, however, complex forest-floor small mammal communities seem to require about 15 percent cover of CWD (large and small) to reach their potential diversity and abundance (Carey and Johnson 1995). This suggests an additional 5 percent cover of smaller CWD would help maintain forest-floor function in moist forests. But research has shown that CWD does not operate independently of other forest elements and that dynamics are important. The full process of decadence from decay in living trees, to decaying standing dead trees, to decaying fallen trees must be kept in mind. A rule of thumb for management is to aim for 10 percent cover of large (more than 50 centimeters in diameter) fallen trees in dry to mesic Douglas-fir forests and 10 percent cover of large and 5 percent cover of small CWD in mesic western hemlock, Douglas-fir, Pacific silver fir, or Sitka spruce forests, beginning with inputs in the form of legacies and continuing with each silvicultural entry to ensure a regular stream of inputs until gap formation begins in the late-seral stage to eventually recover levels of CWD when necessary and then to maintain them thereafter.

Sidenote 52—Processes leading to structural complexity of forests, in general order of occurrence through time (Franklin et al. 2002):

- Disturbance and legacy creation
- Establishment of a new cohort of trees and other plants
- Canopy closure of the tree layer
- Competitive exclusion of ground flora
- Lower tree canopy loss and death and pruning of lower branch systems
- Biomass accumulation
- Density-dependent tree mortality owing to self-thinning, wind, disease, and insects
- Canopy gap formation
- Generation of standing dead and fallen trees
- Uprooting of trees
- Understory reinitiation
- Establishment of shade-tolerant trees, shade-patch or antigap development
- Maturation (achievement of maximum height and crown spread) of the dominant tree cohort
- Canopy elaboration through canopy stratification and reestablishment of lower branch systems
- Development of live-tree decadence
- Development of large branches and branch systems
- Development of rich epiphyte communities
- Loss of original dominants

even spacing among dominant trees. When regeneration is moderately dense or patchy in density, trees "forage" and avoid neighbors by growing toward areas with high resource availability (less competition from neighbors); thus, in many species, tree crowns are rarely positioned directly above the stem. Crowns are displaced toward gap centers, especially subcanopy, and crown depth is greatest toward gaps (Muth and Bazzaz 2002). As trees get large and achieve dominance, the largest branches within their crowns may approach an asymptotic maximum length (around 9 meters in old Douglas-fir) and break, or die back (Ishii et al. 2000a, 2000b). Epicormic branches may then grow to replace the dead or dying branches, especially in the lower crown. Three crown patterns can result in Douglas-fir: mature crown, old crown, and stressed crown. The mature crown has an increasingly wider range of branch diameters toward the lower crown with the diameter distribution of dead branches constant; overall, the crown shape is conical with larger branches lower. The old crown has a few large-diameter branches, with the larger branches in the upper crown, and many dead branches. The stressed crown has small-diameter branches with only a few live branches and limited crown depth owing to insect or pathogen attack. In the lower crown of live old trees, nearly 50 percent of shoots and foliage are epicormic; in the mid and lower crown, reiteration of shoot cluster units maintains the remnants of large, broken branches and helps prolong the tree's lifespan (Ishii and Ford 2001). It is remarkable that median size mid-crown branches in a 400-year-old tree may be more than 20 centimeters in diameter, more than 8 meters long, and more than 150 years old. The effects of this crown elaboration on the ecosystem are profound (Carey 1996). Not only are nest sites for spotted owls, marbled murrelets, and northern goshawks thus produced, but variation in branch size and health allow niche partitioning by cavity-using birds in their foraging (Carey et al. 1991)

Table 24—**Crown-class differentiation in young (40–72 years), mature (80–120 years), and old forest (200–525 years) in the Oregon Coast Ranges as measured by average densities (trees per hectare) in three diameter-at-breast-height (d.b.h.) classes**

D.b.h. class (in centimeters)	Young	Mature	Old
		(Trees per hectare)	
10–49	270	120	27
50–99	30	65	25
>100	2	7	22

Source: Adapted from Carey et al. 1991.

(table 25) and, apparently songbirds as well (Shaw and Flick 1999). Massive seed production provides a large foraging environment for Douglas' squirrels (Shaw and Flick 2002) as well as important winter habitat for a variety of resident birds (Haveri and Carey 2000, Manuwal and Huff 1987). Individual old-growth trees may support 2 to 18 kilograms of epiphytes (totaling 132 to 271 kilograms per hectare), including alectoroid lichens, cyanolichens, other lichens, and bryophytes (Clement and Shaw 1999). Not only do these epiphytes provide nest materials and nest sites for mammals and birds (Carey 1996, Carey et al. 1997, Gillesberg and Carey 1991) (table 26), but the lichens play important roles in nutrient cycling, especially adding nitrogen to the soil during lichen fall, and providing forage for squirrels and ungulates. Thus, retention of live trees with heavy epiphyte abundances provides a source of propagules in newly reorganizing ecosystems and may have profound effects (Carey et al. 1991, Peck and McCune 1997). Collectively, the differentiated crowns form a rugose canopy that in itself provides added niche dimension, for example, for foraging by bats and olive-sided flycatchers (Carey et al. 1991, Wunder and Carey 1996). Thus, differentiation of

Sidenote 53—"At this stage of forest ecology, we should be able to describe the conditions constituting a healthy forest more precisely than 'presettlement' … science-based approach looking quantitatively at the various components, values, and functions of ecosystems may be the key to describing healthy forest ecosystems" (Tiedemann et al. 2000).

Table 25—Partitioning of foraging space by cavity-nesting birds in the Oregon Coast Range, 1985–1986, based on 888 observations of foraging birds

Species	Red-breasted sapsucker	Hairy woodpecker	Pileated woodpecker	Chestnut-backed chickadee	Red-breasted nuthatch	Brown creeper
Vertical location	-Midcanopy	-Midcanopy -Understory	-Upper canopy	-Midcanopy -Lower canopy -Understory	-Midcanopy -Upper canopy	-Midcanopy -Lower canopy -Understory
Horizontal location	-Mainstem	-Mainstem	-Mainstem	-Center[a] -Outer[a]	-Mainstem -Center[a]	Mainstem
Tree species	-Douglas-fir -Bigleaf maple	-Douglas-fir	-Douglas-fir	-Douglas-fir -Western hemlock	-Douglas-fir	-Douglas-fir -Western hemlock
Tree condition	-Live	-Live -Dead—moderately decayed	-Live -Dead	-Live	-Live	-Live
Tree size	-Medium -Large	-Large -Medium	-Large -Very large	-Very small -Small -Medium	-Large -Medium	-Medium -Large
Crown class	-Subordinate -Dominant -Suppressed	-Dominant -Subordinate -Suppressed	-Dominant	-Dominant -Suppressed -Subordinate	-Dominant	-Dominant -Subordinate

[a] Branches.

Source: Carey et al. 1991.

Table 26—Nest materials[a] of arboreal rodents that were taken from artificial nest boxes and tree cavities on treated (variable-density thinning) and control plots in two forests at Fort Lewis, Washington

	Legacy forest[b]		Thinned forest[c]	
Type of nest materials	VDT plots	Control plots	VDT plots	Control plots
Moss species:				
Dicranum tauricum	0.00	0.00	.26	.40
Hylocomium splendens	.10	.36	.08	0.00
Hypnum circinale	.40	.76	1.97	7.19
Isothecium stoloniferum	23.20	40.72	60.03	42.29
Kindbergia oregana	9.60	3.36	11.05	12.24
Kindbergia praelonga	0.00	.08	0.00	0.00
Plagiothecium undulatum	.50	.40	.79	1.31
Rhizomnium glabrescens	0.00	0.00	0.00	.05
Total mosses	38.00	45.68	74.18	63.48
Liverwort species:				
Frullania nisquallensis	0.00	.88	.08	0.00
Porella navicularis	0.00	.04	1.21	.43
Radula complanata	0.00	0.00	0.00	.02
Scapania bolanderi	0.00	0.00	.08	.02
Total liverworts	0.00	.04	1.28	.48
Lichen species:				
Alectoria sarmentosa	23.50	5.16	.03	0.00
Alectoria vancouverensis	0.00	0.00	0.00	0.00
Bryoria pseudofuscescens	0.00	4.64	0.00	.05
Cetrelia cetrarioides	0.00	.44	0.00	0.00
Cladonia ochrochlora	0.00	0.00	.03	0.00
Evernia prunastri	0.00	0.00	0.00	.02
Hypogymnia duplicate	.10	.04	0.00	0.00
Hypogymnia enteromorpha	0.00	.24	0.00	0.00
Hypogymnia imshaugii	0.00	0.00	0.00	0.00
Hypogymnia physodes	0.00	.16	.18	0.00
Hypogymnia tubulosa	0.00	0.00	0.00	0.00
Lobaria pulmonaria	0.00	0.00	.10	0.00
Mengazzia terebrata	0.00	.04	0.00	0.00
Platismatia glauca	.50	.28	0.00	0.00
Ramalina menziesii	0.00	.16	.03	0.00
Usnea filipendula	0.00	0.00	0.00	0.00
Usnea wirthii	2.00	7.24	1.54	1.38
Total lichens	26.10	19.28	1.97	1.45

[a] Mean percentage of nest material. All material that has a mean value of zero occurred in the nests less than 0.01 percent.

[b] The legacy forest had been clearcut in ~1937, but many live and dead trees had been left. The forest had regenerated naturally into even-aged Douglas fir before our treatments (see Carey et al. 1999d).

[c] The thinned forest had been clearcut in ~1927 and later conventionally thinned twice. Few trees were retained from the preceding old-growth forest and dead trees were removed (see Carey et al. 1999d).

Source: Gross 1999.

branches within crowns and crown-class differentiation among trees are interlinked processes fundamental to development of ecosystem complexity. The rate at which differentiation proceeds depends on degree of intertree competition, legacies (biological legacies and the conditions during reorganization, including exogenous disturbances), natural disturbances, and management activities.

Competition—Just as trees jockey for canopy position, various tree species may partition the forest floor for fine root concentration—for example, western hemlock and salal roots become concentrated in the upper forest floor, but western redcedar roots may be found throughout a soil profile (Bennett et al. 2002). Douglas-fir seems to specialize in extending its fine root capacity through symbiosis with numerous ectomycorrhizal fungi. That plants build and maintain themselves from energy and materials in the environment and must share limited resources is the basis for the self-thinning rule, one of the few long-lived quantitative propositions in ecology (Torres et al. 2001). At low light levels (less than 40 percent full sunlight), growth of Douglas-fir is so restricted that little difference can be seen among sites markedly different in quality (Drever and Lertzman 2001). Western redcedar, however, approaches maximum radial and height growth at 30 percent full sunlight. Still, quantification of the relationships between growth in mass, density, basal area, and death owing to suppression has proven intractable (Torres et al. 2001, Zeide 1991), despite considerable economic implications (King et al. 2002).

For Pacific Northwest Douglas-fir, optimum growth occurs at initial seedling spacing of 3.7 to 4.6 meters (470 to 740 trees per hectare), but many naturally regenerated stands and plantations are denser than that (Miller et al. 1993, 2004). Site preparation, burning, and planting Douglas-fir can result in greater dominance by Douglas-fir, more rapid attainment of height, and earlier canopy closure, leading to competitive exclusion. Natural regeneration after site preparation and burning takes place over a longer period, establishes a more even mix of species, may result in slower growth owing to competition with resprouting shrubs, and may keep a diverse plant community longer; furthermore, without burning, growth of advance regeneration and natural seeding may negate the positive effects of planting on wood production (Miller et al. 1993). Even in plantations planted to 1,060 Douglas-fir per hectare, more than 9,900 additional trees per hectare (Douglas-fir, western hemlock, and red alder) may become established naturally. Natural regeneration outside of plantations may be as dense as 3,500 to 14,000 trees per hectare. On the eastern Olympic Peninsula, in the area of the first (1930) extensive plantings of Douglas-fir in the Pacific Northwest, natural regeneration of western redcedar and western hemlock vastly outnumbered that of Douglas-fir following clearcutting in 1917 through 1919 and wildfire in 1924 through 1925; in the Cascade Range, however, Douglas-fir regenerates well naturally (Miller and Anderson 1995). With 9,900 trees per hectare at 9 years, 78 percent of trees may die by 26 years (Miller et al. 1999). But by that time, competition among trees will have taken its toll on other life forms. Still, the process of competition and differences among species in growth rates and shade-tolerance maintains the potential for crown-class and intracrown differentiation, despite the slow growth of the surviving trees. Similar results were obtained in the first experimental planting of Douglas-fir in 1925 in the southern Washington Cascades. Seedlings were planted at 1.2-, 1.5-, 1.8-, 2.4-, 3.0-, and 3.7-meter spacings (6,723 trees per hectare to 746 trees per hectare). By age 70, the densest plantations had declined to less than 2,000 trees per hectare and the least dense retained more than 500 trees per hectare. Dense plantings suffered suppression mortality, reduced growth, and damage from snow and wind. Such stands, if resilient enough to continue to develop through time, may undergo crown-class differentiation in addition to heavy mortality (Carey et al. 1999b, Miller et al. 2004). The least dense plantations, with more than 500 trees per hectare still have sufficient trees to sustain the process of crown-class differentiation—and the trees are larger and more vigorous than in the dense plantations. Silviculturists commonly focus on the 100 largest trees per hectare—these 100 trees will form a dominant class that fully occupies the site on long rotations (say 80 years or more). Additional variability in tree size and subsequent crown condition may be caused by differences in soil type, depth, and water-holding capacity that can occur at fine scales (1 hectare or less) (Miller et al. 2004). After 70 years, the 100 largest trees averaged 28 centimeters in d.b.h. and 23 meters in height in the dense (1.2- to 1.5-meter spacing) plantations compared to 43 centimeters in d.b.h. and 35 meters in height in the plots planted to 3.0- and 3.7-meter spacing (Miller et al. 2004). There is some evidence for a positive effect of high stand density (up to around 3,000 trees per hectare) on early (first 5 years) growth of Douglas-fir (Woodruff et al. 2002). Some of this increased aboveground growth could simply be related to competitive strategies in Douglas-fir aimed at achievement of dominance; other explanations include increased animal browsing in low-density plots, increased interspecific competition in low-density plots, a higher probability that at least some seedlings find exceptionally good microsites in dense plots, and qualitative changes (ratio of red to far-red light) in side-light, such as light reflected from adjacent trees, that influences the allometry of growing seedlings (the plant parts in which growth is concentrated). In any case, the phenomenon is short lived. Without thinning, dense stands eventually suffer high mortality (Wilson and Oliver 2000, Woodruff et al. 2002) after drastically reducing diversity of the biotic community.

Silviculturists emphasizing wood production state "Capturing the full productive potential of a site requires prompt establishment of a uniform stand of trees" (Miller et al. 1993). Of course, they are speaking strictly about rate of tree growth (wood production) and not joint ecological and economic productivity—or even long-term site productivity. Natural regeneration is usually not uniform nor of a single species. Thus, in managing for multiple values, a balance must be struck with planting to promote development of a new forest (versus a shrubland, grassland, or parkland—unless that is a desired condition, as in ponderosa pine on dry sites), managing densities of trees to promote rapid growth (470 to 740 stems per hectare provide for optimum wood production for Douglas-fir), and managing densities, species composition, and spacing of trees to allow for continued development of a diverse plant community supportive of animal life and resilient to disease, insect attack, and other disturbances. When Douglas-fir plantations were thinned experimentally to 740 trees per hectare at 9 years, the volume of Douglas-fir at 26 years was 2.5 times that without thinning, with dominants in the thinned stands twice as large as those in unthinned stands (Miller and Anderson 1995). Of course, as trees grow in size, either further reduction in density or increased crown-class differentiation is needed for continued rapid growth of dominants. Conventional thinning promotes growth but does not necessarily lead to crown-class differentiation (Carey et al. 1999d). Conventional thinning produces a stand of big trees that may develop deep and differentiated crowns; in time, such stands may recruit shade-tolerant trees that add to vertical structure. In the short term, conventional thinning may increase susceptibility to windthrow (for several years) (Huggard et al. 1999). In any case, in densely stocked forests, there seems to be universal potential for age-related declines in growth from competition-related changes in forest structure and resource-use efficiencies of individual trees that can result not only in differentiation but in reduced overall growth (Binkley et al. 2002). Thus, to promote development of complex forest ecosystems, some balance of rapid growth and crown-class differentiation must be achieved. This seems possible through legacy retention, multispecies management, and variable-density thinning (fig. 54).

Competition among trees affects other plants also. Experimental thinning in true fir-hemlock stands in the Pacific Northwest, showed not only markedly increased tree growth (5.8 square meters of basal area versus 40.5 square meters 10 years after thinning) with reductions in tree density (1,750 trees per hectare versus 250 trees per hectare) but also increased understory productivity, including berry production (Curtis et al. 2000). Tree cover was 66 percent in thinned stands and 90 percent in unthinned stands; understory cover increased from 58 percent to 72 percent (with an addition of four species) in thinned stands and decreased from 58 percent to 37 percent (with a loss of five species) in unthinned stands as the trees grew larger and competition increased. Thus, without thinning, trees reduce one another's growth, exclude other plant life forms, and decrease the productivity of the ecosystem, especially for terrestrial herbivores and granivores. An unexpected observation in the thinning trials was colonization by epiphytes in both thinned and unthinned stands by 10 or more cryptogamic epiphytes. Thinning not only increases lights but by causing root gaps also increases the availability of water and minerals to understory plants, resulting in marked increases in understory abundance and diversity (Thomas et al. 1999; Thysell and Carey 2000, 2001a). Fertilization, however, can speed canopy closure and lead to reduced understory (Thomas et al. 1999).

Although light is often the factor most limiting understory development in coastal forests, tree root competition for moisture and nutrients becomes important in western interior forests (Riegel et al. 1995). Establishment of a new cohort of trees may occur only

Figure 54—(A) A forest that was thinned once conventionally shows a dense understory with no midstory species, whereas (B) a forest that was thinned once conventionally and once with variable-density thinning 6 years earlier shows much more diversity in its understory and midstory species. Photos by A. Carey.

infrequently—40 years might elapse in southwestern ponderosa pine forest, and even then, regeneration is often spatially aggregated in groups of 3 to 44 trees in patches of 0.02 to 0.29 hectares (White 1985). This kind of reproduction of ponderosa pine commonly follows the death of one to two large trees in areas intensively burned in an otherwise low-intensity fire area. Ponderosa pine reorganization does not require much crown-class differentiation in its progression to park-like conditions. At a scale slightly larger than the small regeneraton patches, a mosaic may thus be maintained over time (Cooper 1960, White 1985). Cooper (1960) described the pattern of southwestern ponderosa pine as a result of community development governed by fire and shade intolerance. Shade intolerance produces even-aged groups of trees originating in small openings. The identity of the group is maintained by fire as the group matures; young groups of trees are protected by lack of fuel on the forest floor. Litter beneath mature trees provides fuel for fire that prevents establishment of young trees. Thus, fire counteracts the tendency of trees to take on a random (or in mesic sites, a uniform) distribution. Old trees die and groups break up; what took 200 years to develop might be gone in less than 20 years; fire then prepares a seedbed, allowing regeneration. There is now a general consensus on an urgent need to restore ponderosa pine forests to dynamic mosaics (Allen et al. 2002) (sidenote 54). Historically, frequent surface fires, episodic regeneration, insect infestations, and drought produced spatially heterogeneous patterns at local and landscape scales.

Differentiation in crown class among trees occurs not only as a result of intraspecific competition but also interspecific competition, differences among species in growth rates under various conditions, variety in age classes at the time of ecosystem reorganization, spatial heterogeneity in the distribution of trees during and after reorganization, and heterogeneity in the biotope itself. Crown-class differentiation results in growth rates differing among trees and differences in tree diameter, height, crown width, height to live crown, crown depth, branch size, and other elements of tree architecture (Carey et al. 1991, 1999b; Ishii et al. 2000b; Ishii and Wilson 2001) (fig. 55). In forest ecosystem development, organization of foliage in three-dimensional space is more important that total amount of foliage (van Pelt and Franklin 2000). For example, Pacific Northwest old growth has the highest leaf area index of any forest in the world (fig. 56). Even-aged forest with similarly sized trees with foliage in one layer will have dramatically different crown architecture and understory light conditions than a tall forest with high foliage-height diversity with the same amount of leaf area index. Particularly at

Sidenote 54—How to restore ponderosa pine forests (Allen et al. 2002):

- Reduce threat of crown fire.
- Prioritize and strategically target treatment areas.
- Develop site-specific reference conditions.
- Implement multiple conservation initiatives.
- Use existing forest structure as a template.
- Restore ecosystem composition.
- Retain trees of significant size or age.
- Consider demographic processes.
- Integrate process and structure.
- Control and avoid introducing exotics.
- Foster regional heterogeneity by using complex topography, hydrology, and soils.
- Protect sensitive communities.
- Assess cumulative effects.
- Protect from overgrazing.
- Monitor and conduct research.
- Manage adaptively.

high latitudes with low sun angles, the narrow crowns of conifers can help promote three-dimensional structure. With differentiation, stands may move quickly into understory-reinitiation and niche-diversification stages. A significant part of vertical development of old-growth Douglas-fir/western hemlock forests is due to the slow invasion of the canopy by western hemlock and western redcedar (Ishii et al. 2000b). Loss of dominants promotes recruitment of new species and stratification, with Douglas-fir dominating at 30 to 50 meters in height, western hemlock at 10 to 45 meters, Pacific silver fir at less than 45 meters, Pacific yew below 20 meters, and western redcedar throughout the canopy.

Biological legacies and reorganization—Biological legacies can facilitate differentiation and inhibit homogeneous intercrown competition through (1) rapid growth of trees established before reorganization and released by destruction of the overstory, (2) continued growth of surviving overstory and midstory trees, and (3) spatial

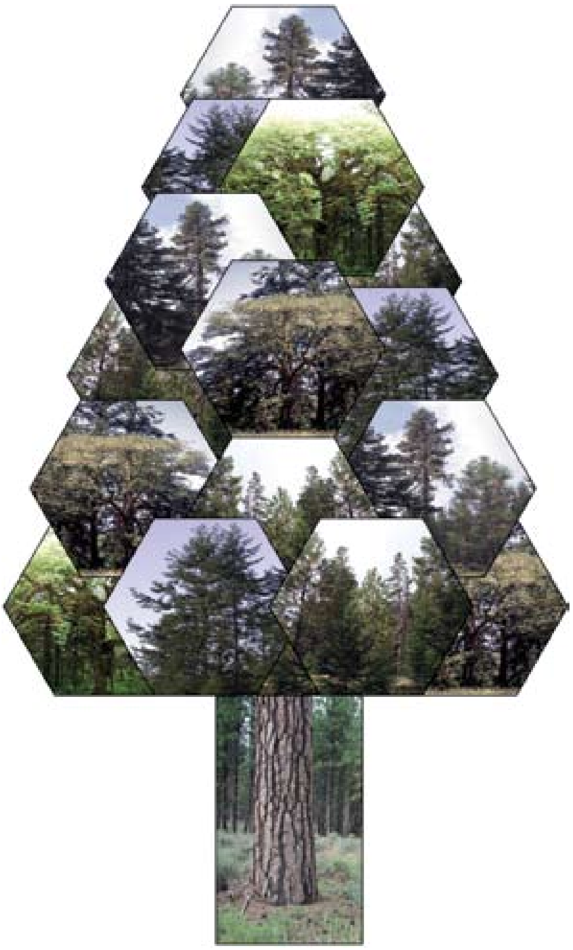


Figure 55—A complex forest has a variety of tree architectures. Graphic by A. Wilson; Photos courtesy of USDA Forest Service.

heterogeneity of tree regeneration during reorganization owing to spatial variation in seed and seedbed availability and owing to falling dead trees (sidenote 55). There is a strong negative nonlinear relationship between gap light and the height, d.b.h., density, and volume of legacy trees, and aggregation of retained trees provides a broad variety of structural elements and environmental conditions, especially photosynthetically active radiation (Drever and Lertzman 2003). Legacy retention produced niche-diversification stages in fewer than 100 years after ecosystem reorganization in the Oregon Coast Ranges (Carey et al. 1999b). Streams also produce discontinuities in canopies that promote crown-class differentiation and species diversity (Carey 1988, Pabst and Spies 1999). Thus, the catastrophic event sets the stage for the ecological play to follow (Hutchinson 1965). Even catastrophic disturbances differ locally in intensity and produce wide ranges in retention of legacies and regeneration of trees. Natural disturbances rarely eliminate all the structural elements of the destroyed forest, even in cases of sequential intense disturbances (Franklin et al. 2000, 2002) (table 27).

Clearcutting for timber production, on the other hand, at the height of its development in the mid-20th century, called for elimination of legacies and species not contributing to commercial value throughout the life of a stand of trees (Barrett 1962, Smith 1962). For example, clearcutting called for cutting all stems more than 5 centimeters in diameter, removal of natural and logging debris by mechanical disruption and burning, elimination of vascular plants through burning and herbicides, planting a commercially valuable tree species, and sometimes fostering growth by fertilization. Stand tending during and after reorganization included continuing removal of vegetation competing with commercially valuable crop trees (cleaning, weeding, application of herbicides, precommercial thinning, and even pruning to produce uniformity) (fig. 57) and killing trees with decadence (defect or decay) during precommercial and commercial thinnings or "improvement cuts." This approach was generalized to areas of markedly different climates and disturbance regimes, often inappropriately so and sometimes compounded by fire exclusion and grazing of livestock (Cooper 1960, Harrod et al. 1999, Tiedemann et al. 2000).

Second growth intensively managed for timber (fig. 58) often has lost many of the elements needed for development into complex forests with high resilience and potential adaptiveness. Indeed, in the 1980s, Pacific Northwest foresters began questioning the wisdom of clearcutting followed by burning with its potential for loss of nutrients through volatilization and leaching; loss of soil through

Figure 56—Multiple layers of understory species contribute to the Pacific Northwest's high leaf area index. Photo by A. Carey.

Table 27—**Biological legacies differ with type of major disturbance in temperate and boreal forests**

Legacy	Wildfire	Windstorm	Clearcutting
Large live trees	Some	Some	None
Standing dead trees	Many	Some	None
Fallen trees	Many	Many	Few
Advance regeneration	Patchy	Much	Little
Undisturbed forest floor	Patchy	Patchy	Little

Source: Adapted from Franklin et al. 2002.

erosion; soil compaction by machinery; loss of genetic diversity in trees; lack of natural legacies, such as coarse woody debris, old large trees, and deciduous trees; and negative effects on values other than timber production (Williamson and Twombly 1983). Decades later, similar concerns are still being raised (Harmon and Marks 2002, Hennon et al. 2002, Stark and Hart 1999, Thompson et al. 2003, Wikstrom and Eriksson 2000). Fear of loss of timber productivity after harvest of old growth and site preparation by burning have not materialized in controlled studies, but loss of nutrients and soil organic matter, soil compaction, stream sedimentation, and effects on tree species composition of the new forest are evident—Douglas-fir and hardwoods are favored over other conifers (Heninger et al. 2002, Miller and Bigley 1990). Retention of 20 to 30 trees per hectare in clearcuts in western Washington ameliorated changes in

Figure 57—Regine Carey stands in a recently pruned conifer forest on the Olympic Peninsula. Photo by A. Carey.

soil and air temperatures but not nutrient loss (Barg and Edmonds 1999). But green-tree retention can have positive effects on vegetation structure, small mammals, songbirds, woodpeckers, spotted owls, Vaux's swifts, and marbled murrelets (Hunter and Bond 2001, Mitchell and Beese 2002, Sullivan and Sullivan 2001, Sullivan et al. 2001, Titler et al. 2001). Tillage of skid trails helps offset soil compaction by machinery. In Alaska, clearcutting had largely negative consequences on wildlife and fish with canopy closure 25 to 35 years later nearly eliminating all understory for wildlife for more than 100 years (Hennon et al. 2002). Legacies, including alder, may mitigate the impacts of clearcutting.

Substantial controversy reigns over the treatment of forests destroyed by natural catastrophes or seminatural catastrophes (e.g., a wildfire arising from anthropogenic ignition may be intensified by the ways humans shaped the environment in the past, and contributed to by their shaping the climate of the present). As usual, positions among conservationists rapidly become polarized (Lach et al. 2003) with Op Ed letters and with emphasis on all-or-none approaches (Adams and Ringer 1994, Beschta et al. 1995, Blaine 2004, Fitzgerald 2002, Lindenmayer et al. 2004, Oregon Forest Resources Institute 2002, Sessions et al. 2003, Thomas 2002). Hyperbole abounds. Jim Strittholt (Director of the "Conservation Biology Institute") is quoted (Blaine 2004) as proclaiming firmly: "There is no ecological justification for post-fire salvage logging in any post-fire environment … Someone will get rich … You see a replanted lush green site with the eye of a forester, and you see a returning resource … You look with the eye of an ecologist, and you see a plantation, not a wild place. If you go in and salvage and plant, that's not a wild place. That

Sidenote 55—Biological legacies influence crown-class differentiation:

- Advanced regeneration responds quickly to overstory removal.
- Large live trees provide structure in themselves, sources of seed, and eventually disrupt the developing canopy by falling.
- Large snags occupy some growing space but provide an opening enhancing unequal distribution of light and water, and they eventually fall disrupting the developing canopy.
- Large fallen trees contribute to patchiness in regeneration by being unsuitable as seedbeds to some species but suitable seedbeds to other species; tall stumps do likewise; both may raise regeneration above browsing animals.
- Deciduous trees may outcompete conifer regeneration and contribute to patchiness as well as species diversity.
- Shrubs can contribute to patchiness and reduced density in tree regeneration.

Figure 58—This recently thinned forest lacks in the important elements necessary for the development of complexity. Photo by A. Carey.

will never be a wild place." Strittholt's position accurately identifies the nature of the debate. Wildness, wilderness, uncontaminated by humans, humans guilty of profaning nature, nature must be protected from humans' corrupting influence—all are perceptions of the urban environmentalist long separated from nature (Dietrich 1992). The opposite stance being that of humans immersed in and making a living from nature—and making deliberate choices about what to destroy, what to exploit, what to intensively cultivate, what to maintain, and what to restore. One view accepts restoration ecology in a variety of forms; another would restrict it to passive management through reserves. One view would promote biological diversity by intentional actions, another would either exploit or reserve. For example, the former might plant and shape the slope with coarse woody debris to minimize erosion and sedimentation of important fish-bearing streams to save a threatened salmon strain; the latter may let nature take its course while the strain becomes extinct, and patiently wait for however long it takes for the forest to regrow, the stream to rehabilitate itself, and another strain of fish to successfully colonize the stream. I have heard serious ecologists state words to the effect "Sooner or later it will become old growth, even if it takes thousands of years" even in the face of reasonably certain climate change that might preclude forests of the past from recurring. Thus, the debate is not science-based; it is based in worldviews, culture, and sources and systems of ways of knowing. It is based on values, not ecology—Is it better to let nature take its course or is it better to attempt to facilitate system recovery to a humanly desired future state? It is in the eye of the beholding person not in the province of nature. Is nature a fine-tuned watch with a place for everything and everything in its place? Little science supports that idea. Is nature totally stochastic and directionless—nature as value-free, no natural catastrophes are possible because they are, after all, natural? Let nature take its course—even if nature has no grand plan, no cybernetic guidance system, and no supreme manager guiding the way? Given the Gaia hypothesis, the only extraterrestrial input is solar energy, everything on the planet is natural, and everything is the result of self-organization and natural selection; thus, even the human population explosion precipitating the sixth major extinction event in the history of the planet (Thomas et al. 2004) is natural. But, nature *is* and ecosystems *are*; outside of this earth-bound reality, our emotional perceptions and intellectual concepts may or may not be accurate assessments of what *is*. Ecology refers to the relationships between organisms and their environments, not to wildness or wilderness or even nature. Wildness, wilderness, and natural are in the eye of the beholder except in the extremes. Are Douglas-firs germinating from seed collected from the cones of old-growth trees but sown from a helicopter no longer natural? What if they were one to two generations grown in a nursery? Is the resulting forest never to be wild—even if one observes a cougar killing a deer there? What about seeing a spotted owl catching a flying squirrel to feed to its young? What about being lost, spending the night, and hearing the wolves howl?

Active management following catastrophic destruction of a forest can take many forms and produce diverse results. Salvage logging can take all to no living trees, all to no large dead trees, or take trees from selected patches. Similarly, seeding or planting can be done in a variety of ways and produce a variety of results. As in every aspect of forest management, the degree of intentionality determines in major part the risks of unintended consequences. Postfire salvage logging has the potential to markedly alter subsequent bird communities, especially year-round resident species, canopy and cavity nesters, and insectivores (McIver and Starr 2001, Morissette et al. 2002). Salvage removal of large wood affects development of the plant community and may reduce species richness while increasing conifer growth in the early years (McIver and Starr 2001). Of course the effects of salvage logging differ depending on the percentage of dead and damaged trees removed, how much of each tree is removed, the degree to which homogeneity and heterogeneity are emphasized, how well retention of legacies (live and dead trees and patches of intact forest) is managed, and the other practices instituted simultaneously with tree removal, such as felling trees perpendicular to slopes to reduce surface runoff and planting appropriate tree species to accelerate forest recovery. Log retrieval systems differ considerably in their effect on soils, with ground-based systems having greater negative effects than aerial systems (Adams and Ringer 1994, Beschta et al. 1995, Sessions et al. 2003). Ground-based logging, however, under certain circumstances can disrupt water-repellent soil layers developed by severe fires and thereby increase infiltration and decrease overland flow. Salvage can mitigate erosion with the use of logging residue to impede overland flow, and thus contribute to ecosystem recovery. Salvage can also reduce the probability of damaging insect outbreaks (McIver and Starr 2001). Post-wildfire seeding, designed to control erosion, may have unintended consequences in limiting conifer establishment, promoting exotic species, limiting establishment of native herbs and shrubs, and yet have no effect on total plant cover; biological legacies and adaptations for dispersal by native plants such as wind dispersal function

Sidenote 56—Postfire logging (McIver and Starr 2001):

- The immediate effects of salvage will differ with severity of burn, slope, soil type, road building, and weather.
- Logging systems differ in impacts.
- Sometimes logging residue decreases erosion.
- The probability of insect population buildups that may infect adjacent intact stands can be reduced.
- Logging can kill volunteer seedlings.
- Broadcast burning can change plant succession.
- Patches of disturbed soil encourage a variety of plant species.
- Skid trails can negatively influence future tree growth.
- Logging can reduce vegetation biomass, increase abundance of exotic species, and reduce native species richness.
- Logging can have negative effects on postfire wildlife populations.
- Cavity-nesting birds are the wildlife most likely to be affected by logging.
- Some wildlife may benefit from salvage logging.

well in the absence of seeding with nonnative grasses and legumes (Schoennagel and Waller 1999). Thus, management of legacies associated with intense disturbances is complex, and a high degree of intentionality is necessary in the analysis of the need for legacy management and in formulating a restoration plan for such sites (sidenote 56). Answers to questions about salvage and restoration after natural or anthropogenic catastrophes are not simple all-or-none answers if conservation is aimed at achieving the diverse values that society needs and wants from forests. The answers can be simple only if the goal is simple—let nature proceed unhindered and unaided (no matter what the short- or long-term consequences are) versus recover economic value before it is lost (no matter what the short- or long-term consequences are). It seems obvious, however, that care must be exercised and substantial legacies must be retained if rapid ecosystem recovery is to be obtained (Franklin et al. 2000, Sessions et al. 2003).

Second-growth forests differ markedly in character depending on how and when they were established and how they were subsequently treated. Simple near-monocultures of Douglas-fir or western hemlock and Douglas-fir/red alder stands are common in the Pacific Northwest. In areas logged from railroad systems during World War II on the Olympic Peninsula, however, some complex second-growth forests have developed under the influence of heavy loads of legacy coarse woody debris; in southwestern Oregon, selective or partial harvests left many legacies that allowed reorganization to produce complex second-growth forests. In the Sierra Nevada of California, railroad logging so efficiently removed all trees that scientists had trouble reconstructing fire histories (Stephens and Collins 2004).

Ecosystem reorganization after natural catastrophic destruction of the tree canopy and reestablishment of a tree canopy may take a long time (more than 50 years, Huff 1995) with substantial coarse woody debris left on site as standing dead trees, decayed fallen trees, and recently fallen dead trees (Spies and Franklin 1991). Numerous live trees and multiple species of trees may be left, germinate, or invade after disturbance, and understory vegetation may persist or quickly recoup. Over large areas, heterogeneity produced by biological legacies, variation in natural regeneration, and intermediate disturbances during a long reorganization stage may result in rapid crown-class differentiation with the competitive-exclusion stage being rare in the landscape and rapid growth of Douglas-fir and other trees (Poage and Tappeiner 2002, Tappeiner et al. 1997). In western Oregon, low tree densities are promoted by (1) lack of seed sources following disturbance, (2) sporadic seed production, (3) seed predation, (4) inadequate safe sites for seedling establishment, (5) climatically unfavorable periods, (6) early competition by herbs and shrubs, and (7) herbivory. On a small site in Washington following catastrophic fire, regeneration was also prolonged—40 years or more—but eventually a high density of trees was attained, followed by significant natural thinning of the original cohort of Douglas-fir (Winter et al. 2002a). Surviving Douglas-fir developed deep crowns. Although some western hemlock may have been present from origin, at least three disturbances (at 90, 250, and 430 years) promoted subsequent major recruitment and growth episodes for western hemlock with many secondary pulses of growth in between (Winter et al. 2002b). The presence of even-aged cohorts in patches is compelling evidence of disturbance (Duncan and Stewart 1991). Similarly, in an Engelmann spruce-subalpine fir-lodgepole pine forest in southern interior British Columbia, pine became established in the first 5 years, spruce increased over the first 50 years, but few fir became established in the first 50 years after catastrophic fire (Antos and Parish 2002). Spruce present in the canopy in the old-growth stages had differentiated in response to a combination of partial disturbances and endogenous autogenic processes. Releases occurred in most decades but were concentrated around 110 years and 300 years after origination; these may have been related to spruce budworm outbreaks that produced canopy thinning. Patchy budworm outbreaks led to patchy establishment of fir. Furthermore, different age categories of trees showed different patterns of aggregation. The oldest trees showed no overall deviation from a random pattern, trees originating at 100 years showed patterns that differed among plots, and trees that originated at 300 years were clumped at distances up to 20 meters. Thus, the process of crown-class differentiation and the development of crown-class differentiation in the trees collectively may recur throughout the duration of structurally and compositionally diverse forests (sidenote 57). Antos and Parish (2002) suggested that most old, fire-initiated forests are similarly structured by a combination of exogenous partial disturbance and autogenic processes and that management should incorporate similar dynamics. There was no evidence of exogenous disturbance in the first 200 years. Then episodes of disturbance were reflected by periods of release in the understory; after disturbance, firs were able to attain positions in the canopy. In boreal forests, regeneration following fire, spruce budworm infestation, windthrow, or timber harvests depends on numerous biotic parameters: (1) production of seeds and asexual regeneration of stems as a function of surviving tree densities; (2)

Sidenote 57—Promoting crown-class differentiation:

- Legacy retention—live trees, standing dead trees, fallen trees, and seed banks
- Promoting multiple tree species during reorganization during planting, weeding, and precommercial thinning
- Variable-density thinning
- Underplanting
- Multiple entries for tree removal
- Individual tree release
- Tree limbing or topping to foster development of reiterated trunks or complex crowns

dispersal of seed by wind; (3) germination of dormant seeds in the soil; (4) organic layer depth after disturbance as it affects germinant mortality; and (5) advance regeneration of shade-tolerant trees (Greene et al. 1999). In dry areas characterized by competition for moisture and by frequent return intervals for fires of light to moderate severity, crown-class differentiation may not be an important process—savannahs and widely spaced groves of trees may form in response to poor, infrequent, or short-lived regeneration (Cooper 1960). But, regeneration occurs in patches, and crown-class differentiation is apparent among patches, and eventually within patches early in the development of those patches.

Timber management—Timber management shortens reorganization and quickly moves the stand into competitive exclusion or biomass accumulation. With limited legacies and a dense cohort of naturally or artificially established trees, the diversity of plant species and many other life forms decreases with canopy closure. The resulting competitive exclusion and biomass accumulation concentrated in trees may last over 70 years (Carey et al. 1996a, 1999b; Long 1977) and recovery of plant species diversity may be slow even at 75 years (Long 1977); peak in diversity may be delayed until old growth (Halpern and Spies 1995). Similarly, small mammal abundance and diversity are reduced as the canopy closes and understory decreases and may remain low for decades (Carey and Harrington 2001, Hooven 1969, Wilson and Carey 2000). In plantations, evenly spaced seedlings may fail to differentiate, are susceptible to diameter-growth stagnation, and may become unstable (Wilson and Oliver 2000). Stagnation can increase susceptibility to windthrow if thinning occurs later. Natural thinning of young Douglas-firs produces small, ephemeral gaps as individual trees die. These small gaps do not contribute much to crown-class differentiation or to recovery of plant species diversity (Spies and Franklin 1989). Nevertheless, small gaps, the relatively thin crowns of Douglas-fir, and random variation in spacing often allow reinitiation of an understory of salal or sword-fern. The density, basal area, foliar productivity, biomass, and cover of salal is related almost exclusively to light, increasing with increasing transmission of light through the tree canopy (Vales 1986). This course of development is typical of forests reorganizing after clearcutting and burning (Carey et al. 1996b, Halpern and Spies 1995, Long 1977, Long and Turner 1975). Intermediate disturbances such as root-rot infestations often produce pockets of understory reinitiation in second-growth stands (Carey et al. 1996b, Holah et al. 1993). In mesic areas where shade-tolerant species are abundant, even denser canopies may form, facilitated by legacies of well-decayed nurse trees. These competitive-exclusion stands may last longer and produce an intense ecological "crunch" on biodiversity as trees strive to compete for a height advantage and exclude smaller life forms (Carey 1995, 1996; Carey and Johnson 1995; Carey et al. 1996b; Stewart 1986, 1988). Overstory cover explains more than 50 percent of the variance in shrub cover, including vine maple cover; even stronger relationships exist with maximum total shrub cover, total herbaceous cover, and the cover of each of the three functional groups of herbs (Carey et al. 1999b, McKenzie et al. 2000a). Thus, severe disturbance followed by dense regeneration results in a stage of development that inhibits biodiversity.

Land use change, grazing, timber management, and fire exclusion have produced dense, relatively homogeneous, mixed-species ponderosa pine forests at risk to catastrophic destruction in areas previously characterized as ponderosa pine woodlands (Wright and Agee 2004 and many others). Not only are present forests more homogeneous, but often large trees have been removed, small trees occur in thickets, community composition has shifted to less fire-resistant species, understory grasses and forbs have decreased in abundance and have been replaced by deep mats of slowly decomposing needles that disrupt nutrient cycling, decrease biological diversity, and disrupt hydrologic cycles. Old-growth ponderosa pine forest is rare and what were meadows associated with these old-growth forests are now forests.

Competitive exclusion stages—If crown-class differentiation is delayed, the ecosystem may enter the competitive exclusion stage of development, wherein the system actually becomes more simplified over time instead of increasing in complexity. Salient features of competitive exclusion are even-aged, dense trees and suppression mortality. Hardwoods, notably red alder, giant chinquapin, Pacific madrone, and bigleaf maple, occasionally produce heterogeneity in competitive-exclusion stands that allows some crown-class differentiation. Shade-tolerant conifers may be rare in the understory during competitive exclusion, especially on dry to mesic sites. Second-growth competitive-exclusion stands 40 to 70 years old averaged 384 live conifers per hectare and 123 snags per hectare in the Oregon Coast Range (Carey et al. 1999b), about 50 percent more than the 85 snags per hectare reported by Carey et al. (1991) for a mixture of natural and managed competitive-exclusion stands there, but similar to second-growth competitive exclusion on the Olympic Peninsula (121 snags per hectare) (Carey 1995). In the Puget Trough of Washington, 60-year-old competitive exclusion averaged 500 Douglas-fir per hectare (34 snags per hectare). For Douglas-fir of this age and size (quadratic mean diameters of 30 to 40 centimeters), excessive restriction of crown development (and concomitant mortality owing to suppression) occurs at densities of 350 to 540 trees per hectare (Curtis 1982, McArdle et al. 1961). In eastern deciduous forests, 490 trees per hectare would be common (Bormann and Likens 1979). In western interior Northwest forests, trees are often smaller and their densities substantially higher. In Wyoming, subalpine spruce-fir forests, both species grow slowly as seedlings and saplings and live suppressed for many years until released by some disturbance (Oosting and Reed 1952). For example, 337-year-old subalpine forest canopies in interior British Columbia may have 450 stems per hectare (with nearly 800 more stems per hectare subcanopy), even after an 80-year period of reorganization followed by 200 years of growing without disturbance followed by major mortality owing to bark beetles (which released suppressed trees also), then another, but shorter, bark beetle outbreak 30 years later, and a small outbreak 60 years after that (Parish et al. 1999). The diversity of effects that disturbance can have on forest dynamics is well recognized. Large fires can produce extensive homogeneous stands of trees, whereas insects, disease, and blowdown create patchiness and fine-scale heterogeneity (Parish et al. 1999). Natural variation in stocking, advance regeneration, and occasional retention of large trees from previous stands may contribute to crown-class differentiation in otherwise dense second growth.

Discussion—A salient feature of Pacific Northwest niche-diversification and old-growth stands is large Douglas-fir with deep crowns and large, platform branches, epicormic branches, and reiterated trunks (Carey et al. 1991, Franklin et al. 1981, Spies and Franklin 1991), architecture unlikely to develop in competitive-exclusion and biomass-accumulation stages. Old stands also have shade-tolerant conifers including grand fir, western hemlock, western redcedar, and incense cedar and sometimes bigleaf maple or Pacific madrone. Presumably, crown-class differentiation in niche diversification and old growth was not only a result of the stage-setting catastrophe that destroyed the previous stand, but also one of multiple species, competition, disease, injury, and mortality of the aging cohort of trees that produced gaps followed by establishment and growth of shade-tolerant conifers. Density-dependent processes (e.g., intertree competition and disease outbreaks such as root rot) are more likely in younger forests and density-independent processes (e.g., gap formation owing to individual large trees falling because of butt decay by velvet-top fungus) are more likely to occur in older forests.

Crown-class differentiation accounts for more variance in stand structure than any other factor. Diameter at breast height alone can separate age classes in broad-scale surveys (Carey et al. 1991), and most variance among age classes across the Pacific Northwest can be reduced to a single canonical variate related to the standard deviation of d.b.h. and the density of large trees (Spies and Franklin 1991). But, large-diameter trees can also be grown in plantations, and, in these simplified ecosystems, d.b.h. no longer serves as a good predictor of stage of ecosystem development; such trees may have quite homogeneous, simply structured crowns (fig. 59). In old forests, as trees became dominant they not only increased in d.b.h., but also in height, crown depth (and often width), limb size, variation in limb size, occurrence of epicormic branching and reiterated branches and trunks, bark rugosity, and root networks (fig. 60). These architectural changes magnified individual tree dimensions, and multidimensionally increased niche space for other animals and plants. Enhanced characteristics included (1) greater, more consistent production of seed for seed-eating birds and mammals (Buchanan et al. 1990, Carey 1991, Manuwal and Huff 1987); (2) increased surface area for mycorrhizae, epiphytic plants, and endophytic parasites—up to 97 species of lichen can occur in a small stand with well-differentiated crowns (Enseen et al. 1996, McCune et al. 2000, Parks and Shaw 1996, Sillet and Neitlich 1996, Stone et al. 1996); (3) bark crevices, foliage, and arboreal soil for invertebrates (Denison 1973, Mariani 1987, Schowalter 1989); (4) crevices for bat roosts and materials and platforms for nests of mammals and birds (Carey 1996, Carey et al. 1997, Forsman et al. 1984, Gillesberg and Carey 1991, Hamer and Nelson 1995, Wunder and Carey 1996); and (5) an increased variety of foraging substrates and prey (and niche separation) for bark-gleaning and wood-pecking birds (Carey et al. 1991, Sharpe 1996). At the stand level, crown-class differentiation results in a rugose canopy that provides unique foraging spaces for bats (Wunder and Carey 1996) and birds (e.g., the olive-sided flycatcher) (Carey et al. 1991).

Figure 59—This conventionally thinned forest has a dense understory, no midstory, and an overstory of trees in intense competition with each other. Photo by A. Carey.

Crown-class differentiation accounted for 25 percent of variance in vegetation structure in a mixed sample of young and old stands in Oregon and provided a major dimension of the realized habitat of Townsend's chipmunks (Carey et al. 1999b). Mean tree d.b.h. also was a good predictor of the abundance of Townsend's chipmunks on the Olympic Peninsula, explaining 61 percent of the variance (Carey 1995). Two alternative explanations of the strong correlations of abundance of chipmunks with crown-class differentiation appear reasonable: (1) crown-class differentiation was a surrogate for the entire process of forest development or (2) chipmunks were responding to heavy seed production by large, dominant trees. Conifer seed is a major dietary component for Townsend's chipmunks, which harvest and store the seed for the winter (Sutton 1993). Townsend's chipmunks seem to be food limited, and their abundance can be increased by adding seed (Sullivan et al. 1983). The same seems true for the third squirrel in Pacific Northwest forests—the Douglas' squirrel, whose behavioral repertoire is geared at safekeeping sources and stores of conifer seed (Smith 1970). Chipmunks have a strategy of capitalizing on seasonally available seeds, fruits, and fungal fruiting bodies, storing food for winter, and facultatively hibernating to reduce energy needs during winter. Crown-class differentiation is a minor dimension of flying squirrel realized habitat; flying squirrels specialize on truffles, mushrooms, and fruits and seeds of shrubs and deciduous trees.

Figure 60—An old-growth forest on the Olympic Peninsula shows complexity in tree architecture. Photo by T. Wilson.

Crown-class differentiation is perhaps the factor of forest development most amenable to management: (1) species composition can be determined managerially at initiation of a new stand by legacy retention, planting, allowing natural regeneration, and maintaining and promoting diversity during precommercial thinning; (2) management of stem density and growth rates is well founded, and quantitative measures exist for the degree of intercrown competition in trees (Curtis and Carey 1996); and (3) spacing can be varied tree to tree or patch to patch within stands to promote both crown-class differentiation and crown development (Carey 1995, Carey et al. 1996a, 1996b). Growth of large trees and the passage of time lead to disease, injury, decay, and death of trees and consequent expansion of multidimensional niche space. Thus, the ecological influence of crown-class differentiation extends beyond tree architecture to interaction with decay processes to produce decadent structures of large biomass. Decay processes seem less deterministic than differentiation; yet, management easily can have marked impacts on decadence.

Decadence

The Oxford English Dictionary (OED) defines *decadence* as "The process of falling away or declining (from a prior state of excellence, vitality, prosperity, etc.); decay; impaired or deteriorated condition." Decadence has long been recognized as playing important ecological roles in forests, not only for soil organisms and plants, but for animal communities as well (Elton 1966, Hamilton and Cook 1940). In forests, decadence refers to both state of the forest (degree of decadence) and to processes by which trees (1) become infected with rots, often as a result of physical damage, insect attack, or disease; (2) balance decadence with renewal—broken tops with reiterated trunks and large dead and broken branches with epicormic branches; (3) develop decayed heart wood, cavities in their tops, and hollow boles; (4) uproot or break and fall to gradually decay to become incorporated into soil; and (5) die while standing and gradually decay to fall or break up into smaller pieces (fig. 61) (table 28).

Contrary to the OED definition, a modicum of decadence in forests contributes to "vitality and prosperity" and renewal. Of particular importance to forest conservation is maintaining long-term site productivity. For example, coarse woody debris can be important in cation cycling in base-poor systems, in maintaining surface organic layers in areas where decay is rapid or fires are frequent, in

Figure 61—Decadence in a second-growth forest in the Puget Trough: a recently snapped tree bole and an adjacent uprooted tree. Photo by A. Carey.

retaining moisture during dry periods and preventing erosion during wet periods, for seedling establishment in coastal Pacific Northwest forests, and as habitat for a variety of organisms (plants, fungi, and animals) in most forests (Laiho and Prescott 1999). In relation to sustaining site productivity and timber harvesting, the question is whether the total nutrient pool left on site in biological legacies (rather than simply coarse woody debris) and the rate of nutrient input through weathering and precipitation are large enough to offset loss of nutrients in harvested timber. Management of faster cycling materials, such as ground vegetation and nonwoody litter, may be as or more important than coarse woody debris. For example, on Rocky Mountain conifer forests in Alberta, Canada, coarse woody debris did not appear to make significant contributions to nitrogen and phosphorous cycling; the organisms producing woody decay may have actually competed with plants for the limiting nutrients that became available. Litter and coarse woody debris, however, do provide refugia during fires for a variety of beneficial fungi, microbes, and inverterbrates that are important to nutrient cycling and decomposition in western interior forests (Niwa et al. 2001) and are thus important to forest resilience. Coarse woody debris is a major component of Rocky Mountain forests and is important to forest soils (Graham et al. 1994). The dynamics of coarse woody debris differ with forest type, seral stage, insect and disease activity, weather events, fire-return intervals, and management activities. The wood lasts 60 to 500 years depending on the ecosystem type, longer in mesic systems and shorter in xeric systems. Amounts range from 66 Mg/ha in cedar-hemlock forests to 23 Mg/ha in ponderosa pine

Table 28—**Density of standing dead trees (snags) by diameter class and age class in young, mature, and old forests in the Oregon Coast Range**[a]

Snag size (d.b.h. in cm)	Young	Mature	Old
>100	0.1	0.3	3.3
>50	0.8	4.3	7.3
20–49	17.6	55.6	8.4
10–19	64.9	39.0	7.0

[a] This illustrates the transition from density-dependent mortality to density-independent mortality and from smaller trees to larger trees with increasing forest development. In Washington, snags larger than 50 centimeters d.b.h. were more abundant in old growth—averaging 24 per hectare—than in second growth—only 1 to 15 per hectare.

Source: Carey et al. 1991.

forest (fig. 62). The abundance of ectomycorrhizal root tips is a good indicator of the health of Rocky Mountain forest soils and exhibits a strong positive relationship with soil organic matter, which is positively related to coarse woody debris inputs. Empirical data suggest that optimum soil organic matter can be maintained by 10 to 20 Mg/ha of coarse woody debris, depending on forest type (sidenote 58). Historically, wildfires left 100 to 600 Mg/ha, depending on forest type. Maintaining well-distributed 15 to 30 Mg/ha on dry sites and 30 to 50 Mg/ha on mesic sites by minimizing roller chopping, chipping, and smashing slash while using prescribed fire to remove needles and branches (hazard fuels) can maintain the ecological roles of coarse woody debris.

In the Pacific Northwest, there has long been an interest in the role of coarse woody debris in nutrient cycling and long-term site productivity; however, our understanding is still limited (Edmonds and Chappell 1994; Edmonds et al. 2000; Edmonds and Murray 2002; Marra and Edmonds 1994, 1996; Sollins 1982; Sollins et al. 1980). In Douglas-fir/western hemlock/western redcedar forests, decay of coarse woody debris over the long term does result in net nitrogen mineralization (Hart 1999). Catastrophic inputs of coarse woody debris assist forest recovery by timing of nutrient release that

Sidenote 58—The role of coarse woody debris in Rocky Mountain forests (Graham et al. 1994):

- Protects the forest floor and mineral soil from erosion and mechanical disturbance
- Protects new seedlings from livestock grazing
- Key habitat element for many species of wildlife
- Important in stream ecology
- Interrupts airflow, provides shade, insulates and protects new forest growth
- In mesic forests, provides seedbeds and nursery area for conifer seedlings
- With advanced decay, holds large amounts of water providing moisture for vegetation during dry periods
- Stores nutrients (sulphur, phosphorous, nitrogen) that are released through decay or burning
- Provides humus for ectomycorrhizal root tips

Figure 62—A fallen ponderosa pine near Sisters, Oregon. Photo by A. Carey.

matches nutrient demands and helping to prevent erosion. In many old-growth forests, more than 20 percent of the area of the forest floor is covered by coarse woody debris (fig. 63) with well-decayed boles covering more than 5 percent of the forest floor. This material can contribute to rapid recovery of the system after disturbance. Tree retained after catastrophic disturbance (natural on managed) often show signs of old age and decadence: fungal infections, large cracks, densely furrowed bark, broken tops, multiple leaders, cavities and basal hollows, large-diameter limbs defective in form, numerous epiphytes, and deep crowns suggestive of an open-grown growth form (Hunter and Bond 2001). Catastrophic fires, insect outbreaks, and epidemics of disease often leave large numbers of snags used by woodpeckers and other cavity-using birds (Imbeau and Desrochers 2002, Johnson and O'Neil 2001, Lundquist and Mariani 1991, Rose et al. 2001). Snags used by cavity excavators may differ markedly in abundance from 453 per square kilometer in Oregon to 233 per square kilometer in British Columbia to 1.3 per square kilometer in the Cariboo Parklands of Alberta (Bonar 2000, Johnson and O'Neil 2001). Reviews of snag abundance and use by wildlife have been

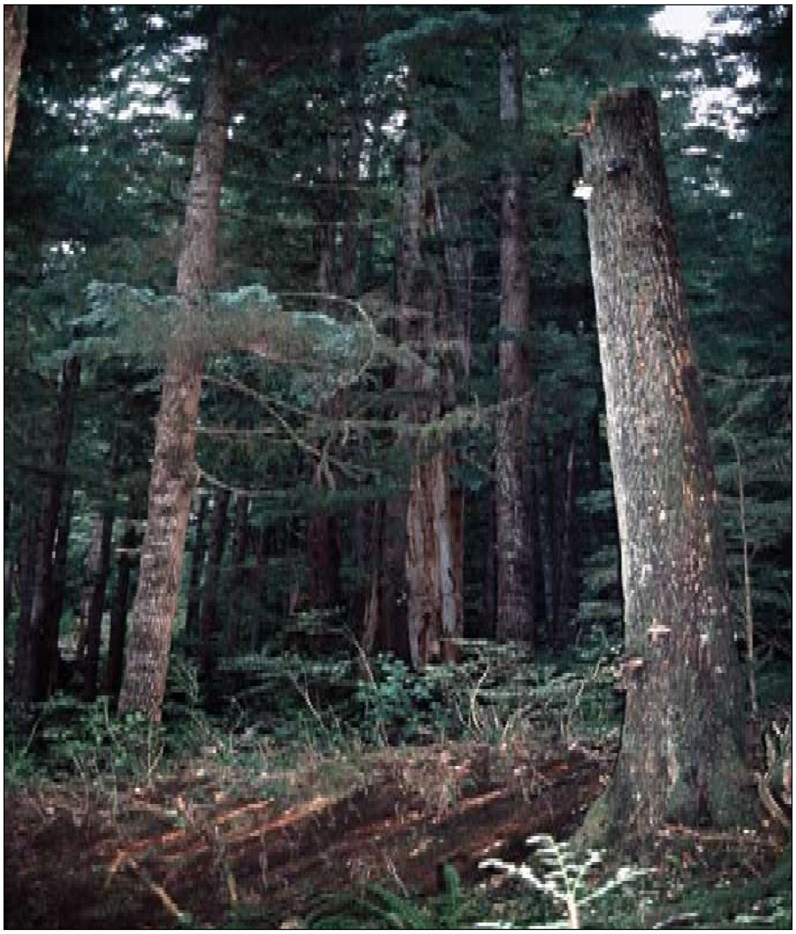


Figure 63—Coarse woody debris, both standing and fallen, provides shelter and places to forage for wildlife. Photo courtesy of USDA Forest Service.

Figure 64—Western redcedar trees can compartmentalize decay and remain alive, even with such large cavities. Photo by A. Wilson.

compiled for practically all regions of North America in wildlife-habitat relationships books; Johnson and O'Neil (2001) provided a recent review for Washington and Oregon. The importance to wildlife of standing dead trees, live trees with moderate to heavy decay (fig. 64), and fallen trees cannot be overstated (Bunnell et al. 1999), and substantial effort has gone into modeling the dynamics of coarse woody debris, including models that produce advisory output for managers (Mellen and Ager 2002; Mellen et al. 2002, 2004; Wilhere 2003). Conventional timber management in Washington includes (1) clearcutting with retention of 7 to 12 wildlife trees per hectare followed by planting 1,075 Douglas-fir per hectare; (2) precommercial thinning at 15 years of the plantation to 741 trees per hectare; (3) commercial thinning at 30 years (if done) to 346 trees per hectare; and (4) clearcutting at 50 years (Wilhere 2003). Such management results in snag densities of about 20 percent of the total snags and 1 percent of the large snags in natural forests. Average predicted densities were 3.9 small snags per hectare, 6.2 medium snags per hectare, and 0.1 large (more than 64-centimeter d.b.h.) snags per hectare. In conifers, it is the moderately decayed large snags and very large (more 80-centimeter d.b.h.) snags that provide most of the cavities used by birds. Similarly, the importance of forest decadence to aquatic systems is profound (Acker et al. 2003).

Live trees with extensive decay, standing dead trees, and fallen trees are used by a tremendous diversity of plants, fungi, microorganisms, invertebrates, and vertebrates (Boddy 2001, Harmon et al. 1986, Jonsson and Kruys 2001, Kruys and Jonsson 1999, Kuuluvainen et al. 2001, Maser and Maser 1988, Maser and Trappe 1984, McComb and Lindenmayer 1999, Siitonen 2001). Coarse woody debris is characteristic of natural forests from the spruce taiga in the Ural Mountains of Russia (36 fallen trees more than 10 centimeters in d.b.h. along 10 meters of transect) to the Pacific Northwestern United States, where up to 27 percent of the forest floor may be covered with coarse woody debris (Marra and Edmonds 1994). In Scandinavian forests, 4,000 to 5,000 species (20 to 25 percent of all species) are associated with coarse woody debris, which averages 60 to 90 cubic meters per hectare in old growth but only 2 to 10 cubic meters per hectare in managed forests (fig. 65). Furthermore, the process of decadence is important in the development of spatial complexity

Figure 65—Coarse woody debris in a managed forest in Sweden. Photo by A. Carey.

in the forest and in the soil. Trees dying lose their foliage and allow light to penetrate the canopy more fully. Falling trees may damage other trees and create larger canopy gaps. Fallen trees provide structure to the forest floor and seed beds for a variety of plant species; eventually they become incorporated into the soil and fully infiltrated by roots; various organisms, especially beetles, convert fallen trees into humus and fine organic matter in the soil. Large dead wood (standing dead trees, fallen trees, and large tree parts) resulting from decadence is often referred to as coarse woody debris.

Abundance of coarse woody debris accounted for 16 percent of the total variance in vegetation structure in managed and natural forests in southwestern Oregon (Carey et al. 1999b). Cover of fallen trees in the Oregon Coast Ranges averaged 10 percent in old growth, 7 percent in niche diversification forest, and 4 percent in competitive exclusion forests. In Washington, cover of fallen trees averaged 13 percent in old growth but ranged from 2 to 13 percent, averaging 8 percent in second growth (Carey and Harrington 2001).

Sites used by flying squirrels averaged a 10 percent cover of fallen trees in both regions. The types and abundance of coarse woody debris resulted from three separate phenomena: (1) retention of live, damaged, and dead trees through and after the catastrophe that initiated the reorganization of the ecosystem; (2) death of young trees through suppression, disease, weather damage, fire, and falling large trees; and (3) development of decadence in live trees over time. Intermediate and small-scale disturbances including wildfires (Juday 1977), diseases such as root rot (Carey et al. 1996b, Holah et al. 1993) and white pine blister rust (Lundquist and Mariani 1991), windstorms (Carey and Johnson 1995), snowstorms, and ice storms (Carey et al. 1997) promote decadence. These disturbances, however, are stochastic and differ in frequency and intensity from place to place and time to time, producing high variance in decadence within age classes of forest that may differ markedly in other elements of structure as well.

Historical clearcutting left substantially less coarse woody debris than did natural catastrophes, removed most or all live trees, and was followed by fast, dense, and monospecific regeneration of trees that quickly moved the stand into the competitive-exclusion stage. Early (about 1910) logging of old growth left 52 to 56 percent of preharvest biomass, contemporary logging of old-growth leaves 33 to 41 percent, and contemporary harvest of second-growth leaves only 31 to 35 percent—a reduction from 500 to 540 megagrams per hectare to 100 to 115 megagrams per hectare (Harmon et al. 1996). The trend has been for intensive management for timber to result in marked loss of biodiversity owing to reductions in coarse woody debris and increases in homogeneity and simplicity of the resulting forest. Management can deconstruct ecological processes and shape them to narrow ends. Maintenance of homogeneity through maintaining evenly spaced trees can promote biomass accumulation without crown-class differentiation, forestall or prevent suppression mortality, and remove trees with incipient decadence. Decoupling of basic processes has profound influences on ecological complexity, diversity, and resilience. Even in natural forests, processes can be decoupled. After especially severe catastrophes, coarse woody debris declines in abundance until old growth is reached at about 190 to 250 years (Spies and Franklin 1991). But when trees are killed or weakened by fire, coarse woody debris recruitment may continue for over 100 years (as in contemporary niche-diversification stands) until death of older trees begins to maintain recruitment of coarse woody debris (Franklin et al. 1987). Managed stands are harvested during competitive exclusion, or if precommercially or commercially thinned, during biomass accumulation, generally at 40 to 70 years old, with high utilization of wood and rapid regeneration through planting (Carey et al. 1999c). With intensive management for timber, recovery of biodiversity by the ecosystem may be restricted severely because of reduced crown-class differentiation and decadence.

Decay in live trees—The entry of decay-causing organisms, the development of decay, and the timing of tree death varies markedly with species (Browne 1956, Eslyn and Highley 1976). Decay in live trees that enables cavity excavation by woodpeckers, allows cavities to develop for squirrels and other mammals, and leads to hollow trees is more common in deciduous trees than in conifers (sidenote 59). The processes leading to decay in deciduous trees are well understood (Carey 1981, Hansen 1966, Manion and Zabel 1979, Shigo 1979, Wagener and Davidson 1954, Wilkes 1982) as are factors underlying the distribution of live cavity trees (Carey 1983). For example, in relatively even-aged oak-hickory forests in West Virginia, the spatial pattern of the occurrence of the various species of oak, hickories, and other trees was roughly determined by slope position, aspect, and other variable site qualities in a small landscape (Carey 1983). But the species differed markedly in their propensity for forming discrete cavities useful to wildlife, for becoming hollow trees, and for longevity. White oaks, especially chestnut oak, were, perhaps, the best cavity providers, with northern red oak and scarlet oaks not as prolific. Older forests, dominated by northern hardwoods had even fewer cavities. In southwestern Oregon old-growth forests, large, old, dead, moderately decayed Douglas-fir provided the majority of cavities for birds (Carey et al. 1991). But on the Olympic Peninsula, large, live western redcedar with heart rots were important to pileated woodpeckers (Aubry and Raley 2002). In the western Washington Cascades, large, old, white pines that died from blister rust provided the greatest number of cavities (Lundquist and Mariani 1991). Grand fir is not as long-lived as Douglas-fir, but it is a good cavity tree and is somewhat unique among the firs in regularly becoming a hollow tree, that, when it falls, provides den sites for American marten and other mammals. Deciduous trees, such as red alder, willow, Pacific madrone, and bigleaf maple are apt to have cavities earlier in the life of a forest than Douglas-fir. Similarly, species differ in their susceptibilities to different diseases and in the timing when mortality might occur and contribute to coarse woody debris on the forest floor. Studies of second-growth forest in the Puget Trough of Washington, surprisingly, found increasing recruitment of large tree boles to the forest floor in stands more than

Sidenote 59—Considerations for managing cavity trees (Bunnell et al. 1999):

- Manage a continuum from live trees to standing dead trees to fallen trees to trees incorporated in the soil.
- Twenty to thirty percent of the vertebrate fauna [of British Columbia] use cavities—57 species in interior Douglas-fir forest; the proportion of species using cavities increases with mean fire size and frequency of fire.
- Decay states differ between deciduous trees (sound sapwood, heart rot) and conifers (moderately decayed sapwood and heartwood).
- Birds and mammals commonly prefer hardwoods over conifers, even small d.b.h. hardwoods, but 66 percent of weak excavators use only dead trees, and some of these are the most threatened by lack of decandence management.
- A number of species (e.g., Vaux's swift, black bears, American marten) use hollow trees that require heart rot and a long time of decay.
- Size matters—densities of cavity users is correlated with densities of large snags but not small snags, and cavity users respond the most to increases in snag densities primarily at low snag densities; conifers more than 80 centimeters and deciduous trees more than 40 centimeters with height more than 20 meters are sought out; 2.4 large snags per hectare supports 50 percent of the maximum density; increase in number of cavity nesters reaches a maximum [levels out] at about 5 large snags per

70 years old as a result of root rot. In natural forests, there is often a dearth of coarse woody debris recruitment between 40 and 150 years or so.

Fallen trees—Pacific Northwest forests have the greatest coarse woody debris loads of any forests, and accumulated dead biomass is thought to be of central importance in promoting ecosystem stability, habitat diversity, and long-term productivity (Carey and Harrington 2001; Edmonds et al. 2000; Graham and Cromack 1982; Marra and Edmonds 1994, 1996). Functions of coarse woody debris include (1) nutrient cycling by adding organic matter to soil (Harmon et al. 1994, Sollins 1982); (2) microhabitats for a rich diversity of microorganisms, arthropods, lichens, and bryophytes and seedbeds for shade-tolerant conifers and ericaceous shrubs (Harmon et al. 1986, Peck et al. 1995); (3) refugia for mycorrhizal fungi and reservoirs of moisture during and after catastrophic disturbance, particularly on dry sites and during droughts (Amaranthus et al. 1989); (4) ectomycorrhizal links among trees and truffle production in late-seral forests (Amaranthus and Perry 1994, Amaranthus et al. 1994, Clarkson and Mills 1994); (5) niche diversification in small mammal communities by enhancing forest-floor structure, soil organic matter, fungi, and invertebrate communities (Carey and Johnson 1995); (6) habitat for salamanders (clouded salamander, Oregon slender salamander, and Ensatina) (Butts and McComb 2000, Corn and Bury 1991b, Gilbert and Allwine 1991); (7) foraging sites for pileated woodpeckers and their prey: ants (e.g., *Camponotus*, *Formica*, and *Lasius* spp.) (Torgersen and Bull 1995); (8) habitat element of primary importance to the western red-backed vole (Hayes and Cross 1987, Tallmon and Mills 1994); (9) physical mediation of competition between blacktail deer and Roosevelt elk (Leslie et al. 1984); (10) elevated seedbeds that protect vascular plants from herbivory by ungulates; and (11) maternal den sites for arboreal rodents (Carey et al. 1997).

Of all the various elements of ecosystems, cover of fallen trees best described high-quality habitat for northern flying squirrels and Townsend's chipmunk in southwestern Oregon (Carey et al. 1999b); 15 percent cover might be optimal for mammals in wet to mesic forest, 10 percent cover in drier forests. Large fallen trees are almost twice as abundant in old growth as in managed forests, although the amount of coarse woody debris in second growth differs markedly with historical logging method and degree of legacy retention (Carey 1995, Carey and Harrington 2001, Carey and Johnson 1995). In the late 20th century, nearly complete removal of tree boles and

hectare in the Pacific Northwest.

- Preferences for snags for foraging are similar to the preferences for nesting.
- The most compelling evidence of declines in vertebrate abundance resulting from forest management practices is in cavity nesters owing to lack of nesting and foraging sites.
- Management that reduces snags includes short rotations and thinnings.
- Sustained provision of cavity trees may require creating cavity trees or snags, withdrawing a portion of the forest from management in the short term; incorporating aging trees into management in the long term; providing a minimum of two large snags per hectare and preferably four large snags per hectare with retention of some smaller snags for foraging. Retaining snags in patches is operationally efficient, safer, takes advantage of spatial clumping of dead trees, and seems effective in attracting cavity-excavating birds.

intensive site preparation had resulted in less than 2 percent cover of coarse woody debris in many second- and third-growth forests (Carey et al. 1996a). Managed forests in general have less coarse woody debris than late-seral forests (Carey and Johnson 1995, Carey et al. 1999d, Spies and Cline 1988), but some, particularly on the western Olympic Peninsula, may have retained substantial biomass (Carey and Harrington 2001). Rebuilding a depleted store of coarse woody debris through retention of tree boles during thinning is possible but expensive (Carey et al. 1996a). Thus, legacy retention is especially important in setting the stage for conserving biodiversity in managed forests (Franklin et al. 1997).

Decadence as a process—If catastrophic disturbance sets the stage, it is small-scale disturbances in the canopy that determine the pace of the ecosystem development. Gaps drive the forest cycle in all forests (Whitmore 1989). The ecological process of tree death (Franklin et al. 1987) is particularly important in expansion of niche space (Carey 1996, Carey et al. 1991, Parks and Shaw 1996, Stone et al. 1996). Only 10 percent of the cells of living conifers are actually alive (Franklin et al. 1987). In eastern Washington and Oregon, four species of mistletoes, 50 species of rusts, and several rots play an important role in decadence (Parks and Flanagan 2001). Indeed, a case can be made that mistletoes are keystone species in forests and woodlands worldwide—97 vertebrate families consume mistletoes and 50 use them as nest sites (Watson 2001). Heart rots account for 20 to 31 percent of the volume of standing trees in Pacific Northwest forests (Hennon 1995, Parks and Shaw 1996). Snapping of boles (often at the site of decay) and standing death constitute 76 percent of gapmakers; uprooting is the least common (21 percent) (Lertzman et al. 1996). In the Oregon Cascades, more than 70 percent of canopy Douglas-fir die standing or from stem breakage and die without disrupting the forest (73 to 88 percent of deaths in late-seral forest); only 12 to 27 percent of the trees in late-seral forests uproot (Spies and Franklin 1989, Spies et al. 1990). In some mature forests, for example, mixed-wood forests in Poland, windthrow is a major source of mortality for individual trees (Bobiec et al. 2000). Competition, however, is the major cause of death of conifers up to 150 years old (Franklin et al. 1987). Mechanical damage from falling trees accounts for 15 percent of mortality in late-seral forests. Decaying and dead standing trees (1) increase structural diversity, (2) alter the canopy and understory microenvironments, (3) promote biological diversity, (4) store nutrients and decomposers, and (5) provide critical habitat elements for wildlife (Parks and Shaw 1996). The role of coarse woody debris in developing complex and productive forest floors and soils is generally accepted but poorly quantified.

Decadence and wildlife—The importance of standing dead trees (snags) and standing live trees with sufficient top rot to allow for formation or excavation of cavities by cavity-using birds and mammals has long been a focus of wildlife conservation, and the literature is large and diverse (Barkalow and Soots 1965, Bellrose et al. 1964, Brewer 1961, Brown and Bellrose 1943, Conner et al. 1976, Dalke 1948, Davis et al. 1983, Dennis 1971, Erskine and McLaren 1972, Fischer and McClelland 1983, Frank 1948, Gysel 1961, Kendeigh 1961, McClelland and Frissell 1975, Panicker 1980, Scott et al. 1977). The densities of cavity-using birds have been correlated with abundances of snags, especially snags over 50 centimeters in d.b.h. in the conifer forests of Oregon (Mannan et al. 1980), Washington (Zarnowitz and Manuwal 1985), and California (Raphael and White 1984). In southwestern Oregon forests, an abundance of large snags (more than 7 per hectare with greater than 50 centimeter d.b.h.) was the primary determinant of a diverse bird community (Carey et al. 1991). Large snags were 10 times more abundant, woodpeckers 4 times more abundant, and cavity-using birds as a group 2 times more abundant in old growth than in competitive-exclusion forests. Cavity-nesting birds constitute a majority of resident overwintering small-bird species. The keystone northern flying squirrel dens primarily in large, live old trees (presumably with heart rot and cavities) in old growth, but in residual old-growth snags in managed forests in southwestern Oregon (Carey et al. 1997). Cavities in large deciduous trees with top rot (e.g., bigleaf maple and Pacific madrone) also were used. Small-diameter conifer snags were rarely used for nesting by birds or mammals. In the Puget Trough, however, small-diameter deciduous snags (e.g., red alder) with cavities excavated by woodpeckers were important cavity sites in intensively managed second-growth stands with few large snags. In second growth with numerous well-decayed large snags and minimally decayed suppression mortality, flying squirrels resorted to stick nests in tightly closed canopies—but in both environments flying squirrel populations were low (Carey et al. 1997). On the Olympic Peninsula, flying squirrels denned in residual large snags and in cavities in live conifers with top rot (formed after tops were killed by freezing 30 years previously) but not in abundant suppressed trees. It seems that suppression mortality in conifers does not contribute greatly to the function of standing decadent trees in either provision of cavities or gap formation. Small snags usually do not have top rot (or cavities) and do not stand very long; they do contribute to coarse woody debris on the forest floor for a relatively short time before decaying (Carey and Sanderson 1981 review of decay processes and cavity formation). The evolution of hole-nesting in birds (and arboreal rodents) is an adaptation that allows year-round residence in temperate forests by providing bioenergetic advantages and protection from predation (Collias 1964, Short 1979). Flying squirrels have evolutionary adaptations of gliding, nocturnality, cavity-nesting (Holmes and Austad 1994), and communal denning (Carey et al. 1997). Nocturnal arboreal travel and gliding have energetic costs that are offset (37 percent reduction in heat loss) by denning in groups in cavities lined with plant material (Carey et al. 1997, Stapp et al. 1991). Thus, den sites large enough to hold more than three squirrels are important, and decay in the tops of large trees is important. In addition, flying squirrels change dens about every 2 weeks (perhaps as a strategy to avoid predators) and large numbers of group dens are needed (Carey et al. 1997).

There is a broad correspondence between large snag abundance and population sizes of flying squirrels across the Pacific Northwest (Carey 1995). This correspondence, however, is more likely a result of large snags as indicators of overall decadence than to provision of den sites (Carey et al. 1997). Trees display a continuum of roles from living, sound organisms to dead, prostrate structures on the forest floor (Franklin et al. 1987). Many of these roles depend on decay forming in living trees of large size; for example, hollow trunks of fallen trees used as dens by American marten. Thus, decadence in Pacific Northwest forests cannot be partitioned functionally into snags and fallen trees without losing the significance of the entire process of tree decay and death and its diverse functions. This is especially true in relation to the role of accumulated organic matter on the forest floor. Fallen trees transform into rotting logs, humus, and organic soil formed through the action (digestion of wood and mechanical mixing of the soil) of invertebrates. Forest-floor organic matter influences a variety of life forms in the forest floor, and its role relative to ectomycorrhizal fungi essential to the growth of many trees and their production of truffles (the food of many mammals that are prey for vertebrates higher on the food chain) has been the subject of much discussion and speculation.

Fallen trees and truffles—What accounts for the ability of decadence to explain variation in space use, activity, and abundance of flying squirrels and other small mammals? It is plausible that the role of decadence in providing den sites is important for an abundance of flying squirrels (Carey 1995, Carey et al. 1997), but abundance of fallen trees predicted flying squirrel abundance almost as well as did decadence (which includes snags as well). Fungal sporocarps (truffles) compose the bulk of the diet of the flying squirrel, and a strong connection has been made between truffle abundance and coarse woody debris in southwestern Oregon. Truffle abundance is 20 to 30 times greater in old forest with more than 25 percent cover of coarse woody debris than in young plantations with less than 15 percent cover of coarse woody debris (Amaranthus et al. 1994). Within old forests in drier parts of the Pacific Northwest, truffles are 10 times greater in well-decayed fallen trees than in mineral soil. Of the eight genera that are common in flying squirrel diets (Carey et al. 2002, 1999b), five (*Rhizopogon*, *Melanogaster*, *Leucophleps*, *Hysterangium*, and *Leucogaster*) were associated with well-decayed coarse woody debris (Amaranthus et al. 1994). Only *Elaphomyces* (the eighth-ranked genus in diets of flying squirrels) was associated primarily with mineral soil. *Balsamia*, the eighth-ranked genus in chipmunk diets (and not present with more than 5 percent frequency in flying squirrel pellets), also was associated with mineral soil. Clarkson and Mills (1994) also found sample plots with fallen trees are more likely to contain sporocarps (twice as likely) and on average to have more biomass (four times more) of sporocarps than sampling plots without fallen trees in late-seral forest in southwestern Oregon. They found that activity of mycophagous western red-backed voles is associated with truffle abundance and coarse woody debris. Of the five most abundant genera (*Melanogaster*, *Hysterangium*, *Gautieria*, *Genebea*, and *Rhizopogon*) found by Clarkson and Mills (1994), four were among the five most abundant in diets of flying squirrels, and three were among the five most abundant in diets of Townsend's chipmunk as well.

Flying squirrels consume 20 to 24 genera of fungal sporocarps year-round (Carey et al. 2002, 1999b; Maser et al. 1986). *Rhizopogon*, *Gautieria*, *Hymenogaster*, *Melanogaster*, *Hysterangium*, *Leucophleps*, *Elaphomyces*, and *Geopora* are the dominant items in spring diets. Seasonal differences in diets include high frequencies of *Elaphomyces* in January-February, decreased frequencies of *Hymenogaster* in summer-fall, and increased frequencies of *Leucogaster* in summer-fall; lichens are important dietary components in January. Diets of northern flying squirrels in the Pacific Northwest differ geographically, but fungal sporocarps still compose the bulk of diets. In the relatively dry forests of northeastern Oregon and California, flying squirrels consume less fungus and more lichen, plant material, and staminate cones than flying squirrels in western Oregon (Carey et al.

1999b; Maser et al. 1985, 1986; Waters and Zabel 1995). *Rhizopogon* still dominates the diet, flying squirrel densities are positively correlated with sporocarp abundance, and fungal sporocarps are twice as abundant in old-growth white fir as in competitive-exclusion stands 75 to 95 years old with little coarse woody debris (Waters and Zabel 1995). In the western Washington lowlands, flying squirrels consume 16 of 21 genera and 40 of 50 species of mycorrhizal fungi found in second-growth Douglas-fir forest (Carey et al. 2002, 1996b). *Rhizopogon*, *Melanogaster*, *Hysterangium*, *Endogone*, and *Leucogaster* are the genera most frequently encountered in the soil, and *Rhizopogon*, *Gautieria*, *Leucogaster*, and *Melanogaster* are the common spores in diets. *Gautieria* was most abundant in stands with high coarse woody debris loads, and *Melanogaster* was most common in stands with little coarse woody debris. Flying squirrels were more than twice as abundant in forests with 6 to 8 percent coarse woody debris than in forests with less than 2 percent coarse woody debris. Mushroom spores (*Russula*, *Peziza*, *Agaricaceae*, and *Boletaceae*) were common in diets; plant material and lichens were relatively infrequent in fecal pellets. Spring diets of flying squirrels in Douglas-fir-western hemlock forests on the Olympic Peninsula of western Washington are dominated by *Rhizopogon*, *Hysterangium*, and *Leucogaster*. Olympic Peninsula squirrels also consume spores of *Boletaceae*, *Octaviana*, *Thaxterogaster*, and *Chamomixia* (Carey 1995). Dietary species richness on the Olympic Peninsula is half that in the Oregon Coast Range (Carey 1995, Carey et al. 1999b) and differs between competitive-exclusion and old-growth forest; but coarse woody debris is not a good predictor of flying squirrel abundance on the Olympic Peninsula. Several differences between the Oregon Coast Range and the Olympic Peninsula can explain the differences in dietary diversities and influence of coarse woody debris.

The Olympic Peninsula has more precipitation, cooler temperatures, and less severe summer drought than the Coast Range; coarse woody debris is generally abundant (Carey and Harrington 2001), and thus coarse woody debris may not be important as moisture reservoirs and refugia for ectomycorrhizal fungi. Coarse woody debris loads on the Olympic Peninsula are higher (8 percent in competitive exclusion, 13 percent in old growth) than in the Coast Range (4 percent in competitive exclusion, 9 percent in old growth), forest-floor organic matter accumulations are greater, and forest floors are moister (Carey and Johnson 1995). Forests on the Olympic Peninsula are dominated by western hemlock, which does not have as many ectomycorrhizal associates as Douglas-fir. Few species are specific to western hemlock, which may have evolved to capitalize on the mycorrhizal associations of pioneering species (e.g., Douglas-fir) that establish quickly after catastrophic disturbance (Molina et al. 1992). Thus, mycorrhizal diversity (and possibly sporocarp abundance) may be relatively low in pure western hemlock competitive-exclusion stands. About 50 species associate with western hemlock in the laboratory, more than 100 species in the field (Kropp and Trappe 1982, Molina et al. 1992, Molina and Trappe 1982). There are 250 species that are specific to, and 2,000 species associated with, Douglas-fir (Molina et al. 1992).

In southwestern Oregon, giant chinquapin, Pacific madrone, tanoak, and salal are broadly receptive to numerous ectomycorrhizal fungi, form ectomycorrhizal associations that facilitate establishment of conifers after catastrophic disturbance, and create spatial and temporal ectomycorrhizal links among tree species (Amaranthus and Perry 1989, 1994; Molina et al. 1992; Molina and Trappe 1982; Smith et al. 1995). Thus, it is not surprising that there are not differences in dietary diversity between squirrels from competitive exclusion and squirrels from old growth in the Coast Range. In summary, dietary diversity was associated with coarse woody debris sometimes, but activity of mycophagous mammals and truffle abundance in southwestern Oregon seem to be strongly associated with coarse woody debris.

Management affects composition of truffle communities in various ways (Carey et al. 2002). More species and genera are found in soil and in feces in forests with old-growth legacies than in thinned forests managed without consideration for legacies or decadence. Second-growth forests in the Puget Trough had 48 species (Colgan et al. 1999). Broad surveys of managed and old-growth forests found 43 species in western Washington (North et al. 1997) and 47 species in Oregon (Luoma 1991). Because total truffle production differs markedly among seasons and years (e.g., 330 to 1,852 grams per hectare) and species production differs even more markedly, often more than tenfold (Luoma 1991), taxonomic diversity is important in providing a consistent food supply to mycophagous mammals. Total truffle diversity, however, differs little among the physiographic provinces of western Oregon and Washington, but the northern forests of the Olympic Peninsula and North Cascades forests seem to have greater dominance by a single species than forests in the Puget Trough or in Oregon (Carey et al. 2002). Flying squirrel diets were rich in Puget Trough legacy forests (seven commonly occurring genera) compared to similarly managed forests on the Olympic Peninsula (four genera) and similar in diversity to diets in old-growth forests on the peninsula (six genera). Diets in thinned forests in the Puget Trough had the same number of genera (four) as diets in the legacy forests on the peninsula. Flying squirrel diets in the Puget Trough and on the Olympic Peninsula had fewer genera than flying squirrel diets from the warmer, drier, southern Oregon Coast Range (12 genera in old growth and 9 in extensively managed forests) (Carey 1995, Carey et al. 1999b).

Truffle production is important to mycophagous animals. Flying squirrel abundance varied with truffle abundance in northeastern California (Waters and Zabel 1995). In southwestern Oregon, local foraging by flying squirrels was correlated with abundance of coarse woody debris (Carey et al. 1999b), and coarse woody debris was positively correlated with truffle abundance (Amaranthus et al. 1994). Even though 20 to 50 species of hypogeous fungi may be present in any one stand, usually fewer than five species account for the bulk of the biomass of sporocarps (Amaranthus et al. 1994, Carey et al. 2002, Colgan et al. 1999, Fogel 1976, Fogel and Hunt 1979, Hunt and Trappe 1987, Luoma 1991, North et al. 1997). These abundant fungi, however, are the ones most frequently tallied in squirrel diets and seem to be narrow (tree genus) to intermediate (tree family) in host range (Molina et al. 1992, Molina and Trappe 1982). Four genera common in flying squirrel diets across the Pacific Northwest (Carey 1995, Carey et al. 1999b), *Gautieria*, *Leucogaster*, *Leucophleps*, and *Elaphomyces*, were less abundant in soil or feces in thinned forests than in forests with legacies of coarse woody debris. Production of truffles by *Gautieria* (and *Hysterangium*) is reduced by thinning in the short term (Colgan et al. 1999) and, apparently with conventional thinning, that effect is long lasting but not universal for species of *Hysterangium*. For example, *H. coriaceum* and *H. crassirhachis* were more abundant in forests with legacies and *H. setchellii* was more abundant in thinned forest—an example of the resilience of the ectomycorrhizal community resulting from species diversity (and redundancy) within a functional group. *Leucogaster citrinus* and *Elaphomyces granulatus* are listed as late-seral species (Castellano et al. 1999, USDA and USDI 1994) and are common in legacy forest but not in conventionally thinned forest, demonstrating that legacy retention can be important in maintaining functional group and species diversity through intentional management disturbances. Moreover, 71 late-seral epigeous (mushroom-producing) fungi also occurred in second-growth forests in the Puget Trough (Carey et al. 1999d). Fruiting of *Melanogaster*, like *H. setchellii*, was favored by thinning (Colgan et al. 1999); *Melanogaster* truffles were six times more frequent in soil and twice as abundant in flying squirrel feces in thinned than in legacy forest. On the other hand, three of four

Rhizopogon species occurred only in thinned forest. Several species of *Rhizopogon* are associated with early stages of forest development and are often abundant on tree roots following disturbance (Molina et al. 1997). Several factors may explain low truffle production by certain species in thinned forest. Species that form hyphal mats may be more susceptible to mechanical damage by logging operations. Thinning may change microclimate to the detriment of these species. *Hysterangium* and *Gautieria* were reduced in abundance in shelterwood stands 17 and 20 years after timber harvest (Waters et al. 1994). *Gautieria* mats were found only in the rooting zone of retained old-growth trees 2 years after a shelterwood harvest in the Oregon Cascades (Aguilera et al. 1993), and *Hysterangium* spores were rare in feces of Siskiyou chipmunks in shelterwood stands in southwest Oregon (McIntire 1984). Shelterwood harvests remove a greater proportion of trees than thinning, and considerable time may be required after disturbance for such taxa to recover and fruit. North and Greenberg (1998) hypothesized that reduction in biomass of *E. granulatus* in managed compared to natural old forests was a consequence of reduction of thick organic layers with high root density in managed forests. *Rhizopogon parksii*, the other species they studied, was not associated with organic layers. The areas studied by North (North and Greenberg 1998, North et al. 1997) are on the cool, moist end of the Western Hemlock Zone. At the opposite extreme (hot, dry) in southwestern Oregon, Amaranthus et al. (1994) found a close association between truffles of various species and decaying logs on the forest floor.

Truffle abundance, although important to mycophagous mammals, is but one of several important factors. On the Olympic Peninsula, flying squirrel abundance was correlated more with understory development (Carey 1995) and abundance of mast-bearing trees (vine maple and bigleaf maple)—ancillary sources of high-quality food—than with coarse woody debris (Carey and Harrington 2001). Flying squirrels were almost twice as abundant in legacy as in conventionally thinned forest, whereas chipmunks were four times more abundant in thinned forest (Carey 2000b, 2001). Food and cover well explain differences in chipmunk abundance (Carey 2000b, 2001) but not differences in flying squirrel abundance, given that (1) truffle biomass was equal in the two forest types, (2) flying squirrels consumed all species of truffles present (Carey et al. 2002, Colgan 1997, Colgan et al. 1999), (3) truffles are nutritionally poor (Claridge et al. 1999, Cork and Kenagy 1989), and (4) vascular plant parts consumed by flying squirrels (Thysell et al. 1997b) have high nutritive value (Cork and Kenagy 1989). Locally, flying squirrel abundance may be determined by (1) availability of dens (Carey 2001, Carey et al. 1997), (2) habitat-mediated predation (Carey et al. 1992, Wilson and Carey 1996), (3) competition with chipmunks and Douglas' squirrels in environments simplified by forest management (Carey and Harrington 2001), and (4) ancillary food sources (Carey and Harrington 2001, Ransome and Sullivan 1997, Thysell et al. 1997b). Studies suggest the hypothesis that simultaneously high populations of northern flying squirrels, Townsend's chipmunks, and Douglas' squirrels in the Douglas-fir keystone complex—a characteristic of old, natural forests (Carey 1995)—results from ecological processes of development of habitat breadth and niche diversification (Carey et al. 1999b) and not a single limiting factor (Carey 2001, Carey and Harrington 2001) or single limiting process.

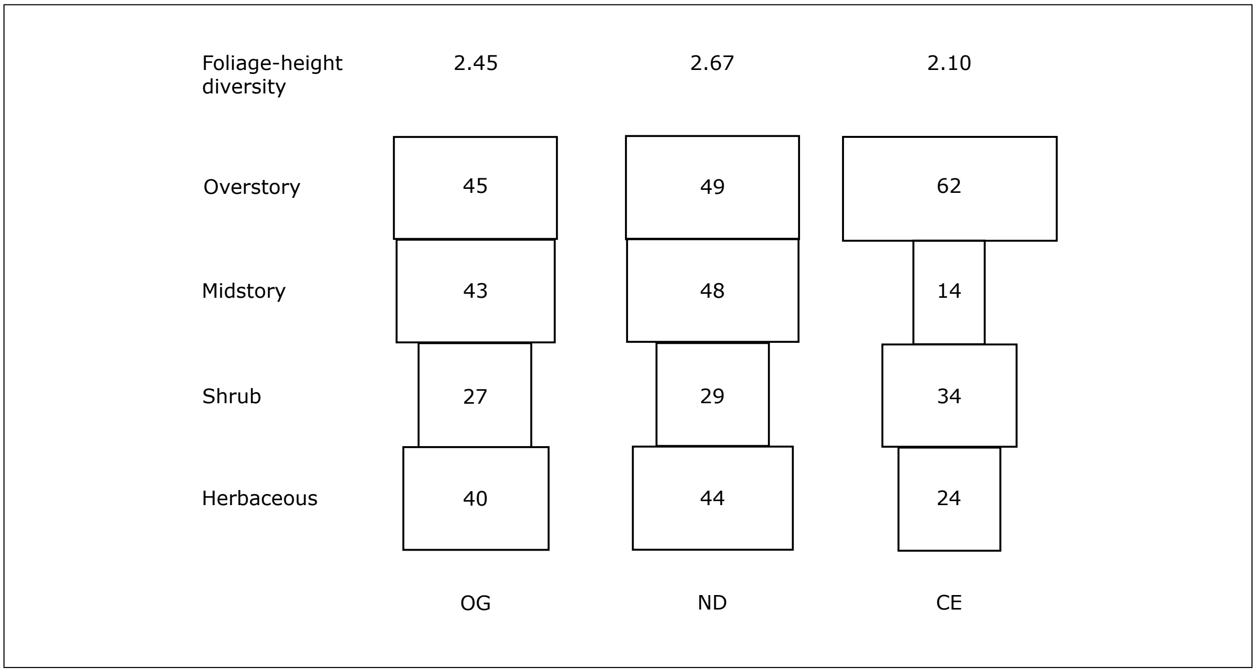
The chemical composition of truffles suggests high food value (Fogel and Trappe 1978), but digestibility of truffles is low, near the minimum for maintenance of squirrels (Cork and Kenagy 1989). Truffle genera differ in digestibility, different taxa provide different nutrients to squirrels, and squirrels differ in ability to extract nutritive value from truffles (Townsend's chipmunk is less capable of extracting nutrients from truffles than the northern flying squirrel). Thus, dietary diversity may be important for nutritional adequacy. Great abundance, high detectability (through odors that attract squirrels), and low handling time for truffles maximize net yield of energy and nutrients to squirrels, but a high-quality diet requires more than just truffles (Cork and Kenagy 1989). Squirrels eat a wide variety of truffles and mushrooms and, sometimes, vascular plant material (especially seeds and other reproductive parts). Townsend's chipmunk and Douglas' squirrel eagerly consume conifer seeds as well as seeds and fruits of other plants and fungi (Maser et al. 1978, Smith 1970, Sutton 1993). Across their range, northern flying squirrels consume a wide variety of lichens, nuts, seeds, fruits, staminate cones, and catkins (Wells-Gosling and Heaney 1984) but not much conifer seed. Flying squirrels in the West primarily are mycophagous year-round, although lichens are important winter foods in some areas (Carey 1995; Carey et al. 2002, 1999b; Currah et al. 2000; Maser et al. 1985, 1986; Rosentreter et al. 1997). Flying squirrels may consume 15 grams of truffle in a single meal; stomach contents (mostly spores) may weigh 24 to 71 grams for squirrels with a live mass of 152 to 165 grams. But even relatively small amounts of high-quality food are nutritionally significant to squirrels given the low food value of truffles (Cork and Kenagy 1989). Thus, flying squirrels are not strictly mycophagous, even though fungi dominate their diets. Flying squirrels and chipmunks eat lichens, mushrooms, staminate cones, pollen (e.g., cottonwood), seed (e.g., bigleaf maple; conifer seed by chipmunks), and fruits (e.g., salal) in addition to truffles.

Importance of soil organic matter and fungal diversity—Fungal diversity does more than provide diverse diets for squirrels. Fungi are essential in many food webs; their exudates and hyphae link above- and belowground processes by providing photosynthetically fixed carbon to rhizosphere consumers such as bacteria, protozoa, and arthropods. Roots and mycorrhizal symbionts account for 70 to 80 percent of net primary productivity; 10 to 40 percent of total photosynthates pass from roots to rhizosphere adding organic material to the soil and enhancing soil structure. Diversity in mycorrhizae provides resilience to environmental stresses and may extend the range of environments within which plants can prosper (Perry et al. 1989). Each fungal species is thought to have its own set of physiological characteristics; thus, their activity differs with temperature and moisture, and they differ in the nutrients they extract from mineral soil and organic matter (Molina et al. 1992, Molina and Trappe 1982, Perry et al. 1989). Diversity in the plant community can be quite important in stabilizing belowground mutualists after catastrophic disturbance (Perry et al. 1989). Although much of the composition of plant communities in Pacific Northwest forests is a result of the processes of canopy stratification and understory development, ectomycorrhizal linkages among plants can reduce competition for resources, promote forest recovery after disturbance, and influence the pattern of plant succession (Amaranthus and Perry 1994, Molina and Amaranthus 1991). Thus, forest-floor structure, plant-community composition, fungal-community composition, and animals interact in mutually reinforcing ways to produce ecosystem resilience and development. Overall, biodiversity stabilizes community and ecosystem processes, if not population processes (Tilman 1996).

Canopy Stratification

Jerry Franklin likes to say that forests mature like men do—the living biomass progressively slips downward (see also Massman 1982). Processes leading to transfer of foliage abundance from overstory to midstory and understory and even the occurrence of a midstory differ among seral stages (fig. 66). In competitive exclusion, a sparse midstory may develop when conifers grow taller than their deciduous contemporaries. This midstory contributes little to foliage-height diversity and seems coincidental with understory development (Carey et al. 1991, 1999b). However, portions of some 40- to 70-year-old stands in the Oregon Coast Range had high foliage-height diversity; these were used for roosting by the northern spotted owl (Carey et al. 1992). In niche diversification, stratification occurs as a result of (1) retention of live old trees and possibly advance regeneration from previous stands, (2) development of a predominant even-aged cohort of conifers of mixed species following catastrophic wildfire (say 100 years before), (3) establishment of deciduous trees following catastrophic wildlife, and (4) subsequent establishment of a third cohort of conifers (including Douglas-fir) after noncatastrophic wildfires. Foliage-height diversity is great, distributed among midstory, overstory, and herbaceous cover with mean values about 45 percent with shrub cover lower, less than 30 percent. Mean midstory cover is much greater than in competitive exclusion (less than 15 percent) and similar to old growth (also 45 percent). Early histories of old-growth stands are generally unknown or only partially explicable from dendrochonology (Tappeiner et al. 1997). Nevertheless, in southwestern Oregon, 210- to 350-year-old overstories were a mix of species, and midstories were primarily shade-tolerant conifers, bigleaf maple, and Pacific madrone. In the Coast Range, bigleaf maple is most abundant in old growth (Carey et al. 1999b, Spies 1991). Shade-tolerant conifers in the overstory (western hemlock, western redcedar, incense-cedar, grand fir) often are contemporaries of the dominant Douglas-fir and a result of midstory trees gradually

Figure 66—Foliage-height diversity profiles showing the Berger-Parker index and percentage of covers (in boxes) by vegetation layers for old-growth (OG), niche-diversification (ND), and competitive-exclusion (CE) stages in Oregon Coast Range, 1986–87 (Carey et al. 1999b). The Berger-Parker index is a scientific measurement for foliage-height diversity—the larger the number, the larger the diversity in vegetation layers.



entering the canopy. Midstories tend to merge with overstories and understories in old growth; foliage-height diversity is high.

Development of high foliage-height diversity and spatial heterogeneity in forest plant communities depends on growth of shade-tolerant tree seedlings in the understory into the midstory. Light is usually the factor limiting seedling development on moist, fertile sites, but root competition for nutrients and moisture among various plants may occur on dry and infertile sites (Coomes and Grubb 2000). Dry woodlands allow 20 times more light to penetrate than wet forests do. Both overstory trees and understory shrubs influence seedling recruitment in ponderosa pine forests (Keyes et al. 2001). Thus, germinants, seedlings, and saplings exhibit significant spatial aggregation. A high prevalence of patches of dense shrub cover in niche-diversification west-side Douglas-fir forest may be due to intermediate-scale disturbances (tree-fall gaps, small wildfires, windthrow, ice storms). Silvicultural thinning has the potential to promote growth of the retained dominants while encouraging growth of shade-tolerant trees in the midstory; the density of retained trees, the timing of multiple entries, and the sizes and crown classes of trees being removed can be varied as appropriate to forest type and local conditions, while also creating spatial heterogeneity and recruiting dead wood to the forest floor (Carey 1995, 2003a, 2003c; Carey and Johnson 1995; Carey et al. 1999b, 1999c; Garman et al. 2003).

Deeply layered vegetation in old growth and niche diversification results in cool and humid conditions in the understory and protection from radiation and drying winds; moistness of forest also increases with amount of decomposing wood (Spies 1991). Thus, late-seral forests have greater covers of herbaceous plants and more diverse shrubs than competitive-exclusion forest. Complexity of structure and resulting variety in microclimates results in greater numbers of plant species and greater percentage of cover per species than in homogeneous stands (Carey 2003a; Carey and Curtis 1996; Spies 1991; Thysell and Carey 2000, 2001a). Deciduous tall shrubs and trees, in particular, add substantially to biodiversity by providing foliage for consumption by insects (especially moths and butterflies, whose larvae are eaten by birds and terrestrial insectivores), an architecture hospitable to lichens, and fruits (flowers, catkins, seeds, and nuts) of high food value for insects, birds, and mammals (Bunnell et al. 1999, Carey 2000a, Muir et al. 2002). Thus, complexity and species diversity translates into habitat breadth and preinteractive niche diversification. Habitat breadth accounts for more variation in small mammal activity than does decadence (Carey and Harrington 2001, Carey et al. 1999b). Canopy stratification, however, was the single best descriptor of the realized habitat of chipmunks. Midstory cover had the most predictive power for chipmunk activity. Decadence and canopy stratification seemed of nearly equal importance in explaining variance in chipmunk carrying capacity. Although canopy stratification explained only 11 percent of the variance in vegetation structure among points, its process seemed to have profound influences on the plant and squirrel communities.

Gaps and stratification—In older forests, development of diversity in vegetation structure and composition stems from small-scale, gap-forming processes (Poulson and Platt 1989). In coastal temperate rain forests, over 50 percent of the forest area is influenced by canopy openings due to the death of 1 to 10 trees (Carey et al. 1999b, Lertzman et al. 1996, Spies and Franklin 1989, Spies et al. 1990, Stewart 1986). Tree-crown overlap in old growth averages only 15 to 30 percent. The median size of gaps is less than 100 square meters in old growth but less than 20 square meters in mature forest (Spies et al. 1990). Death of 5 to 10 large, adjacent trees, although rare, would cause gaps of 1,100 square meters. Gaps more than 0.1 hectare and relative tree densities more than 3.5 promote seedling growth in the understory (Brandeis et al. 2001, Coates 2000). Gaps are rare in competitive-exclusion and biomass-accumulation stages, although diseases like root rot can form small to moderately sized gaps.

Overlap among tree crowns in old growth is due in large part to subdominant western hemlock (Spies et al. 1990). This development of midstory vegetation maintains connectivity among tree crowns that facilitates travel by arboreal rodents (Carey 1996). Full foliage-height profiles, found in niche diversification and old growth, facilitate exit from and entry to the canopy by providing protection from predation associated with gliding over open areas and with tall expanses of clear tree boles characteristic of competitive-exclusion forests (Holmes and Austad 1994, Stapp 1994). Stratified canopies provide increased niche space for summer and winter birds (Carey et al. 1991, Shaw and Flick 1999). For chipmunks, the value of midstory might be in variety and abundance of seed production by conifers, hardwoods, and understory shrubs. To the benefit of all squirrels, gaps may result in increased fungal production through extended root networks of the dominant Douglas-fir, ameliorated microclimate, increased habitat breadth, niche diversification in the forest floor, and ectomycorrhizal linkages among Douglas-fir, western hemlock, grand fir, and coarse woody debris (Molina and Amaranthus 1991, Perry et al. 1989). Furthermore, gaps create a mosaic of open and closed canopy that promotes a mosaic of understory vegetation site types, including areas of high foliage-height diversity. This mosaic affords a modicum of protection to small mammals in areas of heavy cover and opportunities for foraging by predators in more open areas (Carey et al. 1992). Thus, gap formation and canopy stratification are prerequisite to development of complex understories.

Understory Development

In the Pacific Northwest, succession of early seral communities, from the catastrophic release of ecosystem resources to tree canopy closure, depends on the biological legacies retained during disturbance, the degree of soil disturbance, and colonization by ruderals. Succession may be quite variable—a slow progression from herbs to shrubs to trees—with years, or even decades, in between stages, to quick occupancy by conifers. With invasion by grasses, the soil ecology may become dominated by bacteria instead of fungi, and a long delay may occur before trees become established. On the other hand, joint establishment of multiple life forms is common, and there are strong and predictable relationships between herbs and woody plants (McKenzie et al. 2000a). In some cases, deciduous trees may grow quickly and suppress conifers; in other cases, when both are present, conifers may eventually grow through and overtop the deciduous trees. In most cases, trees, by virtue of sustained growth, longevity, and size, quickly dominate the site (Halpern and Franklin 1990, Halpern and Spies 1995, McKenzie et al. 2000a). In Alaska, alder-conifer mixes maintain a species-rich and abundant understory, even compared to old growth. Herbs and shrubs increase after logging then virtually disappear if the tree canopy is dominated by conifers; the understory may remain depauperate for more than 100 years (Hanley, in press). Light precommercial thinning can produce a short-lived increase in shrubs with a slight increase by herbs, especially forbs; heavier thinnings offer more promise of promoting understory that is favorable to other life forms, such as deer; but if thinnings are too heavy, producing over 60 percent full sunlight, then western hemlock will regenerate. Depending on tree density, the tree canopy may quickly close or slowly close but often, without disturbance, the end result is a stage of competitive exclusion with little understory. Sooner or later, the understory will begin to develop. Thus, in areas where trees become well established, understory development contributes relatively little (10 percent) to the variance in forest vegetation. In the relatively dry Oregon Coast Range, much of the differences among stands and seral stages in understory development seemed related to relative abundance of ferns and shrubs and to composition of the shrub community (Carey et al. 1999b). Most competitive-exclusion stands have salal as a component of the shrub layer, with 1 to 3 other species, particularly oceanspray, California hazel, or huckleberry, present in small quantities. Herbaceous layers are dominated by moss, oregongrape (as a low, prostrate shrub), and swordfern (Thysell and Carey 2000). Natural and silvicultural thinning can promote diversity and growth in understory (Muir et al. 2002; Tappeiner and Zasada 1993; Thysell and Carey 2000, 2001a) with profound effects on food webs (Carey 2003a, Hayes et al. 2003, Muir et al. 2002). In niche diversification and old growth, however, Pacific rhododendron, vine maple, and conifer seedlings and saplings were added to salal, oceanspray, and huckleberries. A diversity of species and growth forms occurred in the herbaceous layer: low shrubs, half-shrubs, ferns, forbs, grasses, and mosses. Nonetheless, few plant species in Pacific Northwest coniferous forests are confined to a particular seral stage (Carey et al. 1999b, Franklin and Dyrness 1973, Spies 1991).

Abundances of vascular plants and community diversity increase with stage of forest development (Halpern and Spies 1995, Spies 1991, Stewart 1986). Four processes influence understory development: (1) resource availability, (2) horizontal spatial heterogeneity, (3) vertical diversity of vegetation, and (4) fire (Carey et al. 1999b, Spies et al. 1990). Aggressive shrubs of low to moderate shade tolerance (e.g., salal) form dense patches under uniform, open canopies (Thysell and Carey 2000, 2001a). In tall old-growth and niche-diversification forests, shade-tolerant species are favored. Old-growth understories tend to be relatively cool and humid during dry seasons because they are protected from radiation and drying winds by deep, multiple, canopy layers. Accumulated coarse woody debris and litter on the forest floor act as moisture reservoirs. Gaps in canopies provide marked horizontal heterogeneity in the spatial distribution of light and moisture. Sunflecks of brief duration contribute 37 to 68 percent of total photosynthetically active radiation (Canham et al. 1990). Penetration of light into the understory adjacent to gaps is significant at high latitudes because of sun angle. Even though the mean and range of light levels increase with size of gaps, potential duration of light is still below 4 hours and varies inversely with canopy height (70 meters in old-growth Douglas-fir). Development of shade-tolerant midstories can have significant impacts on the amount of light reaching the understory. Light penetration also differs with gap orientation; north-south gaps admit more light than east-west gaps (Poulson and Platt 1989). Changes in topographic position and edaphic gaps increase heterogeneity in light conditions, and, with 30 percent of the forest area in gaps, 56 percent of the forest area is influenced by canopy openings (Lertzman et al. 1996).

Understory development influences animal populations. For example, understory development is a minor but significant predictor of the realized habitat of flying squirrels, chipmunks, and many other small mammals (Carey 1995, Carey and Harrington 2001, Carey and Johnson 1995, Carey et al. 1999b, Carey and Wilson 2001). Chipmunks increasingly select home ranges with heavy understory as midstory decreases (that is, from old growth to niche diversification to competitive exclusion). The prevalence of patches of ericaceous shrubs also is correlated with abundances of both flying squirrels and Townsend's chipmunks on the Olympic Peninsula. Ericaceous shrubs, snags, and the nature of the catastrophic disturbance originating the stand explained 85 percent of the variance in flying squirrel activity. Patches of ericaceous shrubs covered about 40 percent of flying squirrel habitat. In the middle Oregon Coast Range, abundance of chipmunks across the early stages (ecosystem reinitiation to understory reinitiation) is highly correlated with abundance of salal but no other habitat variables (Hayes et al. 1995). Three explanations exist for correlation with ericaceous shrubs: (1) the fruits of the shrubs provide food, (2) shrubs provide cover from predation, and (3) shrub cover is correlated with some other determinant of chipmunk abundance. The importance of overhead cover to chipmunks has been experimentally demonstrated (Harestad 1991).

Development of Habitat Breadth

Legacies, the four basic structuring processes of crown-class differentiation, decadence, canopy stratification, and understory development, and spatial heterogeneity combine to allow an emergent, or second-order, process to unfold. This process is development of habitat breadth and it consists of the development of a fine-scale (less than 0.2 hectare) mosaic of vegetation patches (or vegetation site types) that differ in species composition, vertical diversity in foliage abundance (foliage height profiles), and in the types and abundance of food and cover available to animals. In southwestern Oregon, spatially complex light, temperature, and moisture conditions produced 21 of these small patch types related in part to (1) landscape-level climatic gradients; (2) among-stand variation in environmental conditions owing to slope, aspect, elevation, edaphic conditions, and stage of forest development; and (3) within-stand variation owing to site moisture, edaphic gaps, regeneration gaps, canopy gaps caused by tree death, and development of shade-tolerant midstories. All site types were found across most stands, suggesting types were more a product of ecosystem development conditioned by temperature and moisture rather than unique local phenomena. Site types can be used to measure fine-scale heterogeneity (degree of development of habitat breadth) arising from disturbance and forest development. Habitat breadth is also an index to biological diversity because diversity of fine-scale patches of vegetation influences fungal, invertebrate, and vertebrate diversity through abundance and diversity of food and cover and ameliorated microclimates (Carey et al. 1999b, Colgan et al. 1999, Schowalter et al. 2003). Fine-scale environmental heterogeneity that promotes biological diversity also is likely to foster mutualisms (Bronstein 2001) as well as mitigating competition and predation. The phenomenon of increased diversity and abundance across all major life forms following increased forest complexity (increased numbers and lengths of axes of the unrealized [unexploited] niche space) is the result of the emergent property, preinteractive niche diversification (Hutchinson 1978) (figs. 67, 68). Development of habitat breadth and niche diversification work against one or two species dominating a functional group and promote the coexistence of species—for example, green-tree retention in variable-retention harvest units in British Columbia helped prevent an irruption of Oregon creeping voles and allowed southern red-backed voles to remain moderately abundant throughout the reorganization and early development of the ecosystem (Sullivan and Sullivan 2001). In western Washington, species common during ecosystem reorganization but usually rare to missing in spatially homogeneous competitive exclusion and biomass accumulation stages are also present in experimental gaps (Gitzen and West 2002), second growth with managerially induced understory reinitiation (Wilson and Carey 2000), and old, natural forests (Carey and Johnson 1995). Thus, differences in habitat breadth along with differences in decadence can explain as much as 50 percent of the variance in flying squirrel activity and 70 percent of the variance in habitat quality.

The roles of different ecological factors differ among biotic communities and even within biotic communities that are environmentally heterogeneous. For example, vegetation heterogeneity plays a dominant role in insect population dynamics and community structure, both of which are important to insectivorous birds and mammals. Differences among species within a trophic level, differences

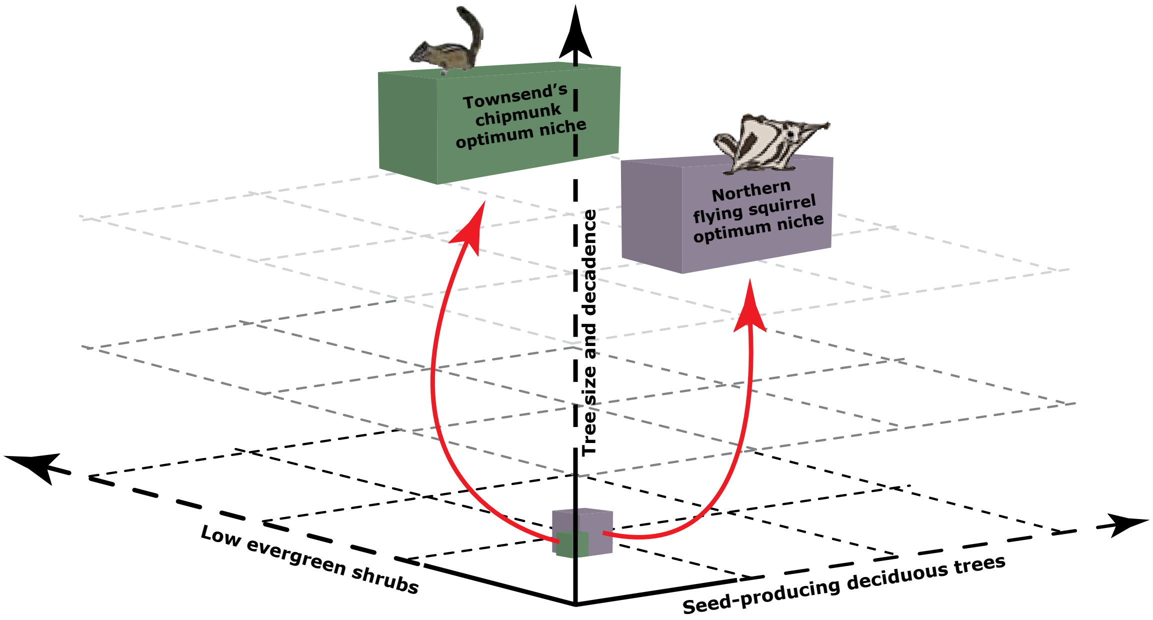


Figure 67—Through preinteractive niche diversification, there is an expansion of overall niche space and niche dimensions (evergreen shrubs, seed-producing deciduous trees, large conifers, decadence, etc.), providing a greater separation of species niches as well as creating more space available for a greater number of individual animals. Graphic by A. Wilson; flying squirrel illustration by J. Perkins.

in species interactions in a changing environment, changes in population demography with population density, identities of individual species, and environmental variation are as important determinants of population and community dynamics as are the number of levels in a food chain, or the position of the system along a resource gradient. The effects of ecological factors can cascade up or down in the trophic system; thus flow of interactions is as important as flow of energy (Hunter and Price 1992). For example, shrubs provide food and cover to squirrels. Marked differences in ability of shrub abundance alone to explain variance in squirrel activity among studies is due to differences among studies in (1) the degree to which shrubs of various kinds are lacking, (2) variances in shrub cover relative to variances in abundance of other habitat elements, and (3) complementarity between midstory, understory, and decadence. In other words, few wildlife-habitat relationships are based on simple linear relationships involving one or two habitat elements. As Billick and Case (1994) stated, "the dynamic behavior of the full community cannot be predicted based on observations of interactions between pairs of species." Rather, almost always a complex of elements is involved, there is redundancy in some functions of some elements, and interactions with other species are important. Large differences in coarse woody debris (5 to 25 percent cover) and shrub abundance (0 to 95 percent prevalence) among stands on the Olympic Peninsula influence the structure of forest-floor small mammal communities and the abundances of various species of shrews, mice, and voles, but even small differences in plant species composition may be as important (Carey and Harrington 2001, Carey and Johnson 1995). Dimensions of potential habitat spaces (usually expressed as statistical distributions of habitat elements) determine not only habitats realized within a given space but also which factors explain the most variance in animal activity in that space. It is generally accepted that factors limiting populations differ among locales and seasons (Fretwell 1972).

Spatial-Scale & Spatiotemporal Heterogeneity

In the ecology of fungi, vascular plants, invertebrates, and vertebrates, many ecological processes take place at a physical scale of less than 50 square meters, the level of individual organisms (the death and decay of a tree), structural features (fruiting of an ectomycorrhizal fungus in a decayed log), and the neighborhood of a dominant tree. The four structuring processes of forest biotic communities (crown-class differentiation, decadence, stratification, and understory development) take place at varying small scales—the first two at the level of individual trees and the last two at the level

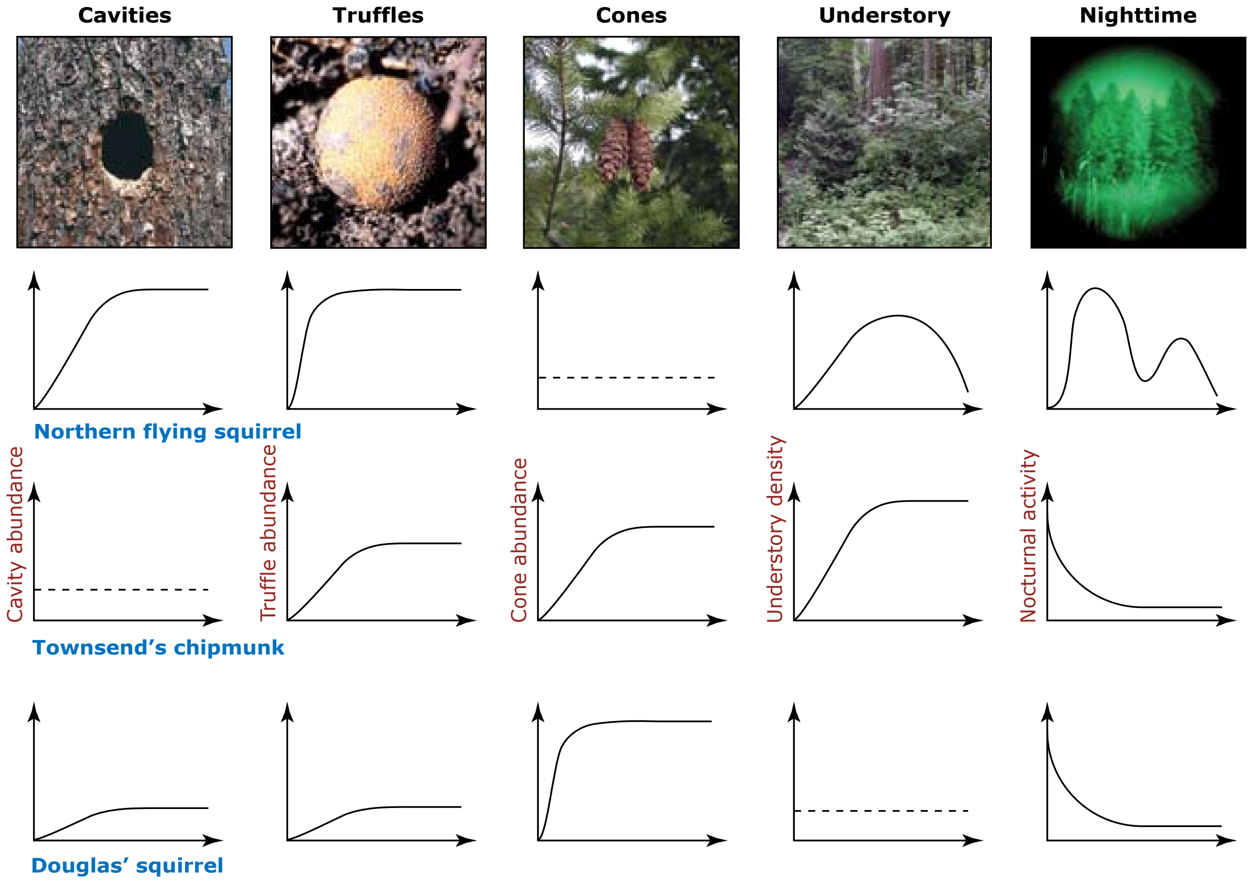
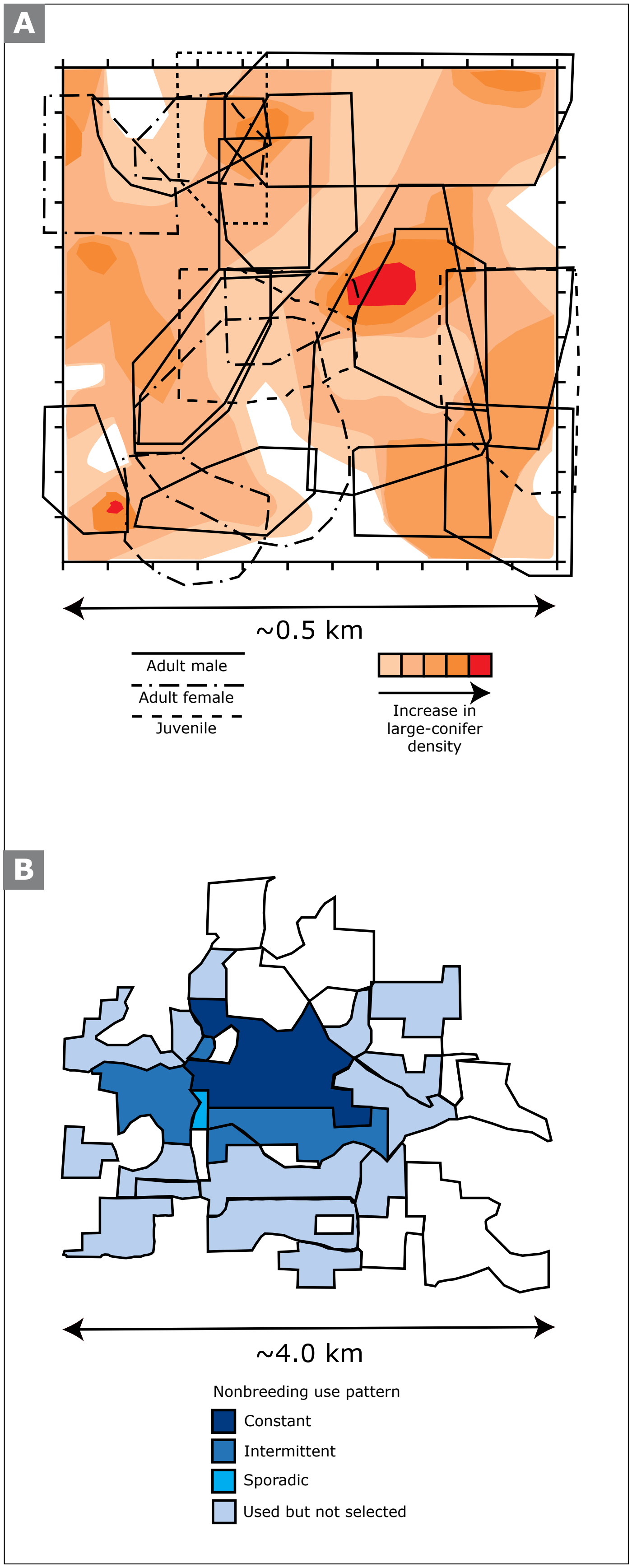


Figure 68—Biocomplexity creates more niche dimensions, which allows different species to coexist together. Blue words represent the X-axes; Brown words represent the Y-axes. Graphic by A. Wilson; Photos courtesy of USDA Forest Service.

of small patches (0.01 to 1.0 hectare). The interactions among these processes that develop habitat breadth, however, are exemplified at scales of 0.1 to 0.5 hectare over areas of 10 to 100 hectares, account for two-thirds of the variance in vegetation structure across biotic communities, and can be used to differentiate realized habitat (actually occupied) from potential habitat (the total multivariate habitat space available) of organisms of intermediate mobility (small amphibians, birds, and mammals) with an accuracy of about 65 percent within biotic communities. But the four structural processes explain less than one-fifth of the variance in animal activity within biotic communities. For example, squirrels do not select any small subset of vegetation site types for their activities; their foraging patches and home ranges may differ little, on average, from the larger biotic communities in which they occur. Differences lie in the proportion of the area of the biotic community used, the size of foraging patches, the size of home ranges, and the densities of the populations (Carey et al. 1999b) (fig. 69). Amount of area used generally tends to increase with body size of mammals: red-backed voles tend to be more restricted in their movements than deer mice, and deer mice are more restricted than eastern gray squirrels (Carey 1981). Still, within a group of similar size, home ranges can differ markedly—the Douglas' squirrel is much localized in its movements (tens of meters), the flying squirrel may travel a kilometer or more in a night, over several hectares (Carey 2000a) (fig. 70). Predators, of course, tend to have larger body sizes and substantially larger home ranges than their prey. Pairs of spotted owls have home ranges spread over 500 to 3,000 square kilometers and larger depending on level of forest fragmentation, prey base, and physiographic province (Carey et al. 1992).

Processes taking place at scales of 1 to 100 hectares, the level of populations (demographic processes) and biotic communities (self-organization of the community), include, for example, competitive exclusion, development of species richness in a plant community, predator-prey interactions, and postinteractive niche separation (multivariate community spaces actually occupied by species population in the presence of other species). Habitat selection of wide-ranging vertebrates and dispersal and colonization processes of many species take place at the scale of 100 to 10,000-hectare landscapes, or even larger. Models that incorporate both demographic and environmental factors suggest that genetic diversity and divergence in populations is most affected by the proportion of biotic communities in the landscape that are occupied (as affected by disturbance frequency) and the density of individuals within the communities as

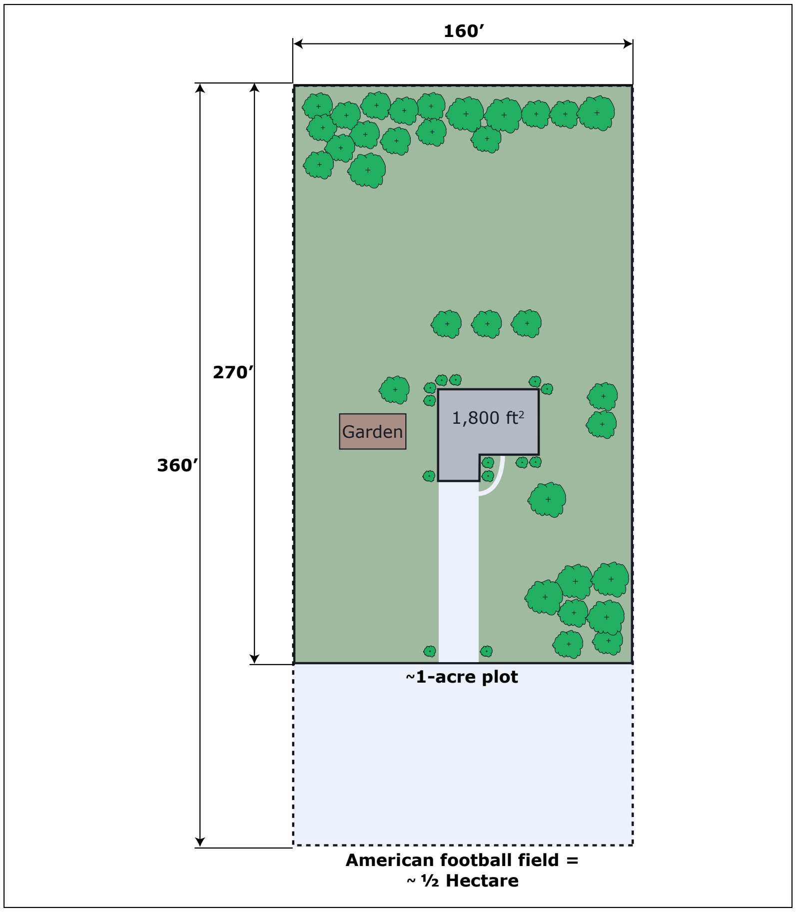
Figure 69—Differences in home range size: (A) Movement patterns of three northern flying squirrels on an approximately 0.5-square kilometer plot of 300-year-old trees—the darker the background color, the higher the density of large conifers; (B) areas used by a northern spotted owl across about 4.0 square kilometers of forest during the nonbreeding season (adapted from Carey et al. 1999b and Carey and Peeler 1995). Graphic by A. Wilson.



determined by habitat quality (Gibbs 2001). This is a key point in landscape design—avoidance of environmental conditions and community structure that leads to depauperate communities (low proportions of communities occupied for many species), with poor-quality habitat for many species that do inhabit them, and that also reduce permeability of the landscape to dispersal. However, highly subdivided local populations suffering frequent local extinction may retain more diversity than less subdivided populations of equivalent size (Ray 2001), suggesting that shifting-steady state mosaics, with a low-to-moderate proportion of the landscape in reorganizing and early-seral states may provide many opportunities for maintaining genetic diversity and maximizing adaptiveness. This, in essence, is part of the creative destruction hypothesis of Holling's Panarchy theory. Thus, understanding how scale interacts with habitat quality is important to AIM for conservation of genetic diversity (table 29).

Across biotic communities in the landscape, various habitat dimensions exhibit high correlations ($r > 0.50$) with one another. That communities may differ in horizontal heterogeneity and vertical heterogeneity is apparent; heterogeneity, habitat space, and habitat breadth generally increase with time since catastrophic disturbance—but with niche-diversification communities having extreme values for some elements (e.g., snags and fallen trees). Structuring processes and habitat breadth explain more among-community variance in squirrel activity than individual habitat elements and provide better models of squirrel activity than even classification of communities into seral stages. Processes explain up to 75 percent of squirrel activity and squirrel carrying capacity. Managed forests in competitive exclusion, in general, have less developed niche space and coarser grain than forests in niche diversification and old-growth forests. Grain in old growth was less than the height of an old-growth tree (around 70 meters); that is, 50 meters for shrub patches, 25 meters for midstory development, and 80 meters for areas of closed canopy (Carey et al. 1999b). Small gaps (loss of one to three dominant trees) at high frequencies across old growth and low sun angles produce fine-scale heterogeneity with close juxtaposition of habitat elements (snags, fallen trees, patches of shrubs, patches of midstory, patches of herbaceous cover, patches of open forest floor) and different species and life forms. In response to increased heterogeneity on a fine scale, foraging patches and home ranges overlap more and total activity increases. Thus, accumulation of processes in late-seral, natural stands results in an emergent property of niche diversification that provides more stable habitat for squirrels; carrying capacities for squirrels have maximum values in old growth.

Figure 70—Visualizing acres and hectares: There are 2.5 acres in 1 hectare. An American football field is approximately a half hectare in size. A 1-acre house plot fills approximately 75 percent of a football field. Thus, a squirrel moves across a good part of a suburban neighborhood in one night. Graphic by A. Wilson.



Nevertheless, individual communities deviate significantly from average conditions within their nominal seral stages in their capacity to support squirrels and in various measures of habitat space. As Carey (1995) reported for the Olympic Peninsula, nominal seral stage may not always be a good predictor of habitat quality. Structuring processes, habitat breadth, and site moisture provide better descriptions of ecosystem development and niche diversification than nominal seral stage. Given process-based community development, AIM has the potential to accelerate niche diversification.

The role of spatial scale can be illustrated by the ecology of fishers in south-central British Columbia (Weir and Harestad 2003), goshawks in the Southwestern United States (Reynolds et al. 1992), and spotted owls in the Pacific Northwest (Carey 1985b, 1993; Carey et al. 1992, 1999b; Carey and Peeler 1995; Carey et al. 1990). Weir and Harestad (2003) described spatial scales as habitat elements within patches within biotic communities within home ranges within landscapes within the geographic range of the species. Fishers avoided areas without overhead (overstory or shrub) cover. The fishers selected areas for foraging at the biotic community and patch scales on the basis of coarse woody debris, foliage height diversity, and shrub cover; in other words, a complex forest floor provided the primary foraging areas for fishers. However, an overly complex forest floor (more than 80 percent shrub cover), may reduce the likelihood of capturing prey, and dense canopies intercept snow, leaving the forest floor more open. Fishers selected particular habitat elements for resting and denning, such as mistletoe brooms in spruce and cavities in deciduous trees, respectively. American marten exhibited similar selectivity in Ontario (Fryxell et al. 1999).

Goshawks exhibit selectivity at multiple spatial scales in the Pacific Northwest (Finn et al. 2002), interior Northwest (Hanauska-Brown and Bechard 2003), and Southwestern United States (Drennan and Beier 2003, Reynolds et al. 1992). The northern goshawk breeds in coniferous, deciduous, and mixed forest in North America (Reynolds et al. 1992). It uses various forest types, ages, structural conditions, and seral stages. The goshawk preys on small birds and mammals including robins, grouse, squirrels, and hares. In the Southwest, it is found in ponderosa pine, mixed species, and spruce-fir forests but has been declining in response to timber harvest, fire suppression, and grazing. Reynolds et al. (1992) developed management recommendations for goshawks based on several tenets: (1) goshawks and their prey are limited by their food and habitat; (2) abundant prey reduces the probability of food limitation on goshawks; (3) a wide variety of prey is less likely to result in goshawk population fluctuations than one or two prey species; and (4) active, intentional management for goshawks can sustain goshawk habitat. They concluded that past management had produced thickets of small trees prone to fire, insects, and diseases and will require disturbance before developing further. They also recognized that forest

Table 29—**The scales and attributes of ecosystems**

	Structure	Composition	Processes
Regional	▪ Major landform features	▪ Regional species pool	▪ Climate, weather, and geologic events
Landscape	▪ Landscape patterns and dynamics	▪ Landscape elements	▪ Disturbance regimes
Biotic community	▪ Relative abundance of life forms, functional groups, and species	▪ Species, genotypes, and ecotypes	▪ Development, mutualism, synergy, competition, and predation
Population	▪ Age structure and sex ratio	▪ Genetic diversity	▪ Colonization, birth, death, and dispersal

Source: Adapted from Noss 1990.

reorganization, growth, and development differ with location and that no single management prescription is likely to be appropriate for all sites. Large live trees, snags, and fallen trees, however, are important elements of the habitat of a variety of plants and animals and *every hectare should contain several*. A landscape most suitable to goshawk persistence would be one of an interspersed mosaic of developmental stages.

Goshawk habitat requirements include two to four nest patches (around 12 hectares) of large old trees with dense canopy cover. A family area of 170 hectares around a nest patch consisting of a variety of forest types and conditions is necessary for fledglings to hide in (patches of dense trees) and to learn hunting techniques (patches of herbaceous and shrubby understory mixed with small openings, snags, and logs). A larger foraging area of around 2,200 hectares is needed. This latter area is best characterized by large trees, relatively open understories, with small (0.1 to 0.8 hectare) to medium (0.8 to 1.5 hectare) openings (with a maximum width of 40 to 60 meters), with dense patches of thickets scattered throughout; the majority should be mid-aged to old forest (Reynolds et al. 1992). Active, intentional management techniques include long (200- to 300-year) rotations, legacy retention with live legacy trees in groups of 3 to 6 with 2 to 5 groups per hectare, 5 to 7 snags per hectare, 7 to 12 fallen trees per hectare, and 12 to 35 megagrams of coarse woody debris per hectare; thinning from below with non-uniform spacing, minimizing road density and permanent skid trails; and prescribed burning to reduce fuels. Projected benefits beyond those to goshawks include improved landscape function, habitat for old-growth species, reduced susceptibility to catastrophic disturbance, increased forest productivity, enriched mycorrhizal communities, forest products, and forage production.

Spotted owls selectively use old forest out of proportion to its occurrence in mosaic landscapes, and concentrations of old forests result in smaller home ranges and more stable social structures (Carey et al. 1992, Carey and Peeler 1995, Carey et al. 1990). Selection for complex forests and forest floors for foraging is related to prey abundance and opportunities to catch prey for spotted owls in the Pacific Northwest (Carey et al. 1992, 1999b); but as old forests are fragmented, prey may be depleted temporarily by owl predation, and owls may switch to younger forests, especially younger complex forests, where prey may be temporarily higher than in the exploited old growth. Thus, at the landscape level, replacement of late-seral forest by ecosystem-reorganization and competitive-exclusion stages has negative effects on spotted owls (Carey and Peeler 1995). These managed forests are avoided or used rarely, although, where dusky-footed woodrats are abundant, owls may forage along forest-clearcut edges (Diller and Thome 1999, Giusti 1999, Solis and Gutierrez 1990, Ward et al. 1998) and in early-seral stages (Carey et al. 1992). But managed and natural forests more advanced in development (understory reinitiation and niche diversification) may be around 25 percent of the areas regularly used by spotted owls for roosting and foraging. The biomass of squirrels (Douglas' squirrel, northern flying squirrel, and Townsend's chipmunk) increases with forest development (Carey 1995). The size of all three squirrels makes them especially attractive to predators common in Pacific Northwest forests, such as hawks, owls, and weasels. The squirrels are near the maximum size limit for many of these predators. Abundances of chipmunks, flying squirrels, and Douglas' squirrels increase with forest development despite overlap in their diets, den site use, and space use (Carey 1991, 1995; Carey et al. 1999b, 1997). The squirrels seem limited by variability in food abundance and dens but not interspecific competition in complex environments. Late stages of forest development provide habitat structure that mediates predation and variety in fruit production that offsets high variability in availability of individual food items. The resulting increased prey biomass attracts and supports predators.

CHAPTER 8

AIM for Resilient Forests

Active, intentional management for resilient, biologically complex forests has the purpose of maintaining forested ecosystems and landscapes that first and foremost are capable of adapting to changing environmental conditions, including global climate change. Managing for resiliency is the first obligation for intergenerational equity. Managing for biocomplexity serves the purpose of maintaining biological diversity and the diverse values contemporary society desires from its forests, including broad values of environmental sustainability, social civility and equity, and economic activity. These values are diverse: clean air and carbon sequestration; clean water with modulated flows; open, green space; aesthetic, natural places for recreation and spiritual renewal; complete biotic communities of plants, fungi, invertebrates, and vertebrates; healthy soils with minimal erosion; abundant populations of various species of wildlife and fish; provision for subsistence hunting, fishing, and gathering guaranteed to Native Americans as obligated by treaties; opportunities for hunting, fishing, and gathering by other people; opportunities for wildlife viewing and nature study; sustainable flows of wood products that allow society to meet its needs domestically from environmentally beneficial forestry without contributing to degradation of the environment in less-developed countries and that contributes to

Sidenote 60—The Seven Stages of Ecosystem Management (Brussard et al. 1998)—Ecosystem management is managing areas at various scales in such a way that ecosystem services and biological resources are preserved while appropriate human uses and options for livelihood are sustained. The stages of ecosystem management are:

- Delineate the system to be managed.
- Define strategic goals [degree of intentionality].
- Develop a comprehensive understanding of the ecosystem.
- Analyze the socioeconomic contexts.
- Link the socioeconomic and ecological understandings in a heuristic model.
- Implement experimental management actions.
- Monitor results, assess long-term success or failure, and apply learning to the next management action.

domestic economic activity and the support of rural communities; sustainable flows of commercial nontimber products such as mushrooms, floral greens, and other natural products; and revenues to landowners be they federal, state, trusts, corporate, or nonindustrial, small, private landowners. This is a tall order.

Management can be passive (the choice is made not to intervene in any way except to reduce or exclude human activities), reactive (responding only to threats or emergencies), or active (deliberate actions are taken). Passive management includes designation of reserves, such as research natural areas, wildernesses, national parks, late-successional reserves, and areas devoted to particular species. The Nature Conservancy has a long history of success in establishing reserves of especially valuable (aesthectically, scientifically, biologically, and rare in the landscape) ecosystems. Some actions, such as fire threat reduction and restoration activities, may be appropriate in some of these reserves. Passive and reactive management contribute to achieving some of the goals of AIM (including some that cannot be achieved with active management, such as protection of old-growth forests) but cannot fully achieve AIM for multiple values. Active management of forests occurs anytime silvicultural practices are implemented, even when the stated intent is management for one or a narrow set of particular products, species, or structures rather than management of processes. This, of course, is not the same as AIM for resilient, complex forests that are valued by people for diverse reasons. This difference between common active management and AIM is in intent. Active, intentional managemant can be evaluated by using the concept of intentionality—the degree to which all information (social, economic, and ecological) has been considered in determining how to manage ecological processes for sustainability of complex social, economic, and ecological systems (that is, what the manager thinks about in deciding "what to chop"). Thus, AIM, and other less-developed forms of ecosystem management (Brussard et al. 1998, Grumbine 1994) (sidenotes 60, 61), are significant in that they focus on whole systems (AIM addresses holarchies), not some few parts of a system; they include public involvement in goal setting (AIM extends that to on-the-ground collaborative management and monitoring); they integrate conservation into economic activity (AIM includes noncommodity instrumental values and aesthetic-spiritual values as well); and they shift from a paradigm of linear comprehensive management to cyclic-incremental or adaptive management (AIM extends this shift to nonlinear thinking and managing for system adaptiveness). Ecosystem management has as its overriding goal to "ensure that ecological services and biological resources do not erode irreversibly as a result of human activities;" sustainable ecosystem management maintains or enhances current utility, future potential, containment, and resilience (Brussard et al. 1998) (sidenote 62). On the other hand, AIM seeks to integrate values for ecological services and biological diversity into the very thought processes underlying management. Active, intentional management attempts to integrate applied sciences—forestry, wildlife management, range management, recreation management, epidemiology, integrated pest management, fire threat reduction, transportation system management, and forest engineering. Also, AIM emphasizes maintaining a high diversity of species, keystone complexes, ecosystem function, and ecosystem adaptability to changing environmental conditions. There are well-documented (1) patterns of commonness and rarity of known species—most are rare (Preston 1948, 1960, 1962a, 1962b, 1969, 1980, 1981); (2) significant roles of randomness and stochasticity in influencing species occurrences (Hubbell 2001); (3) substantial ignorance of most species (most have yet to be described); and (4) inevitable change in ecosystems (sidenote 63) and the composition of their biotic communities through time and space, all of which owing to the increasing stress from increasing human populations, species invasions, global climate change, surprises, and shifts among alternative stable states (Gunderson and Holling 2002, Johnson and Mayeux 1992, Paine et al. 1998, Tausch et al. 1993). Active, intentional management does not pretend to maintain all species in every place where they once occurred or where they could potentially occur under extant conditions. It does seek to conserve biological diversity and recognizes the special values of keystone, flagship, relict, aesthetic, and charismatic species, species diversity, and functional group diversity to ecosystem stability (table 30) and productivity, conservation of nature, and to people; thus, AIM focuses on reality and empiricism when setting goals. For example, species dominance, and even membership, of functional groups might change, but the ecological function may be retained; reduction of the diversity within functional groups, then, may result in loss of system adaptiveness. Active, intentional management seeks to control the introduction of, and to remove, introduced and damaging exotic species but also recognizes species introductions will occur no matter what steps are taken and that not all introduced species will result in significant impairment of ecosystem function or loss of native diversity. And not all introductions of damaging species, from whatever source, will be reversible, even with substantial effort. Thus, AIM focuses as much as possible on (1) management of processes to maintain native diversity and maximize resilience and adaptiveness;

Sidenote 61—What is ecosystem management? (Grumbine 1994)—Ecosystem management is integration of scientific knowledge of ecological relationships within a complex sociopolitical and values framework toward the general goal of protecting ecosystem integrity, including the protection and maintenance of:

- Natural ecosystem types (biotic communities)
- The diversity of native species
- Ecosystem health and integrity
- Ecosystem processes
- Ecosystem services
- Human economies based on ecological principles
- Sustainable production of ecosystem products

Sidenote 62—"Viable" systems (Brussard et al. 1998):

- Currently provide expected goods and services with reasonable efficiency
- Have present uses that are not disrupting processes, which generate and maintain the desired composition, structure, and function of the ecosystem or its future potential
- Have a present use and current condition that does not degrade areas beyond the systems borders
- Have the capacity for self-maintenance and self-regeneration after moderate external stresses or perturbations

(2) use of developmental pathways and trajectories to predict and manage for future conditions; and (3) use of baselines, benchmarks, and monitoring of carefully selected groups of species to judge failure, progress, and success (table 31). Active, intentional management strives to integrate individual, social, economic, and environmental values into a coherent whole that is normative in determining which human demands and management practices are appropriate in managing the interactions of individuals, human communities, and biotic communities. Key fundamental values for AIM for general sustainability include intragenerational, transnational, and intergenerational equity. Intentional management requires broad participation by stakeholders and a new, sophisticated role for scientists as (1) science interpreters; (2) decentered participant-facilitators of issue formulation, debate, and issue resolution; (3) modelers and testers of resolutions; and (4) participant-facilitators in group learning (sidenote 64). Good AIM requires separating the wheat from the chaff in collaborative experimental learning processes, embracing ambiguity, uncertainty, and change, and proceeding with the highest intentions and most decentered views.

Sidenote 63—Ecosystem stability and the balance of nature according to Johnson and Mayeux (1992):

- Common assumptions about ecosystem stability and a delicate balance of nature are unwarranted paleoecologically, biochronologically, and biogeographically.
- Species have been *added* and *removed* without greatly affecting ecosystem function.
- Natural ecosystems exhibit greater stability (inertia) in physiognomic structure and functional processes than in species composition.
- Some ecosystems persist in unstable rather than stable states.

And according to Tausch et al. (1993):

- There is no natural vegetation (equilibrium condition); plant communities differ in space and time.
- No area is without some human impact.
- No management is impossible given human impacts and exotic invasions.

Components

A dozen or more on-the-ground tactics are used in AIM strategies for biodiversity, biocomplexity, resilience, and general sustainability.

Legacy Retention

Active, intentional management extends the concepts of green-tree retention, snag retention, structural retention, and variable-retention harvest systems to retention and maintenance of both biological and geological legacies during every step of active management. In managed forests, variable-retention harvesting is often the catastrophic disturbance/creative destruction event/reorganizing force that sets the stage and determines the species retained onsite to reorganize into a new community. Legacy retention should be integrated with protection of rock outcrops, talus slopes, balds, meadows, seeps, springs, wetlands, headwater streams, colluvial soil, areas of deep-seated landslides, areas of shallow-rapid landslides, streamsides, riversides, and areas of excessively poor potential for growth of trees. These geological features form a template for the retention of intact patches of forest (clumped and linear legacy retention) and form the first basis of a landscape mosaic. The degree of retention of biological legacies outside these patches then differs inversely with rotation age of forests (time between major harvests that result in ecosystem reorganization) and size of harvest units: the shorter the rotation age, the greater the legacy retention in variable-retention harvest systems; the larger the harvest unit, the greater the retention. Both Washington and Oregon (and many other states) have minimum guidelines for retention outside of the geologic areas. The goal of AIM is to maintain a biologically-complex forest over the landscape

Table 30—Characteristics of ecosystem stability and resilience that can be used predictively or in monitoring

Characteristic	Definition	Example
Inertia	▪ Resistance to change in structure, function, or trajectory of development	▪ A gap-phase complex-forest mosaic is unaffected by low to moderate tree mortality because trees regenerate and grow; even gaps of 5 to 7 trees can be assimilated. A conifer forest with poor height : diameter ratio has little inertia in the face of wind, ice, or snowstorms; older ponderosa pine parklands are little affected by low- to moderate-severity surface fires.
Elasticity	▪ Rapidity or time of restoration of structure, function, and trajectory of development	▪ Older closed-canopy Douglas-fir monocultures may have less elasticity than a multispecies multitolerance complex; a multispecies complex may require 120 years to develop from reoganization to niche diversification; fire-prone lodgepole pine forests recover rapidly from crown fires owing to serotinous cones.
Amplitude	▪ Brittleness, or range of disturbances from which the system can recover structure, function, and trajectory	▪ Complex forests in landscapes of complex forests may recover from minor to catastrophic disturbance; simplified forests may not recover complex structure and function from even patch-level disturbances such as root rot; with prolonged fire exclusion, many forest types may not recover after a catastrophic disturbance.
Hysteresis	▪ Degree to which restoration is an exact reversal of the path of degradation, more relevant to chronic than acute disturbance	▪ After disturbance, do the last species to die return first, or are they last in a succession of species? What happens when livestock are removed from a range?
Malleability	▪ Ease of permanent alteration; degree to which the recovered system differs from the original system prior to disturbance	▪ Depending on disturbance regime, a complex forest may return along a continuum from a complex state of high biotic integrity to a species-poor, simplified alternative stable state.

Source: Adapted from Westman 1978.

and each site, biotope, and ecosystem within the landscape. In western Washington, conservation of biodiversity seems to be possible if less than 15 percent of the landscape is in early-seral stages of forest development in any decade and about 15 percent of each variable-retention harvest unit is retained as forest. Actual retention, however, must be determined in major part by the combination of geologic influences on retention and effects of rotation age and harvest unit size on reducing forest influence at the level of site and landscape.

During intermediate treatments (precommercial and commercial thinnings), legacies should be identified, protected, and enhanced. Skips in thinnings can be used to protect ecologically important features such as cavity trees, moderately decayed snags, small wetlands, intact patches of forest floor, and legacies left during the preceding reorganizing disturbance (such as intact patches of older forest). Large fallen trees can be protected and even sometimes moved and replaced to facilitate movement of equipment. Gaps can be used to favor growth of selected trees like bigleaf maple or madrone, promote epicormic branching on legacy trees, and release advanced shade-tolerant regeneration.

Sidenote 64—Roles of scientists, technologists, and land managers in collaborative management:

- Scientists are often (1) historians of the development of new knowledge and new practices; (2) philosophers, relating science to different values (Ph. D. is doctor of philosophy—the study of the nature and principles of knowledge, truth, existence, and moral and aesthetic values); (3) technical or technological experts and advisors; (4) informed public citizens; and (5) critical thinkers.
- Technical specialists play different roles—they (1) help to set organizational priorities and management standards; (2) compile specific local information on environmental variables, populations, and habitat relationships; and (3) make measurement and collect data.
- Land managers often (1) know the history of specific pieces of land—its characteristics, use and utility, and response to management; (2) have conducted case history experiments; (3) serve as implementers of management decisions; (4) may offer a particular land ethic; and (5) may be knowledgeable about economic, agronomic, and ecologic productivity.

Multispecies Management

At each step of active management from variable-retention harvests to planting to precommercial and commercial thinning, care is taken to ensure multiple site-appropriate trees species are maintained. Two or more species of conifers and two or more species of deciduous trees are desirable for numerous ecological and economic reasons, but not, of course, in equal abundance. Beyond trees, in making decisions about what to manipulate, attention is paid to promoting a variety of tall shrubs as well. The relative abundances of species to be promoted differ with site, potential natural vegetation classifications, predictions about what might happen to plant communities with climate change, management of decadence (e.g., maintaining deciduous trees that might become cavity trees and conifers, like grand fir, that have high potential to form hollow trees), and opportunities for diversification of wood products in terms of species (e.g., Douglas-fir, western redcedar, and red alder all have different markets) (figs. 71, 72).

SAVE Trees and Shrubs

Over 50 species of trees and shrubs in the Pacific Northwest have special attributes that are valuable ecologically (SAVE). These SAVE trees exist in almost all forest (see, e.g., Carey and Gill 1980 and Carey and Healy 1981 for Appalachian forests). Wilson and Carey (N.d.) provide a list of these for the Pacific Northwest (table 32) and guidance on marking for retention during precommercial and commercial thinning and variable-retention harvesting. A few of these go a long way. If absent, seeding and underplanting some of these may be appropriate.

Planting, Underplanting, and Seeding

Planting is used to recover a forested condition quickly and to ensure some minimum level of tree species diversity and density. Substantial natural regeneration usually accompanies planting. When management or lack of management has resulted in closed-canopy monocultures, underplanting and seeding can be useful tools to restore lost diversity of trees and shrubs, particularly tall shrubs, deciduous trees, and shade-tolerant trees, depending on site and region.

Precommercial Thinning

After legacy retention, precommercial thinning provides the next most important intervention to ensure that biological diversity is promoted instead of discouraged and to set the stage for the fine-scale mosaic that will characterize the developing ecosystem. Of course, legacy maintenance is an important factor in precommercial thinning. But the main features of precommercial thinning are (1) maintenance of tree and shrub diversity, (2) promotion of crown-class differentiation, (3) promotion of rapid growth, and (4) opportunities to develop isolated dominant trees with deep crowns that provide shelter and foraging normally found only in older trees. Although empirical guidance is lacking, precommercial thinning offers opportunities for experimenting with spatial pattern to produce biocomplexity. Clumps of deciduous trees could be maintained. Shade-intolerant trees can be alternated with shade-tolerant trees to hasten crown-class differentiation and, in time, canopy stratification. Providing growing space to individual deciduous trees like red alder and black cottonwood can lead eventually to cavity tree formation during periods of community development in which few cavities are being formed in conifers. Providing growing space to individual bigleaf maple enhances numerous aspects of biocomplexity.

Commercial Thinning

Heretofore, considerable discussion has been devoted to the benefits of commercial variable-density thinning, and it will not be repeated here. But it is important to recognize, that commercial thinning offers the same opportunities as precommercial thinning to ensure tree and shrub diversity, implement SAVE tree guidelines, and protect legacies. In addition, commercial entries also provide the resources for decadence management—stimulating the development of cavity trees and augmenting coarse woody debris on the forest floor—and underplanting and seeding to restore missing elements of diversity. Thus, thinning also can be used to mitigate effects of past mismanagement and to restore forest health, including increasing resistance to wind and snow damage, reducing susceptibility to crowding, moisture stress, and insect attack, mitigating the effects of dense monocultures on development and spread of root disease, and reducing risk of catastrophic fire. As in all aspects of AIM for resilience, the situations will always be complex and will require site-specific analyses as well as landscape- and regional-scale analysis and planning. In addition to decadence management, underplanting,

Table 31—**Prediction and description of stability and resilience**

Index	Inertia	Recovery
1	▪ Adaptation of indigenous species to environmental fluctuation	▪ Proximity of recolonization sources and landscape permeability
2	▪ Degree of functional redundancy	▪ Mobility of propagules and biological legacy retention
3	▪ Cleansing capacity for pollutants	▪ Physiochemical suitability of site for recolonizaton
4	▪ Chemical and biomass accumulation buffering	▪ Biocomplexity and niche diversification
5	▪ Proximity of key variables to change thresholds	▪ Toxicity of site, presence of ruderal, and exotic species
6	▪ Degree of management efficacy	▪ Degree of management efficacy

Source: Adapted from Cairns and Dickson 1977 and Cairns 1986.

and seeding, prescribed fire at times can be a useful adjunct in commercial thinning. In almost all cases, inducing heterogeneity at a fine sale (0.2 to 1 hectare) will be appropriate and help contribute to achieving biocomplexity, increasing resilience, and mitigating the forest health risks resulting from poor past management.

Decadence Management

Decadence management includes retaining coarse woody debris on the ground throughout a major harvest area. Covers of more than 10 percent in dry-mesic Douglas-fir forest and more than 15 percent in mesic-hydric western hemlock forests seem reasonable targets. The smaller the diameters left and the closer the values are to 10 percent and 15 percent, the sooner the coarse woody debris will need to be augmented. Provision should be made for cavity trees during major harvests. These could include well- to moderately-decayed conifers more than 80 centimeters in diameter at breast height (d.b.h.),

Figure 71—Second-growth clumped legacy retention with hardwoods in an industrial forest. Photo by A. Carey.

lightly- to moderately-decayed trees more than 80 centimeters in d.b.h., live trees more than 50 centimeters in d.b.h. but with evidence of past damage to the top and a reiterated top; live trees more than 50 centimeters in d.b.h. that are sound can be left, topped above two to three whorls of live branches, and branches perpendicular to prevailing wind direction can be lopped to reduce wind resistance. The shorter and more decayed the trees are, the shorter time they will serve as a cavity tree. A well-decayed, short (greater than 5 meters), large snag may be used for nesting only occasionally by small secondary cavity-using birds or small mammals. Large lightly- to moderately-decayed live trees and dead trees will be used for nesting, roosting, perching, and denning often, and simultaneously, by a variety of cavity-using birds and mammals. Retaining deciduous trees to allow them to grow and later be overtopped and become snags (red alder) or to be maintained indefinitely and develop cavities while still alive (madrone and bigleaf maple) is an important aspect of decadence management.

During thinnings, trees with cavities or with high potential for cavities can be marked for retention. Some dominant live trees can be wounded (cavities excavated, lightning scars simulated, and crevices incised with a chainsaw—to more quickly provide cavities and crevices to wildlife and to provide the proximal cues to wildlife that such a tree may have cavities and crevices), topped, and released to promote continued height growth, allow a new crown to develop, accelerate development of epicormic branches, and initiate decay processes that can continue for decades to centuries. Some damage will be caused by the felling of trees and contribute to the decadence

Figure 72—Mixed hardwood-conifer legacy retention along streams and seeps in an industrial forest. Photo by A. Carey.

processes; second and third thinnings in older stands are more likely to promote decadence in some retained dominants. Inoculation with decay-causing fungi also works in some systems, and artificial cavity and nest structures can be used to promote early colonization of young forests by cavity-nesters and to benefit threatened species (Bellrose et al. 1964; Bull 1991; Bull et al. 1997, 1981; Carey 2002b; Carey and Gill 1983; Carey and Sanderson 1981; Carey et al. 1999d; Copeyon et al. 1991; Lewis 1998; McArdle et al. 1961; McComb and Noble 1981a, 1981b, 1981c; Parks et al. 1999). If, because of past management, coarse woody debris is sparse, some felled trees can be left to contribute to maintaining the 10 percent and 15 percent levels; if large fallen trees are absent, smaller trees can be aligned longitudinally and stacked as pyramidally to form coarse woody debris structures with large size and high surface area to promote high biological activity.

Rotation Age and Uneven-Age Management

The longevity of Pacific Northwest conifers allows more flexibility in management than in many other forest types. Many of the techniques presented here can be used in restoration efforts to direct second-growth forests to trajectories that will eventually produce old forests with the biocomplexity of present-day old growth; active management may cease after 1 to 10 decades. Douglas-fir/western hemlock/western redcedar forests, redwood forests, and some other types can be actively managed indefinitely (more than 500 to 1,000 years) without the need for “creative destruction” or an event that leads to fundamental reorganization of the biotic community. Douglas-fir dominated forests can be thinned multiple times with gradual replacement with shade-tolerant trees; at some point, no more dominant Douglas-fir will be taken, a significant Douglas-fir presence can be maintained, and continuous removal and autogenic replacement of shade-tolerants can occur. Uneven-age management systems can be used, but regeneration of Douglas-fir may require group-selection harvests that are essentially small patch cuts around 1 hectare. Uneven-age management can be used in hemlock-cedar forests. At the other end of AIM for multiple values, variable-retention harvests on alternating 70- to 80-year and 130- to 150-year intervals (with no major harvests on unstable slopes, next to streams, and other areas of special value) can be combined with multiple variable-density thinnings to produce robust, resilient forests in landscapes dominated by late-seral complex forest with high capacity for biological diversity, adaptation, and other environmental values while simultaneously contributing greatly to social and economic values. Severe ecological problems arise when rotation ages less than the above are used; rotation ages are prime determinants of cumulative effects in both space and time and determine, in large part, landscape character and potential for impacts on aquatic systems.

Landscape Management

Rotation age does much to determine the nature of the shifting, steady-state mosaic of AIM landscapes. However, the stage must be set before the play unfolds. Stage setting includes geologic and geomorphologic analysis at the watershed scale to identify unstable slopes, fragile soils, fragile biotic communities, riparian areas, reserves, special landscape elements, transportation systems (including public access management), and zoning for equipment use. Once the stage is set, then the condition of the various ecosystems in the landscape must be evaluated. Then the need for, and potential of, various AIM strategies and techniques can be assessed and an AIM implementation plan developed. Care must be taken, however, not to make the

Table 32—Tree and shrub species of the Pacific Northwest with special attributes that are valuable ecologically

Conifers	Broadleaf	Shrubs
Douglas-fir	Bigleaf maple	Black hawthorn
Grand fir	Bitter cherry	California hazelnut
Incense cedar	Black cottonwood	Cascara
Lodgepole pine	Oregon ash	Devil's club
Mountain hemlock	Oregon white oak	Elderberry spp.
Pacific silver fir	Pacific dogwood	Evergreen huckleberry
Pacific yew	Pacific madrone	Huckleberry spp.
Ponderosa pine	Paper birch	Indian plum
Sitka spruce	Red alder	Manzanita spp.
Subalpine fir		Oceanspray
Western hemlock		Oregongrape spp.
Western redcedar		Rosa spp.
Western white pine		Salal
Yellow-cedar		Salmonberry
		Saskatoon
		Sitka alder
		Sitka mountain ash
		Snowberry spp.
		Vine maple
		Willow spp.

Source: Wilson and Carey [N.d.].

analysis and plan the driving goals; conservation of nature is the driving goal with environmental, social, and economic sustainability the ultimate goals. Care must be taken to avoid unnecessary zoning because zoning tremendously complicates efforts at restoration and sustainability (Carey et al. 1999c); the more constraints placed on the landscape, the less operational the landscape becomes. Care should be taken in formulating operating principles and instilling normative values for conducting on-the-ground operations for all involved from those setting specific objectives to those carrying out a narrow action on the ground. If longer rotations and good stage setting were used and the entire management group could come to consensus on a land ethic, much of present day zoning would be unnecessary in AIM landscapes. Similarly, collaborative management must be willing to accept short-term impacts and short-term risks to achieve long-term benefits and long-term risk reduction; overly zealous application of the precautionary principle often is a deliberate, conscious management decision to forego long-term increases in forest health and resilience to avoid short-term responsibility or controversy. If collaborative managers recognize their role as one of disturbance managers—to plan and implement disturbance to foster ecosystem and landscape resilience—some of the fear of short-term disturbance may be ameliorated (sidenotes 64, 65).

Sidenote 65—Roles of scientists (Lach et al. 2003):

- Reporting science results that others use in making decisions
- Reporting and interpreting science results for others involved in decisions
- Working closely with managers and others in integrating science results into management decisions
- Actively advocating for specific and preferred natural resources decisions
- Making decisions about natural resources management and policy

A question still being asked (but more rarely) in the Pacific Northwest is “Should old growth be actively managed?” Old-growth forests in the Pacific Northwest are unique, perishable, and irreplaceable (Carey 1998b). Old growth is a unique heterogeneous set of forests that developed under various unique sets of conditions over multiple physiographic and biogeograpic regions over various time periods ranging from 250 to over 1,000 years. In any one locale, old growth tends to be of the same approximate age (and can be defined by that age) and to have arisen from one or more large-scale fires and to have been affected by a subsequent series of intermediate-scale disturbances by fire, wind, and disease. All old growth shows evidence of small-scale disturbances owing to disease, wind, fire, and decadence that provide a variety of structures from snags to gaps. The various disturbances that originated and shaped the development of old-growth ecosystems produced forests of dimensions in terms of size of structures, biodiversity, complexity, and emergent properties that have not been matched in managed forests. Managers will never be able to recreate the disturbance histories and geographically extensive contexts under which today’s old-growth forests developed; thus, these forests are irreplaceable. Even though old-growth forests are quite stable compared to younger stands, they still are susceptible to catastrophic disturbance, for example, the old growth destroyed by the eruption of Mount St. Helens, tsunamis on the Washington coast, castastrophic windstorms on the Olympic Peninsula, and fire throughout the Pacific Northwest. In addition, the old Douglas-fir that characterizes much of the Pacific Northwest old growth will all eventually die; the loss of Douglas-fir changes the nature of the stand from a successional stage to a quasi-climax stage dominated by shade-tolerant tree species. Thus, old growth is perishable. Science suggests that thoughtful management could produce complex forests that provide many of the functions of old growth and habitat for many of the species found in old growth. Of course, the full biodiversity associated with old growth will never be known. Complex forests created by managers will take hundreds of years to develop the stature of natural old growth. Thus, managers will never know if they were successful in recreating old growth. Thus, for all practical conservation purposes, managers cannot recreate old growth or manipulate old growth with predictable results. The public resistance to further destruction of the natural legacies in the Pacific Northwest suggests further harvesting of old growth will likely evoke more protests, sometimes destruction of equipment, and litigation.

Sidenote 66—President Clinton's five principles (Haynes and Perez 2001):

- Never forget human and economic dimensions
- Protect the long-term health of forests, wildlife, and water
- Use science that is sound, ecologically credible, and legally responsible
- Produce predictable and sustainable flows of timber and nontimber forest products
- Insist on collaboration, not confrontation

Sidenote 67—Lessons from the Northwest Forest Plan (Haynes and Perez 2001):

- A focus on individual species is necessary, but not sufficient.
- Elucidation of the key roles of species, species groups, and biotic communities is important to effective management.
- Providing for long-term evolutionary capacity is important.
- Intermittent streams are important in providing coarse woody debris and sediment to large streams.
- Legacies are important to aquatic communities.
- Collaborative adaptive management is necessary.
- Top down standards and guidelines do not work.
- Physiographic provinces differ in many ways.
- How timber is sold and contracted is as important as how much is sold.
- Communities differ.
- Nontimber forest products are important.
- Fungi are not old-growth dependent.
- Long rotations are good.

Common Questions

The last century of exploitation of natural resources and societal conflicts over the disposition of natural resources has been intense as large numbers of people moved westward across North America and as preindustrial countries developed. These issues culminated and permeated in forests and human communities in the Pacific Northwest (see, e.g., Behan 2001, Daily and Ellison 2002, Golden 1999, Harris 1996, Kemmis 2001, and Satterfield 2002). Many lessons have been rendered about ecology and the sociology of protection, restoration, maintenance, and utilization of biodiversity (sidenotes 66, 67). Whereas silviculture is occasionally questioned in the management of nonindustrial and industrial private forests, its use is coming under closer scrutiny in the management of public forests. In particular, the use of silviculture to achieve ecological benefits in second-growth forests in late-successional reserves has raised several questions. How can such questions, often based on the history of mismanagement and mistrust of agencies and experts, be answered? It appears the sociology of conservation needs more development than ecosystem management does. Dryzek (1992) describes the three main institutions of our society (capitalism, "liberal" democracy, and the administrative state) as thoroughly inept as regards to ecology and conservation. There is no cookbook approach that will achieve intentionality; management must be site specific and in the context of a spatial hierarchy. Thus, I will list only management technique tactics that can be integrated into AIM for multiple values if and when the mechanism for achieving discussion, collaborative learning, and collaborative management replace adversarial, position-based jousting (see Thomas 2002 for further discussion of the "The Conflict Industry").

The toolbox includes legacy retention and maintenance, planting and seeding, control of species composition, exotic species management, precommercial thinning, underplanting, variable-density thinning, coarse woody debris augmentation, cavity tree augmentation, variable-retention harvesting systems, and uneven-age management systems at the level of biotic communities. At the landscape level, management (sidenote 68) includes protection of special landscape elements; transportation systems; recreation opportunities and recreational access management; harvesting of timber and nontimber forest products; aquatic conservation strategies for wetlands, riparian areas, and unstable slopes; extractions of minerals and fossil fuels; locations and routing of highways, power lines, and communication towers; and reserves. Reserve management is a field unto itself: in the Pacific Northwest, 3 million hectares are in congressionally reserved lands; 3 million hectares have been administratively withdrawn into late-successional reserves, over 600,000 hectares have been constrained in adaptive management areas, and 1.1 million hectares are in riparian reserves, for 8.3 million hectares of federally administrated forests on which management is restricted and tightly regulated. Federal lands available for collaborative management include 1.6 million hectares of "matrix" lands embedded in 7.7 million hectares of reserves (Haynes and Perez 2001). Additional state, county, and private lands have been constrained under designation as parks, habitat conservation plans, riparian buffer areas, and areas of unstable soil.

Sidenote 68—General principles of landscape management (Lindenmayer and Franklin 2002):

- Maintain connectivity.
- Maintain landscape heterogeneity.
- Maintain ecosystem complexity.
- Maintain intact aquatic systems.
- Spread risk—do not do the same thing everywhere.

Will Plantations Develop Into Old Growth?

The answer to this question is "No," for the very same reasons that old growth is unique and irreplaceable in the previous discussion. Will plantations in late-successional reserves develop into complex forests that have many of the attributes of old growth? The answer to this question is a qualified "Yes, but it would take centuries." There are two qualifications. First, and most obvious, is that there be no global climate change of sufficient magnitude to change the type of vegetation that would naturally occur in the region. Second, the speed at which second growth develops late-seral character depends on the multitude of factors that led to its current condition. The timber harvest that created the second growth was quite unlike the natural disturbance that led to old growth. Clearcutting, burning, and planting often produce simplified, depauperate forests that could take more than 250 years to develop conditions suitable for recolonization by late-seral species. The sooner the canopy closes and the longer it remains closed in a plantation, the less likely a wide variety of seeds of native species will be retained in the soil, including those of shade-tolerant trees (Halpern et al. 1999). In some cases, the existing stand may have to be destroyed by natural disturbances and replaced by a larger variety of trees before development can proceed. Monocultures of small, dense trees are often more susceptible to disease and wind than natural stands and lack resilience, as well as resistance. Partial cuttings and "sloppy" clearcuts that left substantial legacies from a preceding old-growth stand may function as habitat for many late-seral species within 10 to 200 years depending on the amount of disturbance at harvest and subsequent natural disturbances. The speed of colonization of simplified second-growth forest by missing elements of natural forest will depend on the size and context of the forest in question. Although, modern clearcuts on federal lands often were less than 15 hectares (an area that could be colonized rapidly if surrounded by intact natural systems), extensive areas cumulatively were clearcut over several decades, and recolonization of these areas could take much longer. A key point is that development toward old growth is not inexorable; multiple alternative, relatively long-lived states exist for naturally regenerated forests and are more likely with forests regenerated with conventional silviculture.

Is Active Management Better Than Leaving Second Growth Alone?

The probability of active management accelerating the development of late-seral forest conditions will increase with the intentionality of the management and decrease with time since stand establishment. Certainly, precommercial thinning of densely stocked monocultures less than 20 years old is desirable, and its efficacy will increase with provisions for favoring volunteer seedlings of additional tree species, including deciduous species and for favoring tall shrubs. Conventional commercial thinning is more likely to be deleterious than not. Thinnings that are too light or too heavy are likely to be deleterious. Biodiversity management with variable-density thinning favoring a diversity of species, cavity tree retention, coarse woody debris conservation, and underplanting, cavity-tree creation, and coarse woody debris augmentation, when warranted, should increase the probability that the ecosystem will quickly develop late-seral characteristics (Carey 2000b, 2001; Carey and Harrington 2001; Carey et al. 1999b; Thysell and Carey 2000, 2001a; Wilson and Carey 2000).

Will Active Management of Second Growth Produce Negative Effects?

Short-term negative effects are unavoidable. Thinning will disturb the soil, kill trees, disrupt canopy connectivity, and reduce sporocarp production by belowground fungi. Thinning operations are destructive of plants and animals in the forest floor. Achlorophyllous mycotrophs (e.g., Indianpipe) may be negatively affected over the long term, but these negative impacts might be mitigated by leaving small unthinned patches within the stands. Thinning may decrease northern flying squirrel populations in the short term (less than 5 years). The same can be said of natural disturbances. Commercial thinning requires roads and use of heavy equipment within the forest with attendant disturbance effects. The positive benefits of thinning will most likely begin accruing after 5 years and could continue for a decade or more. Thus, active management for ecological values trades short-term negative effects for long-term gains. Commercial thinnings, by definition, remove biomass in the form of wood. Many second-growth stands contain many more stems than naturally young stands, and reduction in stem density is essential for a number of stand developmental processes. This reduction in biomass, however, can be at the expense of foregone standing dead trees, coarse woody debris recruitment, and total forest-floor organic matter with unintended negative consequences. Thus, high intentionality must be used in taking action to maintain (or enhance) decadence processes during thinning.

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English Equivalents

When you know:	Multiply by:	To find:
Millimeters	.0394	Inches
Centimeters	.394	Inches
Meters	3.28	Feet
Square meters	1.20	Square yards
Square meters per hectare	4.367	Square feet per acre
Cubic meters per hectare	14.292	Cubic feet per acre
Kilometers	.621	Miles
Square kilometers	.386	Square miles
Hectares	2.47	Acres
Hectares	259	Square miles
Kilograms per hectare	.893	Pounds per acre
Megagrams per hectare	.446	Tons per acre
Celsius	1.80 and add 32	Fahrenheit

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Appendix

Common and Scientific Names of Species[a]

Common name	Scientific name
VASCULAR PLANTS:	
Alaska oniongrass	*Melica subulata* (Griseb.) Scribn.
Aleutian maidenhair	*Adiantum aleuticu*m (Rupr.) Paris
American beech	*Fagus grandifolia* Ehrh.
American trailplant	*Adenocaulon bicolor* Hook.
American vetch	*Vicia americana* Muhl. ex Willd.
Antelope bitterbush	*Purshia tridentata* (Pursh) DC.
Artic sweet coltsfoot	*Petasites frigidus* (L.) Fries var. *palmatus* (Ait.) Cronq.
Baldhip rose	*Rosa gymnocarpa* Nutt.
Balsam fir	*Abies balsame*a (L.) P. Mill.
Basswood	*Tilia americana* L.
Bearberry	*Arctostaphylos uva-ursi* (L.) (Spreng.)
Bearded fescue	*Festuca subulata* Trin.
Big chickweed	*Cerastium fontanum* Baumg. ssp. *vulgare* (Hartman) Greuter & Burdet
Bigleaf maple	*Acer macrophyllum* Pursh
Bird's-foot trefoil	*Lotus corniculatus* L.
Bitter cherry	*Prunus emarginata* (Dougl. ex Hook.) D. Dietr.
Bittersweet	*Solanum dulcamera* L.
Black cottonwood	*Populus balsamifera* L. ssp. *trichocarpa* (Torr. & Gray ex Hook.) Brayshaw
Black hawthorn	*Crataegus douglasii* Lindl.
Blackcap	*Rubus leucodermis* Dougl. ex Torr. & Gray
Blue wildrye	*Elymus glaucus* Buckl. ssp. *glaucus*
British Columbia wildginger	*Asarum caudatum* Lindl.
Broadleaf starflower	*Trientalis borealis* Raf. ssp. *latifolia* (Hook.) Hulten
Broadpetal strawberry	*Fragaria virginiana* Duchesne ssp. *platypetala* (Rydb.) Staudt
Bull thistle	*Cirsium vulgare* (Savi) Ten.
Bur oak	*Quercus macrocarpa* Michx.
California blackberry	*Rubus ursinus* Cham. & Schlecht.

California hazelnut	*Corylus cornuta* Marsh. var. *californica* (A. DC.) Sharp
California huckleberry	*Vaccinium ovatum* Pursh
California pinefoot	*Pityopus californica* (Eastw.) Copel. f.
California red fir	*Abies magnifica* A. Murr.
Canada fleabane	*Conyza canadensis* (L.) Cronq.
Canada thistle	*Cirsium arvense* (L.) Scop.
Candyflower	*Claytonia sibirica* L. var. *sibirica*
Canyon live oak	*Quercus chrysolepis* Liebm.
Cascade Oregongrape	*Mahonia nervosa* (Pursh) Nutt.
Cascara buckhorn	*Frangula purshiana* (DC.) Cooper
Chamisso sedge	*Carex pachystachya* Cham. ex Steud.
Chaparral willowherb	*Epilobium minutum* Lindl. ex Lehm.
Chestnut oak	*Quercus prinus* L.
Cleavers	*Galium aparine* L.
Clustered thistle	*Cirsium brevistylum* Cronq.
Coastal burnweed	*Erechtites minima* (Poir.) DC.
Coastal wormwood	*Artemisia suksdorfii* Piper
Colonial bentgrass	*Agrostis capillaris* L.
Columbia brome	*Bromus vulgaris* (Hook.) Shear
Common ladyfern	*Athyrium filix-femina* (L.) Roth
Common nipplewort	*Lapsana communis* L.
Common plantain	*Plantago major* L.
Common prince's-pine	*Chimaphila umbellata* (L.) W. Bart.
Common selfheal	*Prunella vulgaris* L.
Common sheep sorrel	*Rumex acetosella* L.
Common snowberry	*Symphoricarpos albus* (L.) Blake
Common sowthistle	*Sonchus oleraceus* L.
Common St. Johnswort	*Hypericum perforatum* L.
Common velvetgrass	*Holcus lanatus* L.
Creeping buttercup	*Ranunculus repens* L. var. *repens*
Creeping snowberry	*Symphoricarpos hesperius* G.N. Jones
Crinkleawn fescue	*Festuca subuliflora* Scribn.
Curled starwort	*Stellaria crispa* Cham. & Schlecht.
Curly dock	*Rumex crispus* L.
Cutleaf blackberry	*Rubus laciniatus* Willd.
Deer-fern	*Blechnum spicant* (L.) Roth
Desert deervetch	*Lotus micranthus* Benth.
Devilsclub	*Oplopanax horridus* Miq.
Dewey's sedge	*Carex deweyana* Schwein.
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco var. *menziesii*
Drops-of-gold	*Disporum hookeri* (Torr.) Nichols.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.

Elderberry	*Sambucus* spp.
Enchanter's nightshade	*Circaea alpina* L.
Engelmann spruce	*Picea engelmannii* Parry ex Engelm.
English holly	*Ilex aquifolium* L.
English ivy	*Hedera helix* L.
Evergreen violet	*Viola sempervirens* Greene
Field clover	*Trifolium campestre* Schreb.
Field mint	*Mentha canadensis* L.
Fireweed	*Epilobium angustifolium* L.
Flowering dogwood	*Cornus florida* L.
Fragrant bedstraw	*Galium triflorum* Michx.
Giant chinquapin	*Chrysolepis chrysophylla* (Dougl. ex Hook.) Hjelmqvist
Giant sequoia	*Sequoiadendron giganteum* (Lindl.) Buchh.
Giant vetch	*Vicia nigricans* Hook. & Arn. ssp. *gigantea* (Hook.) Lassetter & Gunn.
Glaucus willowherb	*Epilobium glaberrimum* Barbey ssp. *glaberrimum*
Grand fir	*Abies grandis* (Dougl. ex D. Don) Lindl.
Hairy catsear	*Hypochaeris radicata* L.
Hickory	*Carya* spp.
Himalayan blackberry	*Rubus discolor* Weihe & Nees
Howell's violet	*Viola howellii* Gray
Idaho buttercup	*Ranunculus uncinatus* D. Don ex G. Don var. *parviflorus* (Torr.) L. Benson
Idaho fescue	*Festuca idahoensis* Elmer
Incense cedar	*Calocedrus decurrens* (Torr.) Florin
Indian plum	*Oemlaria cerasiformis* (Torr. & Gray ex Hook. & Arn.) Landon
Indianpipe	*Monotropa uniflora* L.
Jack pine	*Pinus banksiana* Lamb.
Lamp rush	*Juncus effusus* L. var. *gracilis* Hook.
Largeleaf avens	*Geum macrophyllum* Willd. var. *macrophyllum*
Largeleaf sandwort	*Moehringia macrophylla* (Hook.) Fenzl
Leafy pea	*Lathyrus polyphyllus* Nutt.
Licorice fern	*Polypodium glycyrrhiza* D.C. Eat.
Little prince's-pine	*Chimaphila menziesii* (R. Br. ex D. Don) Spreng.
Lodgepole pine	*Pinus contorta* Dougl. ex Loud.
Longleaf pine	*Pinus palustris* Mill.
Longstalk starwort	*Stellaria longipes* Goldie
Manzanita	*Arctostaphylos* spp.
Miner's lettuce	*Claytonia perfoliata* Donn ex Willd. ssp. *perfoliata*
Mountain hemlock	*Tsuga mertensiana* (Bong.) Carr.
Mountain woodfern	*Dryopteris campyloptera* Clarkson
Narrowleaf plantain	*Plantago lanceolata* L.
Northern red oak	*Quercus rubra* L.
Northwestern twayblade	*Listera caurina* Piper

Oceanspray	*Holodiscus discolor* (Pursh) Maxim.
Orange honeysuckle	*Lonicera ciliosa* (Pursh) Poir. ex DC.
Oregon ash	*Fraxinus latifolia* Benth.
Oregon white oak	*Quercus garryana* Dougl. ex Hook.
Oxeye-daisy	*Leucanthemum vulgare* Lam.
Pacific bleeding heart	*Dicentra formosa* (Haw.) Walp.
Pacific dogwood	*Cornus nuttallii* Audubon ex Torr. & Gray
Pacific madrone	*Arbutus menziesii* Pursh
Pacific rhododendron	*Rhododendron macrophyllum* D. Don ex G. Don
Pacific silver fir	*Abies amabilis* (Dougl. ex Loud.) Dougl. ex Forbes
Pacific strawberry	*Fragaria crinita* Rydb.
Pacific trillium	*Trillium ovatum* Pursh
Pacific yew	*Taxus brevifolia* Nutt.
Paper birch	*Betula papyrifera* Marsh.
Pennsylvania bittercress	*Cardamine pensylvanica* Muhl. ex Willd.
Pink honeysuckle	*Lonicera hispidula* (Lindl.) Dougl. ex Torr. & Gray
Pink wintergreen	*Pyrola asarifolia* Michx. ssp. *bracteata* (Hook.) Haber
Pioneer violet	*Viola glabella* Nutt.
Ponderosa pine	*Pinus ponderosa* P. & C. Lawson
Poverty rush	*Juncus tenuis* Willd.
Prickly sowthistle	*Sonchus asper* (L.) Hill
Purple foxglove	*Digitalis purpurea* L.
Pursh's buckthorn	*Frangula purshiana* (DC.) Cooper
Quaking aspen	*Populus tremuloides* Michx.
Red alder	*Alnus rubra* Bong.
Red baneberry	*Actaea rubra* (Ait.) Willd.
Red clover	*Trifolium pratense* L.
Red elderberry	*Sambucus racemosa* L.
Redflower currant	*Ribes sanguineum* Pursh
Red huckleberry	*Vaccinium parvifolium* Sm.
Red maple	*Acer rubrum* L.
Red pine	*Pinus resinosa* Soland.
Red spruce	*Picea rubens* Sarg.
Redwood	*Sequoia sempervirens* (Lamb. ex D. Don) Endl.
Reed canarygrass	*Phalaris arundinacea* L.
Riverbank lupine	*Lupinus rivularis* Dougl. ex Lindl.
Robert geranium	*Geranium robertianum* L.
Rose spirea	*Spiraea douglasii* Hook. var. *douglasii*
Salal	*Gaultheria shallon* Pursh
Salebrosa goldenrod	*Solidago canadensis* L. var. *salebrosa* (Piper) M.E. Jones
Salmonberry	*Rubus spectabilis* Pursh
Saskatoon serviceberry	*Amelanchier alnifolia* (Nutt.) Nutt. ex M. Roemer

Scarlet oak	*Quercus coccinea* Muenchh.
Scotchbroom	*Cytisus scoparius* (L.) Link
Scouler willow	*Salix scouleriana* Barratt ex Hook.
Scouler's harebell	*Campanula scouleri* Hook. ex A. DC.
Silver hairgrass	*Aira caryophyllea* L.
Sitka alder	*Alnus viridis* (Vill.) Lam. & DC. ssp. *sinuata* (Regel) A.& D. Löve
Sitka mountain ash	*Sorbus sitchensis* M. Roemer var. *sitchensis*
Sitka spruce	*Picea sitchensis* (Bong.) Carr.
Slender hairgrass	*Deschampsia elongata* (Hook.) Munro
Small camas	*Camassia quamash* (Pursh) Greene
Smallflower nemophila	*Nemophila parviflora* Dougl. ex Benth.
Small-flowered woodrush	*Luzula parviflora* (Ehrh.) Desv.
Smooth hawksbeard	*Crepis capillaris* (L.) Wallr.
Snowberry	*Gaultheria* spp.
Snowbrush ceanothus	*Ceanothus velutinus* Dougl. ex Hook.
Southern beech	*Nothofagus* Blume, nom. cons.
Spike bentgrass	*Agrostis exarata* Trin.
Spoonleaf purple everlasting	*Gamochaeta purpurea* (L.) Cabrera
Starry false Solomon's seal	*Maianthemum stellatum* (L.) Link
Stinging nettle	*Urtica dioica* L.
Subalpine fir	*Abies lasiocarpa* (Hook.) Nutt. var. *lasiocarpa*
Sugar maple	*Acer saccharum* Marsh
Summer coralroot	*Corallorhiza maculata* (Raf.) Raf.
Sweet after death	*Achlys triphylla* (Sm.) DC.
Sweet vernalgrass	*Anthoxanthum odoratum* L.
Sweetcicely	*Osmorhiza berteroi* DC.
Tall blue lettuce	*Lactuca biennis* (Moench) Fern.
Tall oatgrass	*Arrhenatherum elatius* (L.) Beauv. ex J. & K. Presl
Tall Oregongrape	*Mahonia aquifolium* (Pursh) Nutt.
Tanoak	*Lithocarpus densiflorus* (Hook. & Arn.) Rehd.
Tansy ragwort	*Senecio jacobaea* L.
Thimbleberry	*Rubus parviflorus* Nutt.
Threeleaf foamflower	*Tiarella trifoliata* L.
Tiger lily	*Lillium columbianum* hort. ex Baker
Timothy	*Phleum pratense* L.
Toad rush	*Juncus bufonius* L.
Tuliptree	*Liriodendron tulipifera* L.
Twinflower	*Linnaea borealis* L.
Variableleaf collomia	*Collomia heterophylla* Dougl. ex Hook.
Vine maple	*Acer circinatum* Pursh
Wall-lettuce	*Mycelis muralis* (L.) Dumort.
Western anemone	*Anemone deltoidea* Hook.

Western brackenfern	*Pteridium aquilinum* (L.) Kuhn.
Western buttercup	*Ranunculus occidentalis* Nutt.
Western fescue	*Festuca occidentalis* Hook.
Western hemlock	*Tsuga heterophylla* (Raf.) Sarg.
Western pearly everlasting	*Anaphalis margaritacea* (L.) Benth.
Western rattlesnake plantain	*Goodyera oblongifolia* Raf.
Western redcedar	*Thuja plicata* Donn. ex D. Donn.
Western serviceberry	*Amelanchior alnifolia* (Nutt.) Nutt. ex M. Roemer
Western swordfern	*Polystichum munitum* (Kaulfuss) K. Presl
Western white pine	*Pinus monticola* Dougl. ex D. Don
White clover	*Trifolium repens* L.
White oak	*Quercus alba* L.
White spruce	*Picea glauca* (Moench) Voss
White-flowered hawkweed	*Hieracum albiflorum* Hook.
White insideout flower	*Vancouveria hexandra* (Hook.) Morr. & Dcne.
Whiteveined wintergreen	*Pyrola picta* Sm.
Willow spp.	*Salix* spp.
Woodland ragwort	*Senecio sylvaticus* L.
Woodrush	*Luzula campestris* (L.) DC.
Yellow birch	*Betula alleghaniensis* Britton
Yellow-cedar	*Chamaecyparis nootkatensis* (D. Don) Spach
Yellow hairgrass	*Aira praecox* L.
Yerba buena	*Satureja douglasii* (Benth.) Briq.

PLANT PATHOGENS AND PESTS:

Arbutus canker	*Nattrassia mangiferae*
Asian longhorned beetle	*Anoplophora glabripennis*
Bark beetle	*Dendroctonus* spp.
Beech bark desease	*Nectria coccinea* var. faginata
Chestnut blight	*Cryphonectria parasiti*
Deer tick	*Ixodes dammini*
Douglas-fir tussock moth	*Orygia pseudotsugata* McDunnough
Dutch elm disease	*Ophiostoma ulmi*
Dwarf mistletoe	*Arceuthobium* spp.
Emerald ash borer	*Agrilus planipennis*
European pine shoot beetle	*Tomicus piniperda* L.
Groundhog tick	*Ixodes cookei* Packard, 1869
Hemlock woolly adelgid	*Adelges tsugae* Annand
Larch casebearer	*Coleophora laricella* Hubner
Madrone canker	*Fusicoccum aesculi*
Mistletoe	*Phoradendron* spp.
Mountain pine beetle	*Dendroctonus ponderosae*

Root rot	*Phellinus* spp.
Pandora pinemoth	*Coloradia pandora* Blake, 1863
Southern pine beetle	*Dendroctonus frontalis* Zimmerman
Spruce beetle	*Dendroctonus rufipennis* Kirby
Sudden oak death fungus	*Phytophthora ramorum*
Swiss needle cast	*Phaeocryptopus gaeumannii* T. Rohde Petr.
Velvet-top fungus	*Phaeolus schweinitzii*
Western spruce budworm	*Choristoneura occidentalis* Freeman
White pine blister rust	*Cronartivu ribicola*
MOLLUSKS:	
Burrington jumping slug	*Hemphillia burringtoni*
Banana slug	*Ariolimax columbianus*
AMPHIBIANS AND REPTILES:	
Bullfrog	*Rana catesbeiana* Shaw, 1802
Clouded salamander	*Aneides ferreus* Cope, 1869
Cope's giant salamander	*Dicamptodon copei* Nussbaum, 1970
Ensatina	*Ensatina eschscholtzii* Gray, 1850
Larch mountain salamander	*Plethodon larselli* Burns, 1954
Long-toed salamander	*Ambystoma macrodactylum* Baird, 1849
Northern alligator lizard	*Gerrhonotus coeruleus* Wiegmann, 1828
Northern spring peeper	*Pseudacris crucifer* Wied-Neuwied, 1838
Northwestern garter snake	*Thamnophis ordinoides* Baird & Girard, 1852
Northwestern salamander	*Ambystoma gracile* Baird, 1859
Olympic torrent salamander	*Rhyacotriton olympicus* Gaige, 1917
Oregon slender salamander	*Batrachoseps wrighti* Bishop, 1937
Pacific tree frog	*Pseudacris regilla* Barid & Girard, 1852
Red-legged frog	*Rana aurora* Baird & Girard, 1852
Rough-skinned newt	*Taricha granulosa* Skilton, 1849
Rubber boa	*Charina bottae* Blainville, 1835
Spring peeper	*Pseudacris crucifer*
Tailed frog	*Ascaphus truei*
Western red-backed salamander	*Plethodon vehiculum* Cooper, 1860
Western tailed frog	*Ascaphus truei* Stejneger, 1899
Western toad	*Bufo boreas* Baird & Girard, 1852
Wood frog	*Rana sylvatica* LeConte, 1825
MAMMALS:	
American beaver	*Castor canadensis* Kuhl.
American bison	*Bison bison*
American black bear	*Ursus americanus* Pallas, 1780
American marten	*Martes americana*

American porcupine	*Erethizon dorsatum* Linnaeus, 1758
American water shrew	*Sorex palustris* Richardson
Blacktail deer	*Odocoileus hemionus* Rafinesque, 1817
Bobcat	*Felis rufus*
Bushy-tailed woodrat	*Neotoma cinerea*
California myotis	*Myotis californicus* Audubon & Bachman, 1842
California red-backed vole	*Cleithrionomys californicus*
Coast mole	*Scapanus orarius* True, 1896
Columbian deer mouse	*Peromyscus oreas* Bangs.
Coyote	*Canis latrans* Say, 1823
Deer mouse	*Peromyscus maniculatus* Wagner, 1845
Douglas' squirrel	*Tamiasciurus douglasii* Bachman, 1839
Dusky-footed woodrat	*Neotoma fuscipes*
Eastern cottontail	*Sylvilagus floridanus* J.A. Allen, 1890
Eastern gray squirrel	*Sciurus carolinensis* Gmelin, 1788
European red squirrel	*Sciurus vulgaris* Linnaeus, 1758 ssp. exalbudus Pallas, 1778
Fisher	*Martes pennanti* Erxleben, 1777
Golden-mantled ground squirrel	*Spermophilus lateralis* Say
Gray wolf	*Canis lupus*
House mouse	*Mus musculus* Linnaeus, 1758
Keen's mouse	*Peromyscus keeni* Rhoads
Least chipmunk	*Tamias minimus* Bachman, 1839
Long-tailed vole	*Microtus longicaudus* Murriam, 1888
Long-tailed weasel	*Mustela frenata* Lichtenstein, 1831
Lynx	*Lynx canadensis* Kern, 1792
Meadow vole	*Microtus pennsylvanicus* Ord, 1815
Montane shrew	*Sorex monticolus* Merriam, 1890
Moose	*Alces alces*
Mountain beaver	*Aplodonia rufa* Rafinesque, 1817
Mountain lion	*Felis concolor* Linnaeus
Mule deer	*Odocoileus hemionus* Rafinesque, 1817
Northern flying squirrel	*Glaucomys sabrinus* Shaw, 1801
Oregon creeping vole	*Microtus oregoni* Bachman, 1839
Pacific jumping mouse	*Zapus trinotatus* Rhoads, 1895
Pacific marsh shrew	*Sorex bendirii* Merriam, 1884
Racoon	*Procyon lotor* Linnaeus, 1758
Red fox	*Vulpes vulpes* Linnaeus, 1758
Red tree vole	*Arborimus longicaudus* True, 1890
Richardson's ground squirrel	*Spermophilus richardsonii* Sabine, 1822
Rocky mountain elk	*Cervus elaphus nelsoni*
Rocky mountain goat	*Oreamnos americanus*
Roosevelt elk	*Cervus elaphus roosevelti*

Shorttail weasel	*Mustela erminea* Linnaeus, 1758
Shrew mole	*Neurotrichus gibbsii* Baird, 1858
Russian flying squirrel	*Pteromys volans* Linnaeus, 1758
Siskiyou chipmunk	*Tamias siskiyou*
Snowshoe hare	*Lepus americanus* Erxleben, 1777
Southern red-backed vole	*Clethrionomys gapperi* Vigors, 1830
Townsend's big-eared bat	*Plecotus townsendii* Cooper, 1837
Townsend's chipmunk	*Tamias townsendii* Bachman, 1839
Townsend's mole	*Scapanus townsendii* Bachman, 1839
Trowbridge's shrew	*Sorex trowbridgii* Baird, 1858
Vagrant shrew	*Sorex vagrans* Baird, 1858
Virginia opposum	*Didelphis virginiana* Kerr, 1792
Western gray squirrel	*Sciurus griseus* Ord, 1818
Western heather vole	*Phenacomys intermedius*
Western red-backed vole	*Clethrionomys californicus*
White-footed mouse	*Peromyscus leucopus* Rafinesque
Wolverine	*Gulo gulo*

BIRDS:

American crow	*Corvus brachyrhynchos* Brehm, 1822
American dipper	*Cinclus mexicanus* Swainson, 1827
American robin	*Turdus migratorius* Linnaeus, 1766
Bald eagle	*Haliaeetus leucocephalus* Linnaeus, 1766
Band-tailed pigeon	*Columba fasciata* Say, 1823
Barn owl	*Tyto alba* Scopoli, 1769
Barn swallow	*Hirundo rustica* Linnaeus, 1758
Barred owl	*Strix varia* Barton, 1799
Black-capped chickadee	*Parus atricapillus* Linnaeus, 1766
Black-headed grosbeak	*Pheucticus melanocephalus* Swainson, 1827
Black-throated gray warbler	*Dendroica nigrescens* Townsend, 1837
Blue grouse	*Dendragapus obscurus* Say, 1823
Bobwhite	*Colinus virginianus* Linnaeus, 1758
Boreal owl	*Aegolius funereus* Linnaeus, 1758
Brown creeper	*Certhia americana* Bonaparte, 1838
Brown-headed cowbird	*Molothrus ater* Boddaert, 1783
Canada goose	*Branta canadensis* Linnaeus, 1758
Cedar waxwing	*Bombycilla cedrorum* Vieillot, 1808
Chestnut-backed chickadee	*Parus rufescens* Townsend, 1837
Chipping sparrow	*Spizella passerina* Bechstein, 1798
Chukar	*Alectoris chukar* Gray, 1830
Common bushtit	*Psaltriparus minimus* Townsend, 1837
Common nighthawk	*Chordeiles minor* Forster, 1771
Common raven	*Corvus corax* Linnaeus, 1758

Cooper's hawk	*Accipiter cooperii* Bonaparte, 1828
Dark-eyed junco	*Junco hyemalis* Linnaeus, 1758
Downy woodpecker	*Picoides pubescens* Linnaeus, 1766
Golden-crowned kinglet	*Regulus saltrapa* Lichtenstein, 1823
Gray jay	*Perisoreus canadensis* Linnaeus, 1766
Great blue heron	*Ardea herodias* Linnaeus, 1758
Great-horned owl	*Bubo virginianus* Gmelin, 1788
Hairy woodpecker	*Picoides villosus* Linnaeus, 1766
Hermit thrush	*Catharus guttatus* Pallas, 1811
Hermit warbler	*Dendroica occidentalis* Townsend, 1837
Hutton's vireo	*Vireo huttoni* Cassin, 1851
Mallard	*Anas platyrhynchos* Linnaeus, 1758
Marbled murrelet	*Brachyramphus marmoratus*
Mourning dove	*Zenaida macroura* Linnaeus, 1758
Northern flicker	*Colaptes auratus* Linnaeus, 1758
Northern goshawk	*Accipiter gentilis* Linnaeus, 1758
Northern pygmy owl	*Glaucidium gnoma* Wagler, 1832
Northern saw-whet owl	*Aegolius acadicus* Gmelin, 1788
Northern spotted owl	*Strix occidentalis* Xantus de Vesey, 1860
Olive-sided flycatcher	*Contopus borealis* Swainson, 1832
Orange-crowned warbler	*Vermivora celata* Say, 1823
Pacific slope flycatcher	*Empidonax difficilis* Baird, 1858
Passenger pigeons	*Ectopistes migratorius*
Phainopepla	*Phainopepla nitens* Swainson, 1838
Pileated woodpecker	*Dryocopus pileatus* Linnaeus, 1758
Pine siskin	*Carduelis pinus* Wilson, 1810
Purple finch	*Carpodacus purpureus* Gmelin, 1789
Red crossbill	*Loxia curvirostra* Linnaeus, 1758
Red-breasted nuthatch	*Sitta canadensis* Linnaeus, 1766
Red-breasted sapsucker	*Sphyrapicus ruber* Gmelin, 1788
Red-naped sapsucker	*Sphyrapicus nuchalis* Baird, 1858
Red-tailed hawk	*Buteo jamaicensis* Gmelin, 1788
Red-winged blackbird	*Agelaius phoeniceus* Linnaeus, 1766
Ring-necked pheasant	*Phasianus colchicus* Linnaeus, 1758
Ruby-crowned kinglet	*Regulus calendula* Linnaeus, 1766
Ruffed grouse	*Bonasa umbellus* Linnaeus, 1766
Rufous hummingbird	*Selasphorus rufus* Gmelin, 1788
Rufous-sided towhee	*Pipilo erythrophthalmus* Linnaeus, 1758
Sharp-shinned hawk	*Accipiter striatus* Vieillot, 1807
Solitary vireo	*Vireo solitarius* Wilson, 1810
Song sparrow	*Melospiza melodia* Wilson, 1810
Steller's jay	*Cyanocitta stelleri* Gmelin, 1788

Swainson's thrush	*Catharus ustulatus* Nuttall, 1840
Tengmalm's owl	*Aegolius funereus* Kaup, 1829
Townsend's solitaire	*Myadestes townsendi* Audobon, 1838
Townsend's warbler	*Dendroica townsendi* Townsend, 1837
Tree swallow	*Tachycineta bicolor* Vieillot, 1808
Turkey vulture	*Cathartes aura* Linnaeus, 1758
Varied thrush	*Ixoreus naevius* Gmelin, 1789
Vaux's swift	*Chaetura vauxii* Towns.
Warbling vireo	*Vireo gilvus* Vieillot, 1808
Western bluebird	*Sialia mexicana* Swainson, 1832
Western screech owl	*Otus kennicotti* Elliot, 1867
Western tanager	*Piranga ludoviciana* Wilson, 1811
White-crowned sparrow	*Zonotrichia leucophrys* Forster, 1772
Willow flycatcher	*Empidonax traillii* Audobon, 1828
Wilson's warbler	*Wilsonia pusilla* Wilson, 1811
Winter wren	*Troglodytes troglodytes* Linnaeus, 1758
Yellow-rumped warbler	*Dendroica coronata* Linnaeus, 1766

FISH:

Chinook salmon	*Oncorhynchus tshawytscha*
Chum salmon	*Oncorhynchus keta*
Coho salmon	*Oncorhynchus kisutch*
Pink salmon	*Oncorhynchus gorbuscha*
Sockeye salmon	*Oncorhynchus nerka*
Steelhead salmon	*Oncorhynchus nerka*

HYPOGEOUS FUNGI (truffles):

Alpova diplophloeus (Zeller & Dodge) Trappe & Smith
Elaphomyces granulatus Fr.
Elaphomyces muricatus Fr.
Endogone lactiflua Bk. & Bk.
Endogone pisiformis Link:Fr.
Gautieria monticola Harkn.
Gautieria spp.
Genabea cerebriformis (Harkn.) Trappe
Genea harknessii Gilkey
Genea intermedia Gilkey
Glomus spp.
Glomus macrocarpum Tul. & Tul.
Glomus mosseae (Nicol. & Gerd.) Gerd. & Trappe
Hydnotrya variiformis Gilkey
Hymenogaster sublilacinus Smith

Hysterangium coriaceum Hesse
Hysterangium crassirhachis Zeller & Dodge
Hysterangium setchellii Fischer
Leucangium carthusiana (Tul. & Tul.) Paoletti
Leucogaster candidus (Harkn.) Fogel comb. ined.
Leucogaster citrinus (Harkn.) Zeller & Dodge
Leucogaster gelatinosus Fogel nom. ined.
Leucogaster rubescens Zeller & Dodge
Leucogaster spp.
Leucophleps magnata Harkn.
Leucophleps spinispora Fogel
Melanogaster ambiguus (Vitt.) Tul. & Tul.
Melanogaster euryspermus (Zeller & Dodge) Zeller
Melanogaster natsii Wang, Trappe, & Castellano spp.
Melanogaster thiersii Wang, Trappe, & Castellano spp.
Melanogaster trappei Wang spp.
Melanogaster tuberiformis Corda in Sturm
Melanogaster variegatus (Vitt.) Tul. & Tul.
Pachyphloeus thysellii Colgan & Castellano, nom. ined.
Piloderma fallax (Lib.) Stalp.
Radiigera fuscogleba Zeller
Rhizopogon hawkerae Smith
Rhizopogon parksii
Rhizopogon rogersii Smith
Rhizopogon subareolatus Smith
Rhizopogon villosulus Zeller
Rhizopogon vinicolor Smith
Rhizopogon vulgaris (Vittad.) M. Lange
Scleroderma hypogaeum Zeller
Truncocolumella citrina Zeller
Tuber anniae Colgan & Trappe
Tuber gibbosum Harkn.
Tuber monticola Harkn.

EPIGEOUS FUNGI (mushrooms):

Agaricus albolutescens Zeller
Agaricus diminutivus Pk.
Agaricus micromegathus Pk.
Agaricus silvicola (Vitt.) Pk.
Agrocybe praecox (Fr.) Fayod
Albatrellus pes-caprae (Fr.) Pouzar
Aleuria aurantiaca (Fr.) Fuckel

Amanita gemmata var. *exannulata* Lange
Amanita gemmata var. *gemmata* (Fr.) Bert.
Amanita pantherina (DC:Fr.) Schum.
Amanita porphyria (A.& S. ex Fr.) Secr.
Amanita silvicola Kauffm.
Amanita smithiana Bas.
Armillaria mellea (Vahl ex Fr.) Karsten
Auriscalpium vulgare S.F. Gray
Bolbitius spp.
Boletus chrysenteron Fr.
Boletus zelleri Murr.
Cantharellus cibarius Fr.
Cantharellus subalbidus Smith & Morse
Cantharellus tubaeformis Fr.
Clavaria spp.
Clavulina cinerea (Fr.) Schroet.
Clavulina cristata (Fr.) Schroet.
Clavulinopsis corniculata (Schaeff.:Fr.) Corner
Clavulinopsis laeticolor (Berk. & Curt.) R.H. Petersen
Clitocybe coniferophila H.E. Bigelow
Clitocybe deceptiva H.E. Bigelow
Clitocybe dilatata Pers. ex Karsten
Clitocybe inversa (Fr.) Gill.
Collybia acervata (Fr.) Kummer
Collybia alcalivirens Singer
Collybia butyracea (Fr.) Quel.
Collybia confluens (Pers. ex Fr.) Kummer
Collybia dryophila (Bull. ex Fr.) Kummer
Collybia fuscopurpurea (Pers.:Fr.) Kumm.
Collybia oregonensis A.H. Smith
Collybia racemosa (Pers.:Fr.) Quél.
Coltricia cinnamomea (Jacq.:Pers.) Murr.
Conocybe cyanopus (Atk.) Kühner
Conocybe tenera (Schaeff. ex Fr.) Kuhner
Coprinus micaceus (Bull. ex Fr.) Fr.
Coprinus plicatilis (Curt.:Fr.) Fr.
Coprinus sylvaticus Pk.
Cortinarius acutus Fr.
Cortinarius alboviolaceus (Pers. ex Fr.) Fr.
Cortinarius angulosus Fr.
Cortinarius brunneus Fr.
Cortinarius californicus A.H. Smith

Cortinarius cinnamomeus (Fr.) Fr.
Cortinarius corrugatus Peck
Cortinarius cotoneus Fr.
Cortinarius crassus Fr.
Cortinarius crystallinus Fr.
Cortinarius decipiens Fr.
Cortinarius duracinus Fr.
Cortinarius evernius Fr.
Cortinarius glaucopus (Schaeff.:Fr.) Fr.
Cortinarius hemitrichus Fr.
Cortinarius infractus (Pers.:Fr.) Fr.
Cortinarius laniger Fr.
Cortinarius malachius Fr.
Cortinarius mucosus (Bull.:Fr.) Fr.
Cortinarius multiformis (Fr.) Fr.
Cortinarius nigrocuspidatus
Cortinarius obtusus Fr.
Cortinarius olympianus A.H. Smith
Cortinarius paleaceus Fr.
Cortinarius percomis Fr.
Cortinarius phoeniceus (Bull.) R. Maire
Cortinarius pinetorum (Fr.) Kauffman
Cortinarius plumiger (Fr.) Fr.
Cortinarius prasinus Fr.
Cortinarius pseudobolaris Maire *sensu* Smith
Cortinarius rubripes Kauffman
Cortinarius sanguineus (Fr.) Fr.
Cortinarius scaurus Fr.
Cortinarius semisanguineus (Fr.) Gillet
Cortinarius subfoetidus A.H. Smith
Cortinarius subg. *bulbopodium*
Cortinarius subg. *phlegmacium*
Cortinarius subg. *sericeocybe*
Cortinarius subg. *telemonia*
Cortinarius superbus A.H. Smith
Cortinarius triformis Fr.
Cortinarius uliginosus Berk.
Cortinarius uraceus Fr.
Cortinarius vibratilis Fr.
Crepidotus herbarum (Pk.) Sacc.
Crepidotus mollis (Fr.) Stde.
Crucibulum laeve (Huds.) Kamb.

Cudonia monticola Mains
Cystoderma amianthinum (Scop.:Fr.) Fr.
Cystoderma fallax Smith & Singer
Cystoderma granulosum (Fr.) Fayod
Dacrymces palmatus (Schw.) Bres.
Entoloma nidorosum (Fr.) Quél.
Entoloma rhodopolium (Fr.) Kumm.
Fomitopsis cajanderi (Karsten) Kotlaba & Pouz.
Fomitopsis officinalis (Fr.) Bond. & Sing.
Fomitopsis pinicola (Fr.) Karst.
Fusicoccum aesculi (Byther 1999; Elliott 1999a, 1999b)
Galerina autumnalis (Pk.) Smith & Singer
Galerina heterocystis (Atk.) A.H. Smith
Galerina marginata (Fr.) Kühner
Gomphidius glutenosus (Fr.) Fr.
Gomphidius oregonensis Peck
Gomphidius smithii Miller
Gomphidius subroseus Kauffman
Gomphus clavatus (Fr.) S.F. Gray
Guepiniopsis alpinus (Tracy & Earle) Bres.
Gymnopilus bellulus (Peck) Murr.
Gymnopilus liquiritae (Pers.:Fr.) Karst.
Gymnopilus penetrans (Fr. ex Fr.) Murr.
Gymnopilus sapineus (Fr.) Maire
Hebeloma crustuliniforme (Bull. ex St. Amams) Quel.
Hebeloma sinapizans (Paulet:Fr.) Gill.
Helvella crispa Scop. ex Fr.
Helvella elastica Bull. ex St. Amans
Helvella lacunosa Afz. ex Fr.
Hydnum repandum L. ex Fr.
Hydnum umbilicatum Pk.
Hygrocybe miniata (Fr.) Kumm.
Hygrophoropsis aurantiaca (Wulf. ex Fr.) Maire
Hygrophorus calophyllus Karst.
Hygrophorus conicus (Fr.) Fr.
Hygrophorus glutinosus (Schff.:Fr.) Fr.
Hypholoma capnoides (Fr. ex Fr.) Kummer
Hypholoma dispersum (Fr.) Quel.
Hypholoma fasciculare (Huds. ex Fr.) Kummer
Inocybe albodisca Pk.
Inocybe calamistrata (Fr.) Gillet
Inocybe cincinnatula Kühner

Inocybe cookei Bres.
Inocybe eutheles Berk. & Br.
Inocybe fastigiata (Schaeff. ex Fr.) Quel.
Inocybe fuscodisca (Peck) Massae
Inocybe geophylla (Sow. ex Fr.) Kummer
Inocybe lanatodisca Kauffman
Inocybe lanuginosa (Bull. ex Fr.) Kummer
Inocybe lilacina (Boud.) Kauffman
Inocybe maculata Boud.
Inocybe mixtilis Britz.
Inocybe olympiana A.H. Smith
Inocybe pudica Kühner
Inocybe sororia Kauffman
Inocybe subcarpta Kühner & Boursier
Laccaria amethysteo-occidentalis Mueller
Laccaria laccata (Scop. ex Fr.) Cke.
Lactarius affinis Pk.
Lactarius deliciosus (Fr.) S. F. Gray
Lactarius fragilis var. *rubidus* Hels. & Smith
Lactarius pseudomucidus Smith & Hesler
Lactarius rubrilacteus Smith & Hesler
Lactarius subflammeus Smith & Hesler
Lactarius uvidus Fr.
Laetiporus sulphureus (Bull. ex Fr.) Murr.
Lentinus sulcatus Berk.
Leotia lubrica Fr.
Lepiota clypeolaria (Bull. ex Fr.) Kummer
Lepiota rhacodes Pilat
Leptonia gracilipes Peck
Leptonia parva Peck
Leptonia serrulata (Fr.:Fr.) Kumm.
Leptonia undulatella (Peck) Sacc.
Limacella glioderma (Fr.) R. Maire
Lycoperdon foetidum Bon.
Lycoperdon perlatum Pers.
Lycoperdon pyrifome Schaeff.:Pers.
Lyophyllum decastes (Fr.) Singer
Marasmius candidus (Bolt.:Fr.) Fr.
Marasmius copelandii Peck
Marasmius umbilicatus Kauffman
Melanoleuca melaleuca (Pers. ex Fr.) Murr.
Mycena acicula (Schaeff. ex Fr.) Kummer

Mycena amabilissima (Peck) Sacc.
Mycena atroalboides (Peck) Sacc.
Mycena aurantiomarginata (Fr.) Quél.
Mycena capillaris (Schum.:Fr.) Kumm
Mycena citrinomarginata Gillet
Mycena delicatella (Pk.) Smith
Mycena elegantula Peck
Mycena epipterygia (Fr.) S. F. Gray
Mycena maculata Karst.
Mycena murina Murrill
Mycena occidentalis Murrill
Mycena oregonensis Smith
Mycena pura (Pers. ex Fr.) Kummer
Mycena purpureofusca (Peck) Sacc.
Mycena rorida (Fr.) Quel.
Mycena scabripes (Murrill) Singer
Mycena subcana A.H. Smith
Nattrassia mangiferae
Nidula candida (Pk.) White
Nidula niveotomentosa (Henn.) Lloyd
Nolanea mammosa (L.) Quél.
Omphalina luteicolor Murrill
Otidea leporina (Fr.) Fuckel
Paxillus atrotomentosus (Fr.) Fr.
Peziza badia Pers.
Peziza spp.
Phaeolus schweinitzii (Fr.) Pat.
Phellinus pini (Fr.) Ames
Phellinus weirii
Pholiota astragalina (Fr.) Singer
Pholiota decorata (Murr.) Smith & Kessler
Pholiota mutabilis (Schaeff. ex Fr.) Kummer
Pholiota terrestris Overholts
Pleurocybella porrigens (Pers. ex Fr.) Singer
Pleurotus ostreatus (Jacq. ex Fr.) Kummer
Pluteus cervinus (Fr.) Kummer
Polyporus badius (S.F. Gray) Schw.
Polyporus hirtus Quél.
Polyporus volvatus Peck
Psathyrella gracilis (Fr.) Quél.
Psathyrella hydrophila (Fr.) Maire
Psathyrella longistriata (Murre) Smith

Pseudohydnum gelatinosum (Scop. ex Fr.) Karsten
Pseudoplectania melaena (Fr.) Boud.
Ramaria stricta (Fr.) Quél.
Ramariopsis kunzei (Fr.) Donk.
Rhodocybe hirneola (Fr.) Orton
Russula aeruginea Lindl.
Russula albonigra (Krombh.) Fr.
Russula alutacea (Pers.:Fr.) Fr.
Russula bicolor Burl.
Russula brevipes Pk.
Russula cremoricolor Earle
Russula cyanoxantha (Schw.) Fr.
Russula densifolia (Secr.) Gillet
Russula emetica Fr.
Russula fragrantissima Rom.
Russula gracilis Burlingham
Russula placita Burl
Russula sororia (Fr.) Romell
Russula xerampelina (Schaeff. ex Secr.) Fr.
Russulas nigricans Fr.
Sparassis crispa Wulf:Fr.
Stereum complicatum (Fr.) Fr.
Strobilurus trullisatus (Murr.) Lennox
Stropharia ambigua (Pk.) Zeller
Stropharia hornemannii (Fr.) Lundell
Suillus lakei (Murr.) Smith & Thiers
Suillus ponderosus Smith & Thiers
Suillus tomentosus (Kauff.) Singer, Snell, & Dick
Thelephora americana Lloyd
Thelephora palmata Scop.:Fr.
Thelephora terrestris Fr.
Trametes hirsuta (Wulf.:Fr.) Pilat
Trametes versicolor (L. ex Fr.) Pilat
Trichaptum abietinus (Fr.) Donk.
Trichoglossum hirsutum (Fr.) Boudier
Tricholoma flavovirens (Pers. ex Fr.) Lundell
Tricholoma imbricatum (Fr.:Fr.) Kumm.
Tricholoma sulphureum (Bull.:Fr.) Kumm.
Tricholoma terreum (Schaeff.:Fr.) Kumm.
Tricholomopsis rutilans (Schaeff. ex Fr.) Singer
Tubaria furfuracea (Pers. ex Fr. Gillet
Tyromyces caesius (Fr.) Murr.

Tyromyces chioneus (Fr.) Karsten
Xeromphalina campanella (Bat. ex Fr.) Kuhner & Maire
Xeromphalina fulvipes (Murr.) Smith
Xylaria hypoxylon (L. ex Hooker) Grev.

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[a] Common names are provided for plants and animals. However, because many fungi do not have common names, none are provided for any of the included fungi.

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