WILEY

Spatially Explicit Influences on Northern Goshawk Nesting Habitat in the Interior Pacific Northwest
Author(s): Michael T. McGrath, Stephen DeStefano, Robert A. Riggs, Larry L. Irwin and Gary J. Roloff
Source: *Wildlife Monographs*, No. 154, Spatially Explicit Influences on Northern Goshawk Nesting Habitat in the Interior Pacific Northwest (Oct., 2003), pp. 1-63
Published by: Wiley on behalf of the Wildlife Society
Stable URL: https://www.jstor.org/stable/3830854
Accessed: 04-12-2018 21:39 UTC

REFERENCES
Linked references are available on JSTOR for this article:
https://www.jstor.org/stable/3830854?seq=1&cid=pdf-reference#references_tab_contents
You may need to log in to JSTOR to access the linked references.

JSTOR is a not-for-profit service that helps scholars, researchers, and students discover, use, and build upon a wide range of content in a trusted digital archive. We use information technology and tools to increase productivity and facilitate new forms of scholarship. For more information about JSTOR, please contact support@jstor.org.

Your use of the JSTOR archive indicates your acceptance of the Terms & Conditions of Use, available at https://about.jstor.org/terms

Wildlife Society, *Wiley* are collaborating with JSTOR to digitize, preserve and extend access to *Wildlife Monographs*

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Supplement to
The Journal of Wildlife Management
Vol. 67, No. 4, October 2003

WILDLIFE MONOGRAPHS

(ISSN:0084-0173)

A Publication of The Wildlife Society

SPATIALLY EXPLICIT INFLUENCES ON NORTHERN GOSHAWK NESTING HABITAT IN THE INTERIOR PACIFIC NORTHWEST

by

MICHAEL T. McGRATH, STEPHEN DeSTEFANO, ROBERT A. RIGGS,
LARRY L. IRWIN, AND GARY J. ROLOFF

NO. 154 OCTOBER 2003

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

FRONTISPIECE. A juvenile northern goshawk captured near its nest in eastern Oregon. Habitat and demography studies of northern goshawks in the Inland Pacific Northwest focused on breeding ecology and nesting habitat. Landscape-level analyses of forest cover around nests included post-fledging areas (PFA), which are important because they provide hiding cover and foraging opportunities for young birds before they reach independence from adults (photo by Stephen DeStefano, USGS).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

SPATIALLY EXPLICIT INFLUENCES ON NORTHERN GOSHAWK NESTING HABITAT IN THE INTERIOR PACIFIC NORTHWEST

MICHAEL T. McGRATH[1, 2]

Oregon Cooperative Wildlife Research Unit, Department of Fisheries and Wildlife, Oregon State University, Corvallis, OR 97331, USA; and National Council for Air and Stream Improvement, P. O. Box 458, Corvallis, OR 97339, USA.

STEPHEN DeSTEFANO[3]

Oregon Cooperative Wildlife Research Unit, 104 Nash Hall, Oregon State University, Corvallis, OR 97331, USA.

ROBERT A. RIGGS

Boise Cascade Corporation, 1917 Jackson Street, La Grande, OR 97850, USA.

LARRY L. IRWIN

National Council for Air and Stream Improvement, P. O. Box 68, Stevensville, MT 59870, USA.

GARY J. ROLOFF

Boise Cascade Corporation, 1564 Tomlinson Road, Mason, MI 48854, USA.

Abstract: We compared northern goshawk (*Accipiter gentilis atricapillus*) nesting habitat within 1 ha of nest sites and at landscape scales of 10, 30, 60, 83, 120, 150, and 170 ha in 4 study areas east of the Cascade Mountains in Oregon and Washington. Our objective was to describe goshawk nesting habitat at biologically relevant scales and to develop models capable of assessing the effects of forest management alternatives on habitat suitability. We evaluated habitat at 82 active goshawk nests and 95 random sites. Productivity (young fledged per nest) was evaluated at 81 nests. We collected data on forest structure within 1 ha of nests and random points. At scales ranging from 10 to 170 ha, we recorded the abundance and spatial distribution of several forest stages of stand development (i.e., stand initiation, stem exclusion, understory reinitiation, old growth) on aerial photographs. We used logistic regression and classification and regression trees (CART) to (1) evaluate habitat selection, (2) construct models to calculate the probability of nesting, and (3) explore relationships between reproductive output and habitat conditions. We assessed model accuracy via bootstrap and jackknife cross-validation techniques.

By examining goshawk habitat relationships at multiple spatial scales across several study areas, we detected unifying spatial patterns and structural conditions surrounding goshawk nesting habitat. Our ability to discriminate goshawk nest sites from available habitat decreased as landscape scale increased, and different factors influenced goshawks at different scales. The presence and arrangement of forest structural types interacted to influence site suitability for nesting. At the 1-ha scale, the stage of stand development (i.e., stand initiation, stem exclusion, understory reinitiation, old growth), low topographic position, and tree basal area reliably discriminated between nests and random sites. Low topographic position and basal area were more influential than stand structure.

At the landscape scale, modeling indicated that conditions at different scales interact to influence selection of habitat for nesting. A core area exists surrounding goshawk nests in which stem exclusion and understory reinitiation stands with canopy closure $\geq$50% serve as apparent protection against potentially detrimental effects associated with more open forest (e.g., predators and micro-climate). Among several models tested, the model that best discriminated between nests and random sites encompassed 83 ha surrounding the nest and incorporated habitat characteristics from multiple scales nested within that range. This model had a cross-validated classification accuracy of 75%. Positive correlations were found between fledging rate and tree basal area within 1 ha of the nest ($F_{3, 77} = 2.89$,

[1] E-mail: mtmcgrath@state.mt.us.

[2] Present address: Montana Department of Natural Resources and Conservation, 1401 27th Avenue, Missoula, MT 59804, USA.

[3] Present address: U. S. Geological Survey, Massachusetts Cooperative Fish and Wildlife Research Unit, Holdsworth Natural Resources Center, University of Massachusetts, Amherst, MA 01003, USA.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

$P = 0.0407$), and between fledging rate and the percentage of landscape occupied by "stem exclusion" stands of low canopy closure (i.e., <50%) at landscape scales ≥60 ha ($F_{3,77}$, $0.041 \leq P \leq 0.089$). Spatial modeling also showed that timber harvest can be managed to maintain or enhance goshawk nest site suitability over time in the Interior Northwest, and that a non-harvest strategy can be just as detrimental to nesting habitat as can be aggressive, maximum-yield forestry.

We conclude that (1) northern goshawk nesting habitat becomes less distinguishable from the landscape with increasing area, and (2) habitat management based on exclusionary buffers should be re-evaluated in light of the way different habitat factors interact across spatial scales. We present case studies illustrating how landscape scale modeling can be implemented to (1) predict the influences of alternative silvicultural prescriptions on the suitability of potential nesting habitat over time, and (2) characterize large landscapes with respect to abundance and distribution of suitable nesting habitat.

WILDLIFE MONOGRAPHS 154:1–63

Key words: *Accipiter gentilis*, adaptive management, classification and regression trees, geographic information systems, goshawk, habitat selection, habitat suitability model, logistic regression, nesting habitat, Oregon, Washington.

CONTENTS

INTRODUCTION....2
A Historical Perspective....2
A Management Plan for Goshawks, Prey, and Forests....3
Study Perspective and Objectives....4
Acknowledgments....5
STUDY AREAS....5
METHODS....7
Design....8
Data Compilation....9
Nest Tree Characteristics....9
Nest Site Characteristics....10
Physiographic Characteristics....10
Vegetation and Structural Characteristics....10
Landscape Characteristics....11
Delineation of Landscapes....11
Ground-truthing....12
Landscape Variables....12
Univariate Analyses....12
Multivariate Analyses....13
Classification and Regression Tree....13
Logistic Regression....14
Models....15
Model Construction....15
Cross-validation....16
Management Applications....17
Site-specific Forest Growth Simulation....17
Landscape Assessment....18
RESULTS....20
Ground-truthing....20
Stage of Stand Development Attributes....20
Univariate Analysis....22
Nest Tree....22
One-hectare Nest Site....23
Landscape Scale....24
Productivity and Habitat Relationships....30
Multivariate Analysis....30
One-hectare Scale....30
Landscape-scale Habitat Models....32
Cross-validation....35
Forest Growth Simulations....37
Central Washington....37
Northeast Oregon....40
Landscape Assessment....40
DISCUSSION....43
Forest Structural Characteristics....43
Nest-Site Habitat Relationships....45
Univariate....45
Multivariate....47
Landscape-Scale Habitat Relationships....48
Reproductive Data....50
Implications for Our Knowledge of Goshawk Ecology....52
Limitations of This Study....53
Management Applications....54
Site-specific Application....54
Application for Landscape Assessment....55
CONCLUSIONS....56
LITERATURE CITED....57

INTRODUCTION

A Historical Perspective

For nearly 2 decades, wildlife management of coniferous forests in the Pacific Northwest has been focused largely on one species, the spotted owl (*Strix occidentalis*). Certainly other issues, such as those involving salmon (Nehlsen et al. 1991), marbled murrelets (*Brachyramphus marmoratus*; Ralph et al. 1995), biodiversity (Hunter 1999), and ecosystem functions and processes (Dunning et al. 1992), have since risen to national recognition, but the spotted owl has

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

arguably been the primier species and the most recognized symbol of old-growth forests and the controversy surrounding forest management and conservation. The debate over management of late seral stage forests and the role played by the spotted owl has been called a "watershed issue" for conservation (Yaffee 1994). Indeed, it would be a mistake to underestimate the role this single species has played in the history of natural resource conservation in North America.

The spotted owl has brought to our attention the interrelationships of ecosystem management, recovery of threatened and endangered species, conservation of biodiversity, and the role of science in management and policy. It also highlighted the importance and power of the Endangered Species Act, illustrating that attention on a single species can profoundly alter management practices, policies, and regional economies. These issues, however, no matter how important and broad-reaching, were restricted to a relatively narrow band of forest between the Pacific coast and the Cascade and Sierra Nevada Mountain Ranges in Washington, Oregon, and California, those areas inhabited by northern and California spotted owls (*S. o. caurina* and *occidentalis*, respectively).

Recently, petitions have been filed to list the northern goshawk as threatened or endangered under the Endangered Species Act (Silver et al. 1991). Aimed at various populations in the western United States and, most recently, for the United States west of the 100th meridian (U.S. Fish and Wildlife Service 1998), these petitions present potentially more far-reaching impacts than those resulting from the spotted owl listing. Goshawks inhabit a much broader geographic area and a much wider array of forest types (Squires and Reynolds 1997) than do spotted owls. Thus, their environmental, economic, and political implications are potentially more far-reaching. The power of the Endangered Species Act to stop or alter forest management throughout the range of the spotted owl was an important lesson, and a lesson not likely lost on those who petitioned to list the goshawk. Several authors have written and speculated about the chain of events, the motivations, and the potential consequences of such a listing (Kennedy 1997, Crocker-Bedford 1998, DeStefano 1998). Regardless of one's feelings or beliefs as to whether the northern goshawk or some subpopulation thereof should be protected under the Endangered Species Act, there is little doubt that this species rivals and potentially outweighs the controversy that has surrounded the spotted owl.

A Management Plan for Goshawks, Prey, and Forests

In response to concerns about the status of northern goshawks in the western United States and early attempts to list the Apache subspecies (*A. g. apache*) in the southwestern United States, the U. S. Forest Service assembled a panel of scientists to review the literature, consider options, and develop management recommendations for goshawks in coniferous forests. The panel considered then extant goshawk ecology and habitat requirements, the ecology and habitat of the goshawk's principal prey species, and silvicultural and management techniques to promote a mosaic of forest seral stages, including old-growth, across large landscapes. The result was *Management Recommendations for the Northern Goshawk in the Southwestern United States* (Reynolds et al. 1992).

Reynolds et al. (1992) identified 3 nested spatial scales in which to describe how breeding goshawks use southwestern landscapes: (1) a 10- to 12-ha nest area, comprised of 2–3 alternate nests within different stands in the nest area, (2) a 120- to 240-ha post-fledging area, which is an area surrounding the nest used by young from the time of fledging to independence from the adults, and (3) a 1,500- to 2,100-ha foraging area where the breeding pair hunts for food. Reynolds et al. (1992) recognized that variability would occur among nesting pairs in the size of these areas. However, their management recommendations for manipulating forest structure and maintaining a mix of seral stages centered on this concept of 3 nested spatial scales.

The southwestern management recommendations proposed by Reynolds et al. (1992) provide the most comprehensive plan for goshawks in North America. It has been both supported and criticized (Arizona

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Game and Fish Department 1993, Braun et al. 1996). Much of the criticism has focused on the fact that the plan was developed specifically for the southwestern United States, and thus, its applicability to other regions may not be appropriate. Another concern is that many of the premises in the plan comprise untested hypotheses. Despite these criticisms, Reynolds et al. (1992) lays a foundation for additional studies, and such work is especially needed in forested regions outside of the southwestern United States.

Study Perspective and Objectives

In North America, the northern goshawk has been characterized as an inhabitant of continuous forest and a species that can be impacted by forest practices (e.g., Crocker-Bedford 1990, Reynolds et al. 1992, Daw 1996, Desimone 1997). Previous North American research indicates that when selecting nest sites, goshawks favor lower topographic position, greater canopy closure, and larger diameter trees than what is available in the surrounding landscape (Hennessy 1978, Reynolds 1978, Moore and Henny 1983, Hall 1984, Hayward and Escano 1989, Kimmel 1995, Daw and DeStefano 2001). Because goshawks have large home ranges (ca. 2,200 ha) and use a range of forest conditions for foraging and nesting (Reynolds et al. 1992), it seems logical that they may not select nesting sites based on stand-level characteristics alone. Rather, selection of nesting sites may be influenced by landscape-scale patterns and processes. Thus, knowledge of landscape-scale factors may provide information regarding (1) the variety of proximate cues (e.g., landscape pattern and composition) for nest site selection by goshawks, (2) the functional significance of various habitat characteristics (e.g., stand composition, geographic attributes), and (3) a better perspective on how forestry practices influence the likelihood of goshawks nesting at different sites.

In the recent status review of northern goshawks west of the 100th meridian (U. S. Fish and Wildlife Service 1998), it was suggested that the largest impediment to deciding the status of goshawk populations was the lack of empirical data throughout the species' range. The status review concluded that if equal effort were expended for nest searches throughout the potential listing area that was expended in demographic studies, there would be an increase in reported numbers of goshawk territories and an increase in documented goshawk nesting. However, information on habitat use is more available than demographic information (at least for nesting habitat, but much less so for foraging or winter habitat), but is mainly descriptive (rather than predictive); its utility for more sophisticated modeling and use for adaptive management approaches remains undeveloped and untested. This is especially true for landscape scales; forest biologists report that large-scale landscape approaches are among the most needed studies for understanding the effects of forestry practices on wildlife populations (DeStefano 2002).

Furthermore, large-scale approaches are needed because the northern goshawk occurs broadly in western forest ecosystems that Covington et al. (1994) and Everett et al. (2000) have described it as increasingly susceptible to uncharacteristically severe, large-scale wildfires. For example, in the Eastern Cascades subregion of Oregon and Washington, fire suppression and removal of commercially valuable shade-intolerant species like ponderosa pine (*Pinus ponderosa*) have facilitated dominance by shade tolerant Douglas-firs (*Pseudotsuga menziesii*) and true firs (e.g., grand fir, *Abies grandis*) in very high stand densities over the course of several decades (Camp et al. 1997). In turn, these dense conditions have dramatically increased the threat of large-scale wildfires (Agee 1994, Camp et al. 1997, Everett et al. 2000). While it is unknown how those changes in forest composition and density may have modified northern goshawk habitats, the changes have clearly shifted wildfire regimes away from frequent low-intensity fires to less-frequent, high-intensity, stand-replacing fires that destroy goshawk nesting habitats. Thus, detailed information regarding goshawk habitat use can support forest planning efforts and identify silvicultural options that may reduce the likelihood and severity of such uncharacteristic events while conserving suitable conditions for goshawks.

Our research is aimed at developing a modeling procedure that can be incorporated into adaptive management programs for

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

landscapes, and also contribute to the base of knowledge that supports objective decisions regarding the status of goshawk populations in the West. In 1992 we began surveys for nesting goshawks in eastern Oregon, expanding this effort in 1994 to include areas in central Washington. Our goals were to evaluate habitat attributes around goshawk nests at several spatial scales and over a large geographic region that would be characterized by different forest types, forest conditions, land ownerships, and management histories. By comparing these attributes between active nests and random sites, we sought to develop a model that could provide a basis for predicting the distribution of suitable nest sites across these landscapes. In this context, we define habitat suitability in terms of the likelihood that a site would be selected for nesting based on (1) forest stand attributes and (2) the abundance and spatial distribution of stages of forest stand development at landscape scales ranging from 1 to 170 ha. We conclude with case studies illustrating how our model can be integrated with geographic information systems and forest growth models to evaluate (1) the effects of various silvicultural prescriptions on nest-site suitability over time and (2) the suitability of landscapes for nesting, in terms of the abundance and distribution of sites.

Acknowledgments.—We are indebted for the cooperation of: E. Duremas, M. Jackson, R. Stewart, and W. Watkins of the Fremont National Forest, K. Haines and L. Knotts of the Malheur National Forest, R. Anderson, A. Blumton, R. Ghormley, S. Lisle, B. Mason, and C. Mennell of the Wallowa-Whitman National Forest, P. Garvey-Darda and J. Richards of the Wenatchee National Forest, J. Jones, S. Kleinschmidt, B. Messinger, T. Quinn, and B. Ripley of Boise Cascade Corporation, L. Hicks of Plum Creek Timber Company, E. Arnett of Weyerhaeuser Corporation, S. Finn and L. Stream of the Washington Department of Fish and Wildlife, the Washington Department of Natural Resources, and the Yakima Resource Management Cooperative. S. Daw, S. Desimone, S. Finn, and T. Fleming provided valuable data, time, and discussion during the course of this study. T. McDonald and D. Rosenberg provided valuable insight into logistic regression analyses. T. Maan conducted the classification and regression tree analyses, J. Vander Ploeg simulated forest responses to silvicultural prescriptions for the Washington case study. B. Patel developed the moving window landscape assessment under contract with Boise Cascade Corporation. J. Citta, K. Kistler, A. Krawarik, and S. Meiman served as field assistants. R. Anthony provided valuable comments and guidance. The manuscript benefited from constructive reviews by D. E. Andersen, P. L. Kennedy, K. Titus, W. C. McComb, R. T. Reynolds, and D. L. Verbyla. This research was conducted with cooperation of the Oregon Cooperative Wildlife Research Unit, the National Council for Air and Stream Improvement, Boise Cascade Corporation, and the U. S. Forest Service.

STUDY AREAS

Four study areas were located east of the crest of the Cascade Mountains in Oregon and Washington: Central Washington, Northeast Oregon, and the Malheur and Fremont National Forests (Fig. 1). Goshawk nests and random sites occurred in a variety of forest types and landscape conditions within these areas, which were administered by state and federal agencies as well as by several private forestry companies.

The Central Washington study area was on the east slope of the Cascade Mountains surrounding Cle Elum, Washington. Forests were managed by the Cle Elum Ranger District of the Wenatchee National Forest, Washington Department of Natural Resources, Plum Creek Timber Company, and Boise Cascade Corporation. This area is located in the North Cascades, Cascades, and Eastern Cascade Slope provinces (Franklin and Dyrness 1973; Fig. 1). This study area encompassed 2,665 km^2 of land capable of growing forests. Topography ranges from greatly undulating to moderately hilly. Elevations range from 600–1,800 m. Precipitation has averaged 50 cm per year (Franklin and Dyrness 1973). Forested lands were dominated by conifers, including Pacific silver fir (*Abies amabilis*), subalpine fir (*A. lasiocarpa*), grand fir, western larch (*Larix occidentalis*), Engelmann spruce (*Picea engelmannii*), white pine (*Pinus monticola*), lodge-

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

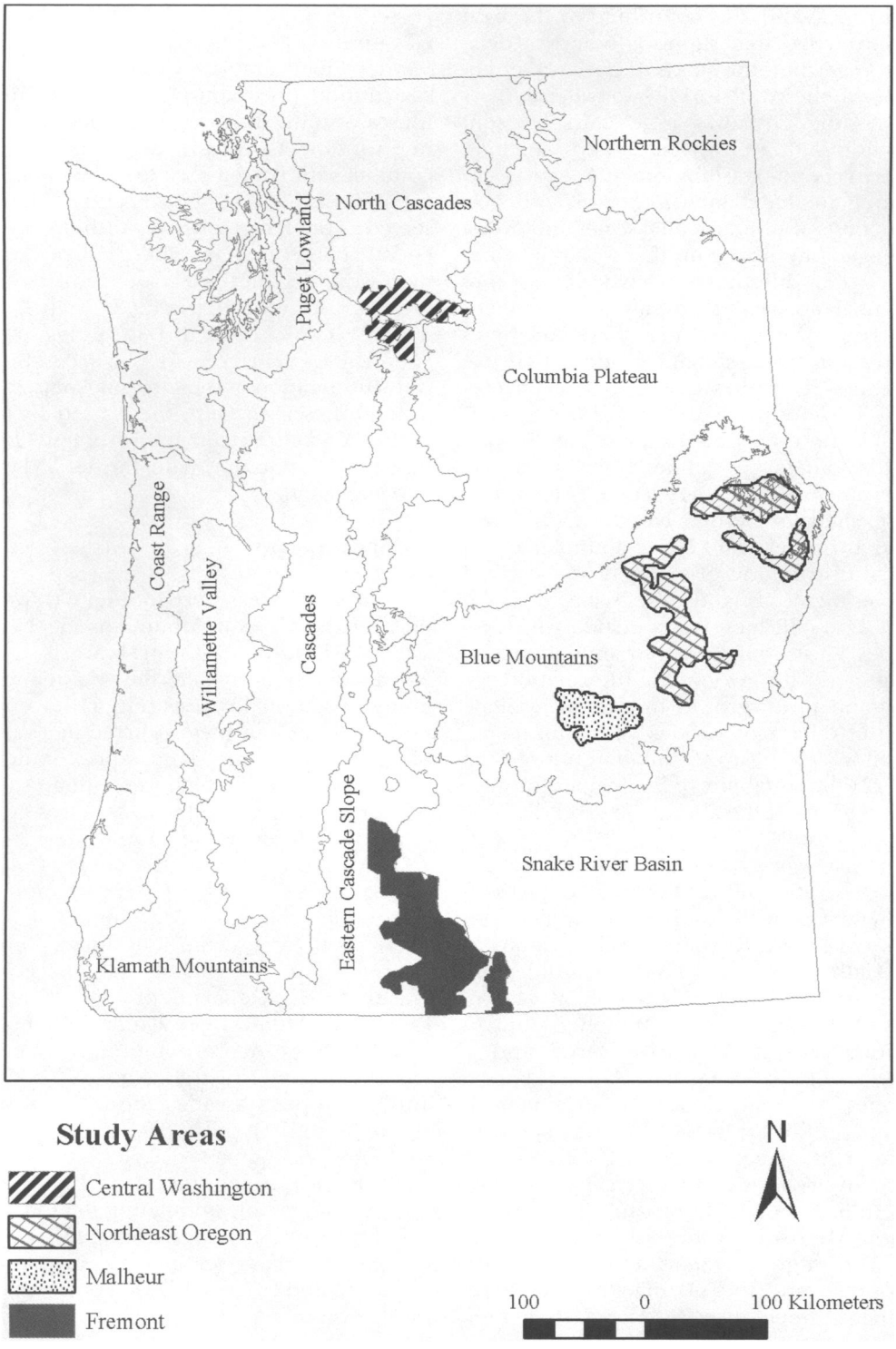

Figure 1. Location of four study areas in eastern Oregon and Washington from which goshawk nests and random sites were sampled, 1994–1995. There were 14, 27, 20, and 21 goshawk nests in the Central Washington, Northeast Oregon, Malheur, and Fremont study areas, respectively, and 20, 25, 25, and 25 random sites, respectively. Boundaries of ecological provinces are after Franklin and Dyrness (1973).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

pole pine (*P. contorta*), ponderosa pine, Douglas-fir, western red cedar (*Thuja plicata*), and western hemlock (*Tsuga heterophylla*; Franklin and Dyrness 1973). Silvicultural practices were predominately even-aged near the Cascade crest, but predominately selection harvests on lower elevation, drier, flatter sites.

The Northeast Oregon study area included lands administered by the Wallowa-Whitman National Forest, Boise Cascade Corporation, and R-Y Timber Company totaling 5,547 km^2 of land capable of growing forests. This area is located in the Blue Mountains province (Fig. 1) and included several mountain ranges separated by faulted valleys and synclinal basins causing highly variable topographic relief, from moderate to steep slopes. A mosaic of forest types occurred interspersed with grasslands throughout the study area (Franklin and Dyrness 1973). Elevations range from 500–2,900 m, and precipitation has averaged 40 cm annually (Franklin and Dyrness 1973). Forests were dominated by ponderosa pine, lodgepole pine, grand fir, subalpine fir, and an abundance of mixed conifer types (e.g., ponderosa pine, Douglas-fir, grand fir, and western larch). Silvicultural practices included a variety of even-aged and uneven-aged management practices (e.g., clear cut, thinning from below, overstory removal, shelterwood harvests, and single-tree and group selection).

The Malheur study area was located on the Bear Valley Ranger District of the Malheur National Forest, immediately south of John Day, Oregon, in the Blue Mountains province (Fig. 1). This area encompassed 1,170 km^2 of land capable of growing forests. Elevations range from 1,300–2,000 m, with topography typified by hills and moderately steep drainages. Precipitation has averaged 35 cm annually (Franklin and Dyrness 1973). A mixture of forest types occurred, including ponderosa pine, Douglas-fir, grand fir, western larch, lodgepole pine, mixed conifer stands, and mountain-mahogany (*Cercocarpus ledifolius*; Franklin and Dyrness 1973). Additionally, the Malheur study area surrounds a large 23,500-ha nonforested valley (Daw 1996). Silvicultural practices were typified by even- and and uneven-aged management (e.g., overstory removal and group selection).

The Fremont study area included the Fremont National Forest and surrounding lands owned by Weyerhaeuser Corporation in south-central Oregon, encompassing a total of 3,993 km^2 of land capable of growing forests (Fig. 1). This area is located primarily on the Eastern Cascade Slope and characterized by fault-blocked mountains and elevations ranging from 1,200–2,500 m. Much of the area has rolling topography with low relief. Precipitation has averaged approximately 35 cm annually and supported a diversity of tree species, including ponderosa pine, sugar pine (*P. lambertiana*), lodgepole pine, Douglas-fir, grand fir, white fir (*A. concolor*), quaking aspen (*Populus tremuloides*), juniper (*Juniperus* spp.), and incense cedar (*Calocedrus decurrens*; Franklin and Dyrness 1973). Silvicultural practices included even-aged (i.e., clear cuts) and uneven-aged (e.g., group selection harvests) management practices.

METHODS

Our objectives were to evaluate goshawk nest habitat selection at multiple landscape scales (sensu Johnson 1980), and develop a resource selection probability function (RSPF; Manly et al. 1993). To achieve these objectives, we developed a hierarchical process of data collection, classification, and analysis that was applied independently in each study area. We examined habitat at scales relevant to the nest tree, nest stand, and post-fledging area (Reynolds et al. 1992). Each scale was characterized by its physiographic, vegetative, and structural conditions. Because the four study areas represent different ecological provinces (Fig. 1; Franklin and Dyrness 1973), land ownership, and harvest histories, a structurally-based habitat classification scheme was developed to capture how goshawks might perceive these diverse environments. To ensure that stages of stand development were correctly assigned, a large scale ground-truthing process was implemented (McGrath 1997). After all data were collected, univariate statistics were used to describe each landscape scale and to reduce data for aiding multivariate model development. Classification and regression tree (CART) analysis (Breiman et al. 1984) was used to develop a vegetative

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

classification for each landscape forested stage of stand development, and logistic regression was used to develop a multiscale RSPF, based on the landscape composition and structure at each scale. These procedures are described in detail below.

Design

We employed a use-versus-availability design (Marcum and Loftsgaarden 1980) to test the null hypothesis that goshawk nesting habitat does not differ from available habitat. We assumed the range of habitat surrounding our sample of goshawk nests was representative of conditions surrounding nests in the larger goshawk population. Most of the landscape scales at which the null hypothesis was tested corresponded to scales considered relevant to goshawk habitat use. These scales consisted of concentric circles centered on trees where goshawks were known to have incubated eggs, and around randomly-located sites, and corresponded to: (1) a nest tree; (2) a 1-ha nest site (radius = 56 m; hereafter referred to as 1-ha nest site); (3) a 10-ha nest "stand" (radius = 178 m; hereafter referred to as 10-ha landscape; after Reynolds et al. 1992); (4) a 30-ha landscape (radius = 309 m) corresponding to the mean area utilized by fledglings prior to hard-penning of flight feathers (after Kenward et al. 1993); (5) a 60-ha landscape (radius = 437 m) corresponding to the area within which Woodbridge and Detrich (1994) correlated a high reoccupancy rate for nest clusters; (6) an 83-ha allometric post-fledging area (APFA; radius = 514 m) based on body size (after Holling 1992); (7) a 120-ha landscape (radius = 618 m) which is near the maximum observed range of nest clusters (Woodbridge and Detrich 1994); (8) an arbitrary 150-ha landscape (radius = 691 m) corresponding to a mid-scale between 120 ha and a 170-ha post-fledging area (PFA); and (9) the 170-ha PFA scale (after Kennedy et al. 1994; radius = 736 m). Use of the terms "landscape" and "landscape-scale" denote the suite of habitat conditions (i.e., patch characteristics) present within concentric circles extending from 10- to 170-ha.

In the absence of an empirical PFA estimate for the Interior Northwest, an analyst can only use empirical estimates for the PFA from other areas, or alternatively, an allometric relationship to predict the appropriate scale for the PFA. We decided to use both of these approaches, by using an allometric relationship and an empirical estimate from another mixed conifer forest (i.e., north-central New Mexico). To account for possible environmental differences between the Interior Northwest and the region where current PFA estimates have been previously described (Kennedy et al. 1994), the 83-ha allometric PFA (APFA) was derived from the generalized relationship of body mass to home range size (Holling 1992). The average mass of 103 female goshawks (Dunning 1984) was used to calculate the allometric home range size for a breeding female goshawk (Holling 1992:473). To be consistent with PFAs derived from radiotelemetry, the allometric home range was multiplied by 0.318, the ratio of core area to home range size (Kennedy et al. 1994:78), to yield the APFA.

The 170-ha PFA was the largest landscape scale analyzed because it is believed to contain the habitat components necessary for fledged young to learn hunting skills and provide cover for concealment from predators before juvenile dispersal (Reynolds et al. 1992, Kennedy et al. 1994). However, as defined by Kennedy et al. (1994), the PFA is a portion of the larger breeding season home range that also contains the goshawk's foraging area, and may vary in size from 2,000 to 19,500 ha (Reynolds et al. 1992, Iverson et al. 1996). Although we employ concentric circles rather than telemetry locations, and our largest scale, the PFA, constitutes <10% of the potential foraging area, the PFA is appropriate because it includes the nest stand and represents habitat conditions most likely to influence survival during the fledgling-dependency period. Lehmkuhl and Raphael (1993) compared habitat patterns in actual home ranges with concentric circles around owl nests and found the conditions to be comparable. Breeding density of most raptor species is contingent upon 2 factors: food supply and nest sites (Newton 1979:61). In areas where prey are abundant and available but few suitable nest sites are present, there typically are many "surplus" birds that are nonbreeding and nonterritorial. When nest sites do become available, these surplus individuals establish territories and breed

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

(Newton 1979). Conversely, breeding density can also be limited by territoriality, even if prey abundance and nest sites are not limiting factors. Thus, understanding how PFA habitat conditions relate to the suitability of potential nest sites is important for territorial species, such as the goshawk, which utilize alternate nest sites within a territory over time.

Data Compilation

Active goshawk nest sites in this study were identified through various methods, including protocol surveys (Kennedy and Stahlecker 1993) of historic territories and extensive land tracts (DeStefano et al. 1994, Finn 1994, Daw 1996), forest stand inventories, and incidental discoveries by forest workers. Goshawk nests were located by personnel from the Oregon Cooperative Wildlife Research Unit, Washington Department of Wildlife, U. S. Forest Service, private companies, and project staff from 1992–1994 (Fig. 1). All nests in this study were known to have been used by an incubating female in 1994. By using nests located through a variety of methods, nests included in this study may not comprise a completely random sample of all goshawk nests in the study areas. However, they do document a range of conditions in which goshawks nest over a large geographic region. Furthermore, Daw et al. (1998) found no within-stand habitat bias among goshawk nests found through systematic (n = 27) and nonsystematic (n = 22) means. Therefore, results from our 1-ha nest site may be more representative of goshawk habitat, although we recognize that inferences from Daw et al. (1998) may not be entirely applicable to our larger landscape analysis.

Productivity (i.e., number of young fledged per active nest and per successful nest) was determined by visiting nests in late July 1994 and counting nestlings either just before or just after fledging (DeStefano et al. 1994). Reproductive terminology follows that of Steenhof and Kochert (1982). Because we used reproductive data from only one year, our sample was not replicated in time. Thus, our productivity data may not be representative of the study areas for a variety of reasons, such as climate, prey abundance and availability (Kostrzewa and Kostrzewa 1990, Penteriani 1997, Patla 1997), and "transient" nest sites (Newton 1979). Thus, our reproductive data do not represent the temporal variation known to occur in goshawk productivity (McClaren et al. 2002).

For use-versus-availability analysis, characteristics of available habitat were sampled for randomly selected sites. The number of random sites required was determined based on 1-ha nest site variability for canopy closure, basal area, and diameter at breast height (dbh) at goshawk nests in 1994, because landscape-scale data had not yet been collected. A sample size equation (Bell and Dilworth 1988:173) was used to determine the sample size required to detect a 15% difference with ≥90% confidence at an $\alpha = 0.05$. Ninety-five universal transverse Mercator (UTM) coordinate pairs were randomly generated in proportion to the occurrence of nest sites in the 4 study areas (Fig. 1), and satisfied the following criteria: (1) the entire 170-ha landscape scale fell within a managed forest landscape (i.e., nonwilderness), (2) the UTM coordinate pair fell within a forested stand, and (3) no overlap occurred at the 170-ha scale with other random circles. Locations not satisfying these criteria were replaced with new random coordinates. Random sites were treated identically to nest sites in terms of data collected and collection methods, with the exception of 5 random sites in which the 1-ha nest site was located in young forest plantations. At these sites, 1-ha nest site data were not collected, but site conditions and other landscape-scale data were collected. Habitat variables were quantified at goshawk nest sites and random sites in 1994 and 1995, respectively.

Nest Tree Characteristics

Nest trees were recorded to species. Diameter at breast height, canopy position (Smith 1986:49), and tree status (i.e., alive or dead) were recorded for each nest tree. Heights were measured using a clinometer for the nest, tree, and lower extent of the live canopy (for live nest trees). Nest location in the tree was characterized by the ratio of nest height to tree height (TRATIO) and also by nest placement in relation to the lower extent of the live canopy (i.e., live canopy height minus nest height; hereafter

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

LCDIST). Tree age was determined using an increment bore.

Nest Site Characteristics

Sites were described by general physiography, vegetative composition, and forest structural development. Random site UTM coordinates were located in the field using a Garmin GPS40™ global positioning system (Garmin International 1994).

Physiographic Characteristics.—Physiography recorded for each 1-ha site included elevation, aspect, slope, topographic position, and proximity to nearest change of forest stage of stand development, water, and nearest human disturbance (e.g., road, timber harvest, dwellings; McGrath 1997). Elevation and proximity to water were obtained from USGS 7.5′ topographic maps. We measured aspect with a compass and slope (%) with a clinometer. Topographic position was categorized as: ridge top, upper 1/3 of the slope, middle 1/3, lower 1/3, drainage bottom, or flat. Proximities to forest change and human disturbance were obtained in the field or from recent 1:12,000–1:16,000 aerial photographs.

Vegetation and Structural Characteristics.—At each nest site we recorded forest vegetation type (McGrath 1997), stage of stand development (after Oliver and Larson 1996), age of dominant strata, canopy closure, basal area, live stem density, quadratic mean diameter, and stand density index (after Reineke 1933). Vegetation for the 1-ha scale was classified into 1 of 5 forest vegetation types based on prevalent tree species: (1) ponderosa pine, (2) mixed conifer/ponderosa pine, (3) mixed conifer, (4) lodgepole pine, and (5) other (McGrath 1997). Stand age was the average number of growth rings from an increment core taken at breast height, obtained from 5 dominant and 5 codominant trees within the 1-ha nest site, following Smith (1986:49). Within the 1-ha nest site, stage of stand development was categorized according to Oliver and Larson's (1996:148) four stages of stand development (i.e., stand initiation, stem exclusion, understory reinitiation, old growth; Fig. 2) to provide structural references characterizing the vertical and horizontal complexity surrounding the nest sites.

Canopy closure, basal area, live stem density, quadratic mean diameter, and stand density index were estimated using a nest-centered concentric hexagonal sampling design within the 1-ha nest site (Fig. 3). The sampling design ensured equal sampling

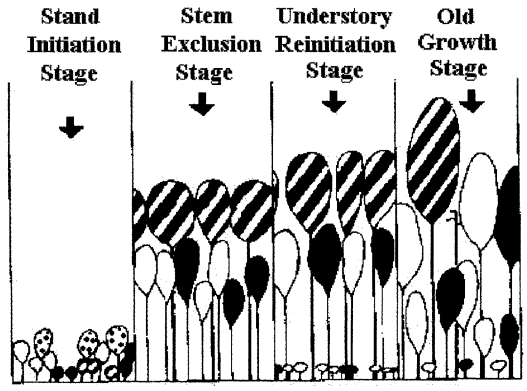

Figure 2. Stages of stand development for forested stands. Stand initiation is characterized by young trees of various species colonizing a site following a disturbance. Stem exclusion is characterized by the absence of seedlings and saplings, the onset of self-thinning through competition, and the beginning of crown class differentiation into dominant and subordinant species. Understory reinitiation is characterized by the colonization of the forest floor by advance regeneration and the continuation of competition in the overstory. Old growth is characterized by the senescence of overstory trees in an irregular fashion and the growth of the understory trees to the overstory. Diagram is adapted from Oliver and Larson (1996:149; this material is used by permission of John Wiley & Sons, Inc.). In this study we subdivide both stem exclusion and understory reinitiation into high and low canopy closure stands (≥50% and <50%, respectively) for landscape scales > 1 ha.

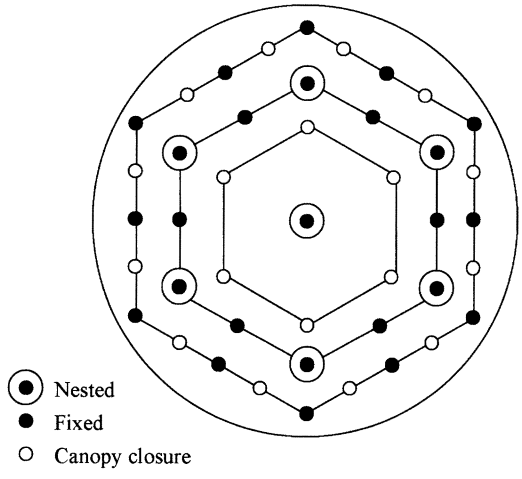

Figure 3. One-ha scale sampling design. Distances from nest-centered plot to first, second, and third hexagons were 17, 34, and 51 m, respectively. Live stem density, diameter at breast height, and canopy closure were measured at fixed-radius plots. Nested plots include basal area and the fixed-radius plot variables. Canopy closure was measured at all plots using a moosehorn.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

intensity around each fixed point (nest or random coordinates), and provided an unbiased estimate of vegetative characteristics at the 1-ha scale. Sampling intensity was calculated based on data collected at pilot 1-ha sites, and using a sample size equation for finite populations (Bell and Dilworth 1988:173) to detect a 15% difference with ≥90% certainty at α = 0.05. The design consisted of 7 nested plots, 18 fixed-radius plots, and 18 canopy closure sampling points (Fig. 3). Nested plots included a variable-radius plot for basal area, an 80-m^2 fixed-radius plot to tally and record dbh for all live trees having dbh ≥2.54 cm and height ≥1.22 m, and a sample point to record canopy closure. Fixed-radius plots were used to tally and record dbh for all live trees having dbh ≥2.54 cm and height ≥1.22 m, and included a sample point to record canopy closure. Canopy closure was recorded at all 18 individual sample points (Fig. 3).

We used a moosehorn (Garrison 1949, Bonnor 1967, Bunnell and Vales 1990) to estimate canopy cover, rather than a spherical densiometer, to avoid overestimating canopy closure (Bunnell and Vales 1990, Cook et al. 1995). Basal area estimates were obtained from 7 variable-radius plots using a 20 basal area factor prism. Live stem density and the number of live trees having dbh ≥2.54 cm and height ≥1.22 m were estimated from fixed-radius plots. Quadratic mean diameter for each 1-ha nest site was calculated from diameters obtained at fixed-radius plots.

Reineke's (1933) stand density index (SDI) is an expression of the relationship between mean tree size and density (trees/ha) within a forest stand (Long 1985). This relationship has been shown to predict density-dependent mortality for several tree species associated with Yoda et al.'s (1963) "self-thinning rule." Thus, stand density index gauges the likely extent of competition among trees (Long 1985), and has been used to illustrate stand management prescriptions for goshawks (Lilieholm et al. 1994). After Reineke (1933), SDI was calculated for each 1-ha nest site as:

$$SDI = LSD(DBH_Q/25)^{1.6}$$

where live stem density is represented by LSD, and quadratic mean diameter by DBH_Q.

Landscape Characteristics

Delineation of Landscapes.—We used mirror stereoscopes with magnification capabilities and the most recent (1988–1994) color and black-and-white aerial photograph stereoscopic pairs (1:12,000–1:16,000 scale) to delineate forest stands within the 170-ha PFA surrounding each goshawk nest and random site. To prepare a meaningful analysis of goshawk habitat across 4 divergent study areas, delineation of the forest stands required that: (1) stand characterization represent how goshawk perceive their environment, and (2) the classification system be repeatable in different vegetative communities across study areas. Because goshawks breed from Alaska to Newfoundland, and south to Arizona and New Mexico (Johnsgard 1990), we hypothesized that goshawks do not necessarily perceive particular vegetation communities *per se*, rather, they respond to vertical complexity and stand density. Thus, we categorized stands into 1 of 9 stages of stand development categories (after Oliver and Larson 1996) including: (1) stand initiation, (2) high canopy closure (i.e., ≥50%) stem exclusion (hereafter high stem exclusion), (3) low canopy closure (i.e., <50%) stem exclusion (hereafter low stem exclusion), (4) high canopy closure understory reinitiation (hereafter high understory reinitiation), (5) low canopy closure understory reinitiation (hereafter low understory reinitiation), (6) old growth, (7) wet openings, (8) dry openings, and (9) water. Thus, at scales >1 ha, 6 stages of forest stand development were used, rather than the original 4, to account for stands with similar vertical development but different stocking densities, which may cause the stand to function differently for goshawks. Criteria for stand delineation included crown diameters, number of visible canopy layers, diversity of crown diameter classes, and canopy closure (Paine 1981). Minimum stand size was constrained by photograph scale to 2.02 ha. Polygon overlays of the typed photographs were digitized using Tosca software (Clark University, Worcester, MA), then corrected for photographic distortion using control points obtained from USGS 7.5' topographic maps and stored in an Idrisi database with 2-m pixel size (Clark Laboratories, Worcester, MA). This formed

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

the foundation for analysis of the habitat conditions in the smaller landscape scales, as these landscape scales were merely subsets of the 170-ha PFA.

Ground-truthing.—After delineating the 9 stages of stand development in each of the 4 study areas, 10% of each stage of stand development was ground truthed via simple random sampling to assess classification accuracy and to quantify structural characteristics for each category. Classification accuracy is agreement (%) between aerial photograph classifications and ground measurements in each stage of stand development. Ground measurements provided a mean and 95% confidence interval for variables describing each category. Personnel conducting the ground truthing had no prior knowledge of the photo-typed structural classification and based their assessment on vertical stratification, herbaceous development, evidence of competition, and advance regeneration (Oliver and Larson 1996). Plots established for ground-truthing were placed systematically along a single straight line aimed at capturing maximum diversity within a stand. These plots alternated between nested and fixed-radius plots, with a minimum of 50 m between nested plots. Nested plots consisted of one 20-factor prism plot and one 80-m^2 fixed-radius plot. Due to a western spruce budworm (*Choristoneura occidentalis*) epidemic in Northeast Oregon, there were difficulties with habitat classification. However, these problems were rectified with detailed ground inspections (McGrath 1997).

Landscape Variables.—We collected information on 14 variables at each landscape scale ≥10-ha surrounding each nest and random point: percent of the landscape in each of the 9 stages of stand development (% LAND), and 5 fragmentation metrics (Table 1). Landscape composition variables were selected to evaluate association between goshawk nests and individual stages of stand development. The two contrast-weighted edge density variables were selected to evaluate whether goshawks were selecting landscapes based on edge density between structural categories or differences in canopy closure. Mean nearest neighbor distance was selected to evaluate preference for proximity between stands of the same type. Simpson's evenness index was selected to evaluate whether goshawks prefer landscapes dominated by single structural stages or landscapes where the structural stages present are equally abundant. Contagion was selected to evaluate preference for large blocks of habitat or dispersed, fragmented landscapes. Values for each variable were generated with FRAGSTATS 2.0 (McGarigal and Marks 1994) on an Idrisi image of each landscape scale. Homogeneity of cover types at the 10- and 30-ha scales precluded meaningful analysis of fragmentation metrics at these smaller scales.

Univariate Analyses

We tested for differences in each continuous variable between active nests and random sites at all landscape scales using two-sample *t*-tests (Zar 1984:126). The univariate analyses primarily served as a data reduction process for the multivariate analysis, identifying variables most important to the modeling process (Hosmer and Lemeshow 1989). At the 1-ha nest site, we analyzed differences

Table 1. Fragmentation metrics calculated from Fragstats 2.0 (McGarigal and Marks 1994) for each landscape-scale ≥10-ha surrounding goshawk nests and random points in eastern Oregon and Washington, 1994–1995.

Fragmentation Metric	Definition
CWED [a]: structure	The sum of the lengths of each edge segment in the landscape multiplied by the corresponding contrast weight for forest structure, divided by total landscape area.
CWED: canopy closure	Same as above with weights based on canopy closure.
Mean nearest neighbor	Average distance to the nearest neighboring stand of the same type, across all types, for those stand types with a neighbor of the same type.
Simpson's evenness index	A measure of the proportional abundances of forest structural categories present in the landscape.
Contagion	A measure of the proportional abundances of each stand type and their interspersion and juxtaposition in the landscape.

[a] Contrast-weighted edge density (McGarigal and Marks 1994).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

in aspect (i.e., circular data) using the Rayleigh test (Batschelet 1981) for nonrandomness, and a two-sample test of angles (Zar 1984:446) for differences between nests and random sites. In the two-sample test we calculated the mean angle, angle deviation, and length of the mean vector. Each variable was screened for normality and homogeneity of variance and transformed when necessary. We used the natural log transformation to correct for variance heterogeneity, square-root transformation to correct for skewness, and arcsine square-root transformation for proportion data. We used $\alpha \leq 0.10$ to denote significant differences between active nests and random sites. Results obtained from transformed versus nontransformed data did not differ; therefore, all results presented here were derived from analysis of nontransformed data.

For categorical variables (i.e., stage of stand development, forest vegetation type, and topographic position), we used a chi-square test of homogeneity ($\alpha = 0.10$) with Bonferroni simultaneous confidence intervals ($\alpha = 0.05$) to test the hypothesis that goshawks selected habitat at the 1-ha nest site in proportion to its availability (Marcum and Loftsgaarden 1980).

We used ANOVA to test for differences in nest productivity (i.e., number fledged) among habitats at each landscape scale. We used a chi-square test of homogeneity to test for differences in categorical data. The null hypothesis was that nest productivity did not vary with landscape composition and fragmentation. Where the expected cell counts for chi-square analyses were <5, number fledged was adjusted to indicate sites that fledged ≤ 1 or ≥ 2 young. All univariate tests were performed using TTEST, FREQ, and GLM procedures in SAS (SAS Institute Inc. 1988).

Tests for differences in nest tree characteristics included dbh, tree age, and species. Two-sample *t*-tests were used to compare dbh and tree age, and a chi-square test of homogeneity compared tree species used for nesting and available at random sites. Because sampling for 1-ha characteristics was centered on a goshawk nest tree or random site UTM coordinates, a tree whose dbh was at least the minimum goshawk nest tree dbh was randomly selected from the center vegetation plot (Fig. 3) for comparison with goshawk nest tree dbh. Additionally, a tree from each random site was randomly selected from among those aged with an increment core for comparison with goshawk nest tree age and species.

Multivariate Analyses

For multivariate analysis we employed classification and regression tree analysis and logistic regression. CART was used to develop models for predicting stage of stand development based on structural attributes within forest stands. Logistic regression was used to distinguish occupied nest sites from random sites at the various landscape scales based on habitat variables. We used logistic regression because it does not require the assumption of multivariate normality (Press and Wilson 1978), and because it can accommodate categorical and continuous variables. Logistic regression allows for analysis of first-order interactions among significant main effects, tests for study area effects, and tests for first-order interactions among main habitat effects and study areas (i.e., to account for geographic differences in the main-effect habitat variables).

Classification and Regression Tree.—CART analysis is a nonparametric technique. When applied to a grouped, multivariable data set, it produces binary decision criteria in the form of a decision tree. Classification and regression trees can be used to assemble an accurate classifier or to uncover the predictive structure of data (Breiman et al. 1984, De'Ath and Fabricius 2000). We used CART to reveal influential forest stand characteristics to determine stage of stand development using each stand's basal area, DBH_Q, and tree densities in six diameter classes. Construction of the CART decision tree was based on an algorithm that divided the data set into descendent binary subsets (i.e., nodes) such that composition of the resulting subsets were "purer" than the data in the parent set. The decision tree was so constructed until each subset, or node, could no longer be split, thus resulting in terminal nodes. Once constructed, the tree was pruned to rectify any overfitting that had occurred without sacrificing goodness-of-fit. We employed S-Plus software (Mathsoft, Inc. 1997) to prune classification trees using a

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

cost-complexity measure, whereby the appropriate decision tree size was determined as a function of the amount of deviance (i.e., a measure of the residual distance between fitted and observed values) reduced with each unit increase in decision tree size (Clark and Pregibon 1992). Classification accuracy of the pruned tree was evaluated as the proportion of correctly classified observations. Our pruned tree was jackknifed (Verbyla and Litvaitis 1989) to evaluate the robustness of its decision criteria. Nodes and decision variables of the CART analysis were held constant during the jackknifing so that variation in the decision criteria and resultant classification could be ascertained.

Logistic Regression.—Logistic regression describes how a binary response variable is associated with a set of explanatory variables. In our study, the binary response values were "1" for active goshawk nests and "0" for random sites. The mean of this binary response results in a probability, bounded between 0 and 1 (Hosmer and Lemeshow 1989). Therefore, in our study a logistic regression model specifies that the probability of a site being a goshawk nest or random site is related to a regression function of explanatory variables. In this context we define nest habitat quality as the probability of a site being selected for nesting, based on the logistic regression function.

In habitat use and availability study designs, "random" sites cannot be confirmed as "not-used" and thus it is possible that some randomly sampled sites actually included goshawk nest habitat. Therefore, the binary response is no longer a discrete "yes" or "no." Under this circumstance Manly et al. (1993) recommend calculating a RSPF, based on values of the logistic regression coefficients, to compensate for possible inclusion of used (i.e., goshawk) habitat in the random sample. The RSPF, as described by Manly et al. (1993:126–127,129), is:

$$\mathrm{RSPF} = \exp[-\ln(P_u/P_a) + \beta_0 + \beta_1 x_1 + \ldots + \beta_p x_p],$$

where RSPF represents the resource selection probability function, $x_1, \ldots, x_p$ are the p variables in the logistic regression equation; $\beta_0, \ldots, \beta_p$ are the $p + 1$ logistic regression coefficients; P_u is an estimate of the proportion of used sites selected as goshawk nests; P_a is the proportion of the available landscape selected as random sites; and the RSPF is manifest in an exponential distribution (i.e., RSPF > 0). Because goshawks must select their sites from the same population of available sites, inclusion of P_u and P_a in the RSPF adjusts the intercept term (β_0) to account for proportions of the goshawk population and number of available sites sampled. The remainder of β_0 in the RSPF represents proportions of the goshawk population and available habitat not sampled, thereby accounting for possible inclusion of used habitat in the random sample.

An estimate of the number of goshawk territories present within all four study areas was necessary to calculate P_u. We used existing estimates for active territory densities that were derived from protocol surveys in which all habitats were surveyed equally (DeStefano et al. 1994, Finn 1995; Table 2). Thus, an active territory, by this definition, is one where nesting was attempted. This yielded a range between 0.043 and 0.072 active territories/km^2 (i.e., 95% CI). Average territory density (0.058 active territories/km^2, SE = 0.005) was multiplied by total forested area for all study areas (12,611.14 km^2) to yield an estimate of 730 active goshawk territories. Because we sampled 82 goshawk nests from an estimated 730 active territories, P_u = 0.1124 for this study. By using territory density estimates collected from our four study areas over a four-year period, inclusive of the year in which we

Table 2. Northern goshawk breeding densities for the Central Washington, Northeast Oregon, Malheur, and Fremont study areas, 1992–1995. Density is defined as the number of active territories/km^2.

Study area	Density survey area	1992	1993	1994	1995
Fremont [a]	Paisley	0.046	0.062		
	Bly		0.038		
Malheur [a]	Bear Valley East	0.088	0.066		
	Bear Valley West		0.086		
Northeast Oregon [a]	Spring Creek	0.070	0.026		
Central Washington [b]	Manastash			0.0425	
	Cle Elum River				0.0541

[a] DeStefano et al. (1994). [b] Finn (1995).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

sampled goshawk habitat, we assumed density estimates were representative of goshawk populations and landscapes in our study. Because P_u modifies β_0 only to account for the proportion of used sites already sampled, variability in territory density affects only the resulting classification accuracy of the RSPF (Manly et al. 1993), not the coefficients from the logistic regression. Thus, we evaluated the effects territory density variability would have on the RSPF to account for potential uncertainty in the territory density estimate.

P_a was calculated from the area capable of growing forests on all study sites. We used only land capable of growing forests to align with the limitations imposed on random point selection (i.e., that the UTM coordinate pair fall within a nonwilderness forested stand). Thus, calculation of the proportion of available sites was restricted to forested lands in the study area. The sampling unit for random sites was 1.7 km^2 (corresponding to the 170-ha PFA), and thus P_a for the entire study was equal to 0.0128 (i.e., [95 $\times$ 1.7 km^2] / 12,611.14 km^2).

Before analysis of the 1-ha data, categorical variables were combined to conserve degrees of freedom. Because no goshawk nests were located in stand initiation stands, a "zero cell" occurred for this category of stage of stand development for goshawk nest sites. Preliminary analyses indicated that stand initiation stands should not be considered nesting habitat within the 1-ha scale; goshawks did not nest in stand initiation stands. Thus, to compensate for logistic regression's difficulties with zero cells in categorical data (Hosmer and Lemeshow 1989:84), random sites located in stand initiation stands ($n = 11$) were removed from the logistic regression analysis so that only structural conditions from which goshawks likely select nest sites would be analyzed. Aspect was converted into 8 categories (i.e., N, NE, E, SE, etc.). We reduced categorical variables such as aspect, topographic position, and forest vegetation type, from multiple indicator variables to a single indicator variable consistent with each variable's structure and relation to selection by goshawks using the method of Ramsey et al. (1994:194). This procedure conserves degrees of freedom while maintaining data structure.

Models.—Several logistic regression models were constructed to differentiate between available habitat and habitat associated with active goshawk nests. These included: (1) a 1-ha nest site model based on the vegetation data collected at that scale, (2) a model for each landscape scale $\geq$10 ha based on the stages of stand development and fragmentation metrics present at each scale, and (3) several models that integrated habitat across multiple landscape scales simultaneously.

Multiple-scale models considered a "base" landscape scale (e.g., 10-ha) with each subsequently larger landscape scale represented by the area and habitat conditions spatially unique to each (Fig. 4). This "ring" method of model construction allowed us to quantify the additional predictive power associated with increasing the analysis area. It also allowed consideration of scale-dependent relationships (i.e., selection of nest site and nest stand may involve different factors than for the PFA surrounding them). For each predictor variable, its values within a given ring are independent of its values in other rings. Therefore, spatial autocorrelation can be reduced, and the unique contribution of each spatial scale can be estimated (Ramsey et al. 1994).

Model Construction.—Transformed variables were screened for inclusion using a two-sample *t*-test at each landscape scale. Variables with *P*-values $\leq$0.25 were retained for the multivariate analysis because more restrictive levels may fail to identify potentially important variables (Hosmer and Lemeshow 1989:86). Variables meeting this criterion were screened for correlation. We used simple linear regression to describe relationships between highly correlated variables. Highly correlated variables ($r > \pm 0.70$) were compared using univariate logistic regression, and the variable explaining the greater deviance was retained for multivariate analysis. In single-landscape-scale logistic regression models, a "manual" stepwise procedure was used to analyze the remaining untransformed variables. For multiple-landscape-scale models, a "manual" forward selection procedure was used in which the model was constructed from the smallest landscape scale outwards, adding variables from each successive ring after controlling

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

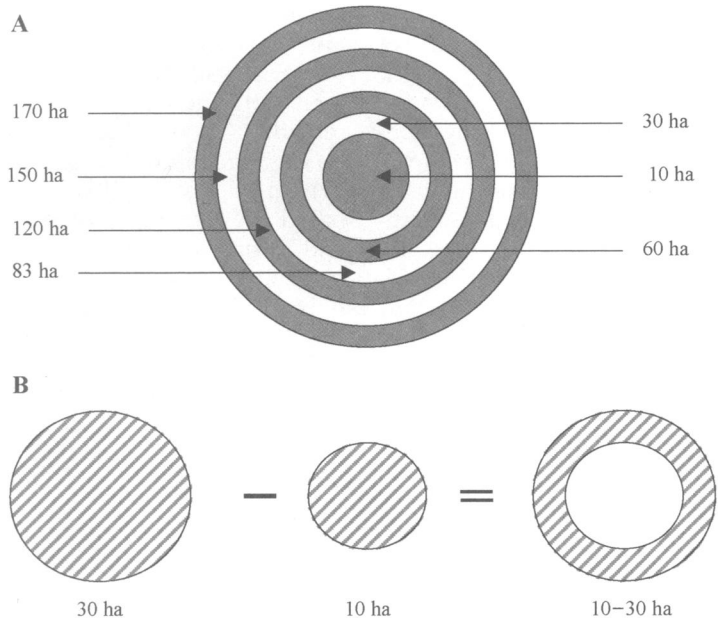

Figure 4. Scales of analysis ≥10 ha surrounding goshawk nests and random sites in eastern Oregon and Washington, 1994–1995. Each landscape scale is shown in relation to other scales (A). Landscape scales were analyzed as both individual landscapes (i.e., circular areas) and as habitat "rings," in which the habitat conditions unique to each scale were analyzed (B).

for variables at smaller scales (Ramsey et al. 1994). For a variable to enter or leave a model, the resulting difference in AIC values had to be ≥2 or <2, respectively (Burnham and Anderson 1998). We used "manual" procedures to control selection of variables exhibiting borderline significance for biological interpretation.

After identifying significant main-effects for each logistic regression model, we tested for study area effects by adding 3 indicator variables for study area (with Central Washington as the reference) to the model simultaneously. If a study area effect was detected (i.e., $P \leq 0.1$, from a drop-in-deviance test), the variable reduction method for categorical data (Ramsey et al. 1994:194) was used to determine the study area(s) responsible for the effect, while controlling for significant main effects. As a result, potentially divergent habitat conditions among study areas could be identified. We then expanded the model to include all first-order interactions among the significant main-effects and study area indicator variables, and AIC was then used to determine if any interactions explained a significant amount of model deviance. Only interactions that significantly reduced model AIC (i.e., ≥2) were retained. Models within 2 AIC units of each other were treated as "competing" models because of the similarity of information explained by each model (Burnham and Anderson 1998).

Cross-validation.—After logistic regression models were constructed, the model having the lowest AIC value was selected as the best landscape-scale discriminator between nest sites and random sites. After the best landscape-scale model was selected, the probability value that produced the highest classification accuracy was estimated with data used to construct the model. We term this the probability breakpoint, and its estimated value was derived by dividing the total number of correctly classified nests and random sites by the total number of observations (n = 177) for each estimate of probability. This estimated probability was then used as the breakpoint to discriminate between goshawk nests and random sites.

After we estimated the probability breakpoint to discriminate nest sites from random sites, we began a cross-validation procedure consistent with our objective of developing a regional goshawk habitat model, by testing a

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

model with data including the variability inherent in all study areas. Conducting a cross-validation of the model with data from a separate study area would be inconsistent with our objective because the habitat selection expressed in the RSPF could be inconsistent with geographic variation and differences in available habitat conditions in a separate study area (Mosher et al. 1986). Thus, we evaluated the classification accuracy of the selected model using bootstrap cross-validation (Verbyla and Litvaitis 1989). A simple random sample (10%) of all goshawk nests (n = 9) and random sites (n = 10) was used to cross-validate, via 1,000 iterations. Where, for each iteration, a 10% random sample was removed, parameters were estimated using the remaining 90% of the data, and the subsequent estimates were tested with the 10% random sample.

Management Applications

Habitat suitability models are ultimately intended for use in management. We envision two relevant management applications of our model for which scale-dependent effects can be important: (1) evaluating the influence of proposed silviculture on the suitability of specific sites (e.g., existing nest sites) over time, and (2) evaluating the suitability of large landscapes in terms of abundance and distribution of suitable nest sites. Although the models are also relevant to predicting the influence of proposed silviculture on large landscapes, we refrain from doing so here because modeling the future habitat conditions as a response to the growth of a landscape is beyond the scope of our study.

Site-specific Forest Growth Simulation.—To illustrate model application in this management context, we used forest inventory data for previously unquantified goshawk nests in our Central Washington and Northeast Oregon study areas. In these illustrations we applied our best landscape-scale model to evaluate how six standardized silvicultural prescriptions (three unique prescriptions for each site) would influence nest-site suitability based on stand-level simulations of forest growth using regional variants of the Forest Vegetation Simulator (FVS, after Wykoff et al. 1982). First, we evaluated each prescription separately because each prescription results in somewhat unique forest stand dynamics over time. By comparing results of the three prescriptions for each nest, a fourth prescription was developed to better maintain nest site suitability over a 100-year period, regardless of economic feasibility. The FVS model's (Wykoff et al. 1982) effectiveness in simulating forest growth has been evaluated (Stage and Renner 1988). For an average prediction length of 38.9 years, the model on average slightly underestimates annual basal area growth (n = 102, mean = 0.3 m^2 ha^{-1}, SD = 4.02) and quadratic mean diameter (n = 102, mean = 0.28 cm, SD = 1.52; Stage and Renner 1988).

The three initial prescriptions for Central Washington were (1) no-harvest, (2) a commercial thin, and (3) a specific prescription that is routinely applied around northern spotted owl nest sites in this study area by the forest industry (G. Roloff, Boise Cascade Corporation, unpublished data). The no-harvest prescription allows trees to grow without management intervention. The commercial thin prescription varied by Daubenmire habitat type (Daubenmire and Daubenmire 1968) and forest cover type (Table 3). The owl prescription thinned trees to different densities, depending on the diameter class (Table 4). During simulation, natural regeneration and tree mortality functions were enabled, and planting was user-dictated at standard spacing. Simulations were monitored at 10-year intervals over a 100-year planning horizon.

Initial prescriptions for the Northeast Oregon case study were (1) no harvest, (2) commercial thinning without pre-commercial thinning (PCT), and (3) commercial thinning with PCT. Stand attributes were monitored at 10-yr intervals, with commercial thinning triggered at any interval when a stand's total basal area stocking was ≥60% of its potential maximum. When invoked in the FVS, the commercial thinning regime was programmed to "thin from below" (i.e., preferentially cut smaller trees first, and irrespective of species) those trees ≥20.32 cm dbh, to a target basal area stocking equal to 40% of the site potential (i.e., grow the stand to 60% of its basal area potential, then cut to 40% of potential, by thinning from below from an initial dbh of 20.32 cm). The PCT

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 3. Commercial thinning prescriptions for forest growth simulation in central Washington. A harvest was initiated if a stand had ≥174.42 m^3/ha (15,000 board ft/ac).

Conditions required for harvest							
Forest cover type [a]	DBH size class (cm)	Stand age (years)	Trees/ha	Action	Goal	Consequences	Purpose
Douglas-fir/ elk sedge	≥20.3	>60	≥197.68 in ≤25.4 cm dbh class.	(1) Thin from below ≤17.8 cm dbh class. (2) Thin from above in >25.4 cm dbh class.	(1) Leave ≥274.3 trees/ha. (2) Leave 9.88 trees/ha.	If goal (1) not met, thin from above in 20.3–25.4 cm dbh class to meet the desired goal.	To release trees in 20.3–25.4 dbh class with the initial thin from below.
Douglas-fir, ponderosa pine, or Engelmann spruce	≥20.3	>60	≥247.1 in ≤25.4 cm dbh class.	(1) Thin from below ≤17.8 cm dbh class. (2) Thin from above in >25.4 cm dbh class.	(1) Leave 323.7 trees/ha. (2) Leave 9.88 trees/ha.	If goal (1) not met, thin from above in ≤25.4 dbh class to meet desired result.	To release trees in 20.3–25.4 dbh class with the initial thin from below.
Grand fir, cedar, subalpine fir, hemlock, or whitebark pine	≥20.3	>60	≥308.9 in ≤25.4 cm dbh class.	(1) Thin from below in 12.7 to 17.8 cm dbh class. (2) Thin from above in >25.4 dbh class.	(1) Leave 360.77 trees/ha (2) Leave 9.88 trees/ha.	If goal (1) not met, thin from above in 20.3–25.4 cm dbh class to meet the desired goal.	To release trees in 20.3–25.4 dbh class with the initial thin from below.

[a] Daubenmire and Daubenmire (1968) habitat types.

strategy utilized the same strategy for commercial thinning, but additionally monitored the density of trees 2.54 to 15.24 cm dbh, periodically invoking pre-commercial thinning to reduce the density of trees within this range to a target of 371 trees per hectare.

Tree-diameter distributions (12.7 cm increments) that were output by the simulation were assigned stage of stand development classes using the CART analysis. The CART-classified forest structures were then transferred to an Idrisi image and the site's landscape attributes were analyzed using FRAGSTATS. These attributes were then used to generate the RSPF habitat model at 10-year intervals.

Table 4. Spotted owl prescription for forest growth simulation in central Washington. A harvest was initiated if a stand had ≥139.54 m^3/ha (12,000 board ft/ac), consisting of trees ≥20.32 cm dbh.

DBH size class (cm)	Action	Goal
≥50.8	thinning from above	leave 12.36 trees/ha
40.6–48.3	thinning from below	leave 49.42 trees/ha
30.5–38.1	thinning from below	leave 61.78 trees/ha
17.8–27.9	thinning from below	leave 370.65 trees/ha

Landscape Assessment.—The RSPF consists of logistic regression coefficients for variables, an estimate of the proportion of sites selected as goshawk nests (P_u), and an estimate of the proportion of the available landscape selected as random sites (P_a). For predicting the probability of goshawk nesting at discrete points in the landscape, P_u and P_a must be based on an empirical sample of goshawk nests, an estimate of potential habitat, and an estimate of goshawk territory density. Conversely, if one considers the entire landscape as a continuous sample of points (or map pixels) in a "moving window" assessment, P_u and P_a no longer provide a legitimate estimate of used to available sites because the sample points are no longer independent (i.e., the windows overlap). This does not negate the utility of the RSPF model for use on continuous samples, but it can no longer be viewed as an absolute probability of goshawk nesting. However, the logistic portion of the equation can still be used as a relative probability of nest site potential (Erickson et al. 1998). This distinction between absolute and relative

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

probabilities is important because most resource management agencies have sparse, discontinuous data on nest site locations and territory density (U.S. Fish and Wildlife Service 1998), and thus their ability to accurately portray P_u and P_a is often limited. We developed a framework for using our best model to conduct landscape assessments in the absence of P_u and P_a estimates. Our exercise is limited to assessing potential nesting habitat, and the model is not spatially explicit with respect to inter-territory spacing among goshawks.

To illustrate this application, we applied the model to a 48,000-ha landscape in Central Washington (see the Study Area Description section for a site description). This involved automating the model in an Arc/Info GIS (Environmental Systems Research Institute, Inc., Redlands, CA), and involved three stages: (1) compiling and formatting the vegetation database and map layers used as inputs to the model, (2) computing spatial metrics required by the logistic function, and (3) implementing a systematic moving window that estimated nesting probability for each pixel in the landscape. Model output is an isopleth map of relative nesting probabilities.

To use the automated model, the area to be assessed was delineated into our 9 stages of stand development at a minimum mapping unit of 2 ha (i.e., polygons <2 ha in size were not mapped; McGrath 1997). The 2-ha scale is compatible with maps used for forest management, and was the minimum mapping unit from which the logistic function was developed (McGrath 1997). We mapped stages of stand development from a supervised classification of multispectral 20-m resolution SPOT satellite imagery using standard image interpretation techniques. The final digital map categorized each image pixel into one of seven cover types: (1) Douglas-fir, (2) ponderosa/lodgepole pine, (3) grand fir, (4) deciduous (including larch and dead grand fir), (5) nonforested, (6) water, and (7) snow; 1 of 4 density classes: (1) open (<10% canopy cover), (2) low (10–40%), (3) medium (41–70%), and (4) high (>70%); and 1 of 4 structural classes: (1) multi-storied all-aged, (2) two-storied, young and mature, (3) one-story, young, and (4) one-story, mature. The SPOT data were then remapped to a 2-ha mapping unit based on the dominant vegetation class. Accuracy of the landscape assessment map was assessed by field verification of 40 sites representing a range of mapped vegetation conditions, without prior knowledge of image classification. Each evaluation consisted of a subjective walk-through assessment of canopy closure, forest structure, and species composition. Estimated accuracy of the digital image based on ground-truthing and air photo interpretation was ~80% for cover type, ~90% for density, and ~60% for structure.

Each mapped vegetation class was associated with a vegetation attribute file. We built an attribute file required by the goshawk model from two data sets. The most detailed data consisted of a geo–referenced systematic timber cruise on 5,600 ha with 1 plot every 0.8 ha. The second data set consisted of 522 geo-referenced plots collected using a stratified random sample. Because the stratification scheme did not match the digital strata we developed for this project, we used an area-weighting procedure to restratify plots into the digital classification. Using these data sets, we were able to assign vegetation attributes to 99% of the landscape. Sample sizes for each image type ranged from 1 to 84 plots, with >94% of the image types represented by at least 5 plots.

The attribute file consisted of data on tree sizes and density by 2.54 cm diameter classes (total of 51 classes). These data were used to classify map polygons or grid cells into stages of stand development (sensu Oliver and Larson 1996) using our CART model. Map units that could not be linked to the vegetation attribute file were removed during the spatial analysis process.

Once map and vegetation databases were formatted and compiled, the automated model assigned a series of spatial metrics to each pixel. The spatial extent of the computation was constrained by the landscape scales in our logistic regression model, centered on each pixel. The model generated proportions of different vegetation communities and spatial metrics required for the RSPF model. These variables were subsequently used as inputs to the logistic function and each pixel in the landscape was assigned a relative probability of nest occurrence.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Because the landscape assessment could be affected by the low estimated accuracy for structure classification (~60%; e.g., multi-storied all-aged, two-storied, young and mature), this could effect the designation of vegetative attributes to each polygon for analysis by the CART model, and subsequent analysis by the RSPF model. We recognize these limitations and stress the need for accurate data prior to any such landscape assessment. We include these data as a procedural case study for implementing the RSPF model for landscape assessment.

RESULTS

By understanding the accuracy of the vegetation mapping and the structural attributes of each category, we attempt to provide the appropriate context in which to view our results and an ability to recognize the various stand structures. Thus, we frame the results section so the reader begins with an assessment of data accuracy and clarification of each stand structure's attributes, followed by results pertaining to univariate goshawk habitat associations, productivity relationships, followed by resource selection probability functions for goshawk nesting habitat, and finally, their application at 2 scales in management contexts.

Ground-truthing

Across 9 stages of stand development (including non-forest), aerial photo classification accuracy averaged 76% and ranged from 44–100% (Table 5). For stages of stand development, classification accuracy was highest for low understory reinitiation and lowest for high understory reinitiation. Old growth was misclassified 50% of the time, either as low understory reinitiation (33% of the time) or as high understory reinitiation (17% of the time; Table 5).

Stage of Stand Development Attributes.— Structural similarities existed among the stages of stand development. Overlaps of 95% confidence intervals for all forest structural attributes (i.e., total basal area, basal area by crown class, quadratic mean diameter, and number of trees/ha for 6 diameter classes) generally demonstrated the expected transitions from younger to progressively older stages of stand development (Tables 6–8). Among high stem exclusion, high understory reinitiation, and old growth, confidence intervals exhibited extensive overlap for total basal area (Table 6); basal area generally increased with older stage of stand development. These patterns held true for most structural attributes and stages of stand development.

The pruned CART had 9 decision pathways (Fig. 5), separating stands into 5 categories

Table 5. Accuracy matrix (proportion) for stages of stand development delineated from 1988–1994 color and black-and-white, 1:12,000–1:16,000 scale aerial photographs surrounding goshawk nests and random sites in eastern Oregon and Washington. Accuracy was based on a random sample of ground measured stands representing approximately 10% of the stands in each stage of stand development. All stands classified as water were correctly classified.

		Ground Measurement							
Aerial photograph categories	No. stands sampled	Stand initiation	High[a] stem exclusion[b]	Low[a] stem exclusion[b]	High understory reinitiation	Low understory reinitiation	Old growth	Wet openings	Dry openings
Stand initiation	16	0.75	0.00	0.19	0.00	0.06	0.00	0.00	0.00
High stem exclusion	30	0.00	0.70	0.17	0.10	0.03	0.00	0.00	0.00
Low stem exclusion	17	0.00	0.06	0.65	0.17	0.12	0.00	0.00	0.00
High understory reinitiation	39	0.00	0.15	0.10	0.44	0.26	0.05	0.00	0.00
Low understory reinitiation	49	0.00	0.00	0.12	0.02	0.86	0.00	0.00	0.00
Old growth	6	0.00	0.00	0.00	0.17	0.33	0.50	0.00	0.00
Wet openings	11	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.00
Dry openings	22	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.95

[a] The terms "high" and "low" refer to total percent canopy closure within a stand, ≥50% and <50%, respectively.

[b] Due to insect infestations in the Northeast Oregon study site, all high and low stem exclusion stands (n = 61 and 22, respectively) were classified on the ground and are correctly classified. These stands are not included in the accuracy assessment.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 6. Basal area and quadratic mean diameter of forested stages of stand development within 170 ha surrounding goshawk nests (n = 82) and random sites (n = 95) in eastern Oregon and Washington, 1994–1995, from a 10% random sample of each stand type, regardless of nest or random site classification.

Forest stage of stand development	n	Basal area (m^2 ha^{-1})			Quadratic mean diameter (cm)		
		Mean	SE	95% CI	Mean	SE	95% CI
Stand initiation	13	2.26	0.97	0.15–4.37	16.53	4.25	5.61–27.45
High[a] stem exclusion	22	27.32	1.93	23.31–31.33	29.44	1.73	25.85–33.03
Low[a] stem exclusion	27	19.04	1.26	16.45–21.64	30.87	1.72	27.33–34.41
High understory reinitiation	25	29.43	1.78	25.75–33.10	39.30	1.83	35.54–43.07
Low understory reinitiation	62	17.53	1.01	15.52–19.55	37.50	1.48	34.53–40.47
Old growth	5	39.86	5.37	24.96–54.76	53.66	5.56	38.21–69.11

[a] The terms "high" and "low" refer to the total percent canopy closure within a stand, ≥50% or <50%, respectively.

Table 7. Basal area (m^2 ha^{-1}) by crown class (Smith 1986:49) for forested stages of stand development within 170 ha surrounding goshawk nests (n = 82) and random sites (n = 95) in eastern Oregon and Washington, 1994–1995, from a 10% random sample of each stand type, regardless of nest or random site classification.

Forest stage of stand development	n	Dominant/Codominant			Intermediate			Suppressed		
		Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Stand initiation	13	1.70	0.76	0.03–3.36	0.14	0.14	0–0.45	0.42	0.25	0–0.96
High[a] stem exclusion	22	16.99	1.83	13.18–20.79	7.23	1.15	4.85–9.61	3.10	0.51	2.04–4.16
Low[a] stem exclusion	27	13.27	1.13	10.94–15.59	4.38	0.54	3.27–5.49	1.39	0.33	0.71–2.08
High understory reinitiation	25	21.23	1.44	18.26–24.21	4.85	0.85	3.09–6.61	3.34	0.62	2.06–4.62
Low understory reinitiation	62	12.67	0.72	11.24–14.11	3.38	0.41	2.57–4.19	1.48	0.27	0.94–2.03
Old growth	5	27.18	4.05	15.94–38.43	9.55	1.85	4.41–14.69	3.12	1.25	0–6.60

[a] The terms "high" and "low" refer to the total percent canopy closure within a stand, ≥50% or <50%, respectively.

Table 8. Number of trees per diameter class category per ha for forested stage of stand development categories within 170 ha surrounding goshawk nests (n = 82) and random sites (n = 95) in eastern Oregon and Washington, 1994–1995. Determined from a 10% random sample of each stage of stand development, regardless of nest or random site classification. Number of trees per ha calculated for the midpoint of each diameter class. For the ≥63.51 cm category, number of trees per ha was calculated for the median of the diameter distribution, of the ≥63.51 cm diameter class, for each forest stage of stand development.

Forest stage of stand development	n	0–12.70 cm			12.71–25.40 cm			25.41–38.10 cm		
		Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Stand initiation	13	334.6	149.9	8.0–661.2	24.78	14.20	0–55.7	1.78	1.21	0–4.4
High[a] stem exclusion	22	1288.3	262.0	743.5–1833.1	283.97	33.03	215.3–352.7	104.82	18.55	66.2–143.4
Low[a] stem exclusion	27	695.0	192.5	299.3–1090.6	200.63	26.29	146.6–254.7	71.06	8.85	52.9–89.3
High understory reinitiation	25	614.7	153.7	297.4–932.0	217.79	27.16	161.7–273.9	96.96	8.36	79.7–114.2
Low understory reinitiation	62	488.7	90.3	308.1–669.3	168.23	17.74	132.8–203.7	54.58	4.43	45.7–63.4
Old growth	5	290.0	183.4	0–799.1	238.40	61.60	67.3–409.5	102.10	39.90	0–212.9

Forest stage of stand development	n	38.11–50.80 cm			50.81–63.50 cm			≥63.51 cm		
		Mean	SE	95% CI	Mean	SE	95% CI	Mean	SE	95% CI
Stand initiation	13	0.5	0.5	0–1.5	0.6	0.6	0–1.8	0.3[b]	0.3	0–1.0
High stem exclusion	22	26.4	4.8	16.5–36.3	6.1	2.0	2.0–10.3	3.1[c]	0.8	1.5–4.6
Low stem exclusion	27	20.6	3.8	12.7–28.5	5.1	1.2	2.7–7.5	2.4[d]	0.8	0.8–3.9
High understory reinitiation	25	37.4	4.3	28.5–46.3	15.0	1.9	11.2–18.9	9.0[e]	1.8	5.2–12.8
Low understory reinitiation	62	18.4	1.8	14.9–22.0	5.8	0.8	4.3–7.3	5.3[f]	1.0	3.4–7.2
Old growth	5	36.7	14.4	0–76.7	24.3	4.3	12.4–36.3	23.5[g]	5.8	7.4–39.6

[a] The terms "high" and "low" refer to the total percent canopy closure within a stand, ≥50% or <50%, respectively.
[b] ≥ 63.51 cm diameter class median diameter at breast height (DBH) = 77.7 cm.
[c] ≥ 63.51 cm diameter class median DBH = 70.1 cm. [d] ≥ 63.51 cm diameter class median DBH = 73.2 cm.
[e] ≥ 63.51 cm diameter class median DBH = 74.7 cm. [f] ≥ 63.51 cm diameter class median DBH = 78.1 cm.
[g] ≥ 63.51 cm diameter class median DBH = 80.9 cm.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

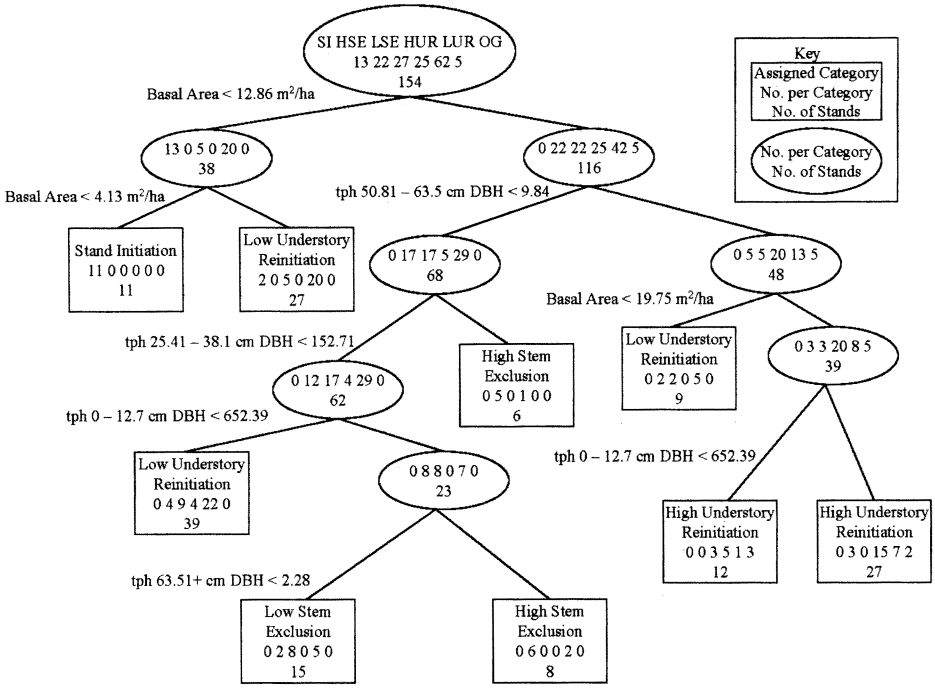

Figure 5. Classification and regression tree (CART) analysis of forest structural data collected in stands identified during the aerial photo stand typing in eastern Oregon and Washington, 1995. The CART constructs classification criteria for each forested stage of stand development based on forest structural characteristics collected during the ground-truthing phase of the map accuracy assessment. Classification criteria could not be developed for old growth stands because of sample size limitations. The order of occurrence of stands in each stage of stand development in each node are stand initiation, high canopy closure stem exclusion, low canopy closure stem exclusion, high canopy closure understory reinitiation, low canopy closure understory reinitiation, and old growth. To follow the decision tree, follow the branch to the left descendant node if a decision criterion is true; otherwise follow the branch to the right descendant node. Classification accuracy of the decision tree is 63% (97 of 154 stands correctly classified).

using only 4 stand attributes: basal area and number of trees per hectare (tph) in the 0–12.7, 25.41–38.1, and 50.81–63.5 cm dbh categories. None of the 5 old growth stands in the CART analysis were classified successfully as such; all 5 were classified as high understory reinitiation, the precursor to old growth (Fig. 5, Table 9; Oliver and Larson 1996). Classification accuracy of the pruned CART varied by stage of stand development. Its prediction of old growth was least accurate (0% correct) and that of stand initiation was most accurate (85% correct; Table 9). Mean classification accuracy of the CART was 63% across all stages (SE = 0.71; Fig. 6). No individual observation in the data set substantially influenced any particular decision criterion (Fig. 6). Each coefficient of variation was <17%.

The CART analysis developed 9 separate pathways in which to classify 5 of the 6 forested stages of stand development (Fig. 5). Several of the forested stages of stand development had multiple pathways for description: stand initiation and low stem exclusion each had 1 pathway, high stem exclusion and high understory reinitiation each had 2 pathways, and low understory reinitiation had 3 separate pathways that described its structural characteristics (Fig. 5).

Univariate Analysis

Nest Tree.—Nest trees ($n = 82$) were usually dominant trees in the canopy (68.3%), but codominants (29.3%) and intermediates (2.4%) were also used for nesting. Nest trees were typically alive (81.7%), but some snags were also used (18.3%). Nests were located an average of 12.95 m above ground, and an average of 1.23 m above the base of the live canopy (Table 10). Nests were usually in Douglas-fir, ponderosa pine, or western larch (Fig. 7), and exhibited extensive variation in dbh (25–127 cm) and age (47–345 years).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 9. Error matrix for the pruned classification and regression tree that uses forest structural characteristics to predict group membership in the structural stages. Accuracy of the classification and regression tree is estimated at 63% (97 of 154 stands correctly classified). Elements of the matrix on the diagonal represent the number of stands for each structural stage that were correctly classified.

	Predicted						
Actual group	Stand initiation	High stem exclusion	Low stem exclusion	High understory reinitiation	Low understory reinitiation	Old growth	Total
Stand initiation	11	0	0	0	2	0	13
High stem exclusion	0	11	2	3	6	0	22
Low stem exclusion	0	0	8	3	16	0	27
High understory reinitiation	0	1	0	20	4	0	25
Low understory reinitiation	0	2	5	8	47	0	62
Old growth	0	0	0	5	0	0	5
Total	11	14	15	39	75	0	154

However, the vertical position of the nest in the nest tree (TRATIO) was relatively consistent, exhibiting a coefficient of variation of 20.12% (Table 10). In comparison with available trees at random sites, goshawk nest tree diameter and age were greater ($P < 0.001$; random site dbh: mean = 42.98 cm, SE = 2.2, range = 25.4–106.9 cm; age mean = 110.54 yr, SE = 7.43, range = 6–369 yr). Thus, while larger in diameter and older than trees available in the landscape, goshawk nest trees were typically only dominant trees within their nest stands. Due to insufficiencies in expected values, nest tree species preference could not be evaluated (Fig. 7).

One-hectare Nest Site.—Goshawk nests were not distributed proportionately among the four stages of stand development ($\chi^2 = 19.8$,

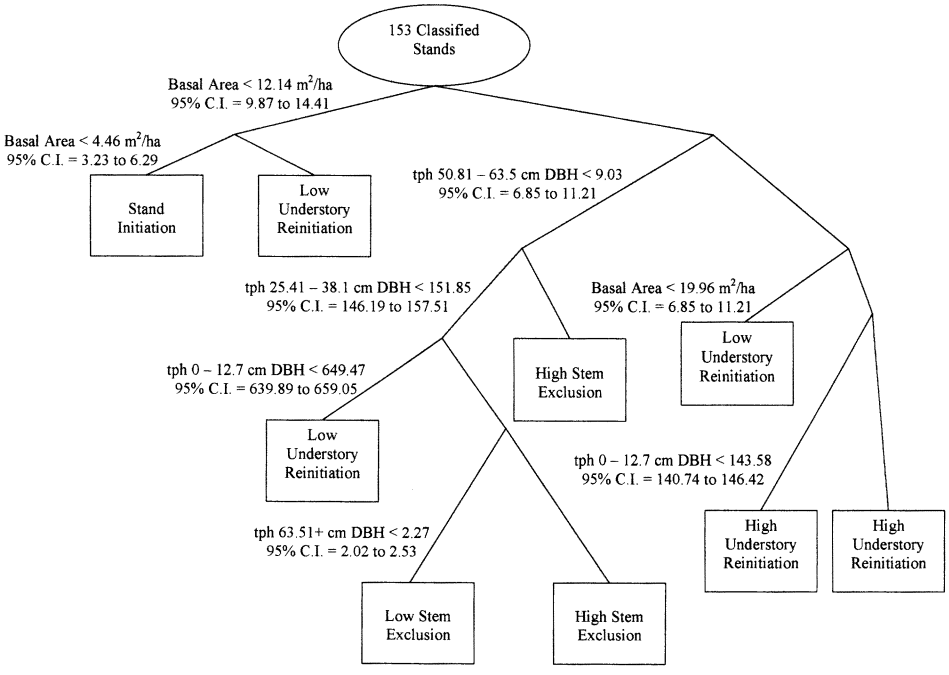

Figure 6. One-point jackknife analysis of the pruned classification and regression tree (CART) for forest structural stage classifications in eastern Oregon and Washington, 1995. Mean values for each classification criterion (n = 153) are presented with 95% confidence intervals presented below its respective criterion. To follow the decision tree, follow the branch to the left descendant node if a decision criteria is true; otherwise follow the branch to the right descendant node. Mean classification accuracy for the jackknifed CART was 63.41% (SE = 0.71, 95% C.I. = 62.02 to 64.8%).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 10. Univariate analysis of goshawk nest trees (n = 82) in eastern Oregon and Washington in 1994.

Variable	Mean	SE	CV (%)	Range
Nest height (m)	12.95	0.48	33.56	4.4–30
Tree height (m)	29.51	0.89	27.31	12.3–48
Height of the base of the live canopy (m)	14.09	0.86	55.27	2.0–33.5
TRATIO [a]	0.45	0.01	20.12	0.17–0.78
LCDIST [b] (m)	−1.23	0.53	−390.19	−12.6–12.4
Tree DBH (cm)	56.32	2.48	39.88	25.0–126.9
Age of nest tree (yrs)	157.91	8.21	47.08	47–345

[a] TRATIO is the nest height divided by the height of the nest tree.

[b] LCDIST is the height of the base of the live canopy minus nest height.

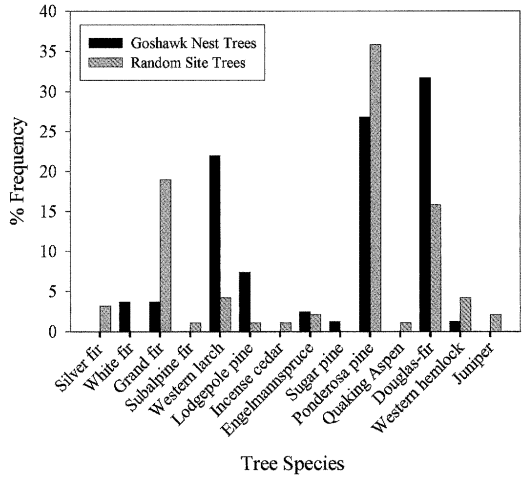

Figure 7. Percent frequency of occurrence for goshawk nest trees (n = 82) and random trees (n = 95) in eastern Oregon and Washington, 1994, by tree species.

3 df, $P = 0.0002$). Nests were found in stem exclusion significantly more often than expected, and in stand initiation less often than expected based on availability. Understory reinitiation and old growth stands were used in proportion to their availability (Table 11). Nest sites were not distributed equally with respect to topographic position (χ^2 = 25.9, 5 df, P = 0.0001; Table 12). Nests occurred on ridge tops and on the upper 1/3 of slopes significantly less than expected, while they occurred on the lower 1/3 of slopes and in drainage bottoms more than expected based on availability. Forest vegetation types (e.g., mixed-conifer, ponderosa pine, lodgepole pine) were used by goshawks in proportion to their availability (χ^2 = 7.0, 4 df, P = 0.1333).

Nests occurred at lower elevations, on different aspects, and were closer to human disturbance than were random sites (Table 13). Seventy-seven percent of 177 human disturbances encountered were forest roads and 22% were timber harvests. Nests occurred in stands typified by greater basal area, greater quadratic mean diameter, greater live stem density, higher stand density index, greater canopy closure, and greater mean age than random sites (Table 13). Of these characteristics, basal area and SDI also were more variable (i.e., greater SE) at goshawk nest sites than at random sites. At random sites, aspects tended to be uniformly distributed around the compass, while goshawk nest sites were nonrandomly distributed, primarily on north-facing slopes (Table 14).

Landscape Scale.—Our analysis of the various landscape scales is intended to provide insight into landscape-level habitat selection by nesting goshawks, and to reduce the landscape data for meaningful multivariate analysis. Analysis of concentric circles surrounding nests (Table 15) indicated that:

Table 11. Bonferroni 90% simultaneous confidence intervals (97.5% individual C.I.) for stage of stand development at the 1-ha scale for goshawk nests (n = 82) and random sites (n = 90) in eastern Oregon and Washington, 1994–1995. Goshawk nest sites were not distributed in proportion to availability of the four stages of stand development (χ^2 = 19.8, 3 df, P = 0.0002).

Stage of stand development	Number of nest sites	P_o	Number of random sites	P_e	90% CI
Stand initiation	0	0	11	0.12	$0.0449 \le P_e \le 0.1995$ [a]
Stem exclusion	36	0.44	24	0.27	$-0.3335 \le P_e \le -0.0111$ [b]
Understory reinitiation	36	0.44	52	0.58	$-0.0305 \le P_e \le 0.3081$
Old growth	10	0.12	3	0.03	$-0.1801 \le P_e \le 0.0027$

[a] Used significantly less than expected based on its availability.

[b] Used significantly more than expected based on its availability.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 12. Bonferroni 85% simultaneous confidence intervals (97.5% individual C.I.) for 1-ha scale topographic position for goshawk nests (n = 82) and random sites (n = 90) in eastern Oregon and Washington, 1994–1995. Goshawk 1-ha sites were not distributed in proportion to available topographic position (χ^2 = 25.9, 5 df, P = 0.0001).

Topographic position	Number of nest sites	P_o	Number of random sites	P_e	90% CI
Ridge top	1	0.01	11	0.12	$0.0280 \le P_e \le 0.1920$ [a]
Upper 1/3 of slope	13	0.16	29	0.32	$0.0211 \le P_e \le 0.3063$ [a]
Middle 1/3 of slope	17	0.21	17	0.19	$-0.1548 \le P_e \le 0.1180$
Lower 1/3 of slope	25	0.30	13	0.15	$-0.3014 \le P_e \le -0.0196$ [b]
Drainage bottom	14	0.17	3	0.03	$-0.2397 \le P_e \le -0.0351$ [b]
Flat	12	0.15	17	0.19	$-0.0846 \le P_e \le 0.1698$

[a] Used significantly less than expected based on its availability.
[b] Used significantly more than expected based on its availability.

Table 13. Univariate habitat characteristics of goshawk and random 1-ha scale sites in eastern Oregon and Washington, 1994–1995. Results are for untransformed data from 2-sample t-tests unless otherwise noted.

	Goshawk sites (n = 82)			Random sites (n = 90)			
Variable	Mean	SE	Range	Mean	SE	Range	P-value
Elevation (m)	1419.0	33.2	728–2131	1504.0	32.1	695–2036	0.068
% Slope	22.7	1.9	2.0–75.0	24.7	2.2	0.5–96.5	0.494
Aspect (°)	0.5	7.1	2–360	164.2	8.1	2–358	<0.001 [a]
Basal area (m^2/ha)	40.6	1.3	11.2–67.2	22.2	1.1	2.3–51.5	<0.001
DBH_Q (cm)	24.1	0.6	12.9–36.9	20.8	0.7	6.9–41.5	0.001
Live stem density (trees/ha)	862.4	52.9	70–2155	721.4	51.6	5–2595	0.058
SDI	705.1	29.0	84–1429	458.4	27.4	11–1190	<0.001
% Canopy closure	53.1	1.7	14.3–89.1	33.2	1.7	2.7–74.1	<0.001
Age	126.3	4.9	60–286	115.4	5.2	22–306	0.035 [b]
Proximity (m) to:							
Forest change	58.2	5.5	0–259	55.5	6.3	0–289	0.742
Human disturbance	144.1	19.8	0–1358	152.4	21.7	0–1200	0.054 [b]
Water	342.4	34.7	4–1415	375.2	47.7	3–3622	0.579

[a] P-value for 2-sample testing of angles.
[b] P-value for log-transformed data.

(1) stand initiation comprised a significantly lower proportion at all landscape scales surrounding nests than was available at random in the landscape; (2) from 10- to 120-ha, low understory reinitiation occurred in significantly lower proportions than was available at random; (3) habitat had less contagion with respect to forest structure from 83- to 170-ha; (4) high stem exclusion, from 10- to 120-ha, and high understory reinitiation, at all landscape scales, occurred in significantly greater proportion than was available at random; (5) the stage of stand development present in the 83- to 170-ha landscape scales was more equally abundant in the habitat surrounding goshawk nests than occurred at random (Table 15). Mean nearest neighbor distance between stands of the same stage of stand development was also significantly greater in the 60-ha around nest sites, suggesting that goshawks were selecting for greater distance between stands of the same

Table 14. Mean aspect angle, angular deviation, r, and P-value for test of randomness or nondirectedness for goshawk and random 1-ha scale sites in eastern Oregon and Washington, 1994–1995, using continuous data for aspect.

	Mean angle	Angular deviation	r	P-value
Goshawk nests (n = 82)	0°	65°	0.36	<0.001
Random sites (n = 90)	164°	77°	0.09	0.471

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 15. Univariate landscape-scale habitat characteristics around goshawk nests and random sites in eastern Oregon and Washington, 1994–1995, by variable and landscape-scale. Values are mean percentages of each landscape scale occurring in each stage of stand development. Results are for untransformed data from 2-sample *t*-tests, unless otherwise noted.

Variable	Landscape Scale (ha)	Goshawk Sites (n = 82)			Random Sites (n = 95)			*P*-value
		Mean	SE	Range	Mean	SE	Range	
Stand initiation	10	1.6	0.7	0–34.9	11.0	2.7	0–100	0.001
	30	2.7	0.8	0–42.3	10.7	2.4	0–100	0.002
	60	3.1	0.8	0–45.2	10.6	2.2	0–99.9	0.002
	83	3.3	0.8	0–44.3	10.5	2.1	0–98.5	0.002
	120	3.6	0.8	0–42.2	10.2	2.0	0–94.9	0.002
	150	3.7	0.9	0–41.8	9.9	1.9	0–90.6	0.003
	170	3.8	0.9	0–41.4	9.8	1.8	0–88.6	0.004
High [a] stem exclusion	10	24.7	3.5	0–100	15.0	2.6	0–100	0.026
	30	22.1	2.9	0–96.7	13.6	2.1	0–94.5	0.018
	60	20.2	2.4	0–92.3	13.1	1.8	0–88.8	0.022
	83	19.3	2.2	0–86.7	13.1	1.7	0–87.3	0.029
	120	18.3	2.0	0–76.6	13.3	1.7	0–83.9	0.070 [b]
	150	17.8	2.0	0–71.6	13.7	1.7	0–81.4	0.117 [b]
	170	17.6	1.9	0–69.2	13.8	1.6	0–78.5	0.139
Low [a] stem exclusion	10	6.2	2.0	0–100	8.5	2.1	0–93.5	0.441
	30	6.5	1.7	0–86.3	8.8	2.0	0–79.7	0.364
	60	7.7	1.6	0–75.9	8.6	1.9	0–72.7	0.713
	83	8.2	1.5	0–70.8	8.3	1.8	0–72.1	0.951
	120	8.3	1.4	0–59.3	8.1	1.6	0–70.8	0.914
	150	8.3	1.3	0–53.8	7.8	1.5	0–69.7	0.823
	170	8.3	1.3	0–51.1	7.7	1.5	0–67.9	0.761
High understory reinitiation	10	47.1	3.6	0–100	25.3	3.2	0–98.7	<0.001
	30	42.6	2.9	0–96.7	24.4	2.6	0–90.7	<0.001
	60	39.7	2.4	0–96.4	24.7	2.3	0–91.6	<0.001
	83	38.5	2.2	0–97.0	24.9	2.2	0–89.3	<0.001
	120	37.2	2.1	0–93.6	24.9	2.1	0–84.9	<0.001
	150	36.6	2.0	0–90.1	24.9	2.1	0–81.3	<0.001
	170	36.2	2.0	0–87.0	24.9	2.1	0–79.1	<0.001
Low understory reinitiation	10	13.9	2.2	0–80.6	32.3	3.4	0–100	<0.001
	30	18.2	2.1	0–78.1	32.7	3.0	0–100	<0.001
	60	21.1	2.0	0–67.3	32.4	2.7	0–99.6	0.001
	83	22.4	2.1	0–67.6	32.4	2.6	0–97.2	0.003
	120	24.0	2.1	0–72.4	32.6	2.5	0–88.8	0.070 [b]
	150	24.8	2.2	0–75.9	32.8	2.5	0–86.2	0.102 [b]
	170	25.2	2.2	0–77.9	32.9	2.5	0–84.8	0.118 [b]
Old growth	10	2.2	1.4	0–82.9	1.2	0.6	0–39.8	0.472
	30	1.6	0.9	0–54.9	1.0	0.5	0–34.1	0.558
	60	1.2	0.6	0–36.5	1.0	0.5	0–42.2	0.799
	83	1.1	0.5	0–28.8	1.0	0.6	0–45.5	0.928
	120	0.9	0.4	0–22.4	0.9	0.5	0–45.1	0.993
	150	0.8	0.4	0–19.1	0.9	0.5	0–42.6	0.949
	170	0.8	0.4	0–17.5	0.8	0.5	0–41.0	0.915
Wet openings	10	1.4	0.5	0–27.4	2.4	0.9	0–46.5	0.306
	30	1.9	0.5	0–25.1	2.4	0.7	0–42.1	0.600
	60	1.9	0.5	0–21.6	2.4	0.7	0–43.8	0.493

(*Continued*)

[a] "High" and "low" denote ≥ or <50% canopy closure, respectively.

[b] *P*-value for arcsine square root transformed data.

[c] Contrast weighted edge density.

[d] *P*-value for log transformed data.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 15 (*continued*). Univariate landscape-scale habitat characteristics around goshawk nests and random sites in eastern Oregon and Washington, 1994–1995, by variable and landscape-scale. Values are mean percentages of each landscape scale occurring in each stage of stand development. Results are for untransformed data from 2-sample *t*-tests, unless otherwise noted.

Variable	Landscape Scale (ha)	Goshawk Sites (n = 82)			Random Sites (n = 95)			*P*-value
		Mean	SE	Range	Mean	SE	Range	
Wet openings (*continued*)	83	1.9	0.4	0–19.8	2.6	0.7	0–44.9	0.425
	120	2.0	0.4	0–17.5	2.6	0.7	0–47.0	0.438
	150	2.1	0.4	0–16.5	2.7	0.7	0–47.2	0.463
	170	2.1	0.4	0–16.2	2.7	0.7	0–47.7	0.477
Dry openings	10	2.8	0.8	0–44.3	4.3	1.0	0–51.1	0.375 [b]
	30	4.4	1.1	0–49.0	6.2	1.2	0–58.6	0.247 [b]
	60	4.9	1.0	0–46.6	7.0	1.3	0–60.6	0.240 [b]
	83	5.1	1.0	0–48.4	7.2	1.3	0–54.3	0.190
	120	5.4	1.1	0–52.4	7.4	1.2	0–53.1	0.325 [b]
	150	5.6	1.1	0–52.8	7.4	1.2	0–54.5	0.282
	170	5.7	1.1	0–52.6	7.4	1.2	0–56.2	0.297
Water	10	0.0	0.0	0–0	0.01	0.01	0–1.2	0.320
	30	0.1	0.1	0–4.1	0.1	0.1	0–7.9	0.736
	60	0.2	0.2	0–14.4	0.1	0.1	0–6.4	0.530
	83	0.3	0.2	0–19.2	0.1	0.1	0–5.3	0.420
	120	0.3	0.3	0–24.5	0.05	0.05	0–4.4	0.371
	150	0.4	0.3	0–27.5	0.04	0.04	0–4.0	0.352
	170	0.4	0.3	0–28.3	0.1	0.1	0 – 3.8	0.344
CWED [c]: Forest structure (m)	60	33.4	2.7	0–134	32.4	2.7	0–146	0.801
	83	33.3	2.6	1–128	33.0	2.5	0–132	0.943
	120	32.7	2.5	3–119	32.0	2.3	0–118	0.844
	150	31.0	2.3	3–112	30.5	2.2	0–110	0.855
	170	29.5	2.2	4–105	28.8	2.0	0–105	0.819
CWED [c]: Canopy closure (m)	60	36.4	3.0	0–145	39.7	2.7	0–145	0.412
	83	36.5	2.8	0–139	39.9	2.5	0–127	0.379
	120	36.3	2.7	2–133	38.7	2.3	1–110	0.496
	150	34.9	2.5	4–126	36.9	2.1	2–102	0.537
	170	33.3	2.4	4–118	35.1	2.0	1.8–96.0	0.574
Mean nearest neighbor distance (m)	60	130.2	9.4	23–566	113.5	7.8	10–362	0.082 [d]
	83	126.6	10.0	32–607	121.3	7.8	27–477	0.677
	120	136.8	9.1	19–474	126.8	8.2	13–429	0.242 [d]
	150	149.8	10.7	21–545	140.8	12.4	20–952	0.588
	170	165.8	11.3	17–545	158.6	12.6	17–952	0.672
Simpson's evenness index	60	77.7	1.8	14–99	73.8	2.0	0–99	0.152
	83	79.6	1.6	9–99	74.5	1.8	6–99	0.038
	120	81.2	1.4	18–98	75.6	1.7	15–100	0.011
	150	82.1	1.3	27–97	76.6	1.5	26–100	0.007
	170	82.3	1.2	35–97	77.0	1.5	28–99.0	0.007
Contagion	60	60.5	0.9	47–88	62.2	1.0	46–99	0.210
	83	59.7	0.8	48–93	62.2	0.9	47–94	0.043
	120	59.1	0.7	48–87	61.8	0.8	47–89	0.013
	150	58.6	0.7	49–82	61.3	0.7	47–83	0.001
	170	58.6	0.7	49–78	61.2	0.7	47–82	0.010

[a] "High" and "low" denote ≥ or <50% canopy closure, respectively.

[b] *P*-value for arcsine square root transformed data.

[c] Contrast weighted edge density.

[d] *P*-value for log transformed data.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 16. Univariate landscape-scale habitat characteristics around goshawk nests and random sites in eastern Oregon and Washington, 1994–1995, by variable and landscape-scale. Landscape scales represent the habitat unique to each successive scale. Values are mean percentages of each landscape scale in each structural stage. Results are for untransformed data from 2-sample *t*-tests, unless otherwise noted.

Variable	Landscape Scale (ha)	Goshawk Sites (n = 82) Mean	SE	Range	Random Sites (n = 95) Mean	SE	Range	*P*-value
Stand initiation								
	10–30	3.2	1.0	0–52.6	10.6	2.3	0–100	0.004
	30–60	3.5	0.9	0–48.0	10.4	2.0	0–99.8	0.002
	60–83	3.8	0.9	0–41.9	10.2	2.0	0–94.9	0.004
	83–120	4.2	1.0	0–37.6	9.6	1.8	0–98.5	0.011
	120–150	4.4	1.1	0–41.6	8.8	1.6	0–81.9	0.026
	150–170	4.7	1.1	0–40.5	8.9	1.6	0–82.3	0.036
High [a] stem exclusion								
	10–30	20.9	2.8	0–95.0	12.9	2.0	0–91.8	0.021
	30–60	18.2	2.1	0–88.0	12.6	1.8	0–83.1	0.042
	60–83	17.0	1.9	0–71.9	12.9	1.7	0–83.5	0.089 [b]
	83–120	16.0	1.8	0–59.8	13.9	1.7	0–76.2	0.383
	120–150	15.8	1.9	0–58.9	15.1	1.8	0–77.7	0.794
	150–170	15.7	1.9	0–61.4	15.4	1.9	0–83.5	0.893
Low [a] stem exclusion								
	10–30	6.6	1.6	0–79.4	9.0	2.0	0–80.7	0.344
	30–60	8.9	1.6	0–65.6	8.4	1.8	0–74.6	0.813
	60–83	9.5	1.5	0–57.4	7.6	1.6	0–73.1	0.251 [b]
	83–120	8.5	1.3	0–42.7	7.4	1.4	0–72.0	0.584
	120–150	8.3	1.4	0–63.6	7.0	1.4	0–65.1	0.504
	150–170	8.4	1.5	0–72.0	6.5	1.4	0–65.7	0.364
High understory reinitiation								
	10–30	40.3	2.7	0–95.0	24.0	2.4	0–91.2	<0.001
	30–60	36.9	2.3	0–96.1	25.1	2.3	0–92.5	<0.001
	60–83	35.2	2.1	0–98.8	25.3	2.2	0–83.4	0.001
	83–120	34.4	2.0	0–86.0	25.0	2.2	0–81.7	0.002
	120–150	34.0	2.2	0–75.8	24.7	2.1	0–74.1	0.003
	150–170	33.1	2.3	0–73.2	24.7	2.2	0–72.2	0.009
Low understory reinitiation								
	10–30	20.4	2.2	0–78.3	32.9	2.9	0–100	0.001
	30–60	24.0	2.2	0–74.4	32.1	2.6	0–99.1	0.084 [b]
	60–83	25.9	2.3	0–74.6	32.5	2.6	0–90.9	0.180 [b]
	83–120	27.5	2.4	0–83.3	33.0	2.6	0–88.3	0.276 [b]
	120–150	27.9	2.5	0–89.8	33.6	2.7	0–88.6	0.272 [b]
	150–170	28.8	2.7	0–92.4	33.5	2.8	0–97.4	0.349 [b]
Old growth								
	10–30	1.3	0.7	0–45.7	1.0	0.5	0–41.1	0.665
	30–60	0.8	0.4	0–20.7	1.0	0.6	0–50.3	0.793
	60–83	0.7	0.3	0–15.1	1.0	0.6	0–54.0	0.659
	83–120	0.6	0.3	0–11.9	0.7	0.5	0–44.2	0.752
	120–150	0.4	0.2	0–13.0	0.6	0.4	0–32.5	0.679
	150–170	0.4	0.2	0–12.9	0.6	0.4	0–28.8	0.539
Wet openings								
	10–30	2.1	0.6	0–30.4	2.3	0.8	0–43.9	0.848
	30–60	1.9	0.4	0–18.2	2.5	0.7	0–45.4	0.422
	60–83	2.0	0.5	0–22.4	2.8	0.7	0–48.0	0.335

(*Continued*)

[a] "High" and "low" denote ≥ or <50% canopy closure, respectively.
[b] *P*-value for arcsine square root transformed data.
[c] Contrast weighted edge density.
[d] *P*-value for log transformed data.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 16 (*continued*). Univariate landscape-scale habitat characteristics around goshawk nests and random sites in eastern Oregon and Washington, 1994–1995, by variable and landscape-scale. Landscape scales represent the habitat unique to each successive scale. Values are mean percentages of each landscape scale in each structural stage. Results are for untransformed data from 2-sample *t*-tests, unless otherwise noted.

Variable	Landscape Scale (ha)	Goshawk Sites (n = 82) Mean	SE	Range	Random Sites (n = 95) Mean	SE	Range	*P*-value
Wet openings (*continued*)								
	83–120	2.2	0.5	0–18.8	2.7	0.7	0–51.6	0.509
	120–150	2.4	0.5	0–16.6	2.8	0.8	0–48.2	0.635
	150–170	2.4	0.5	0–23.7	2.9	0.8	0–49.7	0.600
Dry openings								
	10–30	5.2	1.2	0–51.4	7.1	1.4	0–68.3	0.291
	30–60	5.4	1.1	0–55.5	7.9	1.4	0–62.6	0.272 [b]
	60–83	5.5	1.1	0–52.8	7.7	1.3	0–63.6	0.282 [b]
	83–120	6.3	1.2	0–61.4	7.7	1.3	0–62.4	0.434
	120–150	6.3	1.2	0–54.3	7.4	1.3	0–63.5	0.526
	150–170	6.2	1.2	0–51.0	7.5	1.4	0–70.1	0.456
Water								
	10–30	0.1	0.1	0–6.2	0.1	0.1	0–11.2	0.761
	30–60	0.3	0.3	0–24.7	0.1	0.1	0–4.9	0.380
	60–83	0.4	0.4	0–31.6	0.02	0.02	0–2.5	0.311
	83–120	0.5	0.4	0–36.6	0.03	0.03	0–2.5	0.322
	120–150	0.5	0.5	0–39.4	0.02	0.02	0–2.3	0.309
	150–170	0.5	0.5	0–38.6	0.02	0.02	0–2.2	0.300
CWED [c]: forest structure (m)								
	30–60	33.5	2.6	0–134.8	34.2	2.6	0–137.3	0.855
	60–83	32.3	2.4	2.8–108.1	34.0	2.5	0–119.5	0.624
	83–120	31.1	2.5	5.6–110.1	29.5	2.1	0–105.1	0.614
	120–150	23.9	2.0	3.2–80.9	23.6	1.8	0–87.7	0.926
	150–170	17.4	1.6	0–84.5	15.9	1.4	0–65.7	0.474
CWED [c]: canopy closure (m)								
	30–60	36.9	2.8	0–143.6	40.7	2.7	0–132.9	0.333
	60–83	36.2	2.6	1.6–120.8	39.6	2.5	0–123.3	0.338
	83–120	35.3	2.7	5.5–118.1	35.6	2.1	3.9–111.0	0.937
	120–150	28.8	2.2	2.8–94.1	29.3	1.9	2.1–98.9	0.839
	150–170	20.5	1.7	1.7–71.7	20.2	1.4	2.5–55.2	0.894
Mean nearest neighbor distance (m)								
	30–60	146.9	9.4	22.8–605.7	122.7	6.4	10.0–270.9	0.035
	60–83	175.1	12.1	36.8–722.9	165.6	9.1	36.9–477.0	0.533
	83–120	203.4	14.7	30.9–832.2	174.4	10.3	25.8–519.5	0.113 [d]
	120–150	255.6	18.1	44.7–846.1	217.3	12.9	24.8–584.2	0.088
	150–170	383.5	24.4	2.0–1292.1	362.4	21.7	51.9–1292.8	0.518
Simpson's evenness index								
	30–60	81.3	1.5	15.0–100	76.2	1.9	1.0–100	0.041
	60–83	82.5	1.4	4.0–98.0	75.8	1.8	15.0–99.0	0.004
	83–120	81.6	1.4	38.0–98.0	76.4	1.7	14.0–100	0.016
	120–150	81.1	1.5	28.0–100	76.7	1.5	31.0–100	0.040
	150–170	80.4	1.6	22.0–100	77.2	1.7	8.0–100	0.175
Contagion								
	30–60	58.7	0.8	47.4–87.0	60.8	0.9	46.4–98.6	0.081
	60–83	58.1	0.8	47.7–96.2	61.1	0.8	46.4–89.7	0.010
	83–120	58.9	0.7	49.4–76.2	61.0	0.8	47.3–90.9	0.048
	120–150	59.1	0.7	48.8–80.8	61.3	0.7	47.9–80.3	0.038
	150–170	59.7	0.8	49.3–84.9	61.3	0.8	48.4–93.2	0.145

[a] "High" and "low" denote ≥ or <50% canopy closure, respectively.
[b] *P*-value for arcsine square root transformed data.
[c] Contrast weighted edge density.
[d] *P*-value for log transformed data.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

stage of stand development. However, the mean nearest neighbor distance was only 17 m between the two group means, and may not be biologically meaningful (Table 15).

Results of the ring analyses (Table 16) indicate stand initiation in all rings, and low understory reinitiation in the 10- to 30- and 30- to 60-ha habitat rings, constituted significantly lower proportions of ring landscape around nests than random sites. Habitat contagion was also significantly less around nests than at random sites. Simpson's evenness index was significantly greater in the 30- to 60-, 60- to 83-, 83- to 120-, and 120- to 150-ha habitat rings surrounding nests (Table 16) than in corresponding rings around random sites. High stem exclusion in the 10- to 30-, 30- to 60-, and 60- to 83-ha habitat rings, and high understory reinitiation in all habitat rings occurred in significantly greater proportions surrounding goshawk nests than around random sites (Table 16). Mean nearest neighbor distance in the 30- to 60- and 120- to 150-ha habitat rings was also significantly greater around goshawk nests than in corresponding rings around random sites. However, in the 30- to 60-ha habitat ring a difference of 24 m in the mean nearest neighbor distance may not be biologically meaningful (Table 16).

Upon close examination of the similarities and differences in the circle and habitat ring analyses, Simpson's evenness index and contagion display occasional inconsistencies. Simpson's evenness index and contagion each differ significantly between goshawk nests and random sites within the 30- to 60-ha habitat ring, but not within the encompassing 60-ha scale. This may suggest that habitat characteristics at smaller landscape scales were more influential to habitat selection than characteristics at larger landscape scales. Conversely, these variables were of statistical significance at the 170-ha scale, but not in the unique 150- to 170-ha habitat ring. This suggests that these metrics were important at the 170-ha scale because of their importance at the smaller 150-ha landscape.

Productivity and Habitat Relationships

Reproductive outcome was known for 81 of the 82 goshawk nests (Fig. 8). There was a 90% fledging success rate for breeding pairs, an average of 1.64 young fledged/active nest (SE = 0.09), and 1.82 young fledged/successful nest (SE = 0.07).

The number of young fledged at a nest differed according to 3 habitat attributes: (1) basal area within the 1-ha nest site, (2) proportion of the landscape occupied by low stem exclusion at scales ≥60 ha, and (3) proportion of the landscape occupied by wet openings at scales ≥120 ha (Figs. 8 and 9). Other variables were not statistically significant (1-ha: $P \geq 0.271$; landscape scale: $P \geq 0.115$). Nests that fledged 3 young were characterized by significantly less basal area within the 1-ha nest site than those nests that fledged ≤2 ($F_{3, 77} = 2.89$, $P = 0.041$; Fig. 8). Nests that did not fledge young had lower amounts of low stem exclusion in landscapes ≥60 ha than nests that did fledge young (Fig. 9A). Additionally, the percent of the landscape in wet openings at scales ≥120 ha did not differ among nests with 0, 1, and 2 young fledged/nest. However, nests that fledged 3 young had a greater proportion of wet openings in the larger landscape scales than other production categories ($F_{3, 77} = 2.71$, 2.96, 3.03, $P = 0.051$, 0.037, and 0.034 for the 120, 150, and 170 ha landscape scales, respectively; Fig. 9B).

Multivariate Analysis

One-hectare Scale.—Twelve variables that described stand structure were significant

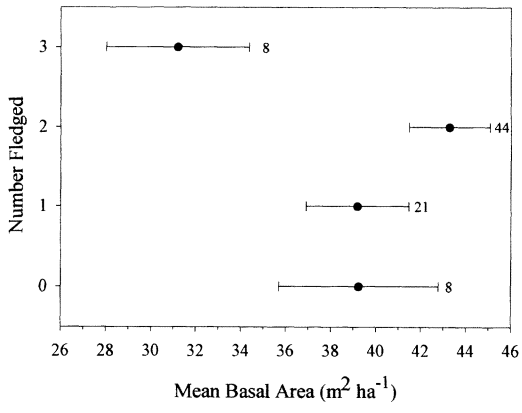

Figure 8. Relationship between basal area in the 1-ha scale surrounding the nest and the number of young fledged. The figure represents the mean basal area, with standard errors, for 0, 1, 2, and 3 fledged young per nest. Sample sizes for number fledged/nest are located to right of each group. ANOVA indicated that mean basal area differed among the groups of fledged young/nest ($F_{3, 77} = 2.89$, $P = 0.041$).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

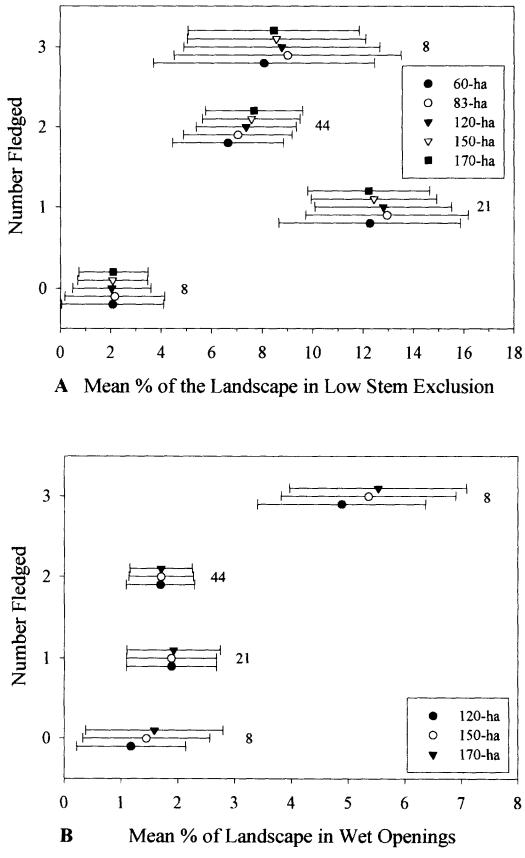

Figure 9. Relationships between low canopy closure stem exclusion at landscape scales ≥60 ha (A), or wet openings at landscape scales ≥120 ha (B), with the number of young fledged/nest. The figure shows the mean percent of area occupied by each stage of stand development, with standard errors, for 0, 1, 2, and 3 fledged young per nest. Sample sizes for number fledged/nest are located to right of each group. Results of ANOVAs for each stage of stand development at each of the landscape scales represented indicated that the mean percent of the area occupied by each stage of stand development at each landscape scale were not the same for each scale of fledged young/nest (low stem exclusion: $F_{3, 77}$, $0.041 \leq P \leq 0.089$; wet openings: $F_{3, 77}$, $0.034 \leq P \leq 0.051$).

($P < 0.25$) within the 1-ha scale (Tables 11–13). Mean canopy closure and stand density index were highly correlated with basal area ($r > \pm 0.70$). Basal area reduced model deviance (drop-in-deviance = 31.13, 1 df) more than mean canopy closure (drop-in-deviance = 3.01, 1 df) and stand density index (drop-in-deviance = 0.96, 1 df). Thus, basal area was retained for manual stepwise regression.

Using the categorical variable reduction method, we reduced the number of indicator variables for aspect and topographic position to 1 and 2, respectively. The indicator variable for aspect (where NW, N, and NE were 1 and all others were 0) discriminated between goshawk nest sites and random sites as well as the full model containing 7 indicator variables (drop-in-deviance = 5.895, 6 df, $P = 0.435$). The 2 indicator variables for topographic position, in which the lower 1/3 of slope and drainage bottoms each were assigned a value of 1 and all others were 0, or where ridge tops and the upper 1/3 of slope were each assigned a value of 1 and all others were 0, distinguished between goshawk nest sites and random sites as well as the full model that contained 5 indicator variables (drop-in-deviance = 6.664, 3 df, $P = 0.083$).

Among the remaining 10 variables, basal area, indicator variables for stage of stand development, and topographic position best described habitat differences between goshawk nest sites and random sites at the 1-ha scale (Table 17). There was no study area effect (drop-in-deviance = 3.435, 3 df, $P = 0.329$). An interaction between low topographic position and basal area reduced AIC by only 1.78, not the requisite reduction of ≥2 for entry into the model. However, due to the reduction in AIC, the model containing the interaction was considered as competing with the main effects-only model (Burnham and Anderson 1998), and thus was retained for comparison with other models (Table 18). This interaction suggested an association between goshawk nest sites and greater basal area on lower slope positions. Basal area was not correlated with topographic position ($r = 0.05$, $P = 0.49$).

In the main-effects model (Table 17), the odds of a site on a ridge-top being a nest site were 63% less than the odds for sites on the middle and lower 1/3 of the slope, drainage bottoms, and flats. Understory reinitiation stands were 74% less likely to contain nests than stem exclusion stands. The 95% confidence interval for old growth overlapped 1, indicating that old growth did not contribute substantially to the logistic regression equation's ability to discriminate between nests and random sites. However, the odds of a 1-ha site being a nest site increased by a factor of 1.18 (i.e., an 18% increase in the odds of a site being a nest site) with each 1 m^2 ha^{-1} increase in basal area above the

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

average basal area for all goshawk nest sites (40.6 m^2 ha^{-1}; Table 17).

For the 1-ha model that incorporates the interaction between topographic position and basal area (Table 18), the odds of a site on a ridge-top being a goshawk nest site were 61% less than the odds for sites on the middle and lower 1/3 of slopes, drainage bottoms, and flats. However, at or above the upper 1/3 of the slope, increasing basal area by 1 m^2 ha^{-1} above average goshawk nest site basal area increased the odds of nesting by a factor of 1.15, or an increase of 15% in the odds. In comparison, increasing basal area by 1 m^2 ha^{-1} above average goshawk nest site basal area on a site in a low topographic position increased the odds of that site being a nest site by a factor of 1.34 times (i.e., a resulting increase of 34% in the odds of a site being a goshawk nest site). In general, the probability of a 1-ha site being a goshawk site increased more rapidly on low topographic positions with increasing basal area, than on sites with higher topographic position and basal area that is more representative of the surrounding landscape (Table 18).

Landscape-scale Habitat Models.—Logistic regression models were constructed for each landscape scale, and additional landscape "rings" were added sequentially to discriminate nest sites from randomly available habitat and to determine the spatial extent of those relationships (Table 19). The logistic regression model selected as the best discriminator between nests and random sites was the 30-ha+ model (Table 19). It incorporated habitat conditions from the larger landscape-scales and had an AIC value of 180.37. This AIC was 3.47 units lower than the next best model (Table 19).

Thirty-two variables were significant ($P <$ 0.25) for the 30-ha scale and for each of the 5 habitat rings that extended to 170 ha (Tables 15–16). Among these, Simpson's evenness index and contagion were highly correlated in each habitat ring ($r > \pm 0.70$; Fig. 10). Simpson's evenness index resulted in a greater drop-in-deviance than contagion at each landscape scale (mean difference = 0.86, SE = 0.44, n = 5); thus, the evenness index was retained in the manual forward selection procedure.

Results of the manual forward selection procedure, in which variables from each successive landscape scale were added to the model after accounting for variables at the 30-ha scale, indicated that the significant main effects included the percentage of the 30-ha scale in high stem exclusion and high understory reinitiation, percentage of the 30- to 60-ha ring in stand initiation, the 30- to 60-ha ring's mean nearest neighbor distance and Simpson's evenness index, and percent of the 60- to 83-ha ring in stand initiation (Table 20). A study area effect was present (drop-in-deviance = 7.66, 3 df, P = 0.054) and could be attributed to only the Northeast Oregon study area (drop-in-deviance = 1.36, 2 df, P = 0.506). After expanding the model

Table 17. Five-variable logistic regression model that best discriminated between goshawk (n = 82) and random (n = 95) 1-ha sites in eastern Oregon and Washington. Eleven random sites that occurred in stand initiation stands were removed prior to analysis to enable modeling of forest structural conditions only in those conditions where goshawks nested. For continuous variables, the odds ratio reflects the change in odds of nesting for a 1 unit increase in the indicated variable from its mean. For categorical variables, the odds ratio reflects that the condition is true. For the following model AIC = 130.239.

Variable	Parameter estimate [a]	SE [a]	χ^2 [b]	P-value [b]	Odds ratio	95% C.I.
Intercept	–4.765	0.971	24.059	<0.001		
Understory reinitiation indicator [c]	–1.348	0.542	6.183	0.013	0.260	0.090–0.752
Old growth indicator [c]	–0.669	0.927	0.521	0.471	0.512	0.083–3.151
Low topographic position [c] indicator	2.135	0.586	13.286	<0.001	8.453	2.683–26.637
High topographic position [c] indicator	–0.992	0.604	2.697	0.101	0.371	0.113–1.212
Basal area	0.162	0.028	34.640	<0.001	1.176	1.114–1.241

[a] Parameter estimates and standard errors based on the model with all 6 variables included.

[b] χ^2 and P-values based on Wald test.

[c] Indicator values for each variable are 1 if stage of stand development is understory reinitiation or old growth, topographic position of the site is either the lower 1/3 of the slope or drainage bottom (low), or topographic position is the ridge top or upper 1/3 of the slope (high). Otherwise, the indicator value is 0.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 18. Six-variable logistic regression model, with interactions, that best discriminated between goshawk (n = 82) and random (n = 95) 1-ha sites in eastern Oregon and Washington. This model competes with that presented in Table 17 for explaining goshawk landscape-scale habitat. Eleven random sites that occurred in stand initiation stands were removed to enable modeling of only those forest structural conditions in which goshawks nested. For continuous variables, the odds ratio reflects the change in odds for a 1 unit increase in the variable from its mean. For categorical variables, the odds ratio reflects that the condition is true. For the following model AIC = 128.457.

Variable	Parameter estimate [a]	SE [a]	χ^2 [b]	*P*-value [b]	Odds ratio	95% C.I.
Intercept	−3.938	0.985	15.997	<0.001		
Understory reinitiation indicator [c]	−1.428	0.547	6.819	0.009	0.240	0.082–0.700
Old growth indicator [c]	−0.666	0.912	0.533	0.465	0.514	0.086–3.069
Low topographic position [c] indicator	−2.043	2.570	0.632	0.427		
High topographic position [c] indicator	−0.930	0.571	2.649	0.104	0.395	0.129–1.209
Basal area	0.139	0.028	24.496	<0.001		
Low topographic position × Basal area	0.155	0.095	2.659	0.103		
Basal area on lower 1/3 of slope or drainage bottom					1.341	1.054–1.707
Basal area on ridge top, middle-, upper 1/3 of slope, or flat					1.149	1.087–1.213

[a] Parameter estimates and standard errors based on the model with all 6 variables included.

[b] χ^2 and *P*-values based on Wald test.

[c] Indicator values for each variable are 1 if stage of stand development is understory reinitiation or old growth, topographic position of the site is either the lower 1/3 of the slope or drainage bottom (low), or topographic position is the ridge top or upper 1/3 of the slope (high). Otherwise, the indicator value is 0.

Table 19. Logistic regression models (excluding intercept) estimating northern goshawk nest suitability in eastern Oregon and Washington. Akaike's information criterion (AIC) was used to evaluate related models; lowest AIC value (in bold) indicates the best model (i.e., the model with the fewest parameters, fits the data, and is biologically reasonable). The first model listed for each landscape scale was constructed from parameters representing the habitat conditions contained only within that scale. The second model listed for each landscape scale (denoted by '+') was constructed by adding parameters from larger scales, while controlling for the parameters at smaller scales. Parameters followed by an 'r' indicate that they represent habitat conditions unique to a larger landscape scale, and the number following the 'r' represents the scale at which those conditions begin (e.g., SI r30 represents the percent of the 30- to 60-ha ring occupied by stand initiation). Otherwise, parameters represent conditions at the specified landscape scale.

Model	Parameters [a]	Number of parameters	Deviance	AIC
10 ha	HSE, HUR	3	204.10	210.10
10 ha+	HSE, HUR, SI r10, SI r30, MNN r30, SIEI r30, HSE × SI r10, HUR × SI r30	9	165.84	183.84
30 ha	NEOR, HSE, HUR	4	198.30	206.30
30 ha+	**NEOR, HSE, HUR, SI r30, MNN r30, SIEI r30, SI r60, NEOR × SIEI r30, HUR × SI r30**	**10**	**160.37**	**180.37**
60 ha	SI, HSE, HUR, SIEI, SI × HUR	6	194.58	206.58
60 ha+	SI, HSE, HUR, SIEI, SIEI r60, SI × HUR	7	190.99	204.99
83 ha	SI, HSE, HUR, SIEI, SI × HUR, SI × SIEI	7	189.85	203.85
83 ha+	SI, HSE, HUR, SIEI, SI × HUR, SI × SIEI	7	189.85	203.85
120 ha	HSE, HUR, SIEI	4	208.42	216.42
120 ha+	HSE, HUR, SIEI	4	208.42	216.42
150 ha	SI, HSE, HUR, SIEI, SI × HUR, SI × SIEI	7	191.04	205.04
150 ha+	SI, HSE, HUR, SIEI, HUR r150, SI × HUR, SI × SIEI	8	188.37	204.37
170 ha	SI, HSE, HUR, SIEI, SI × HUR, SI × SIEI,	7	194.45	208.45

[a] HSE = high canopy closure stem exclusion; HUR = high canopy closure understory reinitiation; SI = stand initiation; MNN = mean nearest neighbor distance; SIEI = Simpson's evenness index; NEOR = Northeast Oregon study area indicator.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 20. Ten-variable logistic regression model, with interactions, that best discriminated between goshawk and random sites at multiple landscape scales in eastern Oregon and Washington, 1994–1995.

Variable	Landscape scale	Parameter estimate [a]	SE [a]	χ^2 [b]	*P*-value [b]
Intercept		–4.9192	1.5178	10.5036	0.001
Northeast Oregon indicator[c]		–5.0199	2.8286	3.1494	0.076
High canopy closure stem exclusion	30	0.0482	0.0110	19.0456	<0.001
High canopy closure understory reinitiation	30	0.0386	0.0095	16.5114	<0.001
Stand Initiation	30–60	–0.0671	0.0682	0.9671	0.325
Mean nearest neighbor	30–60	0.0071	0.0031	5.0344	0.025
Simpson's evenness index	30–60	0.0218	0.0155	1.9707	0.160
Stand initiation	60–83	–0.0812	0.0575	1.9960	0.158
High understory reinitiation × stand initiation	30 × (30–60)	0.0024	0.0011	5.0828	0.024
Northeast Oregon × Simpson's evenness index	30–60	0.0721	0.0351	4.2091	0.040

[a] Parameter estimates and standard errors based on the model with all 10 variables included.

[b] χ^2 and *P*-values based on Wald test.

[c] Indicator value is 1 if the site is located in the Northeast Oregon study area, and 0 if located in one of the three remaining study areas.

to include significant first-order interactions, we detected interactions between the percent of the 30-ha scale in high understory reinitiation and the percent of the 30- to 60-ha ring in stand initiation, and the Northeast Oregon study area effect with Simpson's evenness index in the 30- to 60-ha ring (drop-in-deviance = 16.06, 2 df, $P < 0.001$).

Based on this model, a 1% increase in the amount of high stem exclusion stand structure at the 30-ha scale, with all other model variables held constant, increased odds of a site being a nest site by approximately 5% (Table 21). The study area effect (attributed to Northeast Oregon) on Simpson's evenness index can be seen in the context of the 30- to 60-ha ring. With all other variables in the model held constant, a 1-unit increase in Simpson's evenness among stages of stand development increased the odds of a site in Northeast Oregon being a goshawk nest site by 7.5%, but by only 2.2% in the other 3 study areas (Table 21). The interaction between the study area and Simpson's evenness index, in the 30- to 60-ha ring, indicated that at this scale Simpson's evenness index more strongly influences the probability of nesting at a site in Northeast Oregon than in the other 3 study areas; as evenness of landscape structural composition increased, so did the probability of goshawk nesting, but more so in Northeast Oregon than in the other 3 study areas.

The interaction between the proportion of the 30-ha scale occupied by high understory reinitiation and the proportion of the 30- to 60-ha ring occupied by stand initiation suggested that habitat conditions at different distances from the nest probably interact to influence resource selection by goshawks,

Table 21. Odds ratios for the 10-variable, landscape-scale logistic regression model for goshawk nest sites in eastern Oregon and Washington, 1994–1995. For continuous variables, the odds ratio reflects the change in odds for a 1 unit increase in the variable.

Condition	Landscape scale	Odds ratio	95% confidence interval
High Canopy Closure Stem Exclusion	30	1.049	1.027–1.072
High Canopy Closure Understory Reinitiation [a]	30	1.039	1.020–1.059
Stand Initiation [a]	30–60	0.935	0.818–1.069
Mean Nearest Neighbor	30–60	1.007	1.001–1.013
Simpson's Evenness Index in Northeast Oregon	30–60	1.075	1.003–1.151
Simpson's Evenness Index not in Northeast Oregon	30–60	1.022	0.991–1.054
Stand Initiation	60–83	0.922	0.824–1.032

[a] Does not consider the interaction term between these two variables.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

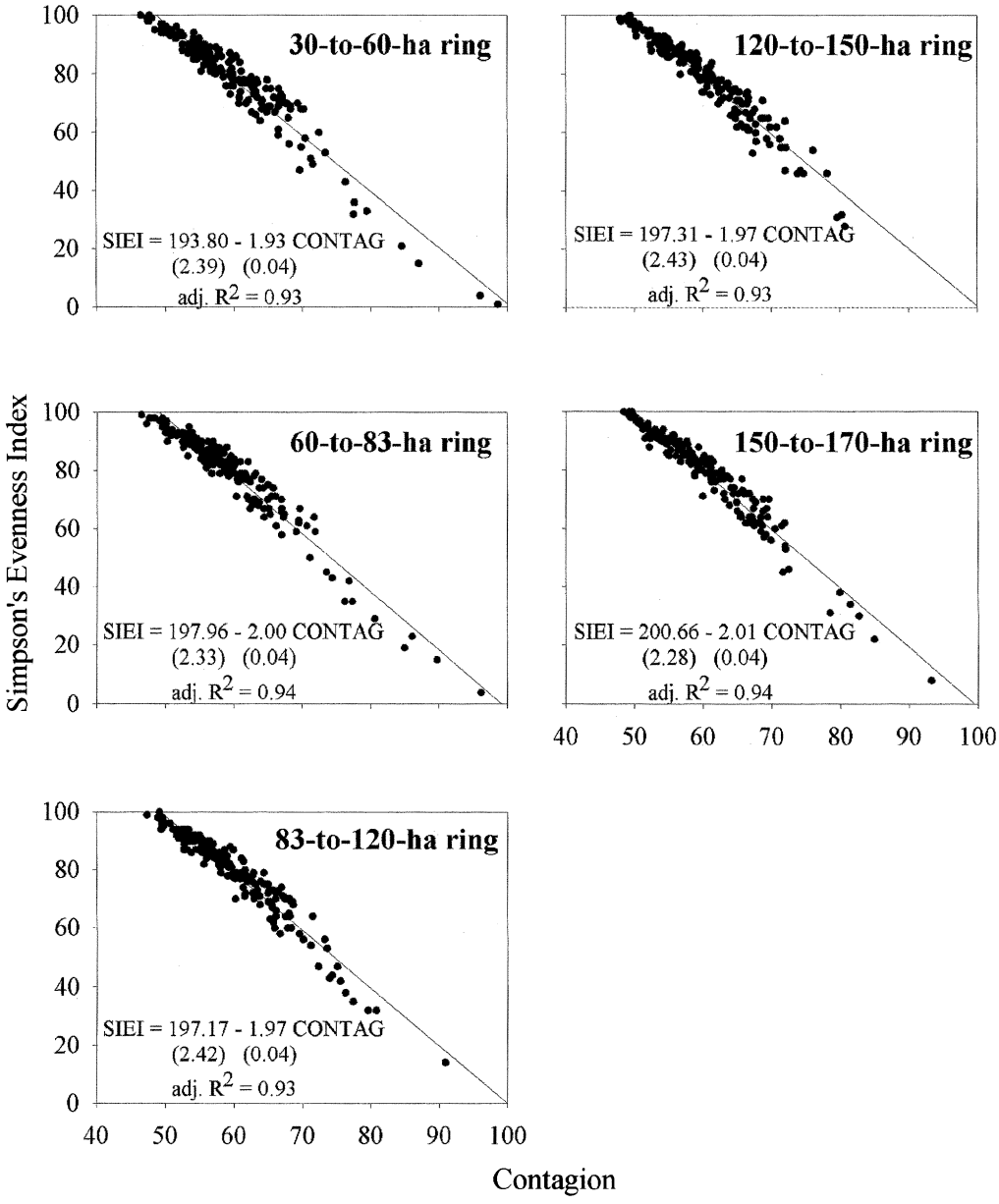

Figure 10. Simple linear regression incorporating Simpson's evenness index and contagion at the 30- to 60-ha, 60- to 83-ha, 83- to 120--ha, 120- to 150-ha, and 150- to 170-ha habitat rings surrounding goshawk and random sites in eastern Oregon and Washington, 1994–1995. Standard errors for the regression coefficients are in parentheses. Each regression equation explained a significant portion of the variation ($F_{1, 175}$, $P < 0.001$).

and that the potential negative effects of stand initiation in the 30- to 60-ha ring may be mitigated, to some degree, by the positive effect of high understory reinitiation within the 30-ha landscape.

Cross-validation

The RSPF computed for each of the 82 goshawk nests and 95 random sites using the best fit model (Table 20) predicted a range of relative probabilities (0.5–100%) for containing a goshawk nest and random sites (<0.001–100%; Fig. 11). Non-cross-validated results suggested that the RSPF had 78% classification accuracy for all 177 observations ($n = 82$ nests and 95 random sites) used

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

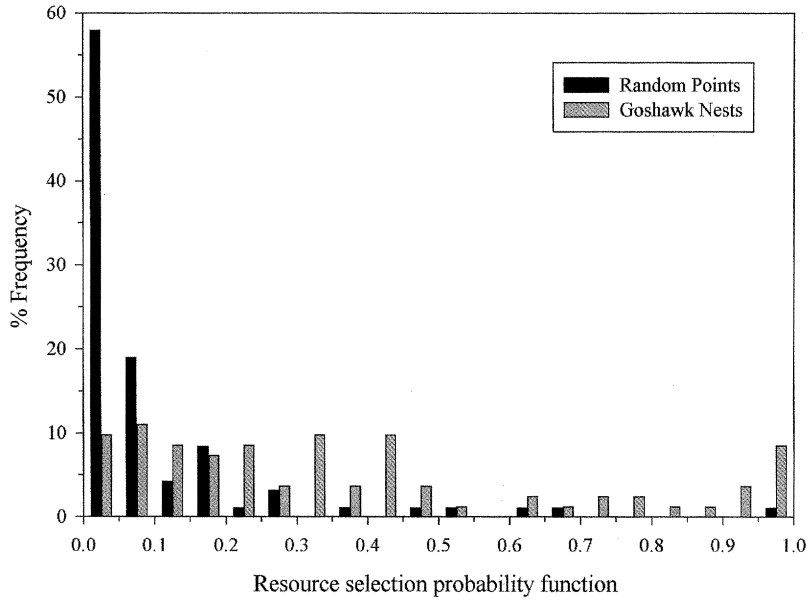

Figure 11. Resource selection probability function (RSPF) of goshawk nest locations versus random locations within 83-ha circles in eastern Oregon and Washington, 1994–1995. The RSPF is the predicted probability that the habitat contains a northern goshawk nest.

in its construction (using estimated relative probabilities between 0.07 and 0.10 as the discriminator between goshawk nest sites and available habitat). However, errors of commission (i.e., random points misclassified as nest sites) and omission (i.e., nest sites misclassified as random points) varied between the two discriminators. Thus, when we cross-validated the RSPF classification accuracy, errors of commission and omission were estimated for both relative probability breakpoints (0.07 and 0.10).

In bootstrap cross-validation, using a relative probability breakpoint of 0.07 to discriminate between goshawk nest sites and available habitat yielded an average classification accuracy of 75.11% (SE = 0.30), with commission error of 18.1% (SE = 0.25) and omission error of 6.84% (SE = 0.17). Using a relative probability breakpoint of 0.10 to discriminate between goshawk nest sites and available habitat yielded a cross-validated classification accuracy of 75.96% (SE = 0.31), with commission error of 13.66% (SE = 0.23) and omission error of 10.37% (SE = 0.21). Thus, a relative probability breakpoint of 0.10 provides a more conservative estimate of goshawk nesting habitat suitability, with respect to errors of commission than does a breakpoint of 0.07, while producing a similar classification accuracy.

Because annual territory density is highly variable, and thus is influential in the calculation of P_u, we assumed that the true territory density was between 0.043 and 0.072 active territories/km^2, the 95% confidence interval for data in Table 2. Thus, such variation in territory densities, and subsequent variation in P_u, produced a range in classification accuracy of 75–79% (Table 22).

Table 22. The effect of territory density (number of active territories/km^2) variability on the classification accuracy (%) of the best fit landscape-scale resource selection probability function (RSPF) at probability breakpoints of 0.07 and 0.10 (for discrimination between goshawk nests and random sites). Territory densities reflect the lower 95% CI, mean, and upper 95% CI from density estimates presented in Table 3. Variability in territory density affects only the calculation of the proportion of used sites sampled (P_u) in the RSPF. Proportion of available sites sampled (P_a) remains constant.

Territory density	P_u	P_a	Classification accuracy 0.07 [a]	Classification accuracy 0.10 [a]
0.043	0.1502	0.0128	78.53	77.40
0.058	0.1124	0.0128	77.97	77.97
0.072	0.0898	0.0128	74.58	77.40

[a] Probability breakpoint used to discriminate between goshawk nests and random sites.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Forest Growth Simulations

Central Washington.—Initial relative probability of nesting for the Central Washington case study was 0.39. Simulating effects of three silvicultural prescriptions (no-harvest, commercial thin, and spotted owl) revealed that no prescription was likely to maintain the relative probability of nesting for our case-study site over the 100-year simulation period (Fig. 12). By the sixth monitoring period (year 2053), all three prescriptions were projected to yield relative probabilities of nesting below 0.10, with reasonable classification accuracy (76% at $P = 0.10$) and relatively low probability of commission error (13.66%).

Beyond 2053 to the end of the simulation (year 2093) each of the three initial prescriptions was low in habitat heterogeneity in the 30- to 60-ha and 60- to 83-ha rings (Fig. 13). Thus, the habitat conditions within the 30-ha scale had the greatest influence on the resulting probability of nesting at this site (Table 23). Beyond 2053, the model ignored habitat conditions beyond 30-ha because those areas grew into more homogeneous landscape conditions (Fig. 13). Under both the "no-harvest" and "owl" prescriptions, this homogeneous landscape was composed of high understory reinitiation. This stage of stand development had not been explicitly recognized by the RSPF in the 30- to 60-ha and 60- to 83-ha rings (Table 20), but is indirectly accounted for in the calculation of mean nearest neighbor and Simpson's evenness index. As a result, the high understory reinitiation effect was zero in the rings and because of this homogeneity, contributed zero to the nearest neighbor distance and evenness index. Thus, habitat homogeneity, rather than the landscape's forest structural composition *per se*, was responsible for the low predicted relative probability of nesting.

We developed a fourth prescription for the Central Washington site to maintain or increase the site's estimated probability of supporting a nest site over time. This prescription was based on our observation that low nesting probabilities under the no-harvest and owl prescriptions were indeed a result of homogenization of the landscape, beginning in the fifth monitoring period (year 2043). Therefore, we simply modified the "owl" prescription to preclude landscape homogeneity. At our case study site, one particular stand of high understory reinitiation bridged all three landscape scales (Fig. 13), and so we periodically simulated thinning this stand after year 2043 in order to produce stand characteristics typical of high stem exclusion (see Fig. 5 for characteris-

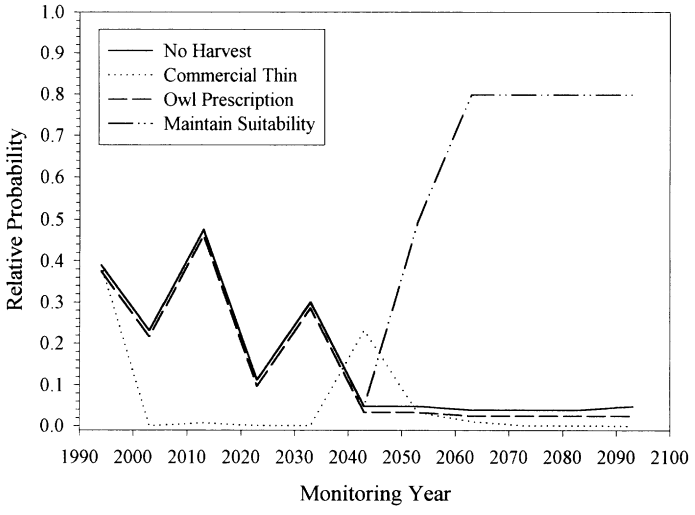

Figure 12. Results of forest growth simulations for 4 silvicultural prescriptions within 83 ha surrounding a goshawk nest in Central Washington. Silvicultural prescriptions include no-harvest, where the landscape is not entered for timber management for 100 years; commercial thin, which varies by forest type and thins from below (trees ≤25.4 cm dbh) and from above (trees >25.4 cm dbh); an owl prescription, which lightly thins the stand; and a prescription that is designed to maintain site suitability through a modification of the owl prescription. Results of the owl prescription are identical to those of the no-harvest, therefore 0.01 was subtracted from the owl prescription results so that each line was visible.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

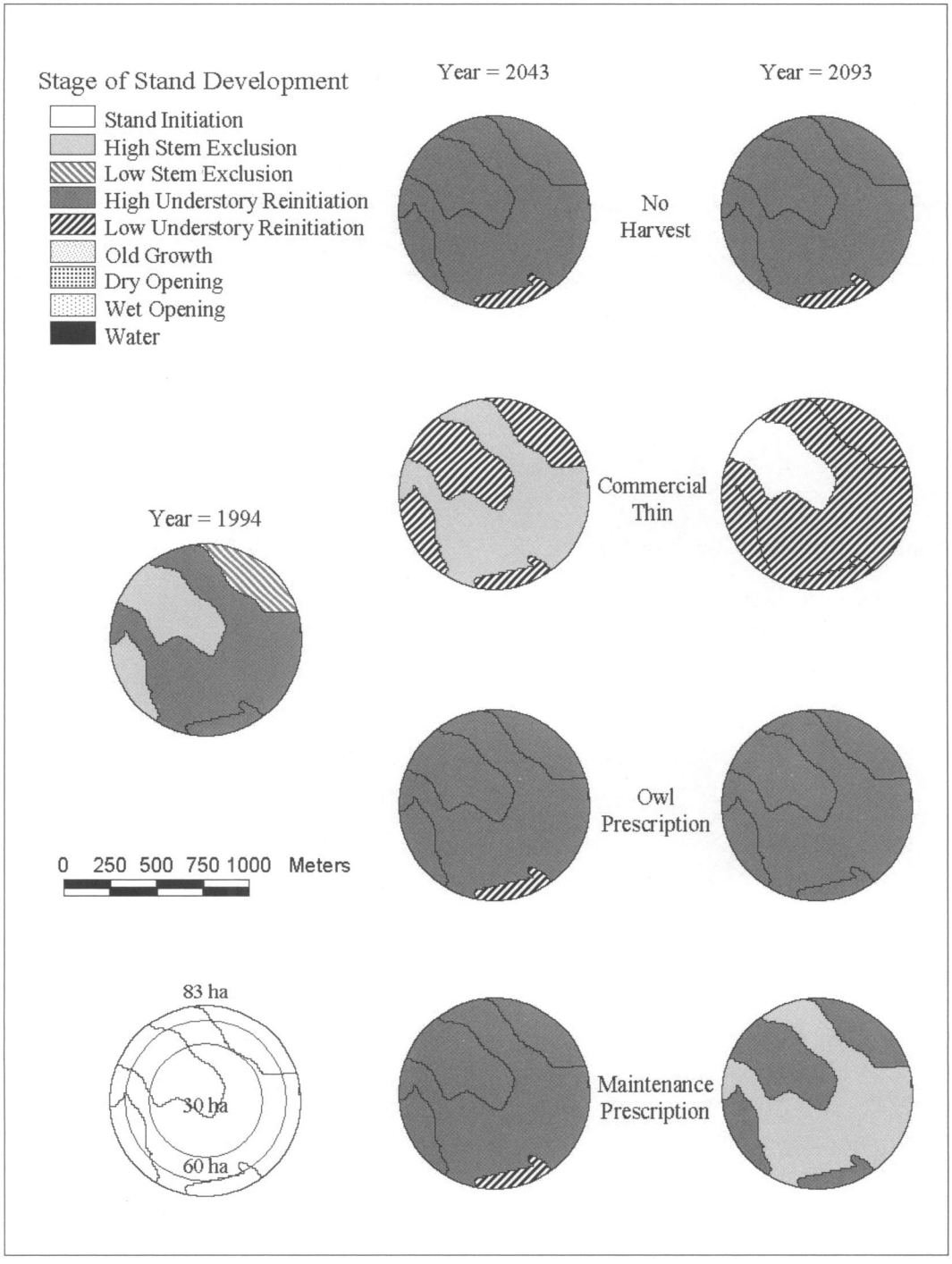

Figure 13. Partial results of forest growth simulations for 4 silvicultural prescriptions surrounding a northern goshawk nest in Central Washington. Silvicultural prescriptions include no-harvest, where the landscape is not entered for timber management for 100 years; commercial thin that varies by forest type; an owl prescription, which lightly thins the stand; and a prescription that is designed to maintain nest site suitability through a modification of the owl prescription. The figure depicts how the structural stages are distributed within 83 ha surrounding the nest (located in the center of each circle) prior to initiation of management activities (i.e., year 1994), and respond to management after 49 years (i.e., year 2043), and at the end of the management activities (i.e., year 2093).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 23. Effects of four silvicultural prescriptions using forest growth simulations (Wykoff et al. 1982), within 83 ha of a goshawk nest in central Washington. Results demonstrate model component response to harvest prescriptions over time. Because this particular nest is in central Washington, the Northeast Oregon study area indicator and its interaction with Simpson's evenness index in the 30- to 60-ha ring both equal 0.

Year	HSE30	HUR30	SI r30	MNN r30	SIEI r30	SI r60	HUR30 × SI r30	Probability estimate
No-harvest prescription								
1994	31.98	68.02	0	46.3	76	0	0	0.390
2003	31.98	68.02	0	6.3	65	0	0	0.232
2013	31.98	68.02	0	102.3	67	0	0	0.476
2023	0	100	0	0	48	0	0	0.112
2033	0	100	0	130	51	0	0	0.301
2043	0	100	0	12.7	5	0	0	0.048
2053	0	100	0	12.7	5	0	0	0.048
2063	0	100	0	0	0	0	0	0.040
2073	0	100	0	0	0	0	0	0.040
2083	0	100	0	0	0	0	0	0.040
2093	0	100	0	12.7	5	0	0	0.048
Commercial thin prescription								
1994	31.98	68.02	0	46.3	76	0	0	0.390
2003	0	0	1.28	12.7	39	12.63	0	0.001
2013	0	0	0	57.1	82	0	0	0.007
2023	0	0	13.53	58.8	55	9.42	0	0.001
2033	0	0	0	0	0	0	0	0.001
2043	68.02	0	0	49.3	92	0	0	0.232
2053	31.98	0	0	150.3	50	0	0	0.033
2063	31.98	0	0	0	47	0	0	0.011
2073	0	0	0	0	0	0	0	0.001
2083	0	0	0	0	0	0	0	0.001
2093	0	0	13.53	0	47	9.42	0	<0.001
Owl prescription								
1994	31.98	68.02	0	46.3	76	0	0	0.390
2003	31.98	68.02	0	6.3	65	0	0	0.232
2013	31.98	68.02	0	102.3	67	0	0	0.476
2023	0	100	0	0	48	0	0	0.112
2033	0	100	0	130	51	0	0	0.301
2043	0	100	0	12.7	5	0	0	0.048
2053	0	100	0	12.7	5	0	0	0.048
2063	0	100	0	0	0	0	0	0.040
2073	0	100	0	0	0	0	0	0.040
2083	0	100	0	0	0	0	0	0.040
2093	0	100	0	0	0	0	0	0.040
Maintenance prescription								
1994	31.98	68.02	0	46.3	76	0	0	0.390
2003	31.98	68.02	0	6.3	65	0	0	0.232
2013	31.98	68.02	0	102.3	67	0	0	0.476
2023	0	100	0	0	48	0	0	0.112
2033	0	100	0	130	51	0	0	0.301
2043	0	100	0	12.7	5	0	0	0.048
2053	68.02	31.98	0	49.3	70	0	0	0.494
2063	68.02	31.98	0	49.3	92	0	0	0.798
2073	68.02	31.98	0	49.3	92	0	0	0.798
2083	68.02	31.98	0	49.3	92	0	0	0.798
2093	68.02	31.98	0	49.3	92	0	0	0.798

Notes: HSE30 = % of 30-ha scale in high stem exclusion. HUR30 = % of 30-ha scale in high understory reinitiation. SI r30 = % of 30- to 60-ha ring in stand initiation. MNN r30 = mean nearest neighbor distance for the 30- to 60-ha ring. SIEI r30 = Simpson's evenness index for the 30- to 60-ha ring. SI r60 = % of the 60- to 83-ha ring in stand initiation. HUR30 × SI r30 = interaction between % of 30-ha scale in high understory reinitiation and % of 30- to 60-ha ring in stand initiation.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

tics). This resulted in relative probabilities of nesting that exceeded the site's original 1994 estimated probability of 0.3902 (Table 23), and thereafter maintained it at 0.7984 from year 2063 until the end of the simulation in year 2093 (Table 23; Fig. 12).

Northeast Oregon.—Initial relative probability for nesting in the Northeast Oregon case study was 0.002. Although the case study site was not one of the sites used in the logistic regression analysis, nesting did occur and two young were fledged. Simulating effects of three silvicultural prescriptions (no-harvest, commercial thin without PCT, and commercial thin with PCT) for the Northeast Oregon site revealed that no prescription was likely to produce suitable and sustainable relative probabilities of nesting for the site over the 100-year simulation, and relative probability of nesting was in fact highly variable (Fig. 14). In all three prescriptions the relative nesting probabilities were strongly positively correlated with evenness in the 30- to 60-ha habitat ring ($r \geq 0.7$), with Simpson's evenness index scores ≥ 83 yielding relative nesting probabilities >1.0 in Northeast Oregon (Table 24). These specific results are directly linked to the interaction between the Northeast Oregon study area effect and Simpson's evenness index in the 30- to 60-ha habitat ring (Table 20). The particular importance for habitat evenness in the Northeast Oregon study area can be seen by modeling the results for this site as if it were located in one of the other three study areas (Table 24): as habitat in the 30- to 60-ha habitat ring became more evenly distributed, the resulting relative nesting probability increased more rapidly in Northeast Oregon. Thus, developing a silvicultural prescription that would produce sustainable goshawk nesting habitat would be facilitated by maximizing evenness in the 30- to 60-ha habitat ring while producing desirable structural conditions within 30-ha of the nest.

We developed a fourth prescription for the Northeast Oregon site that produced less variable habitat conditions capable of supporting a nest site over time. This required unique modification of two stands (stands F and P; Fig. 15) rather than one, as in the Central Washington case study. For the remainder of the stands surrounding the Northeast Oregon site, we modeled commercial thin with PCT. For stand F, we wanted to set the stand to high stem exclusion as soon as possible in order to provide landscape heterogeneity, and accomplished this by removing all trees 25.4–50.8 cm dbh initially and followed with maintaining the stand using the commercial thinning with PCT prescription. As a result, Stand F achieved characteristics of high stem exclusion by year 2021. For stand P, we needed to consider the surrounding landscape's structure and composition over time so that we could schedule harvest to produce conditions at a time appropriate to maintain evenness in the landscape. As a result, we simulated harvest of stand P in year 2051 to produce high stem exclusion characteristics in the stand (Fig. 5) by year 2071. This dual stand modification of the commercial thin with PCT prescription yielded relative probabilities of nesting above 0.10 in all monitoring periods after 2011, except 2091, where it falls to 0.056, which was still higher than the initial conditions in 2001 (Table 24; Fig. 15).

Landscape Assessment

Results of the landscape assessment of the

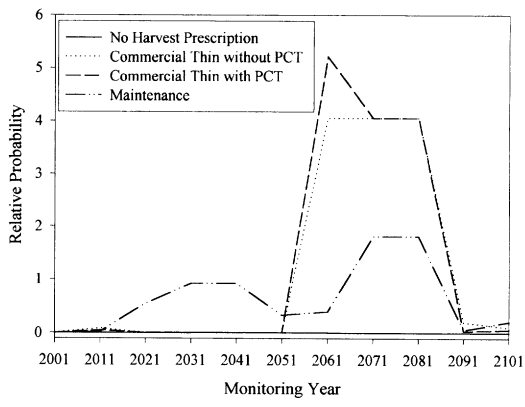

Figure 14. Results of forest simulations for 4 silvicultural prescriptions within 83 ha surrounding a goshawk nest in Northeast Oregon. Silvicultural prescriptions include no-harvest, where the landscape is not entered for timber management for 100 years; commercial thin without pre-commercial thinning (PCT), whereby trees $\geq$ 20.32 cm are thinned to a target of 40% stand maximum basal area once stand basal area $\geq$60% of the stand maximum; and commercial thin with PCT, which proceeds with the commercial thin identically to the previous prescription, but also checks for the need to pre-commercially thin trees 2.54 < dbh $\leq$ 15.24 cm. Results present the resulting RSPF, by year, as a relative probability. Thus, relative probabilities $\geq$1 may result.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 24. Effects of four silvicultural prescriptions using forest growth simulations (Wykoff et al. 1982), within 83 ha of a goshawk nest in Northeast Oregon. Results demonstrate model component response to harvest prescriptions over time. Relative probabilities are presented for the site as it occurs in Northeast Oregon (NEOR = 1) and as if it occurred elsewhere (NEOR = 0) to demonstrate the impact of the interaction between study area and Simpson's evenness index in the 30- to 60-ha ring.

								Probability	
Year	NEOR	HSE 30	HUR 30	SI r30	MNN r30	SIEI r30	SI r60	In NEOR	Not in NEOR
No-harvest prescription									
2001	1	0	37.9	4.61	83.66	54	9.97	0.002	0.007
2011	1	0	94.44	4.61	83.87	41	9.97	0.006	0.046
2021	1	0	97.7	0.55	89.09	19	2.99	0.002	0.078
2031	1	0	97.7	0	89.09	19	0	0.003	0.103
2041	1	2.3	97.7	0	89.09	27	0	0.006	0.137
2051	1	2.3	97.7	0	0	27	0	0.003	0.073
2061	1	2.3	97.7	0	0	27	0	0.003	0.073
2071	1	0	100	0	0	0	0	0.000	0.039
2081	1	0	100	0	0	0	0	0.000	0.039
2091	1	0	100	0	0	0	0	0.000	0.039
2101	1	0	100	0	0	0	0	0.000	0.039
Commercial thin without PCT prescription									
2001	1	0	37.9	4.61	83.66	54	9.97	0.002	0.007
2011	1	44.84	94.44	4.61	83.87	41	9.97	0.084	0.658
2021	1	0	97.7	4.61	89.09	27	9.97	0.002	0.040
2031	1	0	97.7	0	89.09	27	0	0.006	0.123
2041	1	0	97.7	0	89.09	27	0	0.006	0.123
2051	1	0	97.7	0	0	27	0	0.003	0.065
2061	1	56.54	43.46	0	0	97	0	4.053	0.563
2071	1	56.54	43.46	0	0	97	0	4.053	0.563
2081	1	56.54	43.46	0	0	97	0	4.053	0.563
2091	1	94.44	5.56	0	0	61	0	0.198	0.370
2101	1	41.16	2.3	0	0	82	0	0.096	0.039
Commercial thin with PCT prescription									
2001	1	0	37.9	4.61	83.66	54	9.97	0.002	0.007
2011	1	44.84	94.44	4.61	83.87	35	9.97	0.048	0.577
2021	1	0	97.7	4.61	89.09	27	9.97	0.002	0.040
2031	1	0	97.7	0	89.09	27	0	0.006	0.123
2041	1	0	97.7	0	89.09	27	0	0.006	0.123
2051	1	0	97.7	0	0	27	0	0.003	0.065
2061	1	53.56	46.44	0	0	100	0	5.220	0.584
2071	1	56.54	43.46	0	0	97	0	4.053	0.563
2081	1	56.54	43.46	0	0	97	0	4.053	0.563
2091	1	0	43.46	0	0	75	0	0.034	0.023
2101	1	97.7	2.3	0	0	48	0	0.060	0.287
Maintenance prescription									
2001	1	0	37.9	4.61	83.66	54	9.97	0.002	0.007
2011	1	31.31	94.44	4.61	83.87	35	9.97	0.021	0.259
2021	1	53.56	44.13	4.61	72.15	77	9.97	0.543	0.319
2031	1	53.56	44.13	0	72.15	77	0	0.919	0.540
2041	1	53.56	44.13	0	72.15	77	0	0.919	0.540
2051	1	0	44.13	0	0	99	0	0.329	0.040
2061	1	0	46.44	0	0	100	0	0.395	0.044
2071	1	40.87	59.13	0	0	90	0	1.807	0.416
2081	1	40.87	59.13	0	0	90	0	1.807	0.416
2091	1	0	59.13	0	0	74	0	0.056	0.041
2101	1	6.24	55.87	0	0	86	0	0.206	0.063

Notes: NEOR = Northeast Oregon. HSE30 = % of 30-ha scale in high stem exclusion. HUR30 = % of 30-ha scale in high understory reinitiation. SI r30 = % of 30- to 60-ha ring in stand initiation. MNN r30 = mean nearest neighbor distance for the 30- to 60-ha ring. SIEI r30 = Simpson's evenness index for the 30- to 60-ha ring. SI r60 = % of the 60- to 83 ha ring in stand initiation. HUR30 × SI r30 = Interaction between % of 30 ha scale in high understory reinitiation and % of 30- to 60-ha ring in stand initiation. PCT = pre-commercial thin.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

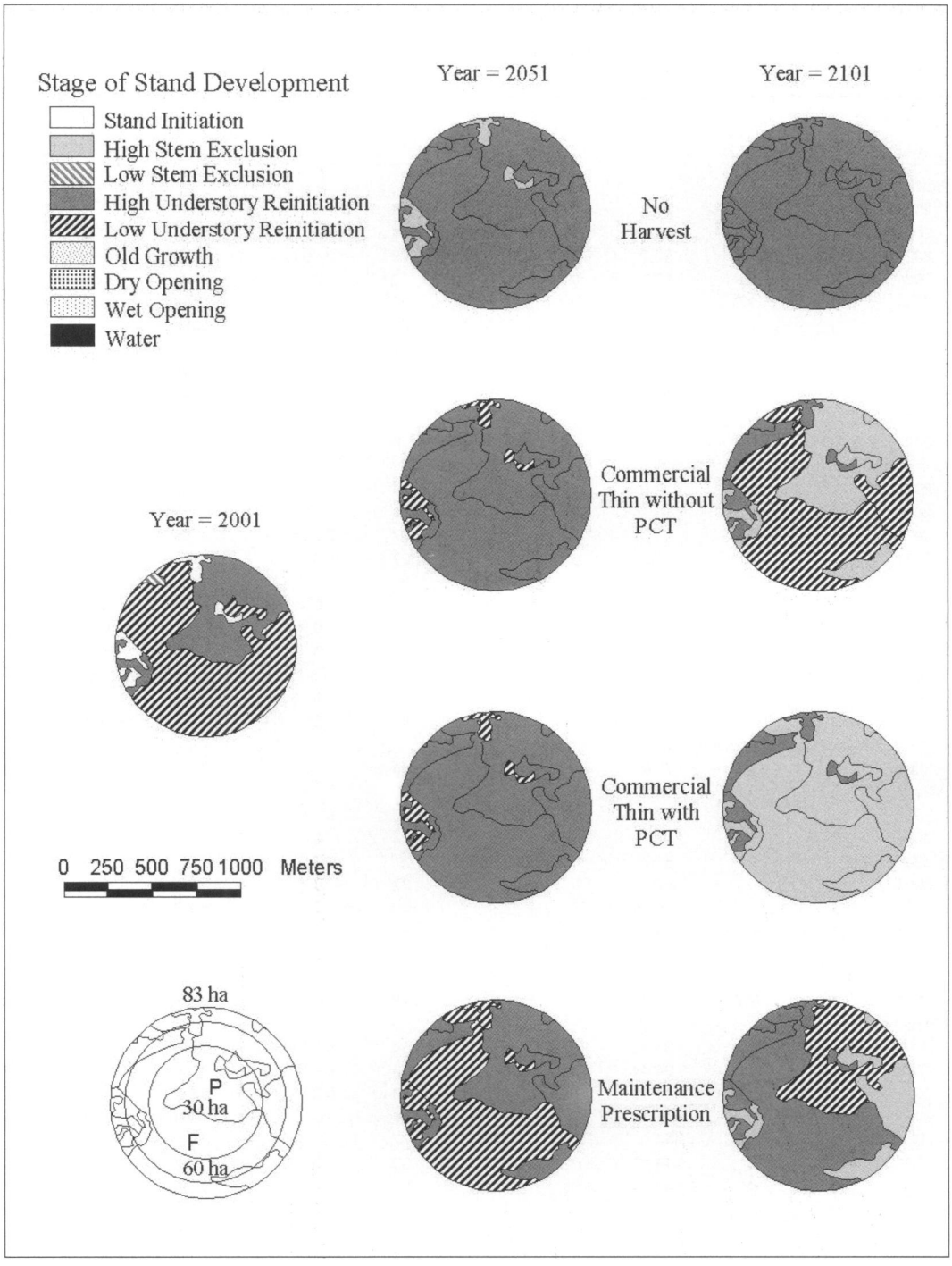

Figure 15. Partial results of forest growth simulations for 4 silvicultural prescriptions surrounding a northern goshawk nest in Northeast Oregon. Silvicultural prescriptions include no-harvest, where the landscape is not entered for timber management for 100 years; commercial thin without pre-commercial thinning (PCT); commercial thin with PCT; and a prescription that is designed to increase and maintain nest site suitability through a modification of the commercial thin with PCT prescription.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Central Washington landscape indicated a wide range of relative probabilities for goshawk nest site suitability (Fig. 16). Relative probabilities for the 48,000-ha landscape ranged from 0.00 to 0.99, with areal coverage being concentrated between relative probabilities of 0.51 and 0.90 (Table 25).

DISCUSSION

Results of this study are more statistically robust than those of earlier studies because we measured stand characteristics in detail, ground-truthed 10% of photo-interpreted data, and cross-validated our predictive model. Most previous research on northern goshawk habitat in North America focused on habitat within 1 or 2 ha surrounding the nest (Speiser and Bosakowski 1987, Lilieholm et al. 1993, Speiser 1993, Bull and Hohmann 1994, Lang 1994, Siders and Kennedy 1996, Squires and Ruggiero 1996). With the exception of Reynolds (1978) and Siders and Kennedy (1996), these studies sampled <40 nests each and concentrated their efforts on individual study areas. Several studies utilized use-availability-type designs, but usually with small sample size and fixed landscape scale (Hall 1984, Crocker-Bedford and Chaney 1988, Falk 1990, Hargis et al. 1994, Allison 1996, Patla 1997). Our analysis benefits from a large data set (n = 82 nests, n = 95 random sites), substantial geographic variation among four study areas, and multiple-scale analysis.

Our analysis revealed three critical considerations when evaluating habitat selection among nesting goshawks. First, habitat must be evaluated multidimensionally. Second, important habitat relationships become apparent only at certain scales (Brandt et al. 1995). Third, some factors interact and those interactions can be scale-specific.

Table 25. Assessment for a 48,000 ha landscape in Central Washington with the goshawk habitat model. Results of the analysis yielded relative probabilities because the proportion of used sites and proportion of available sites were not used in the landscape assessment calculations.

Relative Probability	Area (ha)
0.00–0.10	6.66
0.11–0.20	11.34
0.21–0.30	14.58
0.31–0.40	36.45
0.41–0.50	83.52
0.51–0.60	19275.30
0.61–0.70	19067.76
0.71–0.80	8748.54
0.81–0.90	971.82
0.91–0.99	24.12

At the 1-ha nest site, goshawk nests typically occurred on the lower 1/3 or bottom of north facing slopes in stands characterized by relatively higher basal area, higher quadratic mean diameter, greater canopy closure, and greater live stem densities, compared to random sites. Goshawk nests were associated with mid- to late-forest structure with canopy closure ≥50% (i.e., high stem exclusion and high understory reinitiation) within the 30-ha scale. Nesting probability was negatively influenced by presence of stand initiation between the 30- and 60-ha scales and also between the 60- and 83-ha scales.

What follows is a discussion regarding: (1) the inherent variability in our forest structural classifications and our ability to describe them; (2) interpretation and perspective on the nest-site and landscape-scale habitat relationships associated with goshawk nests; (3) the inferences and pertinent limitations of our reproductive data analysis; (4) the implications of the study to goshawk ecology; (5) its limitations; and (6) its implications for forest management.

Forest Structural Characteristics

The structure of the 6 forest stages of stand development (Tables 6–8) revealed substantial overlap with respect to several variables. Such overlap should be expected whenever any classification system attempts to encapsulate structure when there are several transitional stages among the various sequential stages of structural development.

We developed our classification system for stage of stand development using CART because this technique is able to split the data into "pure" classes based on deviance measures (Breiman et al. 1984). Nevertheless, as with any classification system based on highly variable data, there are often misclassifications. In our analysis (Fig. 5), the overall classification accuracy was 63%, with most misclassifications occurring between closely related stages of stand development (Table 9). For example, of the 25 high understory reinitiation stands, 20 were classi-

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

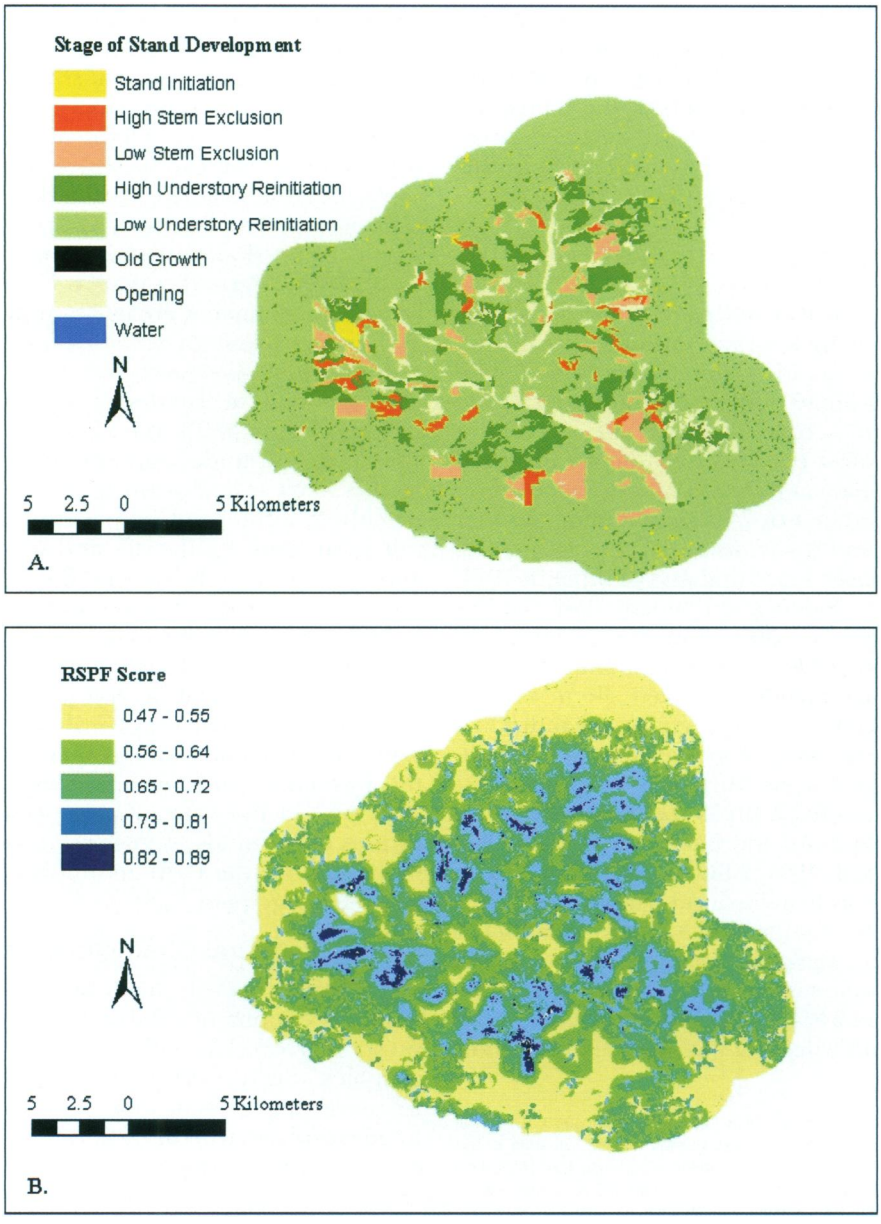

Figure 16. Assessment results of a 48,000 ha Central Washington landscape with the goshawk nesting habitat model. Figures show distribution of the stages of stand development (A), and results of the resource selection probability function model (B). The proportion of sites selected as goshawk nests (P_u) and proportion of the available landscape selected as random sites (P_a) were not used in the assessment. Hence, results are relative probabilities of goshawk nest site potential. Each pixel and the 83 ha surrounding it were evaluated with the goshawk habitat model.

fied correctly by the CART analysis; one was misclassified as high stem exclusion and the remaining four were misclassified as low understory reinitiation. For the high understory reinitiation stands misclassified as low understory reinitiation, the stands were classified correctly as understory reinitiation, but tree densities may not have been great enough to warrant classification as "high canopy closure" (i.e., canopy closure ≥50%). Hence, some of the natural variation inherent in the forest stages of stand

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

development was reflected in the CART analysis.

The variability in the CART classification accuracy also speaks to the effects of timber harvest and natural perturbations (e.g., insects) on habitat classification. As previously described, uneven-aged management predominated in the silvicultural systems across study areas. Through such management practices, representatives of all diameter classes are harvested to release the intermediate crown classes and stimulate natural regeneration (Smith 1986). Where harvesting is selective, the resulting stand often closely resembles that of naturally occurring low canopy closure stem exclusion or understory reinitiation stages. This, coupled with the length of time and range of diameter classes that comprise the stem exclusion stage (Oliver and Larson 1996), and the 2:1 sample size of low understory reinitiation and low stem exclusion stands sampled explains a large portion of the CART misclassifications (Table 9).

CART analysis did not differentiate old growth stands based on structural characteristics (Fig. 5). All 5 old growth stands were classified into the high understory reinitiation stand type, which is the stage of stand development immediately preceding old growth. The inability to develop a discrete classification for old growth should not be surprising, given the small sample size (n = 5) and high variability relative to sample sizes and variability characteristic of other stages of stand development (Tables 6–8).

Nest-Site Habitat Relationships

Univariate.—When data were collected within 1-ha surrounding the nest across the four study areas, we noted nest sites exhibited relatively uniform stand condition, basal area, live tree density, and canopy closure. In contrast, conditions surrounding random points were more variable. Similar patterns have been observed throughout western North America (Hennessy 1978, Reynolds et al. 1982, Moore and Henny 1983, Hayward and Escano 1989, Squires and Ruggiero 1996, Daw et al. 1998). Although the absolute values for each variable may vary among studies throughout the range of the goshawk in western North America due to differing site ecologies, it is more important to recognize that these patterns are generally consistent and may be important for determining goshawk nest site potential.

Canopy closure surrounding goshawk nests, up to a 10-ha scale, is often cited as being ≥60% (e.g., Johnsgard 1990). Such descriptions are consistent with most previous literature (Table 26). However, mean canopy closure in our study was 53% and several other studies also documented average canopy closure surrounding nest sites in their study areas to be <60% (Table 26).

Table 26. Habitat characteristics in a 10-ha area surrounding goshawk nest trees in North America. Mean (SE, if available) presented.

Study Area	n	Basal area (m^2 ha^{-1})	Canopy cover (%)	Tree density (tph)	Distance to water (m)	% slope	Aspect
NW California (Hall 1984)	10	90 (3)	94 (0.4)	427 (32)	355 (55)	41 (2)	NE
NE California (Hargis et al. 1994)	20	37 (2.0)	31 (2.9)			12 (2.5)	
N. California (Saunders 1982)	12		76.9	749		12	NE
New Mexico (Kennedy 1988)	11	21.1		959 (99.5)	292	17	No pref.
New Mexico (Siders and Kennedy 1996)	42	37	66.3	1055			
E. Arizona (Lang 1994)	15	30.8	31.3	791			
Utah (Fischer 1986)	10		68.4				
Idaho/Montana (Hayward and Escano 1989)	17	40.6 (1.9)	80.0 (1.4)	1135 (128.3) [a]			
S. Idaho (Patla 1997)	26	28.5 (2.1)	75 (3.0)	387 (27.9)	543 (121)		N and W
Wyoming (Squires and Ruggiero 1996)	39	50.8 (2.1)	66.7 (2.0)	1345 (85.0) [a]		11 (1)	No pref.
E. Oregon (Reynolds et al. 1982)	7		59.8 (7.8)	482 (55.2)			N
E. Oregon (Moore and Henny 1983)	34	51.9 (3.0) [p]		1007 (72.4) [a]	199 (41.0)	14.0 (1.8)	No pref.
E. Oregon/Washington (This study)	82	40.6 (1.3)	53.1 (1.7)	862.4 (52.9)	342.4 (34.7)	22.7 (1.9)	N
Pennsylvania (Kimmel 1995)	56	36.8 (1.0)	95.2 (0.6)		328 (32.4)		No pref.
Wisconsin (Rosenfield et al. 1998)	37	30.3 (2.5)	81.6 (2.9)	423.0 (40.4)	213.5 (40.0)		

[a] Adjusted to a per-ha estimate.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Such results may be attributable to differences in methodology or site ecology. Methodological differences may result from use of spherical densiometers and ocular estimates versus moosehorns and ocular sighting tubes. The former two methods have been shown to consistently overestimate canopy closure (Bunnell and Vales 1990, Cook et al. 1995); consequently, studies using these methods probably overestimated canopy closure at goshawk nest-sites. Differences in site ecology may also provide insight into differences in canopy closure estimates, with lower estimates coming from relatively xeric conifer sites (e.g., eastern Oregon, northeastern California, and eastern Arizona), and higher estimates found in mesic conifer or deciduous sites (Table 26). Although average canopy closure estimates tend to vary widely among studies (31–95%; Table 26), this measure of forest development is consistently higher within 10-ha of goshawk nests than the available landscape, regardless of methodology or site ecology (Table 27). For the studies that observed significant differences between goshawk nests and random sites, canopy closure at nest sites ranged from 9 to 60% higher than at random sites (Table 27). In our study of eastern Oregon and Washington sites, canopy closure, estimated with a moosehorn, averaged 53% and was normally distributed with a slight tendency for nests to be associated with canopy cover >50%.

Despite canopy closure's consistency of use among previous studies, basal area may be a better descriptive criterion for predicting goshawk nest sites. Basal area is also correlated with goshawk nesting habitat (Crocker-Bedford and Chaney 1988, Squires and Reynolds 1997), yet it is often overlooked by researchers in preference for canopy closure at nest sites, perhaps because of the ease with which canopy closure is

Table 27. Comparison of habitat characteristics within 10 ha of goshawk nest trees for those studies that have compared known goshawk habitat with random points.

		Goshawk nests			Random sites		
Variable	Study area	*n*	Mean	SE	*n*	Mean	SE
Basal area (m^2/ha)							
	NW California [a]	10	90.0	3.0	10	89.0	2.0
	NE California [b]	20	37.0**	2.0	102	26.0	2.9
	E. Arizona [c]	15	30.8**		15	20.7	
	S. Idaho [d]	26	28.5**	2.1	26	21.2	2.1
	Wyoming [e]	39	50.8**	2.1	33	42.5	3.4
	E. Oregon/Washington [f]	82	40.6**	1.3	90	22.2	1.1
	Pennsylvania [g]	56	36.76**	1.0	56	27.96	1.2
Canopy cover (%)							
	NW California	10	94.0**	0.4	10	86.0	1.0
	NE California	20	31.0**	2.9	102	21.0	3.4
	E. Arizona	15	31.3		15	28.2	
	S. Idaho	25	75.0	3.0	25	71.0	3.0
	Wyoming	39	66.7	2.0	33	60.0	3.8
	E. Oregon/Washington	82	53.1**	1.7	90	33.2	1.7
	Pennsylvania	56	95.2**	0.5	56	83.6	1.2
	SE Alaska [h]	39	49.6	1.2	39	42.9	2.1
Tree density (trees/ha)							
	NW California	10	427.0	32.0	10	502.0	17.0
	E. Arizona	15	791.0		15	978.0	
	S. Idaho	26	387.0	27.9	26	347.0	38.2
	Wyoming	39	1345.0	85.0	33	1322.5	135.0
	E. Oregon/Washington	82	862.4	52.9	90	721.4	51.6

[a] Hall (1984). [b] Hargis et al. (1994). [c] Lang (1994). [d] Patla (1997). [e] Squires and Ruggiero (1996).
[f] This study. [g] Kimmel (1995). [h] Titus et al. (1996).
** Indicates significant differences ($P \leq 0.05$) between means from a 2-sample *t*-test.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

estimated. Our 1-ha nest site logistic regression model did not include canopy cover because basal area had considerably more explanatory power than any other covariate. Results from 6 of 7 North American goshawk studies, including ours, that compared goshawk nest sites with random sites indicated that basal area estimates were greater at nest sites ranging from 28.5 to 50.8 m^2 ha^{-1} at goshawk nest sites and from 20.7 to 42.5 m^2 ha^{-1} at random sites (Table 27). However, in these same 6 studies, canopy cover was significantly greater at nest sites than available at random in only 3 studies (Table 27). Both basal area and canopy cover may influence nest site selection. However, basal area may be the better descriptor of stand conditions and be the most applicable for maintenance of canopy cover. Basal area (i.e., the cross-section of a stand occupied by tree boles) may influence nest site selection through the provision of hiding cover for fledglings learning to hunt, via tree boles (McTague and Patton 1989). Tree boles could serve as hiding cover for fledglings through disruption of sight-distance of avian predators. Typically, in studies where significant differences were detected for basal area between goshawk nests and random sites (Table 27), the average basal area estimate was 7 to 11 m^2 ha^{-1} greater at goshawk nest sites. Our study's average basal area estimate for nest sites was 18.4 m^2 ha^{-1} greater than that for random sites.

Goshawk nest sites at the 1-ha scale are often described as consisting of mature to old growth conditions (Reynolds et al. 1982, Moore and Henny 1983, Speiser and Bosakowski 1987, Hayward and Escano 1989). We found goshawks placed their nests within stem exclusion stands significantly more often than expected based on availability, and used understory reinitiation and old growth stands at the 1-ha nest-site scale in proportion to their availability (Table 11). These results may: (1) indicate variability in habitat selection; (2) result from low amounts of old growth forest available in the landscape (Everett et al. 1993); or (3) be indicative of low power (i.e., 10 goshawk nests and 3 random sites in old growth). Nevertheless, the work of Squires and Ruggiero (1996), who found goshawks in Wyoming nesting in single-storied lodgepole pine forests, would seem counter to the notion that old-growth *Abies*, *Pseudotsuga*, or ponderosa pine is an essential aspect of goshawk habitat. Other variables often cited as being associated with goshawk nests include slope, topographic position, and aspect. Goshawk nest sites are typically described as being on relatively low topographic positions and on moderate slopes (Squires and Reynolds 1997). Goshawk nests in our study were more strongly associated with the lower 1/3 of slopes or drainage bottoms ($P < 0.001$) but no preference was observed for % slope ($P = 0.494$). Similarly, Hennessy (1978) found 50% (of 28) of goshawk nests on the bottom 1/3 of slopes and 21% on the upper 1/3 of slopes.

We found that goshawk 1-ha nest sites occurred primarily on north-facing aspects in this study ($P < 0.001$). Although several studies have failed to demonstrate selection for aspect (Kennedy 1988, Moore and Henny 1983, Kimmel 1995, Squires and Ruggiero 1996), others have found goshawk nest sites predominately on NW to NE aspects (Reynolds et al. 1982, Hall 1984, Hargis et al. 1994, Patla 1997; Table 26). Only in Alaska (McGowan 1975) were southern aspects selected.

Multivariate.—Although individual variables such as canopy closure, basal area, structural stage, and topographic position each uniquely contribute to selection, it seems reasonable to assume that nest selection is triggered by a *gestalt* perception of the environment (Lack 1933) which incorporates several factors simultaneously. Our logistic regression analysis for the 1-ha nest site indicated that stage of stand development, topographic position, and basal area best discriminated between goshawk and random sites in eastern Oregon and Washington (Tables 17 and 18). Analysis of the coefficients of the remaining factors indicated that a stand's occurrence in a given stage of stand development and its topographic position were insufficient by themselves for differentiating between random sites and nest sites at this landscape scale. With the exception of basal area and the interaction term (i.e., low topographic position × basal area; Table 18), the other variables were negatively related with goshawk nesting. Basal area, in conjunction

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

with these other factors, appeared to be the major factor in discriminating between random and nest sites at the 1-ha scale, explaining 68% of model deviance by itself (deviance = 84.8, 1 df). Basal area and its interaction with low topographic position explained 73% of the total explained deviance. The interaction term did not contribute much to the amount of deviance explained by the model, and thus, basal area appears to be the single most important variable in the model. Goshawks may be selecting for high basal area and low topographic position, rather than a particular stage of stand development *per se* at this scale.

We speculate that the tendency of goshawks to place their nests at the base of the live canopy in dense, larger diameter stands on the lower portions of the slope may confer protection from aerial predators (e.g., Janes 1985:176), such as red-tailed hawks (*Buteo jamaicensis*) and great horned owls (*Bubo virginianus*), or it may result in favorable microclimate for the incubating female and nestlings (Reynolds 1978, Reynolds et al. 1982). However, we caution that we did not specifically measure relationships between habitat and vulnerability, and this relationship requires field investigation.

Landscape-Scale Habitat Relationships

Nest sites, important for goshawks because they represent where the young are raised, have been well-studied (Hennessy 1978, Reynolds et al. 1982, Moore and Henny 1983, Hayward and Escano 1989, Squires and Ruggiero 1996, Daw et al. 1998). Yet, they also represent a small portion of the goshawk's environment, and are the final stage in nesting habitat selection (after Johnson 1980). Important insights into goshawk nesting ecology may be gained by examining gradients in scale that examine important ecosystem features and their relationship to the nest (Frost et al. 2001). By examining goshawk habitat relationships at multiple spatial scales, from the nest tree to the PFA (170 ha), across four study areas in six ecological provinces, we detected unifying spatial patterns and structural conditions that are associated with goshawk nesting habitat.

Frost et al. (2001) suggest that to understand human effects and stressors on a species' habitat, an appropriate scale of aggregation must be determined that has a strong potential for maximizing understanding and optimizing the information obtained. Our analysis has empirically determined 83 ha (514 m radius) to be this scale among those analyzed (Table 19). Our best model (Table 20) explained more variation than models of greater spatial extent, and included habitat conditions from several smaller landscape scales. These results may simply be due to landscape heterogeneity being directly proportional to the spatial extent being studied (Forman and Godron 1986); the process of sampling habitat conditions from a wider spatial extent will often encounter larger-scale ecological systems and will require larger sample sizes to acquire the statistical power necessary to detect spatial patterns in more heterogeneous data sets. Although this may be true, goshawk habitat selection is nonetheless probably more discriminating closer to the nest, with habitat associations becoming more general and diversified at larger scales. For example, the proportion of the 30-ha landscape that was occupied by high understory reinitiation and high stem exclusion accounted for nearly 65% of the total variation explained by the model. This reflects the importance of habitat conditions near the nest. Additionally, relatively advanced stages of stand development (e.g., stem exclusion, understory reinitiation, and old growth) were not specifically identified as important beyond the 30-ha scale, where landscape fragmentation indices (i.e., Simpson's evenness index and mean nearest neighbor distance) predominated (Table 20). We interpret the predominance of fragmentation indices beyond the 30-ha scale to indicate that the goshawk's reliance on specific habitat conditions for nesting decreases as distance from the nest increases. Thus, our understanding of how anthropogenic change affects and stresses goshawk nesting habitat should focus on (1) the composition of the 30-ha surrounding the nest and (2) the spatial patterns and relationships in the remainder of the 83 ha. Our study cannot address the goshawk's association with successional stages for other aspects of their life history requirements.

Other landscape-scale studies have found

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

similar results. Allison (1996) found that most habitat differences between goshawk nests and random sites in northern California occurred within 12-ha nest plots and that these plots contained more mature-old mixed fir and slightly more dense mid-aged fir than did the surrounding 201-ha PFA. Similarly, Daw (1996) found more dense, late forest habitat (≥15 live tph >53 cm dbh and ≥50% canopy closure) within 12-ha and 24-ha circles than in the surrounding landscape (P = 0.061), with the effect diminishing as circle size increased.

Our model demonstrates that habitat evenness and nearest neighbor indices are important in predicting nest selection by goshawks. Goshawks selected landscapes characterized by greater evenness among the stages of stand development present, than around random sites, and with greater distance between stands of the same type. This result is corroborated by earlier studies. Hall (1984) found that habitat changes occurred at shorter intervals with fewer habitat type changes at random sites than at nest sites, such that goshawk nests in northern California were associated with more heterogeneous landscapes than random points. Hargis et al. (1994) found nestling phase and post-fledging phase home ranges for goshawks (n = 10) to have a greater number of vegetation types/km^2 than random circles (n = 10). Thus, goshawk nest locations tend to be more often associated with heterogeneous landscapes beyond a certain core area that encompasses the nest tree.

The initial purpose behind our use of the "ring" method of model construction was to be able to quantify the additional predictive power associated with increasing the scale of the analysis, by removing spatial autocorrelation. It also allowed us to put into perspective the spatial patterns we observed with changes in observational grain and subsequent goshawk nest habitat associations (Wiens 1989). Logistic regression models developed for each spatial scale (Table 19) indicated Simpson's evenness index, while present in all models >30 ha, was most strongly associated with goshawk nests within an area of 30 to 83 ha (309 m and 514 m radii, respectively) surrounding the nest. While present in each model >30 ha, Simpson's evenness index only made unique contributions to discriminating between goshawk nests and random sites in the 30- to 60-ha and 60- to 83-ha rings (30 ha+ and 60 ha+ models, respectively; Table 19), because spatial autocorrelation was removed. Thus, Simpson's evenness index is present in all models >83 ha due to the strength of its association with goshawk nests at spatial extents between 30 and 83 ha in area.

Because we systematically varied the observational grain and extent during our analysis using predefined scales, we were able to provide important insight into the landscape dynamics associated with goshawk nests and determine which patterns most strongly interact with each other to influence goshawk nesting (Kemp et al. 2001). Through our analysis, two interactions became clear: a cross-scale interaction involving high understory reinitiation with stand initiation, and another involving Simpson's evenness index with the Northeast Oregon study area effect. Our models indicated that conditions at different landscape scales interact to influence selection of habitat for nesting. This is apparent in the interaction between the proportion of high understory reinitiation at 30-ha with the proportion of stand initiation in the 30- to 60-ha ring. Examination of the coefficients for the interaction term, along with the main effects that comprise the interaction (Table 20), shows that high understory reinitiation within the 30-ha scale may counteract some of the negative effects of stand initiation stands, but only where the stand initiation stands are in the 30- to 60-ha ring.

The interaction between high understory reinitiation and stand initiation, in the 30-ha scale and 30- to 60-ha ring, respectively, appeared to influence goshawk nest site selection. An interaction between these 2 stages of stand development was found in all habitat models, except for those representing the 120-ha landscape scale (Table 19). Additionally, for those models with base landscapes <60 ha, the interaction between high understory reinitiation and stand initiation was always of a cross-scale nature. Once the base landscape scale for the habitat models was ≥60 ha, the interaction between these variables became intra-scale. We interpret this to indicate that a "core area" exists around goshawk nests, in which

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

high understory reinitiation or high stem exclusion serve to protect the nest from potentially detrimental effects related to more open habitats, such as the presence of stand initiation. In more open habitats, the nest may be more vulnerable to predation, and its microclimate may be affected to a greater extent than if placed in heavier cover. This implies that core areas of high canopy closure stem exclusion and understory reinitiation surrounding a nest should be considered when evaluating the spatial extent to which management prescriptions may influence suitability of forests for goshawk nesting. The implications of the high understory reinitiation and stand initiation interaction should be tested to better understand the basis for this interaction. One result of our multi-area study design was the identification of how localized differences in landscape pattern affect the process of nest site selection by goshawks. As evidenced by the inclusion of the Northeast Oregon study area effect in the 30 ha and 30 ha+ models (Table 19; the latter being our "best" model), the landscape within 30 ha of goshawk nests and in the 30- to 60-ha habitat ring is slightly different in Northeast Oregon, in comparison to the other three study areas. Our best model (Table 20) indicated, through an interaction term, that goshawks selected for greater evenness in the 30- to 60-ha habitat ring in Northeast Oregon. Thus, in Northeast Oregon, habitat evenness may be more strongly associated with goshawk nests than in the other study areas. This may also be an artifact of differences in ownership patterns and harvest histories among study areas.

A re-examination of nest site management strategies is necessary in light of our ring analysis. Currently, several conservation-reserve strategies exist for goshawk habitat management in the Pacific Northwest, as well as for northern spotted owls and bald eagles (*Haliaeetus leucocephalus*) (e.g., Forsman et al. 1985, Stalmaster et al. 1985, Riggs 1994, Schommer and Silovsky 1994). Such reserves, or exclusionary buffers, have failed to address 3 contingencies that can influence their effectiveness: (1) factors external to the buffer can influence its effectiveness, (2) further forest management will influence the subsequent suitability of the site, and (3) natural stand dynamics influence site suitability over time. The first contingency was demonstrated in the spatial modeling portion of this paper (regarding the interaction between high understory reinitiation within 30-ha of the nest and stand initiation in the 30- to 60-ha ring). Our spatial modeling showed how timber harvest can be planned so as to maintain goshawk nest site suitability over time, and that indeed, a nonharvest strategy can be just as ineffective as aggressive, maximum-yield forestry. Management strategies that account for interactions among habitat factors and their spatial and temporal effects on habitat suitability are likely to be more successful over time than prohibitive buffers that exclude timber management. This is particularly true for fire-adapted systems such as those in the Interior Northwest, where periodic fires historically created patchy distributions of the various forest structures. However, our data speak only to the Interior Northwest, which is characterized by relatively dry and disturbance-adapted forests compared to some others. For example, in temperate rainforests, such as those in southeastern Alaska, creation of large, no-harvest buffers may be consistent with the region's disturbance ecology. Although our results for the 83 ha surrounding goshawk nests indicate a strong association for particular structural conditions and spatial arrangements, these conditions are more likely to promote the production and survival of fledglings rather than confer survival to adults. The spatial extent of this scale amounts to <10% of goshawk breeding home ranges and typically smaller proportions of the nonbreeding home range. Thus, habitat associations identified from our study are more likely to influence goshawk populations through the quantity and distribution of suitable nesting habitat in the landscape (e.g., see Landscape Assessment).

Reproductive Data

Reproduction at 81 goshawk nests in this study averaged 1.64 fledglings/active nest (SE = 0.09) and 1.82 fledglings/successful nest (SE = 0.07). These estimates are within the ranges reported in other western North American studies (Table 28).

Because literature on goshawks lacks definitive connections between reproductive

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Table 28. Goshawk reproductive output reported in western North America.

Study	Location	Year	*n*	Fledglings/ active nest	Fledglings/ successful nest
McGowan (1975)	Alaska	1971–1973	33	2.0	2.7
Reynolds and Wight (1978)	Oregon	1969–1974	48	1.7	
Hennessy (1978)	Utah	1973–1974	28	1.4	2.1
Herron et al. (1985)	Nevada	1976–1981	88	2.2	
Bloom et al. (1986)	California	1981–1983	127	1.7	
Bull and Hohman (1994)	Oregon	1992	12	1.2	1.4
DeStefano et al. (1994)	Oregon	1992–1993	50	1.3	
Reynolds et al. (1994)	Arizona	1991–1992	36	1.9	2.2
Patla (1997)	Idaho	1989–1994	68	2.0	2.1
This study	Oregon/Washington	1994	81	1.6	1.8

performance and specific habitat variables, we attempted to analyze reproductive performance in the context of the habitat variables we measured. By evaluating the relationship between reproductive performance and habitat composition, we hypothesized habitat composition in the surrounding landscape influences reproductive performance. We found that reproductive performance may have increased slightly as basal area increased at the 1-ha nest site (Fig. 8), and productivity also varied somewhat with the proportion of landscape occupied by low stem exclusion at landscape scales ≥60 ha and wet openings at landscapes ≥120 ha. However, trends were not consistent or statistically significant (Figs. 8 and 9).

With one year's reproductive data it is not likely that strong correlations between productivity and habitat conditions would be observed. With merlins (*Falco columbaris*), Bibby (1986) was able to predict nest site occupancy with a high degree of certainty based on vegetation characteristics within 4 km of the nests, yet could not predict the reproductive outcome of the nests based on the same characteristics. Inability to detect habitat differences with regard to reproduction suggest: reproduction is not sensitive to landscape pattern; goshawk reproductive rates are sensitive to landscape pattern but our 1-year analysis was not powerful enough to detect the association; or goshawk reproduction in any one year reflects multiple factors (Lehmkuhl and Raphael 1993, McClaren et al. 2002). Both Newton (1986) and Franklin et al. (2000) demonstrated the need for reproductive data from several years to determine associated factors for nest abandonment, or failure, and reproductive success. For sparrow hawks (*Accipiter nisus*), breeding success increased with early laying dates, parental attentiveness (see also Goodburn 1991, Sydeman et al. 1991, Reynolds et al. 1994, Wiebe and Martin 1998), and frequent prey deliveries, which could be related to habitat (Newton 1986). For spotted owls, weather was highly associated with nesting success, whereby success was lower with cold, wet springs (Franklin et al. 2000; see also Kostrzewa and Kostrzewa 1990, Patla 1997, Penteriani 1997), which would also influence prey abundance and availability.

Our interpretation of the habitat analyses is relevant to a couple of aspects of goshawk ecology not previously mentioned in the literature: (1) security of the nest site, and (2) the influence of the surrounding landscape on reproductive output. For proper perspective, the RSPF models determined that nest sites were best characterized: (1) at landscape scales ≤83-ha, (2) by a heterogeneous landscape with a 30-ha core of high understory reinitiation and high stem exclusion forest surrounding (3) a nest stand with higher basal area than the surrounding landscape on low topographic positions. This architecture suggests a "protective" core of forest vegetation in immediate proximity to the nest tree that grades into more open foraging habitat with increasing distance from the nest. Reproductive analyses suggested that reproductive output varied (1) with basal area within 1 ha of the nest, and (2) with the proportion of landscape in

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

low stem exclusion and wet openings (at landscape scales ≥60-ha). The variation in reproduction with low stem exclusion stands and wet openings suggests linkage of reproduction with prey availability in the more open habitats in eastern Oregon and Washington (see DeStefano and Cutler 1998 and Watson et al. 1998 for prey species). Furthermore, goshawks may find higher levels of avian biomass within the tall, open stands characteristic of the stem exclusion stage (R. Sallabanks, Sustainable Ecosystems Incorporated, Eagle, Idaho, unpublished data). However, while we have observed relationships between productivity and habitat, the relationships are weak in our limited sample from a single year. Thus, the RSPF model will predict the probability of a nest site occurring in a location, but it will not predict the site's potential reproductive output.

Implications for Our Knowledge of Goshawk Ecology

Habitat models can aid managers in understanding the environmental conditions that most likely influence habitat selection or are correlated with those that do (e.g., prey). Our models can be most helpful when viewed in terms of Johnson's (1980) hierarchical model of selection. According to Newton (1979), prey abundance and availability, coupled with available habitat conditions, probably control home range selection among raptors (Johnson's [1980] second-order selection). In selecting among possible nest sites in eastern Oregon and Washington, goshawks probably first narrow their search to a landscape with a sufficiently abundant supply of prey so that the energetic rewards of foraging are beneficial for both adults (Newton 1979, Orians and Pearson 1979, Kennedy 1988). Kennedy (1988) stated that goshawk nest sites may be selected because they are central points within an area of high food availability within the home range (third-order selection). Within this localized area (i.e., home range), goshawks may then avoid areas that have higher concentrations of stand initiation stands while seeking relatively equivalent amounts of other stages of stand development that are present. Additionally, the habitat surrounding the nest site (i.e., PFA) is expected to provide opportunities for young hawks to learn how to approach prey and provide concealment cover from predators for fledglings (Reynolds et al. 1992). As goshawks narrow their search, they may seek nest sites in high understory reinitiation or high stem exclusion stands that also have low topographic position and higher basal area than other available stands. These conditions may then provide suitable access to prey in the adult's home range, provide shelter from predators and competitors (i.e., "competitive coexistence"; sensu Rosenzweig 1981), good visibility for detecting adults with prey, ease of flight, and desirable microclimatic conditions in which to nest. These hypotheses tend to be supported by the consistencies in nest-site habitat descriptions from goshawk studies in North America and Europe (Hennessy 1978, Reynolds 1978, Moore and Henny 1983, Speiser and Bosakowski 1987, Anonymous 1989, Squires and Ruggiero 1996, this study), by observed fledgling behavior (Zachel 1985), and the consistencies in habitat conditions in the landscapes surrounding goshawk nests (Hall 1984, Allison 1996, Daw 1996, Desimone 1997, this study).

Habitat conditions within 83-ha (514-m radius) may be especially important to fledgling goshawks prior to the hardening of their primary feathers and rectrices at 62–66 days after hatching (approximately 4 weeks post-fledging; Kenward et al. 1993). Prior to 4 weeks post-fledging, over 95% of observed fledgling locations occurred within 500 m of the nest (Zachel 1985, Kenward et al. 1993, Kennedy et al. 1994). During this time, when flight feathers are not fully grown and hardened at their bases, fledglings are not very adept in flight and may be more susceptible to predation. Zachel (1985) noted that one of the major developments during the fourth week post-fledging was the onset of hunting activity. Thus, habitat conditions within 500 m (approximately 80 ha) may be especially important at providing escape cover from predators and concealment cover so that awkward fledglings can learn to capture prey.

In light of a hierarchical habitat selection process, and viewed in conjunction with "competitive coexistence" (Rosenzweig 1981), differences in habitat selection among different subspecies of goshawk may be meaningful. In Europe, woodland/farm-

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

land mosaics are considered optimal habitat for goshawks (*Accipiter gentilis gentilis*; Kenward 1996). Kenward (1996) postulated that potential differences in habitat selection between the two subspecies are due to differences between European and North American raptor guilds. Data on *A. g. gentilis* in Europe indicate that nesting habitat is similar to *A. g. atricapillus* (Anonymous 1989), but foraging occurs where food is most abundant (Kenward 1982), rather than based on habitat structure (Bright-Smith and Mannan 1994, Kenward 1996, Beier and Drennan 1997). Hence, by avoiding potential nest sites that are within a 30 ha area of forest clearings (e.g., meadows or stand initiation stands), the North American subspecies (*A. g. atricapillus*) may be reducing the likelihood of nest predation by other North American raptors (e.g., red-tailed hawk and great-horned owl) that frequent such habitats.

Limitations of This Study

With the use of P_u in the RSPF, we assumed that the estimates for territory densities used were representative of the densities in our study area. Because P_u is a constant in the RSPF and the coefficients for the covariates from the logistic regression are not affected by P_u, variability in territory density will only affect the resulting classification accuracy of the RSPF (Manly et al. 1993). Because rigorous territory density estimates require a minimum of 3–5 years of intensive surveys to calculate (R. T. Reynolds, USDA Forest Service, personal communication), and we used the mean territory density from our sample (Table 2) to calculate P_u, we evaluated the effects territory density variability would have on the RSPF (Table 22). Assuming that territory density estimates used in the calculation of P_u were representative for our study area, territory density was between 0.043 and 0.072 active territories/km^2. Thus, such variation in territory densities, and subsequent variation in P_u, produced a range in classification accuracy of 75–79% (Table 22).

Using a resource selection function, we must assume that (1) territory density estimates used in calculation of P_u are representative for our study area; and (2) some proportion of the available habitat sampled (P_a) is also occupied. The former assumes: (1) survey site selection is unbiased (e.g., not selected based on logistics or habitat composition); (2) all habitats are sampled equally; and (3) survey method efficacy is equal among study areas. Thus, insertion of bias into calculation of territory density is quite possible, and the resulting estimate may not be truly representative as a result. Within the resource selection function, calculating the proportion of available habitat that may be occupied is contingent upon representative estimates of territory density. To improve the precision of future resource selection functions, while reducing bias, greater effort should be placed on (1) random selection of survey areas, to ensure equal assessment of all habitats, and (2) efficacy testing of survey methodology among regions and habitats to evaluate survey precision (e.g., Watson et al. 1999).

Habitat models developed in the Interior Pacific Northwest may not apply to regions outside of our study areas and indeed may only be valid within the conditions of prey and climate present during the course of our study. Mosher et al. (1986) developed habitat models for woodland hawks in Maryland and Wisconsin and found that predicting habitat use in one region on the basis of data from another produced mixed results due to differences in available habitat conditions among regions. Thus, to determine appropriateness of these models for other regions requires representative samples of available habitat and goshawk nests to determine the model's predictive capabilities.

The controversy surrounding the goshawk as an indicator species for old growth forests warrants discussion in light of the results of this study (Silver et al. 1991). Results of our 1-ha nest site analysis and landscape scale analyses (Tables 11, 15, and 16) indicated that old growth forest structural stage (as defined by Oliver and Larson 1996) was not useful in determining goshawk nest site selection. Results from the 1-ha analysis suggest that high understory reinitiation and old growth stages of stand development may function equivalently in terms of perception by goshawks when selecting nest sites (Table 11). Similarly, we hypothesize functional equivalence of these

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

stages of stand development at landscape scales. Despite similarities in forest structural characteristics for low understory reinitiation, high understory reinitiation, and old growth (Tables 6–8, Fig. 5), our difficulty discerning between the old growth and high understory reinitiation structural stages through aerial photo interpretation (Table 5), and the Interior Columbia Basin Ecosystem Management Project's (Everett et al. 1993) low detection of old growth forest in eastern Oregon and Washington, using a coarser scale habitat inventory, goshawk reproduction (fledglings/active nest) in our study was typical of other goshawk studies in western North America (Table 28). However, the role of old growth structure in goshawk nest site selection could be further evaluated with samples in landscapes where old growth is more abundant.

Management Applications

To have value to managers, habitat models must enable practitioners to predict the influences of land management practices on species, and enable prediction of the distribution and abundance of a species given management assumptions. Spatially explicit models provide resource managers with a method of examining possible responses of species to local and regional management strategies (Dunning et al. 1995). Our models have the potential for use in adaptive management situations and can be used to assess landscape suitability for nesting goshawks. However, we recommend caution in their application beyond the areas included in this study. Application of these data to other regions may be inappropriate based on differences in available habitat conditions among regions (Mosher et al. 1986). Nonetheless, our modeling approach can be used as a template for other areas that have similar data.

Site-specific Application.—The major benefit of a site-specific habitat model is its ability to predict the responses of individuals to specific management applications (Dunning et al. 1995). Our model can be used as a site-specific model to evaluate the effects of different silvicultural prescriptions on nest-site suitability over time. To illustrate this utility, we coupled the model with silvicultural prescriptions and a forest growth and yield model to evaluate the effects of competing silvicultural strategies and to identify useful modifications for goshawk nesting (Figs. 12 and 14; see Results for details). Although the simulation involves a 3-stage modeling process (i.e., model stand growth, interpret stand structure from stand-yield tables with CART analysis, and then analyze the landscape's stand structure and distribution using the habitat model), our purpose was to demonstrate an application of the landscape-scale habitat model and determine some of the model's possible limitations.

Developing a silvicultural prescription to maintain or improve site suitability was an iterative process in which the beneficial and detrimental effects of each prescription had to be evaluated. For the nest sites evaluated in our two case-studies, development of an appropriate prescription finally relied on determining: (1) the factor in the RSPF that limited nesting suitability of the site over time, (2) which stand(s) had the greatest effects on the limiting factor(s), and (3) how and when to modify the stand(s) to meet landscape objectives. Determining which stands were most influential to goshawk nesting required knowledge of their initial structural characteristics (i.e., basal area, tree densities, and structural stage), spatial extent, and spatial relationship to the nest. For the Central Washington site, a single stand was key to regulate evenness in the 30- to 60-ha ring, and thus, the resulting nesting suitability. In Northeast Oregon, two stands were key to nesting suitability because they controlled the 30-ha scale composition, evenness of the 30- to 60-ha ring, and were easily manipulated to provide the desired stand characteristics. In order to achieve and maintain nesting suitability at these sites, careful, repeated thinnings were required. Similarly, several authors have suggested the use of timber harvest to achieve wildlife objectives (Leopold 1933, Nyberg et al. 1987, Reynolds et al. 1992, McComb et al. 1993, Riggs et al. 1993, Oliver et al. 1994). As part of an adaptive management process, the validity of our model for predicting landscape suitability for goshawk nesting should be assessed through rigorously designed manipulative experiments whereby differing silvicultural options are tested simultaneously and modified as necessary (Irwin and Wigley 1993).

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Developing adaptive experiments to test the relationship between nesting occupancy, or fitness, and habitat management is critical for many species and for managing multiple resources. In an adaptive experiment, the experimental units could be stands surrounding several goshawk nests within territories (because goshawks use alternate nests within a territory) that are treated using different silvicultural prescriptions (e.g., thinning from below, prescribed burning, PCT, etc.), and the evaluated response would be the change in amount of use (before vs. after vs. control). Functionally, it will be much more challenging to evaluate population response due to the large sample size (>75) and long time frames (>10 years) that are likely to be required.

In our simulations, some potential limitations in the CART analysis and landscape-scale models became apparent. Use of the CART model for classifying forest stages of stand development based on vegetation characteristics was limited in that it could not classify stands as old growth. Therefore, stands classified as high understory reinitiation could not progress naturally into an old growth classification when true old growth structural characteristics were present. The limitations of the CART model also illuminated problems the landscape model had with homogeneous landscapes.

Our landscape model consists of a Northeast Oregon study area effect, 2 "mature" stand types (i.e., high stem exclusion and high understory reinitiation) in the 30-ha scale; 1 early successional stand type (i.e., stand initiation), Simpson's evenness index and mean nearest neighbor distance in the 30- to 60-ha ring; and 1 stand type (i.e., stand initiation) in the 60- to 83 ha ring (Table 20). Given these limitations, the model is only able to assess habitat in the 30-ha scale for high stem exclusion and high understory reinitiation, and for stand initiation in the 30- to 60 ha and 60- to 83-ha rings. As a result, if those habitat conditions are not present at their respective landscape scales, those variables essentially are removed from the model and the estimate of site suitability is dependent only on habitat conditions in the other landscape scales. If stand initiation is not present in the 30- to 60-ha ring, Simpson's evenness index and mean nearest neighbor nevertheless can be computed, providing input into the model for this scale. However, homogeneous 83-ha landscapes, or a homogeneous 30- to 60-ha ring, do not allow mean nearest neighbor or Simpson's evenness index to be computed because the area consists of 1 stand (McGarigal and Marks 1994). As a result, in a non-stand initiation, homogeneous 30- to 60-ha ring, the 30- to 60-ha ring is essentially removed from the model, forcing the estimate of site suitability to be calculated on habitat conditions at the other landscape scales. In the forest growth simulation, when the 83-ha landscape was a homogeneous stand of high understory reinitiation, the site suitability from the RSPF could only be calculated from the proportion of the 30-ha scale in high understory reinitiation, which resulted in low site suitability estimates (Figs. 12 and 14, Tables 22 and 23).

Application for Landscape Assessment.—To this point in the discussion, application of the goshawk habitat model has emphasized the area (83 ha) around individual, discrete points in the landscape. Site-level analysis is most suited for operational-level management decisions regarding the manipulations of individual stands, particularly where goshawk nests already exist, or where the manager wishes to facilitate nesting over time through proactive management. Our model can also be used to assess the relative quality of potential nesting habitat across extensive landscapes. The results of such analysis could be meaningful for viability analyses and status reviews (U.S. Fish and Wildlife Service 1998).

When the model is implemented in a moving window landscape assessment, as it was in our Central Washington case study, the output is a contour map of relative goshawk nesting probabilities (Fig. 16). As such, relative probabilities must be evaluated with respect to each other, rather than 0 or 1 (Erickson et al. 1998). Such maps can be used for a multitude of resource decisions. At the individual pixel level, the effects of management on goshawk nesting habitat potential could be evaluated. For groups of pixels within goshawk territories, areas of concentrated nesting habitat can be identified and integrated into resource plans. At larger scales, probability-contour maps can

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

serve as tools for identifying and delineating groups of goshawks that may constitute subpopulations. This information could be useful for stratifying goshawk searches and for spatially allocating forest management activities. In resource management, these types of landscape-scale assessments are particularly important for strategic planning (e.g., evaluating the management alternatives for a National Forest plan).

Another application of our model involves fire-adapted ecosystems like the Interior Northwest, where periodic fires historically created patchy distributions of various forest structures (Covington et al. 1994, Everett et al. 2000). Now, many of these forests are more continuously dense and therefore at risk for uncharacteristically severe wildfire events. Recognizing the extent of forest changes over the past century, management of goshawk habitats in such modified forest ecosystems will be complicated. The effectiveness of large scale forest ecosystem restoration in accommodating species like goshawks will depend upon the extent to which future landscape patterns and processes support population persistence over the long term (Wilcove 1999). While goshawks may be adapted to low intensity-high frequency wildfires, reduction in habitat is probable following severe wildfires. As Laverty et al. (2000:9) noted, that without intervention in susceptible forests, "fire could eventually push declining populations beyond recovery." It is possible, then, that without mitigating current hazards, the goshawk might ultimately be listed as regionally threatened west of the 100th meridian. Thus, recommendations for silvicultural activities should be developed with concerns for uncharacteristic wildfires in mind.

Our model can be used as a decision-support tool to aid planners in identifying which areas and how much of a landscape surrounding goshawk nests should be treated to reduce density and continuity of forest fuels. Goshawk nest sites in lower-slope stands with high basal area and high stem densities probably are susceptible to fires because of their high fuel loads (Agee 1994, Everett et al. 2000). Therefore, fuel reductions could occur via thinning from below or basal area limit harvests that maintain high understory reinitiation and high stem exclusion stands in the 30 ha immediately surrounding nest sites. Beyond the 30-ha scale, we recommend maximizing habitat heterogeneity while minimizing the proportion of area in stand initiation conditions. This should facilitate proactive thinning, and enhance flexibility in stand selection for management, while discouraging large-scale clearcutting.

Although not illustrated here, we hasten to point out that the methods we describe for assessment of silvicultural prescriptions can be integrated with those we have described for assessing landscapes, thereby providing a tool suited to assessing the influence of silvicultural strategies on nesting habitat across landscapes over time. The utility of such analyses will depend on the accuracy of stand-based landscape inventories and regional growth and yield models such as the FVS.

CONCLUSIONS

In the Inland Northwest, goshawk nesting habitat becomes much more defined as plot size surrounding the nest decreases. Landscapes surrounding goshawk nests are more heterogeneous than available habitat and contain core areas of high canopy closure understory reinitiation and stem exclusion forest within 30 to 60 ha surrounding the nest. Within these core areas, 1-ha nest-sites are typically located in stem exclusion stands on the lower 1/3 of north-facing slopes where basal area and canopy closure are greater than at random sites. Thus, nesting habitat is composed of a mid- to late-successional forest core within a more heterogeneous landscape. A RSPF can be developed for 83-ha units. This function predicts the relative probability of a site being a goshawk nest site, and it can be used to predict effects of silviculture on nest-site suitability and the distribution and abundance of probable nesting areas within a landscape.

Habitat conditions at different landscape scales interact to influence the probability of goshawk nesting. Existence of such cross-scale interactions suggests that the dominant conservation management practice of placing no-harvest buffers around goshawk nests will be ineffective at maintaining site suitability because of habitat alterations beyond the buffer. The landscape-scale RSPF (Table 20)

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

demonstrates that different landscape components work synergistically to determine the spatially explicit likelihood of nesting. Given appropriate silvicultural prescriptions and timing of silvicultural practices that does not conflict with the nesting season, it should be possible to manage timber stands at varying distances from goshawk nests, including light thinning near the nest. Proactive harvest can maintain or even enhance nesting habitat over time. However, the timber harvest strategy to do this requires careful, long-term planning with wildlife habitat as the primary objective.

Principles in King et al. (2001) suggest that because our study was designed to remove spatial autocorrelation among scales, and several study areas were examined, interpretation as to how goshawks perceive habitat for nesting and how differences in landscape potential affect goshawk nesting habitat associations have been improved. We have provided insight into how: (1) landscape composition at various scales interact, (2) habitat composition within 30-ha of a nest and (3) habitat heterogeneity influence nesting suitability. Such insight into goshawk ecology should improve forest resource management for this species.

We have demonstrated the utility of our results through two possible management applications. For individual goshawk nests, the RSPF can be used to determine the effect that specific silvicultural prescriptions will have on suitability of sites for nesting and to develop prescriptions for maintaining or enhancing suitability over time. At larger landscape scales, the RSPF can identify regions that have a high likelihood of containing nesting habitat, help evaluate large areas (e.g., national forests, large ownerships) for goshawk nesting habitat, and facilitate the development of land management plans. However, other factors, including prey abundance, availability, overwintering, dispersal, and habitat conditions beyond 83 ha from the nest should be considered as well. The RSPF is intended to identify only potential goshawk nesting habitat, without respect to other aspects of life history.

Although the variables in the RSPF were reliable discriminants of nest sites and random points, they were poor predictors of nest productivity in 1994. Several researchers suspect that factors such as parental experience, weather, and prey abundance and availability are the most influential in determining nest productivity (Goodburn 1991, Lehmkuhl and Raphael 1993, DeStefano and McCloskey 1997, Reynolds and Joy 1998, Franklin et al. 2000). Prey abundance and availability may be most germane to resource managers because it has been shown to directly influence nest-site occupancy and productivity for the goshawk in many regions of North America (McGowan 1975, Doyle and Smith 1994, Reynolds and Joy 1998, McClaren et al. 2002).

Results of our analyses and the habitat models presented here should only be used as a portion of the conservation planning process for goshawks. As such, conservation planning for goshawks should include provisions for life history requirements, prey, winter, nesting, and foraging habitat needs, dispersal and colonization, and gene flow between populations. Much of the information that is needed to develop a complete conservation plan for the goshawk is lacking in North America (DeStefano 1998). To date, only two studies (Squires and Ruggiero 1995, Titus et al. 1996) have examined goshawk winter ecology and another has specifically examined goshawk foraging habitat ecology (Beier and Drennan 1997). More research into winter habitat, goshawk foraging ecology, population dynamics, and dispersal and colonization needs to be accomplished before a comprehensive conservation plan for the goshawk can be developed in North America. Nevertheless, our results can help forest managers evaluate the influence of their actions on the likelihood of goshawk nesting in landscapes to a spatially explicit extent never before possible.

LITERATURE CITED

AGEE, J. K. 1994. Fire and weather disturbances in terrestrial ecosystems of the eastern Cascades. U. S. Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-320.

ALLISON, B. 1996. A landscape characterization of northern goshawk habitat in northern California using remote sensing and GIS. M.S. Thesis, Southern Illinois University, Edwardsville, Illinois, USA.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

ANONYMOUS. 1989. Goshawk breeding habitat in lowland Britain. British Birds 82:56–67.

ARIZONA GAME AND FISH DEPARTMENT. 1993. Review of U. S. Forest Service strategy for managing northern goshawk habitat in the southwestern United States. Arizona Game and Fish Department, Phoenix, Arizona, USA.

BATSCHELET, E. 1981. Circular statistics in biology. Academic Press, New York, USA.

BEIER, P., AND J. E. DRENNAN. 1997. Forest structure and prey abundance in foraging areas of northern goshawks. Ecological Applications 7:564–571.

BELL, J. F., AND J. R. DILWORTH. 1988. Log scaling and timber cruising. OSU Book Stores, Inc., Corvallis, Oregon, USA.

BIBBY, C. J. 1986. Merlins in Wales: site occupancy and breeding in relation to vegetation. Journal of Applied Ecology 23:1–12.

BLOOM, P. H., G. R. STEWART, AND B. J. WALTON. 1986. The status of the northern goshawk in California, 1981–1983. Administrative Report 85-1. State of California, Department of Fish and Game, Sacramento, California, USA.

BONNOR, G. M. 1967. Estimation of ground canopy density from ground measurements. Journal of Forestry 65:544–547.

BRANDT, C. A., J. K. PARRISH, AND C. N. HODGES. 1995. Predictive approaches to habitat quantification: dark-rumped petrels on Haleakala, Maui. Auk 112:571–579.

BRAUN, C. E., J. H. ENDERSON, M. R. FULLER, Y. B. LINHART, AND C. D. MARTI. 1996. Northern goshawk and forest management in the southwestern United States. The Wildlife Society, Bethesda, Maryland, USA.

BREIMAN, L., J. H. FRIEDMAN, R. A. OLSHEN, AND C. J. STONE. 1984. Classification and regression trees. Wadsworth International Group, Belmont, California, USA.

BRIGHT-SMITH, D. J., AND R. W. MANNAN. 1994. Habitat use by breeding male northern goshawks in northern Arizona. Studies in Avian Biology 16:58–65.

BULL, E. L., AND J. H. HOHMANN. 1994. Breeding biology of northern goshawks in northeastern Oregon. Studies in Avian Biology 16:103–105.

BUNNELL, F. L., AND D. J. VALES. 1990. Comparison of methods for estimating forest overstory cover: differences among techniques. Canadian Journal of Forest Research 20:101–107.

BURNHAM, K. P., AND D. R. ANDERSON. 1998. Model selection and inference: a practical information-theoretic approach. Springer-Verlag. New York, New York, USA.

CAMP, A., C. D. OLIVER, P. HESSBURG, AND R. L. EVERETT. 1997. Predicting late-successional fire refugia predating European settlement in the Wenatchee Mountains. Forest Ecology and Management 5:63–77.

CLARK, L. A., AND D. PREGIBON. 1992. Tree-based models. Pages 377–419 *in* J. M. Chambers and T. J. Hastie, editors. Statistical models in S. Wadsworth & Brooks. Pacific Grove, California, USA.

COOK, J. G., T. W. STUTZMAN, C. W. BOWERS, K. A. BRENNER, AND L. L. IRWIN. 1995. Spherical densiometers produce biased estimates of forest canopy cover. Wildlife Society Bulletin 23:711–717.

COVINGTON, W. W., R. L. EVERETT, R. STEELE, L. L. IRWIN, T. A. DAER, AND A. N. D. AUCLAIR. 1994. Historical and anticipated changes in forest ecosystems of the inland west of the United States. Journal of Sustainable Forestry 2:13–63.

CROCKER-BEDFORD, D. C. 1990. Goshawk reproduction and forest management. Wildlife Society Bulletin 18:262–269.

———. 1998. The value of demographic and habitat studies in determining the status of northern goshawks (*Accipiter gentilis atricapillus*) with special reference to Crocker-Bedford (1990) and Kennedy (1997). Journal of Raptor Research 32:329–336.

———, AND B. CHANEY. 1988. Characteristics of goshawk nesting stands. Pages 210–217 *in* R. L. Glinski, B. G. Pendleton, M. B. Moss, M. N. Le Franc, Jr., B. A. Milsap, and S. W. Hoffman, editors. Proceedings of the southwest raptor management symposium and workshop. National Wildlife Federation.

DAUBENMIRE, R., AND J. B. DAUBENMIRE. 1968. Forest vegetation of eastern Washington and northern Idaho. Washington Agricultural Experiment Station Technical Bulletin 60.

DAW, S. K. 1996. Northern goshawk nest site selection and habitat associations at the post-fledging family area scale in Oregon. M.S. Thesis, Oregon State University, Corvallis, Oregon, USA.

———, AND S. DESTEFANO. 2001. Forest characteristics of northern goshawk nest stands and post-fledging areas in Oregon. Journal of Wildlife Management 65:46–58.

———, ———, AND R. J. STEIDL. 1998. Does survey method bias the description of northern goshawk nest-site structure? Journal of Wildlife Management 62:1379–1384.

DE'ATH, G., AND K. E. FABRICIUS. 2000. Classification and regression trees: a powerful yet simple technique for ecological data analysis. Ecology 81:3178–3192.

DESIMONE, S. M. 1997. Occupancy rates and habitat relationships of northern goshawks in historic nesting areas. M.S. Thesis, Oregon State University, Corvallis, Oregon, USA.

DESTEFANO, S. 1998. Determining the status of northern goshawks in the West: Is our conceptual model correct? Journal of Raptor Research 32:342–348.

———. 2002. Regional and national issues for forest wildlife research and management. Forest Science 48:181–189.

———, AND T. L. CUTLER. 1998. Diets of northern goshawks in eastern Oregon. Unpublished report, Arizona Cooperative Fish and Wildlife Research

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

Unit, University of Arizona, Tucson, Arizona, USA. 10 p.

———, S. K. DAW, S. M. DESIMONE, AND E. C. MESLOW. 1994. Density and productivity of northern goshawks: implications for monitoring and management. Studies in Avian Biology 16:88–91.

———, AND J. MCCLOSKEY. 1997. Does forest structure limit the distribution of northern goshawks in the Coast Ranges of Oregon? Journal of Raptor Research 31:34–39.

DOYLE, F. I., AND J. M. N. SMITH. 1994. Population responses of northern goshawks to the 10–year cycle in numbers of snowshoe hares. Studies in Avian Biology 16:122–129.

DUNNING, J. B., JR. 1984. Body weights of 686 species of North American birds. Western Bird Banding Association Monograph No. 1.

———, B. J. DANIELSON, AND H. R. PULLIAM. 1992. Ecological processes that affect populations in complex landscapes. Oikos 65:169–175.

———, D. J. Stewart, B. J. Danielson, B. R. Noon, T. L. Root, R. H. Lamberson, and E. E. STEVENS. 1995. Spatially explicit population models: current forms and future uses. Ecological Applications 5:3–11.

ERICKSON, W. P., T. L. MCDONALD, AND R. SKINNER. 1998. Habitat selection using GIS data: a case study. Journal of Agricultural, Biological, and Environmental Statistics 3:296–310.

EVERETT, R., P. HESSBURG, M. JENSEN, AND B. BORMANN, editors. 1993. Eastside forest ecosystem health assessment. Volume I: Executive Summary. USDA Forest Service, Portland, Oregon, USA.

———, R. SCHELLHAAS, D. KEENUM, D. SPURBECK, AND P. OHLSON. 2000. Fire history in the ponderosa/Douglas-fir forests on the east slope of the Washington Cascades. Forest Ecology and Management 129:207–225.

FALK, J. A. 1990. Landscape level raptor habitat associations in northwest Connecticut. M.S. Thesis, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, USA.

FINN, S. P. 1994. Northern goshawks in the upper Yakima River Basin. Unpublished report, Yakima Resource Management Cooperative Wildlife Technical Committee. Yakima, Washington, USA.

———. 1995. Northern goshawks in the upper Yakima River Basin. Unpublished report, Yakima Resource Management Cooperative Wildlife Technical Committee. Yakima, Washington, USA.

FISCHER, D. L. 1986. Daily activity patterns and habitat use of coexisting Accipiter hawks in Utah. Ph.D. Dissertation. Brigham Young University, Provo, Utah, USA.

FORMAN, R. T. T., AND M. GODRON. 1986. Landscape ecology. John Wiley & Sons, New York, USA.

FORSMAN, E. D., K. M. HORN, AND G. W. MIRES. 1985. Northern spotted owls. Pages 259–268 *in* E. R. Brown, editor. Management of wildlife and fish habitats in forests of western Oregon and Washington. US Forest Service, Pacific Northwest Region, Portland, Oregon. Publication number R-6F&WL-192–1985.

FRANKLIN, A. B., D. R. ANDERSON, R. J. GUTIERREZ, AND K. P. BURNHAM. 2000. Climate, habitat quality, and fitness in northern spotted owl populations in northwestern California. Ecological Monographs 70:539–590.

FRANKLIN, J. R., AND C. T. DYRNESS. 1973. Natural vegetation of Oregon and Washington. US Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-8.

FROST, T. M., R. E. ULANOWICZ, S. C. BLUMENSHINE, T. F. H. ALLEN, F. TAUB, AND J. H. RODGERS, JR. 2001. Scaling issues in experimental ecology: freshwater ecosystems. Pages 253–280 *in* R. H. Gardner, W. M. Kemp, V. S. Kennedy, and J. E. Petersen, editors. Scaling relations in experimental ecology. Columbia University Press, New York, USA.

GARMIN INTERNATIONAL. 1994. GPS 40 Personal Navigator owner's manual. Garmin International. Taiwan.

GARRISON, G. A. 1949. Uses and modifications for the "Moosehorn" crown closure estimator. Journal of Forestry 47:733–735.

GOODBURN, S. F. 1991. Territory quality or bird quality? Factors determining breeding success in the Magpie *Pica pica*. Ibis 133:85–90.

HALL, P. A. 1984. Characterization of nesting habitat of goshawks (*Accipiter gentilis*) in Northwest California. M.S. Thesis, Humboldt State University, Arcata, California, USA.

HARGIS, C. D., C. MCCARTHY, AND R. D. PERLOFF. 1994. Home ranges and habitats of northern goshawks in eastern California. Studies in Avian Biology 16:66–74.

HAYWARD, G. D., AND R. E. ESCANO. 1989. Goshawk nest-site characteristics in western Montana and northern Idaho. Condor 91:476–479.

HENNESSY, S. P. 1978. Ecological relationships of Accipiters in northern Utah—with special emphasis on the effects of human disturbance. M.S. Thesis, Utah State University, Logan, Utah, USA.

HERRON, G. B., C. A. MORTIMORE, AND M. S. RAWLINGS. 1985. Northern goshawk. Nevada raptors: their biology and management. Biological Bulletin No. 8, Nevada Department of Wildlife, Reno, Nevada, USA.

HOLLING, C. S. 1992. Cross-scale morphology, geometry, and dynamics of ecosystems. Ecological Monographs 62:447–502.

HOSMER, D. W., AND S. LEMESHOW. 1989. Applied logistic regression. John Wiley & Sons, New York, USA.

HUNTER, M. L., JR. 1999. Maintaining biodiversity in forest ecosystems. Cambridge University Press, Cambridge, UK.

IRWIN, L. L., AND T. B. WIGLEY. 1993. Toward an experimental basis for protecting forest wildlife. Ecological Applications 3:213–217.

IVERSON, G. C., G. D. HAYWARD, K. TITUS, E. DEGAYNER,

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

R. E. LOWELL, D. C. CROCKER-BEDFORD, P. F. SCHEMPF, AND J. LINDELL. 1996. Conservation assessment for the northern goshawk in southeast Alaska. U.S. Forest Service, Pacific Northwest Research Station, Portland, Oregon. General Technical Report PNW-GTR-387.

JANES, S. W. 1985. Habitat selection in raptorial birds. Pages 159–188 *in* M. L. Cody, editor. Habitat selection in birds. Academic Press, New York, USA.

JOHNSGARD, P. A. 1990. Hawks, eagles, & falcons of North America. Smithsonian Institution Press, Washington, D.C., USA.

JOHNSON, D. H. 1980. The comparison of usage and availability measurements for evaluating resource preference. Ecology 61:65–71.

KEMP, W. M., J. E. PETERSEN, AND R. H. GARDNER. 2001. Scale-dependence and the problem of extrapolation: implications for experimental and natural coastal ecosystems. Pages 3–60 *in* R. H. Gardner, W. M. Kemp, V. S. Kennedy, and J. E. Petersen, editors. Scaling relations in experimental ecology. Columbia University Press, New York, USA.

KENNEDY, P. L. 1988. Habitat characteristics of Cooper's hawks and northern goshawks nesting in New Mexico. Pages 218–227 *in* R. L. Glinski, B. G. Pendleton, M. B. Moss, M. N. Le Franc, Jr., B. A. Milsap, and S. W. Hoffman, editors. Proceedings of the southwest raptor management symposium and workshop. National Wildlife Federation.

———. 1997. The northern goshawk (*Accipiter gentilis atricapillus*): is there evidence of a population decline? Journal of Raptor Research 31:95–106.

———, AND D. W. STAHLECKER. 1993. Responsiveness of nesting northern goshawks to taped broadcasts of 3 conspecific calls. Journal of Wildlife Management 57:249–257.

———, J. M. WARD, G. A. RINKER, AND J. A. GESSAMAN. 1994. Post-fledging areas in northern goshawk home ranges. Studies in Avian Biology 16:75–82.

KENWARD, R. E. 1982. Goshawk hunting behaviour, and range size as a function of food and habitat availability. Journal of Animal Ecology 51:69–80.

———. 1996. Goshawk adaptation to deforestation: does Europe differ from North America? Pages 233–243 *in* D. M. Bird, D. E. Varland, and J. J. Negro, editors. Raptors in human landscapes. Academic Press, New York, USA.

———, V. MARCSTROM, AND M. KARLBOM. 1993. Post-nestling behavior in goshawks, *Accipiter gentilis*: I. The causes of dispersal. Animal Behavior 46: 365–370.

KIMMEL, J. T. 1995. Spatial hierarchy of habitat use by northern goshawks in two forest regions of Pennsylvania. Ph.D. Dissertation, Pennsylvania State University, University Park, Pennsylvania, USA.

KING, A. W., R. H. GARDNER, C. A. HATFIELD, S. NAEEM, J. E. PETERSEN, AND J. A. WIENS. 2001. Terrestrial perspectives on issues of scale in experimental ecology. Pages 281–298 *in* R. H. Gardner, W. M. Kemp, V. S. Kennedy, and J. E. Petersen, editors. Scaling relations in experimental ecology. Columbia University Press, New York, USA.

KOSTRZEWA, A., AND R. KOSTRZEWA. 1990. The relationship of spring and summer weather with density and breeding performance of the buzzard *Buteo buteo*, goshawk *Accipiter gentilis* and kestrel *Falco tinnunculus*. Ibis 132:550–559.

LACK, D. 1933. Habitat selection in birds. Journal of Animal Ecology 2:239–262.

LANG, P. A. 1994. Spatial analyses of northern goshawk ponderosa pine nest site habitat in east-central Arizona. M.S. Thesis, Northern Arizona University, Flagstaff, Arizona, USA.

LAVERTY, L., J. WILLIAMS, AND M. DOMBECK. 2000. Protecting people and sustaining resources in fire-adapted ecosystems: a cohesive strategy. The Forest Service management response to the GAO Report GAO/RCED-99-65. October 13, 2000. U. S. Department of Agriculture, Forest Service. Washington, D. C., USA.

LEHMKUHL, J. F., AND M. G. RAPHAEL. 1993. Habitat pattern around northern spotted owl locations on the Olympic Peninsula, Washington. Journal of Wildlife Management 57:302–315.

LEOPOLD, A. 1933. Game management. University of Wisconsin Press, Madison, Wisconsin, USA.

LILIEHOLM, R. J., W. B. KESSLER, AND K. MERRILL. 1993. Stand density index applied to timber and goshawk habitat objectives in Douglas-fir. Environmental Management 17:773–779.

———, J. N. LONG, AND S. PATLA. 1994. Assessment of goshawk nest area habitat using stand density index. Studies in Avian Biology 16:18–23.

LONG, J. N. 1985. A practical approach to density management. Forestry Chronicle 61:23–27.

MANLY, B. F. J., L. L. MCDONALD, AND D. L. THOMAS. 1993. Resource selection by animals: statistical design and analysis for field studies. Chapman and Hall, London, U. K.

MARCUM, C. L., AND D. O. LOFTSGAARDEN. 1980. A nonmapping technique for studying habitat preferences. Journal of Wildlife Management 44:963–968.

MATHSOFT, INC. 1997. S-Plus user's guide. MathSoft, Seattle, Washington, USA.

MCCLAREN, E. L., P. L. KENNEDY, AND S. R. DEWEY. 2002. Do some northern goshawk nest areas consistently fledge more young than others? Condor 104: 343–352.

MCCOMB, W. C., T. A. SPIES, AND W. H. EMMINGHAM. 1993. Stand management for timber and mature-forest wildlife in Douglas-fir forests. Journal of Forestry 91:31–42.

MCGARIGAL, K., AND B. J. MARKS. 1994. FRAGSTATS—spatial pattern analysis program for quantifying landscape structure. Version 2.0. Forest Science Department, Oregon State University, Corvallis, Oregon, USA.

MCGOWAN, J. D. 1975. Distribution, density, and pro-

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

ductivity of goshawks in interior Alaska. Unpublished final report, Federal Aid in Wildlife Restoration, Alaska Department of Fish and Game, Juneau, Alaska, USA. 57 p.

MCGRATH, M. T. 1997. Northern goshawk habitat analysis in managed forest landscapes. M.S. Thesis, Oregon State University, Corvallis, Oregon, USA.

MCTAGUE, J. P., AND D. R. PATTON. 1989. Stand density index and its application in describing wildlife habitat. Wildlife Society Bulletin 17:58–62.

MOORE, K. E., AND C. J. HENNY. 1983. Nest-site characteristics of three coexisting accipiter hawks in northeastern Oregon. Journal of Raptor Research 17:65–76.

MOSHER, J. A., K. TITUS, AND M. R. FULLER. 1986. Developing a practical model to predict nesting habitat of woodland hawks. Pages 31–34 *in* J. Verner, M. L. Morrison, and C. J. Ralph, editors. Wildlife 2000. University of Wisconsin Press, Madison, Wisconsin, USA.

NEHLSEN, W., J. E. WILLIAMS, AND J. A. LICHATOWICH. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16:4–21.

NEWTON, I. 1979. Population ecology of raptors. Buteo Books, Vermillion, South Dakota, USA.

———. 1986. The sparrowhawk. T & A D Poyser, Staffordshire, UK.

NYBERG, J. B., A. S. HARESTAD, AND F. L. BUNNELL. 1987. "Old-growth" by design: managing young forests for old-growth wildlife. Transactions of the North American Wildlife and Natural Resources Conference 52:70–81.

OLIVER, C. D., C. HARRINGTON, M. BICKFORD, R. GARA, W. KNAPP, G. LIGHTNER, AND L. HICKS. 1994. Maintaining and creating old growth structural features in previously disturbed stands typical of the eastern Washington Cascades. Journal of Sustainable Forestry 2:353–387.

———, AND B. C. LARSON. 1996. Forest stand dynamics. McGraw-Hill, New York, USA.

ORIANS, G. H., AND N. E. PEARSON. 1979. On the theory of central place foraging. Pages 155–177 *in* F. N. Hamerstrom, Jr., B. E. Harrell, and R. R. Olendorff, editors. Analysis of ecological systems. Ohio State University Press, Columbus, Ohio, USA.

PAINE, D. P. 1981. Aerial photography and image interpretation for resource management. John Wiley & Sons, New York, USA.

PATLA, S. M. 1997. Nesting ecology and habitat of the northern goshawk in undisturbed and timber harvest areas on the Targhee National Forest, Greater Yellowstone Ecosystem. M.S. Thesis, Idaho State University, Pocatello, Idaho, USA.

PENTERIANI, V. 1997. Long-term study of a goshawk breeding population on a Mediterranean mountain (Abruzzi Apennines, central Italy): density, breeding performance and diet. Journal of Raptor Research 31:308–312.

PRESS, S. J., AND S. WILSON. 1978. Choosing between logistic regression and discriminant analysis. Journal of the American Statistical Association 73:699–705.

RALPH, C. J., G. L. HUNT, JR., M. G. RAPHAEL, AND J. F. PIATT. 1995. Ecology and conservation of the marbled murrelet. U.S. Forest Service, Pacific Southwest Research Station, Albany, California. General Technical Report PSW-GTR-152.

RAMSEY, F. L., M. MCCRACKEN, J. A. CRAWFORD, M. S. DRUT, AND W. J. RIPPLE. 1994. Habitat association studies of the northern spotted owl, sage grouse, and flammulated owl. Pages 189–211 *in* N. Lange, L. Ryan, L. Billard, D. Brillinger, L. Conquest, and J. Greenhouse, editors. Case studies in biometry. John Wiley & Sons, New York, USA.

REINEKE, L. H. 1933. Perfecting a stand density index for even-aged forests. Journal of Agricultural Research 46:627–638.

REYNOLDS, R.T. 1978. Food and habitat partitioning in two groups of coexisting accipiters. Ph.D. Dissertation, Oregon State University, Corvallis, Oregon, USA.

———, R. T. GRAHAM, M. H. REISER, R. L. BASSETT, P. L. KENNEDY, D. A. BOYCE, JR., G. GOODWIN, R. SMITH, AND E. L. FISHER. 1992. Management recommendations for the northern goshawk in the southwestern United States. U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Ft. Collins, Colorado. General Technical Report RM-217.

———, AND S. M. JOY. 1998. Distribution, territory occupancy, dispersal, and demography of northern goshawks on the Kaibab Plateau, Arizona. Unpublished final report, Arizona Game & Fish Department, Phoenix Arizona. Arizona Game and Fish Heritage Project, No. I94045. Phoenix, Arizona, USA.

———, ———, AND D. G. LESLIE. 1994. Nest productivity, fidelity, and spacing of northern goshawks in Arizona. Studies in Avian Biology 16:106–113.

———, E. C. MESLOW, AND H. M. WIGHT. 1982. Nesting habitat of coexisting *Accipiter* in Oregon. Journal of Wildlife Management 46:124–138.

———, AND H. M. WIGHT. 1978. Distribution, density, and productivity of accipiter hawks breeding in Oregon. Wilson Bulletin 90:182–196.

RIGGS, R. A. 1994. Guidelines for modifications of forestry prescriptions at *Accipiter* nest sites. Unpublished report, Boise Cascade Corporation, La Grande, Oregon, USA.

———, J. G. COOK, L. L. IRWIN, AND J. L. SPICER. 1993. Relating timber management to cover for big game on interior northwest winter range: some thoughts on reducing conflict. Pages 18–36 *in* R. L. Callas, D. B. Kock, and E. R. Loft, editors. Proceedings of the Western States and Provinces Elk Workshop. California Department of Fish and Game, Sacramento, California, USA.

ROSENFIELD, R. N., J. BIELEFELDT, D. R. TREXEL, AND T. C.

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

J. DOOLITTLE. 1998. Breeding distribution and nest-site habitat of northern goshawks in Wisconsin. Journal of Raptor Research 32:189–194.

ROSENZWEIG, M. L. 1981. A theory of habitat selection. Ecology 62:327–335.

SAS INSTITUTE, INC. 1988. SAS/STAT user's guide, release 6.03 edition. SAS Institute, Cary, North Carolina, USA.

SAUNDERS, L. B. 1982. Essential nesting habitat of the goshawk (*Accipiter gentilis*) on the Shasta-Trinity National Forest, McCloud District. M.S. Thesis, California State University, Chico, California, USA.

SCHOMMER, T., AND G. SILOVSKY. 1994. Goshawk monitoring, management, and research in the Pacific Northwest Region USDA Forest Service. Unpublished report, U. S. Forest Service, Pacific Northwest Region, Portland, Oregon, USA.

SIDERS, M. S., AND P. L. KENNEDY. 1996. Forest structural characteristics of Accipiter nesting habitat: is there an allometric relationship? Condor 98:123–132.

SILVER, R. D., P. GALVIN, S. HIRSCH, S. M. HITT, S. W. HOFMAN, A. MACFARLANE, C. I. SANDELL, M. SAUBER, T. SCHULKE, G. WARDWELL, AND S. WOTKYNS. 1991. Letter to Department of the Interior, petitioning to list the northern goshawk (*Accipiter gentilis*) in Utah, Colorado, New Mexico and Arizona, under the Endangered Species Act. Maricopa Audubon Society, Phoenix, Arizona, USA. 61 p.

SMITH, D. M. 1986. The practice of silviculture. John Wiley & Sons, New York, USA.

SPEISER, R. 1993. Use of landmarks in nest site selection by woodland raptors. Records of New Jersey Birds 19:2–5.

———, AND T. BOSAKOWSKI. 1987. Nest site selection by northern goshawks in northern New Jersey and southeastern New York. Condor 89:387–394.

SQUIRES, J. R., AND R. T. REYNOLDS. 1997. Northern Goshawk. The birds of North America, No. 298. A. Poole and F. Gill, editors. The Academy of Natural Sciences, Philadelphia, PA and the American Ornithologists' Union, Washington, D. C., USA.

———, AND L. F. RUGGIERO. 1995. Winter movements of adult northern goshawks that nested in southcentral Wyoming. Journal of Raptor Research 29:5–9.

———, AND ———. 1996. Nest-site preference of northern goshawks in southcentral Wyoming. Journal of Wildlife Management 60:170–177.

STAGE, A. R., AND D. L. RENNER. 1988. Comparison of yield-forecasting techniques using long-term stand histories. Pages 810–817 *in* A. R. Ek, S. R. Shifley, and T. E. Burk, editors. Forest growth modeling and prediction: Proceedings of the IUFRO conference, August 23–27, 1987, Minneapolis, Minnesota. U. S. Forest Service, North Central Forest Experiment Station, Minneapolis, Minnesota. General Technical Report NC-120.

STALMASTER, M. V., R. L. KNIGHT, B. L. HOLDER, AND R. J. ANDERSON. 1985. Bald eagles. Pages 269–290 *in* E. R. Brown, editor. Management of wildlife and fish habitats in forests of western Oregon and Washington. US Forest Service, Pacific Northwest Region, Portland, Oregon. Publication number R-6F&WL-192–1985.

STEENHOFF, K., AND M. N. KOCHERT. 1982. An evaluation of techniques used to estimate raptor nesting success. Journal of Wildlife Management 46:885–893.

SYDEMAN, W. J., J. F. PENNIMAN, T. M. PENNIMAN, P. PYLE, AND D. G. AINLEY. 1991. Breeding performance in the western gull: effects of parental age, timing of breeding and year in relation to food availability. Journal of Animal Ecology 60:135–149.

TITUS, K., C. FLATTEN, AND R. LOWELL. 1996. Goshawk ecology and habitat relationships on the Tongass National Forest: selected analyses and 1995 field season progress report. Federal Aid in Wildlife Restoration Research Progress Report, Grant SE-4–2. Alaska Department of Fish and Game, Douglas, Alaska, USA. 55 p.

U. S. FISH AND WILDLIFE SERVICE. 1998. Northern goshawk status review. U. S. Fish and Wildlife Service, Portland, Oregon, USA.

VERBYLA, D. L., AND J. A. LITVAITIS. 1989. Resampling methods for evaluating classification accuracy of wildlife habitat models. Environmental Management 13:783–787.

WATSON, J. W., D. W. HAYS, S. P. FINN, AND P. MEEHAN-MARTIN. 1998. Prey of breeding northern goshawks in Washington. Journal of Raptor Research 32:297–305.

———, ———, AND D. J. PIERCE. 1999. Efficacy of northern goshawk broadcast surveys in Washington state. Journal of Wildlife Management 63:98–106.

WIEBE, K. L., AND K. MARTIN. 1998. Age-specific patterns of reproduction in white-tailed and willow ptarmigan *Lagopus leucurus* and *L. lagopus*. Ibis 140:14–24.

WIENS, J. A. 1989. Spatial scaling in ecology. Functional Ecology 3:385–397.

WILCOVE, D. S. 1999. The condor's shadow—the loss and recovery of wildlife in America. W. H. Freeman and Company, New York, USA.

WOODBRIDGE, B., AND P. J. DETRICH. 1994. Territory occupancy and habitat patch size of northern goshawks in the southern Cascades of California. Studies in Avian Biology 16:83–87.

WYKOFF, W. R., N. L. CROOKSTON, AND A. R. STAGE. 1982. User's guide to the stand Prognosis model. Intermountain Forest and Range Experiment Station. U. S., Forest Service, Intermountain Forest and Range Experiment Station, Ogden, Utah. General Technical Report INT-133.

YAFFEE, S. L. 1994. The wisdom of the spotted owl: policy lessons for a new century. Island Press, Washington, D.C., USA.

YODA, K., T. KIRA, H. OGAWA, AND K. HOZUMI. 1963. Self-thinning in overcrowded pure stands under cultivated and natural conditions. Journal of Biology Osaka

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms

City University 14:107–129.

ZACHEL, C. R. 1985. Food habits, hunting activity, and post-fledging behavior of northern goshawks in interior Alaska. M.S. Thesis, University of Alaska, Fairbanks, Alaska, USA.

ZAR, J. H. 1984. Biostatistical analysis. Prentice Hall, Englewood Cliffs, New Jersey, USA.

Received 3 April 2000
Accepted 21 January 2003

This content downloaded from 170.144.245.238 on Tue, 04 Dec 2018 21:39:23 UTC
All use subject to https://about.jstor.org/terms