Managing for Biodiversity in Young Douglas-Fir Forests of Western Oregon

Biological Science Report
USGS/BRD/BSR– 2002-0006

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Suggested citation:
Muir, P.S., R.L. Mattingly, J.C. Tappeiner II, J.D. Bailey, W.E. Elliott, J.C. Hagar, J.C. Miller, E.B. Peterson, and E.E. Starkey. 2002. Managing for biodiversity in young Douglas-fir forests of western Oregon. U.S. Geological Survey, Biological Resources Division, Biological Science Report USGS/BRD/BSR–2002-0006. 76 pp.

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Conversions

Length
To convert centimeters to inches, multiply by 0.394.
To convert meters to yards, multiply by 1.094.
To convert kilometers to miles, multiply by 0.621.

Area
To convert square meters to square feet, multiply by 10.76.
To convert hectares to acres, multiply by 2.47.

Mass
To convert grams to pounds, multiply by 0.0022.

Symbols
< = less than
≤ = less than or equal to
> = greater than
≥ = greater than or equal to

Managing for Biodiversity in Young Douglas-Fir Forests of Western Oregon

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Abstract: This project addressed potential contributions of forest thinning to enhancing biodiversity and accelerating development of old-growth characteristics in relatively young Douglas-fir forests typical of those managed according to the Northwest Forest Plan. Studies focused primarily on 32 paired unthinned and thinned stands and 20 associated old-growth stands in the Coast Range and Cascade mountains of western Oregon. Data were collected on vascular plants in most stands surveyed, and on epiphytic lichens and bryophytes, moths, and birds in subsets of these stands. Studies assessed whether or not (1) communities of organisms differed among stand types, (2) communities in thinned stands were more similar to those in old-growth stands than were those in unthinned stands, (3) species diversity or abundance was related to specific stand features, and (4) these specific stand features were shared across taxa. Results

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indicated that communities differed among stand types, and that communities in thinned stands were not necessarily more similar to old-growth communities than were those in unthinned stands. Variation in stand conditions appeared to enhance biodiversity, and hardwood trees and shrubs were important for many species. These and other results form the basis for general thinning guidelines, which are presented here, and will guide future research.

Key Words: biodiversity, bryophytes, community analysis, epiphytes, forest management, functional groups, hardwoods, lichens, moths, neotropical migratory songbirds, Northwest Forest Plan, old-growth forests, remnant trees, shrubs, thinning, variable-density thinning, vegetation.

Project Introduction

Overview

The Forest

Today the Douglas-fir/western hemlock forests of western Oregon comprise both **young-growth stands**[1] of small, relatively even-aged trees, and older, more complex stands of large trees, including **old-growth** stands (see Figure 1). Some of these forests are located on federal lands within the area now managed according to the **Northwest Forest Plan** (USDA and USDI 1994; Figure 2). These federal lands support an estimated 2,335,628 hectares of small **conifer** stands (trees <53 centimeters in diameter) in Washington, Oregon, and California. Medium/large conifer stands (trees >53 centimeters in diameter[2]) on these federal lands include 1,623,550 hectares of single-storied stands and 1,821,255 hectares of **multistoried stands** (FEMAT 1993). Thus, about 40 percent of these federal forests are relatively young-growth stands, many of which have regenerated after timber harvest or forest fire. Nonfederal Oregon forests include those forests managed by state and private industry, most of which have been logged and maintained in young age classes.

The Northwest Forest Plan

The Northwest Forest Plan incorporates seven land-allocation categories for the ~10 million hectares of federal **forest lands** located within the range of the northern spotted owl[3] (Figure 2). These categories include **congressionally reserved areas**, **administratively withdrawn areas**, **managed late-successional areas**, **late-successional reserves** (LSRs; e.g., Figure 3), **riparian reserves**, **adaptive management areas** (AMAs), and **matrix lands**, i.e., areas not reserved (USDA and USDI 1994). The allocation of large areas to **reserves** represents a major change from the past, when most forest areas were not protected or were managed with a major emphasis on timber production. With the implementation of the Northwest Forest Plan, new attention has been focused on **adaptive management** (Figure 4), and on maintaining and enhancing **biodiversity**, both in reserves and on matrix lands from which timber will be harvested.

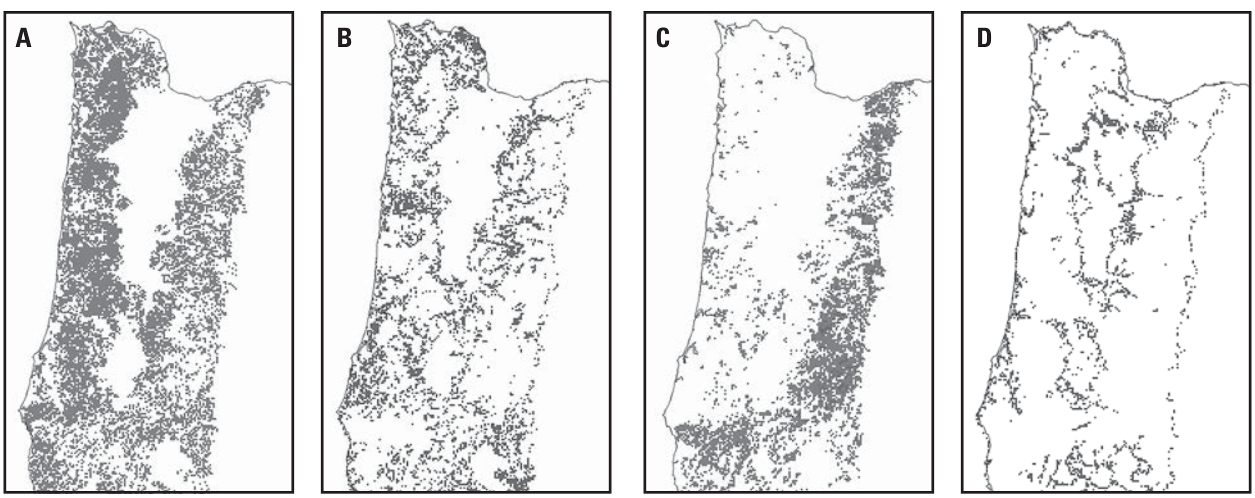

Figure 1. Vegetation in western Oregon from the coast to the crest of the Cascade mountains in 1988. (A) Young stands (<80 years old) with >70 percent conifer cover. (B) Hardwood stands with >70 percent cover and mixed vegetation. (C) Mature (>70 percent conifers between 80 and 200 years in age) and old-growth (>70 percent conifers >200 years in age) vegetation. (D) Open areas with <70 percent green vegetation cover. Maps originator: Warren Cohen, USDA Forest Service, Pacific Northwest Research Station, Forestry Sciences Lab, Corvallis, Oregon.

[1] Terms related to forest ecology and forest management are set in boldface type at first mention and defined in the Glossary of Forest Ecology and Management Terms.

[2] Ranges and cut-offs for size and age parameters vary, depending on the study objectives and data available, throughout this report. Specific age and size parameters are provided to clarify study context and applicability, and to aid interpretation.

[3] One of three subspecies (*Strix occidentalis caurina*) of the spotted owl that ranges from British Columbia, Canada, into northwestern California. The northern spotted owl is listed as a threatened species under the U.S. Endangered Species Act by the U.S. Fish and Wildlife Service.

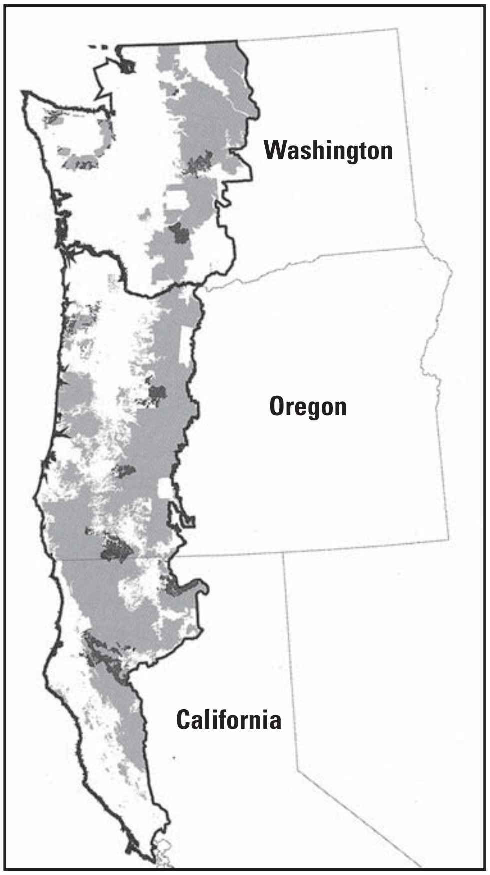

Figure 2. The area of concern for the Northwest Forest Plan in Washington, Oregon, and northern California, delineating federal land ownership (light gray) and adaptive management areas (dark gray). The Northwest Forest Plan area is the habitat range of the northern spotted owl. Adapted from: Haynes and Perry 2000.

The Project

The *Managing for Biodiversity in Young Forests Project* addresses the need to understand the potential contribution of thinning as a management practice that may be used to increase biodiversity in reserves, as well as on matrix lands. This report presents the project rationale and major results relating biodiversity to stand characteristics for each of the organisms studied. It is intended to supplement work highlighted in the project video, Managing for Biodiversity in Young Forests (Tappeiner et al. 2000), which depicts a day in the field with researchers (see Appendix A[4]) concerned with managing young Douglas-fir forests for biodiversity. In the video, Joe Lint, USDI Bureau of Land Management Wildlife Biologist, teams up with Oregon State University Professor Pat Muir to visit researchers comparing vegetation and fauna among Douglas-fir stands, including unthinned and thinned young-growth, and old-growth stands in western Oregon. The researchers share their findings on trees, **shrubs**, and herbaceous vegetation (John Tappeiner), epiphytic **lichens** and **bryophytes** (Eric Peterson and Abbey Rosso), moths (Jeff Miller), and birds (Joan Hagar).

Project results have important implications for **forest management**, and researchers provide selected recommendations for management actions that may enhance biodiversity in young Douglas-fir forests. Recommendations are intended primarily for agencies, groups, and individuals who manage the Douglas-fir forests of western Oregon. Results of complementary research in the region are included, and data and interpretations presented are based on the understanding of young forests and their response to thinning at the time of publication. The young-growth stands studied in this project ranged from 50 to 120 years in age (average 79 years in age). The concepts and recommendations, however, probably apply to stands ranging from approximately 15 to 120 years in age.

Because the project is a retrospective analysis (i.e., stands were studied after they had been thinned, rather than before and after), cause-and-effect relationships between specific stand characteristics and the diversity of the organisms chosen for study cannot be inferred directly from the results. Even so, the project reveals correlations between forest characteristics and biodiversity—correlations that can be tested experimentally in subsequent studies. In addition, results from these and other studies (e.g., Carey et al.

Figure 3. A late-successional reserve near Triangle Lake, Oregon, northwest of Eugene, indicating young forest over a large, contiguous expanse. Late-successional reserves are highly variable in age and cover. Photograph by John Tappeiner.

[4] Researcher biographies are provided in Appendix A.

Managing for Biodiversity

Biodiversity, or biological **diversity**, has been defined as the variety of life forms and processes, including the **species**, **communities**, gene pools, and ecological functions of a given system—e.g., see Wilson (1988) and Eldredge (1998) for overviews. As such, biodiversity is more than the sum of species that occupy a forest. It includes the functional relationships among organisms as well. The literature on the planet's loss of biodiversity is filled with photographs, tables, and lists of organisms now **threatened**, **endangered**, or extinct, as well as discussion of the profoundly serious nature of the issue.

Ecosystem management for biodiversity requires an understanding of the distribution and abundance of species on the **landscape** and within stands, and an understanding of the responses of these species to change—in both the short and the long term. Because environmental conditions affect forest stand **structure** over time, essential **habitat** (provided by environmental conditions and stand structure, composition, and processes) changes over time as well. Trophic interactions, i.e., the **food web**, involve important **ecosystem** processes that interconnect organisms in a given habitat. Energy stored by plants is passed through the ecosystem by a series of consumers. As a result, changes in vegetation may influence organisms at a variety of trophic levels.

More information is needed about how forest practices and resulting changes in stand structure and environmental conditions are likely to affect organisms, and how these effects move through food webs. Understanding the functional relationships among organisms, as well as the organisms themselves, is essential for those involved in managing forest ecosystems and maintaining biodiversity in **young**, **managed forests**.

1999a; Colgan et al. 1999, 2000; Carey 2000; Haveri and Carey 2000; Carey and Wilson 2001; Thysell and Carey 2001; Carey et al. 2002) can be used now to help design treatments that may enhance biological diversity in reserves, as well as on matrix lands. Although references are made to current concerns of land managers about implementation of the Northwest Forest Plan, research findings are relevant to the practice of all agencies, groups, and individuals concerned with enhancing biodiversity in young forests typical of those found in western Oregon.

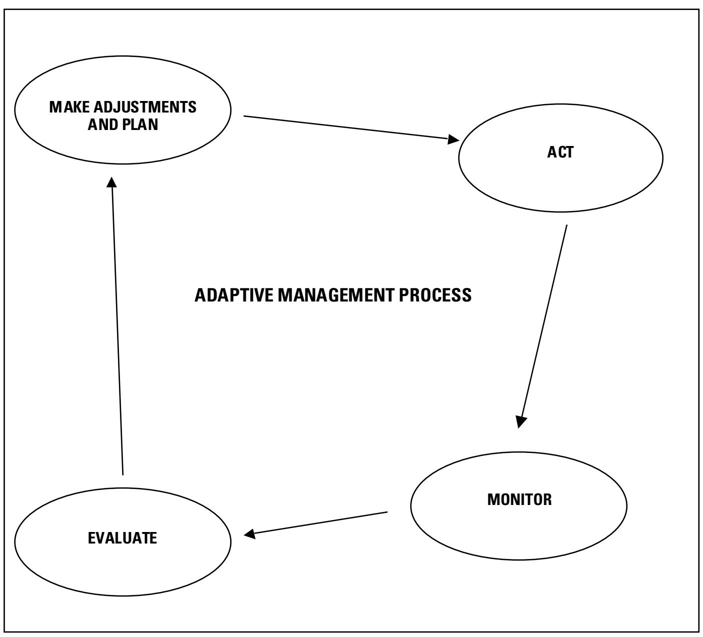

Figure 4. Forest managers implementing the Northwest Forest Plan focus efforts on an adaptive management process through which management activities are monitored, evaluated, considered along with findings of ongoing research, and adjusted to increase the degree to which they meet management objectives over time.

Reserves, AMAs, and Matrix Lands

A variety of land areas, in large part, are reserved from timber management. These areas include congressionally reserved areas (e.g., national parks and wilderness areas) and administratively withdrawn areas (e.g., identified recreation and visual areas), as well as the LSRs and riparian reserves set aside under the Northwest Forest Plan. Late-successional reserves are managed to protect or foster development of late-successional forest conditions and to provide habitat for species that depend on late-successional habitat. Riparian reserves are riparian areas located outside of LSRs and have similar management objectives, as well as broad aquatic-conservation strategy objectives.

Stand management in LSRs and riparian reserves is intended to encourage late-successional characteristics and riparian values, respectively, rather than timber production. Some stand-management practices in these reserves do produce wood, but this production is not the motivation behind their implementation. For example, thinnings and other **silvicultural practices** are encouraged, both to accelerate the development of young stands (generally <80 years old) into stands with late-successional characteristics and to reduce the risk of severe impacts from large-scale disturbances (USDA and USDI 1994).

Adaptive management areas are areas in which adaptive management is mandated (see Figure 4). At present, ten AMAs have been set aside for developing and testing management approaches that help integrate ecological and economic health objectives.

Matrix lands are areas that are not reserved, i.e., they are located outside of reserves. The objectives for matrix lands remain largely the same as they were prior to the development of the Northwest Forest Plan, with some added objectives, such as protection of sensitive plants, animals, and fungi (i.e., **survey and manage species**) and the important habitat features (e.g., remnant green trees, **coarse woody debris**, and **snags**). Most scheduled timber harvest (other than harvest in adaptive management areas) takes place on matrix lands.

Forest Stand Development

John Tappeiner

According to generally accepted theory, forest stands tend to develop in a sequence from small **seedlings** and saplings to dense, closed-**canopy** stands with narrow age ranges, and then to complex, multistoried, old-growth stands (see Oliver and Larson 1996). At present, many young forests in western Oregon comprise trees with a narrow range of ages (Figure 5a), in keeping with the first part of this sequence.[5] Increasing evidence, however, suggests that existing **old-growth forests** started under conditions quite different than those found in the dense, closed-canopy stands from which today's young forests generally develop (e.g., Tappeiner et al. 1997; Poage 2001; Figure 6).

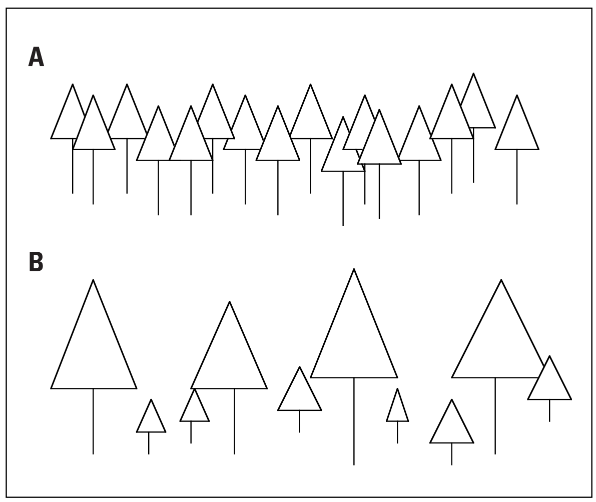

Figure 5. Representation of forest stand development. Diagrams depict: (A) trees in unthinned young-growth stands today, with slow growth rates and a narrow range of age, and (B) recent findings on existing old-growth forests, which indicate that trees developed with fast growth rates during the early years and a wide range of age.

Based on the 40 stands included in these studies, old-growth stands appear to have comprised trees of a range of ages and sizes. Thus, disturbance and tree establishment may have been ongoing and common processes on sites similar to those on which studies described in this report were conducted. The old-growth stands sampled by Tappeiner et al. (1997) and Poage

[5] See "Douglas-Fir Forests in Western Oregon" in the Project Introduction section of this report.

Figure 6. A young forest, between 30 and 50 years in age, started following timber harvest in the Oregon Coast Range near Harlan. Existing old-growth forests may have started under conditions that differ from the dense, closed-canopy conditions of stands from which young forests generally develop today. Photograph by John Tappeiner.

(2001) at sites in the Oregon Coast Range contained trees that grew under low stocking densities and sustained high growth rates during their first 100 years. The growth and age of large trees in these old-growth forests, measured by counting rings on stumps in stands that have been **clearcut** (Tappeiner et al. 1997; Poage 2001), indicate that the **density** of large trees (>75 centimeters) in these former old-growth stands was variable and low—often <50 trees per hectare. Tree-ring analyses also indicate rapid diameter growth rates during the first 50–100 years of growth in these large trees. In addition, tree size and/or growth rate at age 50 years explained >70 percent of the variation in tree size at age 200 years (Poage 2001). Thus, these old trees apparently grew quickly at low densities during early stages of their lives, and maintained diameter growth as they aged (Figure 7). Spies and Franklin (1991) also have reported low tree densities for old-growth forests in western Oregon and Washington. By comparison, current densities of canopy trees in the Oregon Coast Range are much higher in unthinned young-growth stands (Bailey and Tappeiner 1998). In the thinned young-growth stands studied in the *Managing for Biodiversity in Young Forests Project*, tree densities generally were lower than in unthinned young-growth stands, but were quite variable (between 59 and 289 trees per hectare), depending on the **thinning prescription**. The densities in these thinned young-growth stands generally were much higher than densities found in old-growth stands (see Figure 5b).

Comparisons of the diameter growth rates at 50 years of age in trees in unthinned young-growth stands planted for timber production to those of old trees at the same age indicate that the diameter growth of the 50-year-old trees is consistently less than that of the old trees. However, researchers have found that the growth of young trees thinned to about 125 trees per hectare is similar to that of old trees (Curtis and Marshall 1986). These young-growth stands are productive and have accumulated biomass rapidly (Curtis and Marshall 1986). Therefore, the relatively slower diameter growth of trees in unthinned young-growth stands (Figure 8) is

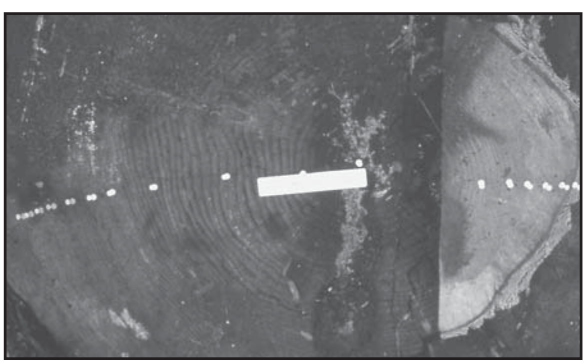

Figure 7. Stump of an old tree and disk from the stump of a young tree in the Oregon Coast Range just west of Corvallis. Marks are set at intervals of 10 years, and indicate rapid growth of the old tree and slower growth of the young tree during the early years. Photograph by John Tappeiner.

Figure 8. Unthinned young-growth stand, approximately 20 years in age. Note the high density of trees with little development of the understory. Photograph by John Tappeiner.

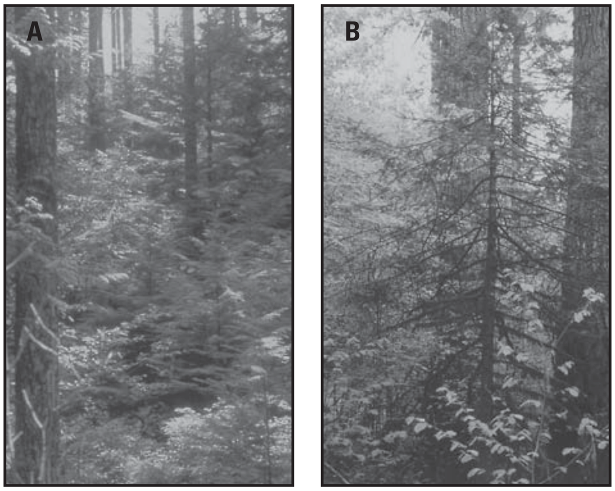

Figure 9. (A) A thinned site typical of those surveyed during studies that were part of the *Managing for Biodiversity in Young Forests Project* and (B) old growth in the Oregon Coast Range. The young-growth stand was thinned fairly heavily and has developed an understory containing shrubs and conifers. The old-growth stand supports relatively few large trees spaced widely, and an intermediate structure in the understory. Thinning may help accelerate the development of old-growth characteristics in dense young stands. Photographs by John Tappeiner (A) and John Bailey (B).

likely a result of high tree density (commonly >250 trees per hectare) and competition among trees, rather than a change in site productivity. Density reduction (thinning) will be necessary in young-growth stands if these stands are to develop trees with the characteristics of large trees in old-growth stands quickly.

Another consideration is that trees in current old-growth stands appear to have become established over a period of many years, and often vary in age by a range of several hundred years (Figure 5b). For example, in a single plot, large trees can range from 100 to >300 years in age (Tappeiner et al. 1997; Poage 2001). In contrast, the range of ages in young-growth Douglas-fir stands is often quite small, e.g., 5–10 years (Figure 5a). Therefore, the old-growth stands appear to have developed by a gradual establishment of trees over time, probably in conjunction with intermittent disturbances.

These results, and others, support the conclusion that **regeneration** of these old-growth stands occurred over a prolonged period, and that trees grew at low densities with little self-thinning. In contrast, after timber harvest, young-growth stands often develop with high densities of trees of similar age and considerable self-thinning. Young-growth stands today primarily contain trees that were established at about the same time, and thus are developing as a single cohort of even-sized, competing trees (Tappeiner et al. 1997). The rationale for thinning is based, in part, on the contrast between diameter growth rates that trees in old-growth forests achieved when they were young and growth rates that trees in today's young-growth stands achieve. Thinning may help accelerate the development of old-growth characteristics in dense young-growth stands (Tappeiner et al. 1997; Poage 2001; Figure 9). Old-growth characteristics include not only characteristics of the trees themselves but also functional and compositional features of the forest ecosystem.

Douglas-Fir Forests in Western Oregon

Wayne E. Elliott

Most of the federal lands in western Oregon are managed by the USDI Bureau of Land Management (BLM) and the USDA Forest Service. The history of the federal lands managed by BLM is provided here to illustrate the nature of these forests, their age-class distribution, and the basic philosophy that has guided their management.

History of Forest Management

The USDI Bureau of Land Management (BLM) manages a diverse array of natural resources on over 1 million hectares in western Oregon. These lands primarily comprise an extensive checkerboard ownership pattern, as a result of the history of land grants and revestments involving the federal government and private partners, primarily railroad companies. The lands include nearly 850,000 hectares of revested Oregon and California Railroad lands (O & C lands), nearly 162,000 hectares of **public lands**, and about 30,000 hectares of Coos Bay Wagon Road lands.

Forested lands make up approximately 890,000 hectares (~90 percent) of the BLM-managed lands in western Oregon. Extensive areas of these forest lands are covered by young, relatively even-aged forest stands (<40 years in age), with low structural and compositional diversity (see Figure 10). These young-growth stands are the result of management with a major emphasis on wood production according to the principles of **sustained-yield** management, traditionally defined as "management intended to sustain the long-term production of wood volume." This philosophy guided BLM-management activities for many decades prior to current changes related to implementation of the Northwest Forest Plan.

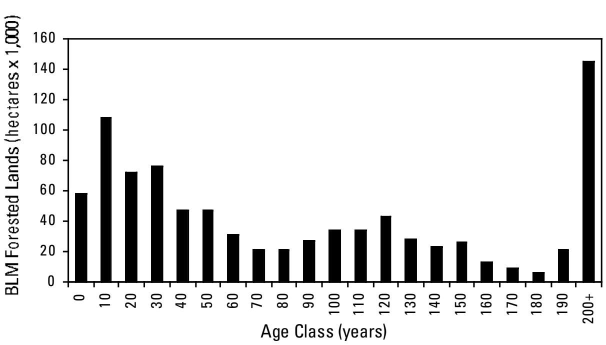

Figure 10. Age-class distribution of all forest lands managed by BLM in western Oregon. Source: USDI Bureau of Land Management.

The O & C lands constituted a unique public trust in the Pacific Northwest in the early 1900s. The lands were transferred to railroad-company ownership as a subsidy to help finance a critical north-south railway link from Portland, Oregon, to northern California. The subsequent sale of these lands was intended to stimulate economic development and community stability in struggling counties in western Oregon. Although the railroad was completed, the construction company declared financial bankruptcy and the federal government reclaimed remaining O & C lands in 1917. In 1937, Congress passed the O & C Act (50 Stat. 875, chapter 876, 43 USC 1181f), which directed that these lands be placed within the Department of the Interior and be managed:

- "for permanent forest production in conformity with the principles of sustained-yield management,"
- to "fix allowable cuts of timber, protect watersheds, regulate stream flow, contribute to local economic stability and provide recreational facilities," and
- to "distribute timber receipts to O & C counties and to the federal treasury for O & C land management."

In July 1946, Congress approved President Truman's plan to merge the General Land Office and the U.S. Grazing Service to form BLM. The challenge for BLM was to manage these lands and meet the multiple provisions of the 1937 O & C Act. Foresters regarded these forest lands to be among the most productive forests in North America. Douglas-fir was the dominant conifer species, and provided wood material of great strength and quality to a nation eager to construct houses and move beyond the Depression years. In general, managers regarded short-rotation, even-aged forest management as the appropriate management direction for these lands to meet the congressional directive, as well the as legislative, funding, and other directives.

During the postwar era of the 1950s, timber management intensified on BLM lands in western Oregon. Emerging silvicultural practices in North America included clearcutting, removing logs and snags, slash burning, thinning, and planting single-species stands on cutover areas (FEMAT 1993). These practices were based on the assumption that forests managed in this way could be cut and regrown at relatively short intervals (e.g., 40–80 years) without negatively affecting long-term site productivity or other resources, such as water quality and soils.

Harvests continued to be guided by these principles through the 1960s and 1970s, and averaged slightly less than 5.66 million cubic meters (1 billion board feet) per year on BLM lands in western Oregon. Further, harvest records indicate annual averages on BLM lands of 5.02 and 5.50 million cubic meters for the respective periods 1970–1979 and 1980–1989 (886 and 971 million board feet, respectively; Oregon Department of Forestry 1999). However, these annual harvests continued to be less than the calculated sustained-yield harvest of 6.80 million cubic meters (1.2 billion board feet) for these lands. Timber harvest was reduced during the 1990s with the listing of the northern spotted owl as threatened under the U.S. Endangered Species Act in June 1990. Additional listings, e.g., the marbled murrelet and various stocks of anadromous fish, occurred soon afterwards and resulted in further reductions in timber harvest.

Reforestation, necessary for timber production and watershed protection, included site preparation, usually by broadcast burning or burning slash piles; planting with nursery-grown seedlings from local seed sources or genetically improved stock; and brush control, if needed, to reduce competition around conifer seedlings. Initial planting densities varied, as did the frequency and intensity of precommercial or **commercial thinning**. These practices focused on timber management and left a legacy of dense, rapidly growing, young Douglas-fir stands.

Current Age-Class Distribution of Young-Growth Stands

Past harvest and reforestation activities have resulted in the even-aged stands characteristic of young growth in the region today. Current age-class distribution data for all land-use allocations (USDI Bureau of Land Management 1992) show that young-growth stands occupy extensive areas of lands managed by BLM in western Oregon. Approximately 35 percent of the agency's 890,000 hectares of forest lands in western Oregon have an average tree age of <40 years (Figure 10). Approximately 14 percent of these lands support forests in the 40-, 50-, and 60-year age classes. Current stand age-class distributions reflect past harvest rates and disturbance events such as fire. Harvest activity in the 1940s and 1950s is reflected in the 50- and 40-year age-class distributions, respectively. Similarly, increased harvest activity in the 1960s and 1970s is reflected in the larger areas in the 30- and 20-year age classes. Harvest rates in the 1980s are reflected in the 10-year age class, which occupies over 100,000 hectares of BLM lands in western Oregon (USDI Bureau of Land Management 1992).

These forest stands are young, densely stocked, and relatively uniform in age. Variation in tree age is usually <10 years, because these stands were planted with nursery stock and had some **natural regeneration** within 10 years of planting. Structural and biological diversity often are low, and areas that have been

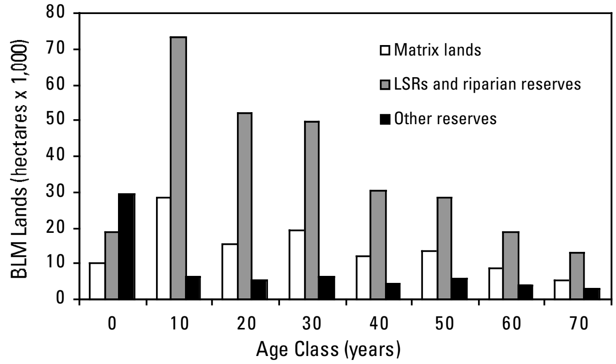

Figure 11. Age-class distribution of forest stands <80 years in age on BLM lands in western Oregon. Source: USDI Bureau of Land Management.

clearcut and artificially regenerated show little age variation. Before the Northwest Forest Plan, these stands would have been managed to produce high yields of wood.

Changing Forest-Management Objectives

Forest management changed significantly on BLM lands in the 1990s with the completion of the Forest Ecosystem Management Assessment Team report (FEMAT 1993) and the Northwest Forest Plan (USDA and USDI 1994). Whereas 90 percent of the land base had been dedicated to a "non declining even flow of timber," now 65 percent of the BLM land base within the area covered by the Northwest Forest Plan is designated as late-successional and riparian reserves. Although the Northwest Forest Plan significantly changed allocations and objectives for forest management, it did not, and could not, rapidly change the condition of the forests, which have been created over decades.

These young, unnaturally dense, Douglas-fir forest stands on BLM lands in western Oregon today provide abundant opportunities for thinning to help develop more biologically diverse and structurally complex forests. Stands <40 years old and those in the 40–60-year age class are located primarily in reserves (Figure 11), where treatments, including thinning, are being focused on enhancing biodiversity and accelerating the development of old-growth characteristics. On matrix lands, the opportunity for commercial wood production exists as a result of needed treatments. As the research studies that are part of the *Managing for Biodiversity in Young Forests Project* indicate, thinning on these lands may contribute to stand vigor and increase vertical and horizontal vegetative structure for a variety of plant and wildlife species.

Project Objectives

The *Managing for Biodiversity in Young Forests Project* is a retrospective analysis, initiated with studies by John Bailey and John Tappeiner, of forest stands typical of those being managed on federal lands in western Oregon. The main question addressed by the project is whether or not biodiversity tends to increase in areas that have been thinned, an observation often made by people who spend time in forests. Such observations have encouraged managers to consider thinning as a management tool that supports the development of old-growth characteristics, including the increased diversity of organisms often considered to be old-growth-associated, in young forests.

Among the specific questions addressed by the project with regard to thinning are the following:

1. Do communities of selected organisms differ among unthinned young-growth, thinned young-growth, and old-growth stands?
2. If communities do differ among stand types, is there evidence that thinning may accelerate the development of community similarity between young-growth and old-growth stands?
3. Do the diversity and abundance of selected forest organisms appear to be related to specific stand features, such as shrubs, **hardwood trees**, remnant old trees, and snags?
4. Are there commonalties across the various organisms studied in terms of stand features that seem important for supporting a relatively high diversity or abundance? In other words, can key structural or compositional features be identified, and will enhancement or protection of these features during management of young-growth stands foster maintenance or development of high native biodiversity?

In addressing these questions, the studies share the following overall objectives[6]:

- To contribute to existing understanding of young forests and their management.
- To contribute to guiding the direction of work that can be done to enhance biodiversity through management of young forests in western Oregon. Project results may provide a basis for forest-ecosystem management in the Pacific Northwest from which future management strategies can be refined (i.e., through ongoing adaptive management; see Figure 4).
- To inform those who manage forest lands in western Oregon of the potential effects of management practices.
- To increase understanding of factors influencing native biodiversity in forests of western Oregon, and how these factors might be manipulated to enhance forest biodiversity.

[6] Additional objectives of individual studies that are part of this project are provided in the Study Objectives, Results, and Recommendations for Management section of this report.

Materials and Methods[7]

Project Study Area

Description of Study Area

The *Managing for Biodiversity in Young Forests Project* comprises studies conducted primarily in young- and old-growth stands typical of the Douglas-fir forests in the Coast Range and Cascade mountains of western Oregon. Stands chosen for research (Table 1; Figure 12) included 32 pairs of unthinned and thinned young-growth stands and 20 old-growth stands originally inventoried by Bailey (1997). The old-growth stands usually were located within 10 kilometers of, and were similar in site conditions to, 20 of the 32 paired unthinned-thinned stands. This group of stands, i.e., the unthinned-thinned pair of young-growth stands and the associated old-growth stand, is referred to as a "stand triad." Additional stands were included for several of the studies (see Table 2; Figure 13). Most of the stands inventoried were located on federal lands managed by BLM.

The study area in which stands were located included the region from just south of the Columbia River in the Cascade mountains, to west of Tillamook in the Coast Range, and west of Medford in southwestern Oregon (Figure 12). Stand elevations ranged from 250 to 800 meters, and precipitation, primarily in the form of rain, was 100–300 centimeters annually (Bailey 1997). Most stands were in the Western Hemlock Zone (Franklin and Dyrness 1988).[8] The shrub layers largely comprised common **understory** species such as salal, bracken fern, vine maple, Oregon-grape, and sword fern (see Appendixes B–C[9]). Each stand was large enough to allow for sampling of 10 hectares of interior habitat (see Bailey 1997). Researchers sampled not only various combinations of the same stands but also generally within the same portions of each of the selected stands as were sampled by Bailey (1997).

Young-Growth Stands

The criteria met by the 32 pairs of unthinned and thinned young-growth stands included the following:

- Stands were ≥50 years in age at the beginning of the study.
- Thinned stands were similar to the unthinned stands with which they were paired in terms of slope, **aspect**, elevation, and potential natural vegetation type.
- Documentation of the year and intensity of thinning implemented was available.
- No additional management treatments other than thinning had been conducted in any of the young-growth stands.

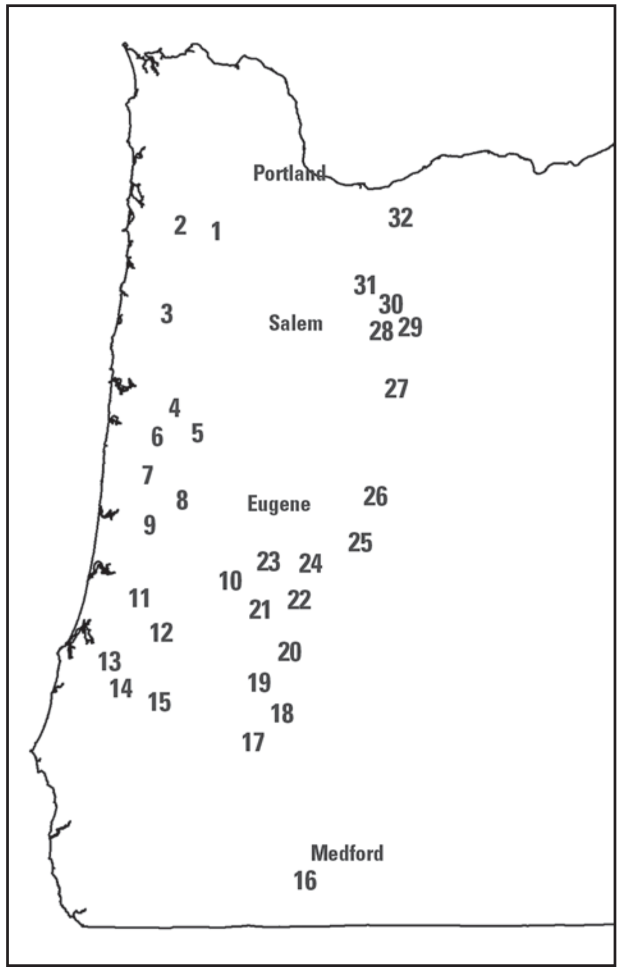

Figure 12. Study area in western Oregon and approximate locations of study sites surveyed during the *Managing for Biodiversity in Young Forests Project*.

An even-sized cohort of Douglas-fir dominated the **overstory** of the young-growth stands. Few residual large trees or snags from previous stands remained in the stands. Prior to thinning, each young-growth stand occupied the area that would become adjoining unthinned and thinned stands, with an arbitrary separating line between them. Thinning was completed

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[7] Additional detail can be found in Hagar et al. (1996), Bailey (1997), Peterson and McCune (2000a–b, 2001), Peterson et al. (2000), and Rosso (2000).

[8] Several of the southern sites were located within or near the transition into the Douglas-fir Zone (Franklin and Dyrness 1988).

[9] Common and scientific names of vegetation referred to in the text are provided in Appendix B. Selected taxonomic resources are listed in Appendix C.

Table 1. Description of unthinned and thinned young-growth stands and old-growth stands surveyed during the *Managing for Biodiversity in Young Forests Project* (modified from Bailey 1997). Approximate locations are indicated by site number in Figure 12.

Site	Location	Organisms[a]				Young-growth stand description				Density (trees per hectare)		
		V	E	M	B	Stand age (years)	Site index[b]	Year thinned	% volume removed	Young-growth stands		Old-growth stands
										Unthinned	Thinned	
1	Bald Mountain	*				70	120	1976	33	249	146	--
2	Bear Creek	*	*			100	134	1972	27	133	128	81
3	Sand Creek	*	*		*	70	128	1971	32	415	289	54
4a	Beaver Flat	*	*	*	*	50	130	1974	51	323	151	47
4b[c]	Marys Peak paired young-growth				*	50	--	1980	30	530	120	--
5	Highpass Road	*				90	114	1971	20	160	133	49
6	Bummer Ridge	*				95	98	1976	25	178	111	--
7	Gnome	*	*	*	*	60	120	1983	43	494	146	64
8	D-Line Road	*	*		*	60	121	1972	12	388	183	77
9	Clay Creek	*				70	119	1980	48	252	180	--
10	North Ward Creek	*	*	*	*	50	130	1985	50	237	153	54
11	Elliott State Forest	*	*			100	131	1973	54	230	121	104
12	Little Wolf Creek	*			*	60	102	1980	55	291	143	52
13	Blue Ridge 26	*	*			50	127	1976	10	447	230	62
14	Blue Ridge 35	*				50	127	1982	28	447	163	--
15	Burnt Creek	*	*			80	117	1975	33	153	77	62
16	Panther Gap	*		*		120	78	1981	20	156	99	89
17	Days Creek	*				90	117	1977	40	242	69	--
18	Windy Ridge	*	*			80	115	1977	40	388	175	69
19	Little River	*				110	96	1978	30	272	109	--
20	Honey Creek	*	*	*		100	98	1971	21	198	128	54
21	Big River	*				80	130	1977	15	259	175	--
22	Wildwood	*				65	121	1981	22	541	252	--
23	Perkins Creek #1	*	*			60	134	1981	36	259	195	106
24	Perkins Creek #2	*				60	115	1981	30	360	225	--
25	Eagle' s Rest	*	*			90	90	1974	50	146	77	96
26	Marten Ridge	*	*			70	127	1981	50	272	59	69
27	Keel Flat	*	*			60	141	1971	25	289	148	42
28	Fawn Creek	*				120	110	1972	8	111	84	--
29	Rooster Rock	*	*			110	114	1971	22	183	163	69
30	Horse Creek	*				110	82	1971	20	188	153	--
31	Meyer Creek	*				120	106	1970	23	269	126	--
32	Gordon Creek	*	*			60	118	1985	60	291	121	84

[a] V = vegetation, E = epiphytes, M = moths, and B = birds.
[b] King (1966), base age 50.
[c] Unthinned-thinned pair of young-growth stands on Marys Peak, Siuslaw National Forest, sampled in place of Beaver Flat young-growth stands after that site was harvested.

through BLM timber sales, generally 10–20 years before the project was initiated (Table 1).

Stands were thinned only once, and thinning ranged from heavy to light. Typically, approximately 25–30 percent of the stand volume was removed during thinning operations, and removal ranged from 8 to 60 percent across all stands. Relatively large dominant and codominant trees were left in the stands, and relatively small trees of commercial size were removed from the main canopy to favor the development of conifers with large **crowns** and stems (i.e., "thinning from below"). In general, conifers <15 centimeters in diameter at breast height (**DBH**) and hardwoods were left in the stands. No other treatments were applied to the thinned

Table 2. Summary of forest stands surveyed during the *Managing for Biodiversity in Young Forests Project.*

Project study organisms	Major forest stands (number)[a]		Additional stands
	Stand triads[b]	Paired young-growth stands	
Trees, shrubs, and herbaceous vegetation	20	12	--
Epiphytes	17	--	17 hotspots
Moths	5	--	4 clearcuts, 1 meadow
Birds	6	--	1 paired young-growth[c]

[a] Sites studied by Bailey (1997).
[b] Paired unthinned and thinned young-growth stands, with associated old-growth stand.
[c] Pair of unthinned and thinned young-growth stands located on Marys Peak, Siuslaw National Forest.

stands. Overstory density of trees >20 centimeters DBH ranged from 111 to 541 trees per hectare in unthinned stands, and from 59 to 289 trees per hectare in thinned stands during the time that the studies were conducted.

Old-Growth Stands

Old-growth stands located near 20 of the unthinned-thinned pairs of young-growth stands supported trees >200 years in age, and exhibited characteristics described by Franklin and Spies (1991)—e.g., the overstory trees were large (>100 centimeters DBH) and the stands were **multilayered** with relatively low tree densities. Old-growth stands had 47–106 trees >20 centimeters DBH per hectare and a highly variable understory of seedlings, saplings, and shrubs. Little evidence of human disturbance was present in the old-growth stands.

Project Study Stands

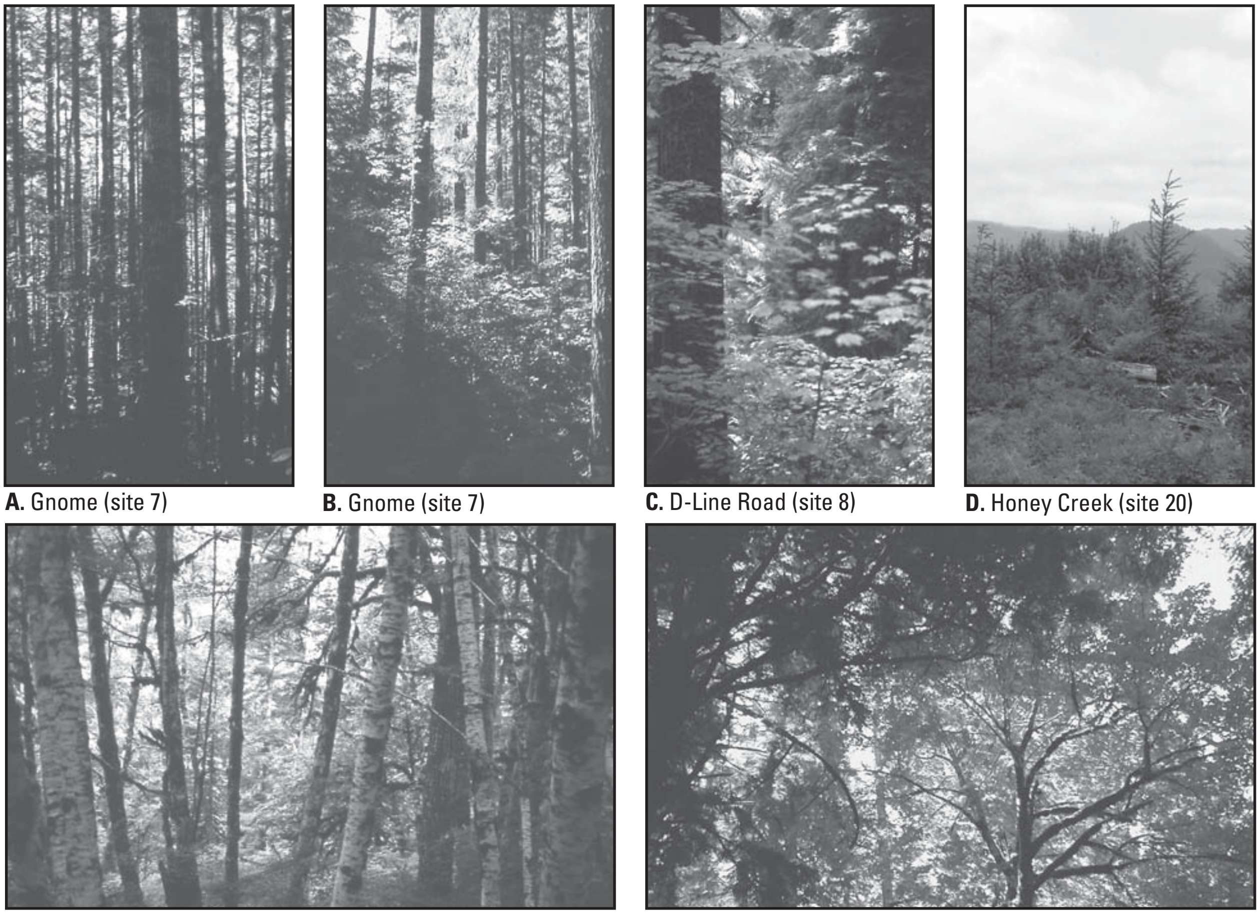
Data on over- and understory trees, shrubs, and herbaceous vegetation were collected on 32 pairs of unthinned and thinned young-growth stands, and 20 old-growth stands, i.e., all except site 4b, Table 1 (see also Figure 12; Bailey 1997; Bailey and Tappeiner 1998; Bailey et al. 1998). Research on other organisms was conducted on various combinations of these particular stands, as follows (Tables 1–2; Figure 12):

- **Epiphytes**—sites 2–4a, 7–8, 10–11, 13, 15, 18, 20, 23, 25–27, 29, and 32.
- Moths—sites 4a, 7, 10, 16, and 20.
- Birds—sites 3–4a/b, 7–8, 10, and 12.

Additional project study stands included (1) 17 landscape-level **hotspots**, one associated with each of the 17 stand triads inventoried for epiphytes, (2) 4 clearcuts and a meadow (site 16), one associated with each of the 5 stand triads sampled for moths, and (3) an unthinned-thinned pair of young-growth stands (site 4b) on Marys Peak, Siuslaw National Forest, associated with one of the 6 stand triads (site 4a) sampled for birds.

Researchers studying epiphytes worked at 17 of the stand triads (Tables 1–2; Figure 12) and at associated landscape-level hotspots. The hotspots were areas that seemed likely to support an unusually high abundance or diversity of epiphytes, or epiphytes that generally are uncommon in relatively homogeneous, conifer-dominated forests. Much of the within-stand diversity and abundance of epiphytes in managed young coniferous forests often is associated with unusual stand features, such as hardwoods or remnant trees (Neitlich and McCune 1997). Hotspots were included in these studies because relatively less is known about the importance of unusual large-scale (landscape-level) features for epiphytes than about the importance of within-stand features. Hotspots were located through examinations of aerial photographs of the area near each set of young- and old-growth stands, and subsequent observations on the ground. Aerial photographs helped in identifying hotspots by structure (e.g., areas with hardwood-dominated gaps) and topography (e.g., **riparian** areas and those with rocky outcrops). On the ground, researchers looked for species normally associated with rich communities, primarily **nitrogen-fixing** species. Hotspots were chosen near (usually within 4 kilometers of) each unthinned-thinned pair of young-growth stands sampled. Hotspots sampled in the epiphyte studies included 11 riparian areas, 3 hardwood gaps (relatively open forest areas occupied by hardwood trees or shrubs), 2 rocky outcrops, and an opening that had been created by a road.

The moth study was focused on five of the stand triads (Tables 1–2; Figure 12). Four clearcuts and a meadow (site 16) were included in the study to increase the degree to which samples represented the range of forest conditions found in the study area. The clearcuts were located near the remaining stand triads sampled, and were harvested up to 15 years prior to the initiation of the project. The clearcuts and meadow had site conditions and associated vegetation that differed



A. Gnome (site 7) **B.** Gnome (site 7) **C.** D-Line Road (site 8) **D.** Honey Creek (site 20)

E. D-Line Road (site 8) **F.** Typical site

Figure 13. Organisms in a range of habitats were sampled during the *Managing for Biodiversity in Young Forests Project*. Stand types surveyed for vegetation, epiphytic lichens and bryophytes, moths, and birds included: (A) unthinned, (B) thinned, and (C) old-growth stands. In addition, (D) clearcut stands were surveyed for moths, and hotspots were surveyed for epiphytic lichens and bryophytes. (E) Riparian areas and (F) hardwood gaps were among the types of hotspots sampled. (See also Figure 12 and Table 1.) Photographs by Ruth Jacobs (A–B), Eric Peterson (C, E), Jeff Miller (D), and Bruce McCune (F).

considerably from those found in young- and old-growth stands, and seemed likely to support different moth communities.

Birds were surveyed in six of the stand triads (Tables 1–2; Figure 12). An additional pair of young-growth stands on Marys Peak (site 4b), Siuslaw National Forest, was included for this portion of the project, because one pair of young-growth stands (site 4a) was harvested before bird sampling was completed. This additional pair of unthinned and thinned young-growth stands was located near the old-growth stand sampled with the harvested pair of stands.

Study Organisms

Organisms chosen for study as part of the Managing for Biodiversity in Young Forests Project *included trees, shrubs, and herbaceous vegetation; lichens and bryophytes growing on trees and shrubs (epiphytes); moths; and birds. These organisms have complex interdependencies that are only partially understood (Figure 14), as described in this section. Selection was limited to these particular organisms primarily by logistics and available funding.*

Trees, Shrubs, and Herbaceous Vegetation

Forests of western Oregon are prominent features of the landscape. Trees, shrubs, and herbaceous vegetation in these forests provide shelter, substrate, and food for forest organisms. In addition, they provide organic matter to soils, play a major role in nutrient cycling, protect watersheds from erosion, and enhance the aesthetics of forest ecosystems. Because forest composition and structure change with age, communities of forest organisms that depend on vegetation often change as well. Forest managers need information on such changes in vegetation and associated species, and on how these changes can be influenced by management activities, in their efforts to foster biodiversity in forests. Effects of various forest-management strategies on vegetation in the Pacific Northwest have received increased attention recently through both retrospective (e.g., Thysell and Carey 2000; Traut and Muir 2000) and experimental (e.g., Halpern et al. 1999; Thysell and Carey 2001) approaches. Results from such studies, and the findings of studies reported here, will inform managers' attempts to enhance the diversity of vegetation and associated species in forests typical of those located in western Oregon.

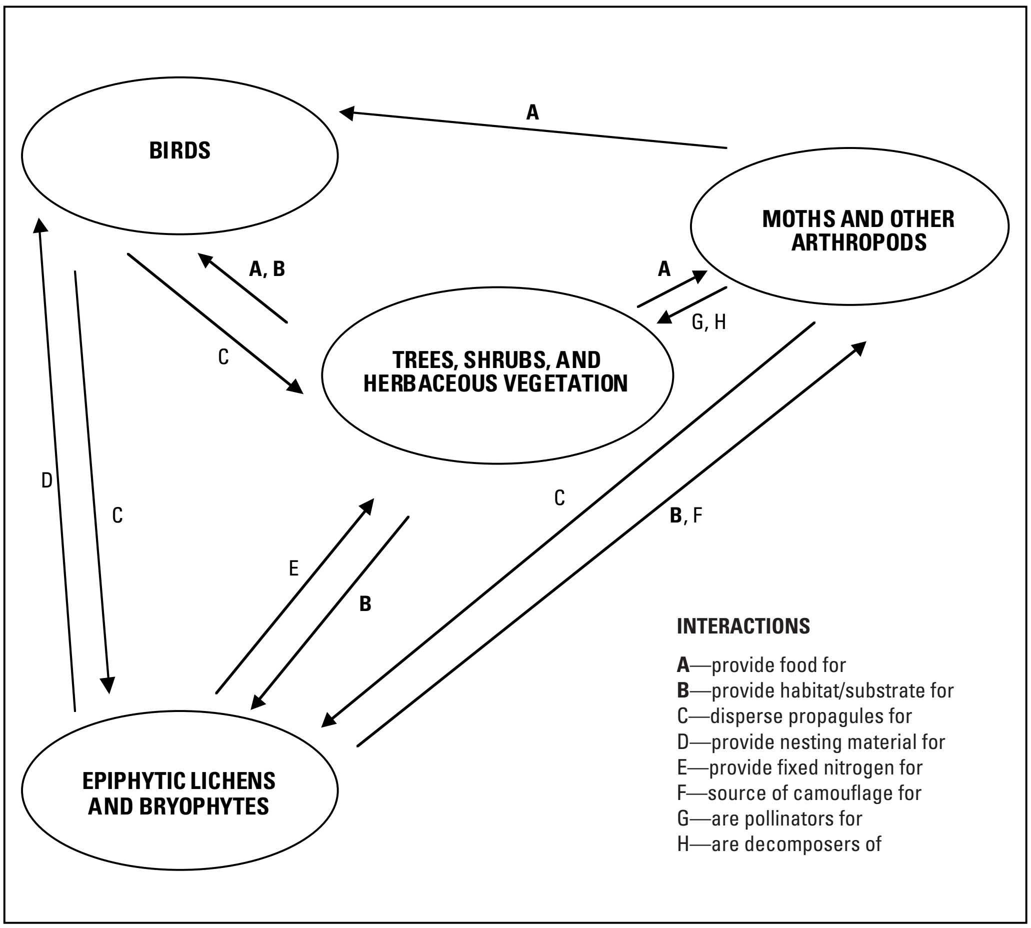


Figure 14. Some of the interactions that occur among groups of organisms studied during the *Managing for Biodiversity in Young Forests Project*. Interactions studied as part of the project are indicated by boldface type.

Epiphytic Lichens and Bryophytes

Epiphytes

Lichens and bryophytes are common epiphytes in forests of western Oregon. Epiphytes are nonparasitic organisms that grow on plants. They derive most of their moisture and nutrients from the atmosphere.

Lichens

Lichens are symbiotic associations between a fungus and a photosynthetic partner (green algae, cyanobacteria, or both). Lichens generally are grouped into three forms on the basis of their overall habit and morphology. These forms are:

- *foliose:* leaflike, flat and only partially attached to the substrate.
- *crustose:* crustlike, tightly attached to the substrate along the lichen's lower surface.
- *fruticose:* shrublike, standing out from the surface of the substrate.

The foliose and fruticose lichens together are known as *macrolichens*, and these were the focus of the studies included in this project.

Macrolichens often are divided into three functional groups, based on their role in the ecosystem:

- *forage lichens*: generally fruticose lichens, also known as "alectorioids" (including *Alectoria* spp. and *Bryoria* spp.), used for forage by a variety of mammals.
- *matrix lichens*: the remainder of the macrolichens, which typically are dominant lichen species in young forests. These macrolichens sometimes are known as "green algal foliose lichens" to distinguish them from nitrogen-fixing and forage lichens.
- *cyanolichens*: lichens containing cyanobacteria as the primary photosynthetic partner, which enables them to fix atmospheric nitrogen. These lichens also are known as "nitrogen-fixing macrolichens."

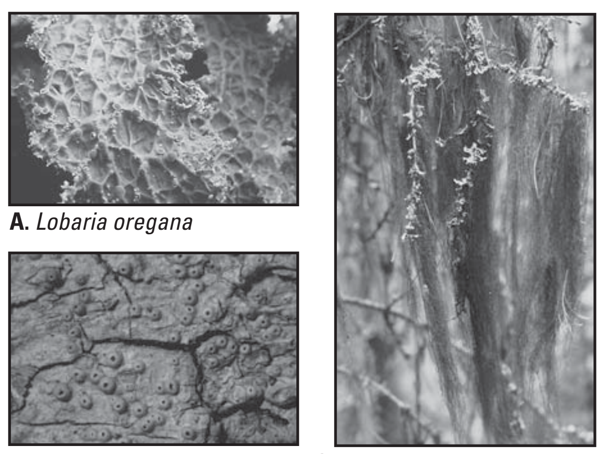
Bryophytes

Bryophytes include mosses, liverworts, and hornworts. For purposes of this project, bryophytes were divided into:

- *mats:* spreading along the surface.
- *tufts*: standing out in a spherical to hemispherical arrangement from a main point of attachment.

Epiphytic Lichens and Bryophytes

Lichens (Figure 15) and bryophytes (mosses, liverworts, and hornworts) are prominent epiphytes in western Oregon forests, and are important components of these ecosystems. They serve as nitrogen-fixers (e.g., *Lobaria oregana*), providing important inputs of plant-available nitrogen to ecosystems; as hydrological buffers, by absorbing, storing, and releasing water (e.g., moss mats); as part of food webs (e.g., in the diet of arthropods, flying squirrels, deer, and elk); as nesting material for marbled murrelets, flying squirrels, and other birds and mammals; and as habitat for insects and other arthropods. In addition, epiphytic bryophyte mats are harvested as a secondary forest product (see Peck and Muir 2001). In many Pacific Northwest forests, the biomass of lichens and bryophytes on trees exceeds several tons (dry mass) per hectare (McCune 1993).



A. *Lobaria oregana*

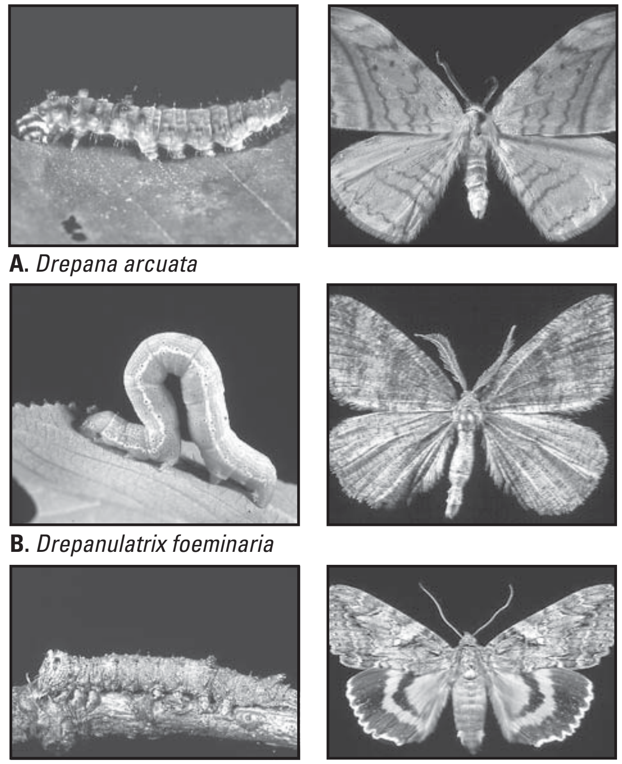
B. *Thelotrema lepadinum*

C. *Bryoria pseudofuscescens*

Figure 15. Lichens generally are grouped into three forms: (A) foliose, (B) crustose, and (C) fruticose. The foliose and fruticose lichens together are known as macrolichens. Photographs by Bruce McCune.

Communities of lichens and bryophytes develop slowly. Because of this, many of these species are considered to be associated with old-growth forests (Lesica et al. 1991; McCune 1993; Neitlich 1993). Old-growth forests generally have a higher diversity and abundance of epiphytes than do stands <150 years old, and the epiphyte communities present in old-growth forests differ from those in young forests (Lesica et al. 1991; McCune 1993; Neitlich 1993). Changes occur in abiotic conditions as forest stand structure changes over time (e.g., light and moisture in the mid- and lower canopy generally increases), and these changes appear to facilitate epiphyte community development. Nonetheless, the factors that limit epiphyte distribution are poorly understood. For most of these species, it is not known whether they require specific structural and biological features characteristic of relatively old forests, or simply are slow to **disperse**, establish, or grow—thus slowing the rate at which they recolonize an area after tree harvest and thereby resulting in an association with relatively old forests (Peck and McCune 1997; Sillett et al. 2000).

Because of their importance in forest ecosystems, and the association of many species with old-growth forests, epiphytic lichens and bryophytes are increasingly being considered in the practice of forest-ecosystem management (FEMAT 1993; USDA and USDI 1994). More than 65 species of lichens and bryophytes are listed as potentially sensitive to management practices, and specifications about epiphyte survey and management are prescribed in the **Record of Decision** and **Standards and Guidelines** (USDA and USDI 2001). More than 20 of these species occur only in the Pacific Northwest.



A. *Drepana arcuata*

B. *Drepanulatrix foeminaria*

C. *Catocala aholibah*

Figure 16. Although numerous moths are generalists and can feed on a range of vegetation species, some are specialists and can survive only if the particular food for which they are specialized is available. Moths shown are specialized on: (A) alder, (B) various species of *Ceanothus*, and (C) oak. Photographs by Jeff Miller.

Moths

Moths function in the dynamics of forest ecosystems during both their caterpillar (immature) and flying (adult) stages as defoliators, decomposers, prey or hosts to carnivores, and pollinators. The biodiversity of moths is linked to the ecosystem through their influences on nutrient cycling, plant population dynamics, and food-web dynamics (Miller 1993). Most of the moth species in the forest are specialists (Figure 16) and can feed on

Moths

Moths and butterflies are insects that belong to the Order Lepidoptera, and insects, along with spiders, crustaceans, and some other invertebrates, are all arthropods. Moths, which comprise far more species than do butterflies, are nocturnal and have threadlike or feathery antennae. In the study reported here, moths were categorized by functional group based on their food source, which emphasizes one aspect of their function in the ecosystem (i.e., herbivory). Nearly all moths are plant-feeders in their caterpillar stage, and functional groups were based on the following host plants: *conifers, hardwood trees and shrubs, mixed conifers-hardwoods, herbs and grasses,* and *detritus*. Moths also can be grouped according to whether they are specialists or generalists. Specialists require specific circumstances, e.g., a particular food plant, in order to live, develop, and reproduce. In contrast, generalists can survive under a wide range of conditions, and are not specialized such that they can live only under a particular set of circumstances—in this case, the particular food types available.

only a few, if not one, plant species. If that plant species is lost from the forest, then the moth and the function that it provides are lost as well. Thus, patterns in the biodiversity (i.e., species richness and relative abundance) of moths are related to the biodiversity of host plants in forests.

Reciprocally, moths influence plant communities, and plant communities may change if moth abundances change. In addition, populations of species that prey on moths (e.g., some birds and bats) may change if forest moth abundance and species composition change. Thus, patterns in moth biodiversity, which can be observed and used to compare and contrast ecological situations and practices involved in forest management, have important implications for other organisms in the ecosystem. Despite their ecological importance and potential value as indicators of forest condition, no policies or mandates exist concerning the management of moths.

Birds

Natural resource agencies increasingly are including neotropical migratory birds in conservation management goals (Finch and Stangel 1993). Forest-management practices influence habitat for neotropical songbirds by altering stand structure (Hansen et al. 1995; Hagar et al. 1996) and landscape patterns (McGarigal and McComb 1995). Although changes in the abundance of some species of songbirds have been observed following forest-management activities such as thinning, the functional mechanisms underlying these changes have not been studied. Responses of organisms on which birds depend for food, e.g., plants and arthropods (including moths), to forest-management practices may influence the responses of birds by influencing food availability.

Although most bird species are not directly associated with particular plant species, they may be linked to certain plants through their arthropod prey. Arthropods are an important part of the diet of most neotropical migratory birds that breed in forests of the Pacific Northwest (Ehrlich et al. 1988). Most arthropods select specific host-plant species (Edwards and Wratten 1980), and arthropod community composition changes with stand and tree age, structure, and size (Jackson 1979; Schowalter 1989). Forest-management practices can affect stand structure and composition, with consequences for arthropods. For example, commercial thinning can influence **cover**, density, and frequency of shrubs in the understory (Bailey and Tappeiner 1998; Bailey et al. 1998). Alterations in forest structure that affect understory shrubs may affect moths and other arthropods (Doolittle 2000), and hence bird populations and communities. In fact, availability of food may be the ultimate factor (Hilden 1965) causing changes in bird abundance related to management-induced changes in stand structure in forests of the Pacific Northwest. Although only a few studies have examined changes in bird abundance in relation to management-induced changes in stand structure in forests of the Pacific Northwest (e.g., Hagar et al. 1996; Haveri and Carey 2000), even fewer have examined how management practices influence the availability of arthropod prey for insectivorous forest birds (e.g., Hagar 1993; Weikel and Hayes 1999).

Birds

This study included the resident and neotropical migratory songbirds, woodpeckers, and hummingbirds. Songbirds are known also as the passerines, i.e., the perching birds. Neotropical migratory songbirds migrate across the United States-Mexico border.

Study Methods

Trees, Shrubs, and Herbaceous Vegetation

Research on trees, shrubs, and herbaceous vegetation involved inventories of species at several places in each stand. Approximately ten (6–12) points were established on a grid at intervals of 50–75 meters in an interior area (>10 hectares in size) of each stand. The species, DBH, total height, **live-crown ratio**, and crown radius were tallied for each living codominant and dominant overstory tree with a DBH >20 centimeters at each center point with variable-radius plots. Five 70.8-square-meter circular plots, one at the center point and the others at 15 meters from the center point in each cardinal direction, were used to inventory understory trees at each point. Understory trees (2.5–20.0 centimeters DBH and below the main canopy) were tallied in each of these plots, and tree seedlings (<2.5 centimeters DBH, >15 centimeters in height) were tallied in smaller, 17.6-square-meter circular subplots nested within the understory-tree plots. Shrubs were tallied in the subplots as well, and were segregated into two layers: tall shrubs (>150 centimeters in height) and low shrubs (50–150 centimeters in height). Densities (number of stems per subplot) of tall shrubs were recorded by species, and percent cover of low shrubs was estimated visually. Low shrubs included nonwoody species, such as bracken fern and sword fern, if these species fell within the bounds of the low-shrub height class. Percent cover of each herbaceous species was estimated in several additional 1-square-meter subplots in each understory-tree plot.

Epiphytic Lichens and Bryophytes

Epiphytic lichens and bryophytes were examined in two studies: one that focused on all macrolichens present on both trees and shrubs, and one that considered both macrolichens and bryophytes on shrubs only.

Macrolichens on Trees and Shrubs

An ocular search for macrolichens on trees and shrubs was conducted in one 0.38-hectare (34.5-meter radius) circular plot within each stand. The ocular search, limited to a 2-hour period, included all macrolichens on woody vegetation (living or dead) that were >0.5 meter above the ground and accessible without climbing trees. The search also included recent macrolichen litterfall. Coarse abundance ratings (1 = 1–3 individuals; 2 = 4–10 individuals; 3 = >10 individuals; 4 = occurs on >50 percent of substrate) were assigned to every macrolichen species found in each circular plot. In addition, data were gathered on tree species, basal area, canopy density, and shrub species present.

Macrolichens and Bryophytes on Shrubs

Studies of macrolichens and bryophytes on shrubs ≥2 meters in height included two methods: time-constrained ocular surveys of a single, large, circular plot in each stand sampled, and fine-scale cover estimates made on a subset of tall shrub stems from each large plot. Ocular surveys were intended to increase the total number of species sampled, whereas the finer-scale cover estimates were focused on detecting relatively small-scale, but potentially important, differences in abundance (percent cover) of species. The tall-shrub species sampled included vine maple, oceanspray, California hazel, and Pacific rhododendron. Shrubs in the genera *Rosa*, *Rubus*, and *Vaccinium*, which appeared to provide poor substrate for epiphytes, were excluded from sampling.

The ocular surveys were constrained to 1.5 hours in each stand, and the species and abundance class (1 = 1–3 individuals; 2 = 4–10 individuals; 3 = >10 individuals; 4 = occurs on >50 percent of substrate) of macrolichens and bryophytes present on tall shrubs were determined within each large plot. Fine-scale cover estimates were made on 20 shrub stems, chosen without bias, from throughout each large plot. A stem microplot, i.e., a 0.5-meter section centered 1.5 meters from the base of the stem, was sampled on each shrub stem, and percent cover (the percentage of the stem microplot occupied by each macrolichen or bryophyte species) was recorded. Some stands had <20 tall-shrub stems, and no stem-microplot surveys were conducted in these stands. Ocular surveys were made in all stands, except for the few that lacked tall shrubs entirely. The species, diameter, age, and life-class group (young whip, vigorous mature, declining, decadent) of each sampled stem was recorded. Densities of tall-shrub stems were estimated by sampling randomly selected subplots (3-meter radius) within each large plot.

Moths

Moths were sampled 9–12 times a year in each stand. Sampling involved placing three 22-watt blacklight traps in one location within each stand (minimum size = 2–5 hectares) during each sampling period (Figure 17). Traps within a given plot were placed 100–150 meters apart. They were operated for two consecutive nights once every 3 weeks from May through October. Collections were not made on the 3 days prior to and following the full moon.

Trapping records from each stand type were pooled, and moths were counted to assess abundance (total number of individuals collected) and species richness (number of species) of resident fauna. Moths then were sorted into functional groups based on their food

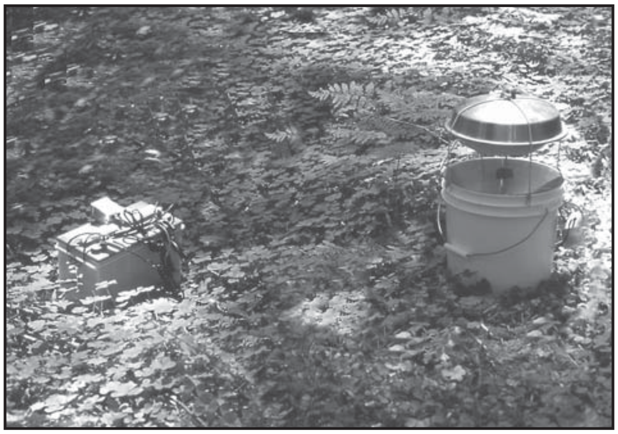


Figure 17. Adult moths were captured at night with an ultraviolet blacklight trap. Moths were identified, counted, and sorted into functional groups based on their food resources. Photograph by Jeff Miller.

resources—conifers, hardwood trees and shrubs, mixed conifers-hardwoods, herbs and grasses, detritus, and unknown.

Birds

Data on abundance and community composition of resident and neotropical songbirds, woodpeckers, and hummingbirds were gathered during four visits (Ralph et al. 1995) to at least ten stands each year during three consecutive early spring–summer seasons. Observations were made by point counts (Reynolds et al. 1980) at 1–6 point-count locations in each stand. Point-count locations were visited between a half hour before and 4 hours after sunrise. This protocol allowed for comparisons of the abundance of common species (i.e., species that occurred in ≥75 percent of the 20 stands) among stand types. Abundance was calculated as the mean number of observations per stand per year for each species, and species richness as the total number of species observed in each stand per year. Although bird abundance is not necessarily an indicator of overall habitat quality (Van Horne 1983), it does provide information on the stand conditions in which each species was observed most commonly. Differences in abundance and species richness among stand types were analyzed by analysis of variance.

Bird diets were described by identifying arthropod fragments from fecal material collected from two species of forest birds mist-netted in the spring (Figure 18). These analyses focused on Swainson's thrushes and Wilson's warblers, because these species forage primarily in the forest understory, where it was feasible to capture them and sample food availability (i.e., arthropods). Fecal material was stored in alcohol (Rosenberg and Cooper 1990) pending identification of arthropod fragments. In addition, arthropods were collected within 8 days of collecting the fecal samples to provide a reference collection and estimates of arthropod availability. Individual branches of foliage from nine major understory shrub and tree species (bracken fern, California hazel, Douglas-fir, oceanspray, salal, salmonberry, sword fern, vine maple, and western hemlock) were clipped and beaten to dislodge arthropods. Each beaten branch constituted a sample of arthropods. The branches themselves were dried and weighed individually after arthropods were collected to provide a standardized estimate of arthropod abundance (number per mass of dried plant material). These shrub, tree, and arthropod samples allowed comparisons to be made between the frequency of occurrence (number of samples of occurrence/total number of samples) of arthropod orders in bird diets and their frequency and abundance on understory shrubs and trees.

Figure 18. Swainson's thrush and Wilson's warbler were captured with mist nets. After fecal samples were collected, the birds were released. Arthropod fragments then were sorted from the fecal samples and identified. Photograph by David Vesely.

Variation in the abundance of selected bird species among stands was modeled (multiple regression) as a function of vegetation characteristics for the 14 young-growth stands from which point-count data were collected. Habitat data (cover of dominant trees, low and tall shrubs, herbs, and canopy foliage) were collected at each of the point-count locations. In addition, stand-level habitat data (from Bailey 1997; Rosso 2000; and Peterson and McCune 2001) were used in the analysis.

Study Objectives, Results, and Recommendations for Management

Trees, Shrubs, and Herbaceous Vegetation

Researchers: John Bailey and John Tappeiner[10]

Study Objectives

The primary objectives of this portion of the *Managing for Biodiversity in Young Forests Project* were to: (1) describe the species composition and structural development of understory vegetation in stands typical of young forests in western Oregon, (2) compare these results to those for understory vegetation in old-growth stands, and (3) describe the apparent influence of thinning on young-growth stand structure, development, and species composition.

Major Findings

Total species richness of herbaceous plants, i.e., number of species present, was consistently higher in thinned stands relative to unthinned and old-growth stands (Table 3), as was percent cover by herbs. Little evidence was found for consistent differences in species composition, especially herbaceous vegetation, among stand types. Herb communities generally differed more by geography (location of stands) than by stand type. All of the native plant species that occurred in the old-growth stands, and a few additional species, were found in the thinned and many of the unthinned young-growth stands. No species were unique to old-growth stands, one was unique to unthinned young-growth stands, and several species were found only in thinned young-growth stands (Table 3). Although thinned stands had a greater number of **exotic plants** than did unthinned or old-growth stands, including two species that were found only in thinned stands, exotic plant cover in all stand types was low.[11] Furthermore, only a small portion of the greater species richness measured in thinned stands resulted from the presence of exotic species (Table 3). The numbers of native grasses and vines, as well as nitrogen-fixing species, also were greater in thinned stands than in unthinned or old-growth stands.

The density and frequency of occurrence of conifer seedlings, primarily western hemlock, were highest in thinned stands. The higher rate of conifer establishment in the understory of thinned stands was the largest and most consistent difference measured between unthinned and thinned stands (Table 4). Of 32 unthinned-thinned pairs of young-growth stands, 29 thinned stands had conifer seedlings in the understory; in contrast, only seven unthinned stands demonstrated such regeneration. Conifer seedling density and frequency were strongly and negatively correlated with shrub cover in thinned stands. Conifer seedling density and frequency in old-growth stands were intermediate between those found in unthinned and thinned stands. Soil disturbance associated with thinning, along with the reduction of overstory density and increased seed production after

Table 3. Herbaceous species richness (number of species) by stand type across 27 paired unthinned and thinned young-growth stands and 17 old-growth stands, with species unique to each stand type (from Bailey et al. 1998).

Stand type	Species richness	Unique species
Unthinned young-growth	114	Coastal burnweed
Thinned young-growth	133	Blackcap raspberry
		Blue wildrye[a]
		Chaparral willowherb
		Coastal monkey-flower
		Corn lily
		Elk clover
		Evergreen blackberry[b]
		Groundsel
		Lupine species[c]
		Ox-eyed daisy[b]
		Pacific water-parsley
		Pearly everlasting
		Pinesap[d]
		Western waterleaf
Old-growth	91	None

NOTE: Scientific names of vegetation species are given in Appendix B.
[a] Grass species.
[b] Exotic species.
[c] Nitrogen-fixing species.
[d] Monotropoid species, i.e., nongreen plants that obtain nutrients through fungi.

[10] Research reported here is based primarily on Bailey (1997). Details on species composition and stand structural development are reported also in Bailey et al. (1998) and Bailey and Tappeiner (1998), respectively.

[11] The range in exotic cover (percent of plot area covered) and frequency (proportion of plots in which a species was found) in thinned stands was 0.01–0.30 percent and 0.0–0.3, respectively. In old-growth stands, these values were 0.0–0.1 percent and 0.0–0.1, respectively.

Table 4. Stand-level averages for understory characteristics of 32 paired unthinned and thinned young-growth stands and 20 old-growth stands in western Oregon (from Bailey and Tappeiner 1998).

Characteristic	Stand-level averages (standard error)		
	Young-growth stands		Old-growth stands
	Unthinned	Thinned	
Tree seedling density (stems/hectare)	232 (4)	1,432 (52)	1,010 (57)
Tree seedling frequency	0.14 (0.01)	0.51 (0.01)	0.38 (0.02)
Tall-shrub[a] density (stems/hectare)	1,336 (28)	2,085 (40)	2,429 (67)
Tall-shrub frequency	0.56 (0.01)	0.82 (0.01)	0.93 (0.02)
Tall-shrub leaf area index	0.23 (0.01)	0.44 (0.01)	0.42 (0.01)
Salal cover (%)	12 (0.4)	23 (0.5)	10 (1)
Bracken fern cover (%)	2 (0.7)	7 (0.3)	1 (0.1)
Sword fern cover (%)	17 (0.4)	13 (0.5)	14 (1)
Oregon-grape cover (%)	10 (0.3)	10 (0.5)	10 (1)
Total low-shrub[b] cover (%)	42 (1)	56 (1)	38 (1)
Low-shrub leaf area index	0.91 (0.02)	1.40 (0.02)	0.78 (0.02)

[a] Shrubs >150 centimeters in height.
[b] Shrubs 50–150 centimeters in height.

thinning, probably played a role in seedling regeneration in thinned stands.

Survival and growth of understory trees, i.e., trees 2.5–20.0 centimeters DBH, were greater in thinned than in unthinned young-growth stands. Understory trees had average densities of 158 trees per hectare in thinned stands, and 88 trees per hectare in unthinned stands. In thinned stands, understory tree populations comprised released intermediate or suppressed trees, together with regenerating western hemlock and western redcedar. In thinned stands, 83 percent of these stems were alive, compared to 89 percent in old-growth stands. In contrast, only 52 percent of the understory trees were alive in unthinned stands, and comprised suppressed trees and a few regenerating, shade-tolerant saplings. Live-crown ratios in thinned stands averaged 66 percent, as compared to averages of 44 percent and 48 percent, respectively, in unthinned young-growth and old-growth stands.

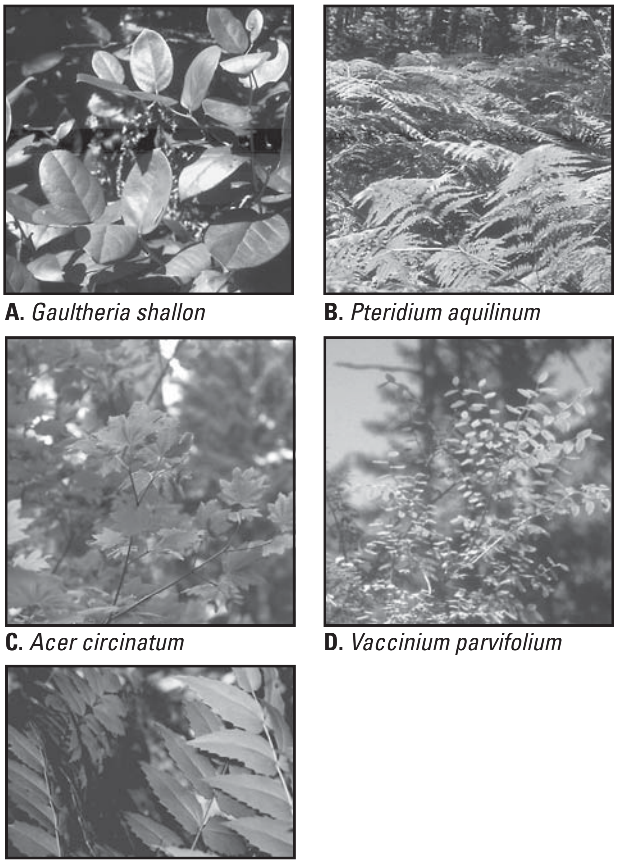
Similar to findings for most seedling variables, tall-shrub characteristics (density, frequency, and leaf-area index) were more similar between thinned and old-growth than between unthinned and old-growth or between unthinned and thinned young-growth stands (Table 4). Tall-shrub density generally was higher in thinned than in unthinned young-growth stands (Table 4), but was more variable than conifer seedling density and frequency. In pairwise comparisons between the 32 pairs of unthinned-thinned young-growth stands, tall-shrub stem density was significantly higher in 14 thinned stands and 5 unthinned stands.

Total low-shrub cover generally was highest in thinned young-growth stands (Table 4). Thinned stands had greater low-shrub cover than did unthinned stands in 16 of the 32 individual unthinned-thinned pairs, and cover was significantly greater in thinned stands across the 32 pairs of stands. Total low-shrub cover was greater in thinned stands than in either unthinned or old-growth stands for 11 of the 20 stand triads (Bailey 1997). Higher cover by salal and bracken fern in thinned stands was particularly notable.

Thus, thinning appeared to promote the development of multilayered stands (Bailey and Tappeiner 1998), primarily by providing conditions that favored the establishment of shrubs, hardwoods, and conifers in the understory after thinning (e.g., see Figure 19), and by releasing saplings and intermediate-crown class trees in the stand. The number of seedlings and amount of shrub cover established depended on stand density, both before and after thinning, and on the productivity of the site (Figure 20). Unlike thinned stands, unthinned stands had very few seedlings or saplings in the understory, and no or little initial development of a multilayered stand (Figure 8).

Additional Research

The results of this work were supported by research extended to 29 additional sites in the central portion of the Cascade mountains and Coast Range of Oregon, and to six sites each in the Cascades, Siskiyous, and coastal forests of southwestern Oregon. The results of these additional studies were essentially the same as those given for this study (Poage 2001; Tom Sensenig, Oregon State University, personal communication). These studies also compared live-crown and height:diameter (H:D) ratios of trees in young-growth stands managed for timber production to those of trees in old-growth stands (Poage 2001; Tom Sensenig,



A. *Gaultheria shallon* **B.** *Pteridium aquilinum* **C.** *Acer circinatum* **D.** *Vaccinium parvifolium* **E.** *Berberis nervosa*

Figure 19. Typical understory vegetation in stands located in the project study area included: (A) salal, (B) bracken fern, (C) vine maple, (D) red huckleberry, and (E) Oregon-grape. Photographs by Joan Hagar (A–D) and Alyssa Doolittle (E).

Oregon State University, personal communication). Live-crown ratios averaged about 50 percent or higher in the old trees, and 30 percent or less in trees in young-growth stands, depending on stand density and whether or not the trees had been thinned. Old trees also had low H:D ratios (often <40–50), which suggests that they are resistant to disturbance by agents such as wind, fire, and ice (Wilson and Oliver 2000; Wonn and O'Hara 2001). In young-growth stands, these ratios were often closer to 70, which suggests that these trees are relatively unstable, and have relatively low resistance to wind, fire, and ice. Thus, thinning may help trees develop resistance to these environmental variables. **Density management** of young-growth stands is important for growing large, stable trees over much of the landscape.

Conclusions

1. Commercial thinning practices conducted for timber production apparently helped initiate development of diverse, multilayered stands, which should provide habitat for a variety of plant and animal species. Specifically, thinned young-growth stands often had better-developed understories and more tree regeneration than did unthinned young-growth stands. Furthermore, small trees that had no commercial value were freed from some level of competition by thinning, and grew to enhance forest structure.
2. Thinning practices, particularly relatively heavy thinnings early in the development of a stand, may maintain or enhance stand-level, plant species diversity. For example, species richness for herbaceous species (Table 3) and total species richness across trees, shrubs, and herbaceous vegetation (Bailey et al. 1998) were greater in thinned stands than in unthinned and old-growth stands. A portion of this increased species richness was associated with exotic species, but grasses and nitrogen-fixing species also were more abundant in thinned stands. All of the native species that were found in old-growth stands, plus additional species, were found in the thinned and many of the unthinned stands.
3. Many old trees grew rapidly when they were young (30–100 years), and produced large stems and crowns. Recent evidence (Tappeiner et al. 1997; Poage 2001) suggests that old-growth stands developed with low densities. In contrast, most young-growth stands in the region today are developing as dense, uniform, even-sized stands. Thinning of these dense, young-growth stands is likely to promote rapid growth of trees with some characteristics normally associated with old trees in old-growth stands.
4. Thinning of young-growth stands may be useful from the perspective of enhancing both wood production and forest biodiversity.

Recommendations for Management

1. Thin young (<60 years old), dense forests[12] that have regenerated after harvest to promote biodiversity and abundance of understory plants in young-growth stands.[13] Although many years may be needed to achieve the full benefits of this practice for biodiversity, thinning simultaneously allows for commercial wood production.

[12] As noted in the video, Managing for Biodiversity in Young Forests (Tappeiner et al. 2000), in some cases, begin thinning at 10–20 years of age, and continue until 40–50 years of age.

[13] See similar recommendations in "Epiphytic Lichens and Bryophytes," "Moths," and "Birds" in the Study Objectives, Results, and Recommendations for Management section of this report. Also see Thysell and Carey (2000, 2001).

Figure 20. (A) A lightly thinned stand in the Oregon Coast Range. (B) Ten years after thinning, this site supports abundant sword fern and is developing understory vegetation. Results from this study suggest that thinning promotes the development of multilayered stands. Photographs by John Tappeiner.

2. Modify some thinning practices to maintain or enhance forest biodiversity. Variable-density thinning (which also entails leaving some areas unthinned) will provide habitat for a diversity of plants.[14] Some plants thrive in relatively open conditions, whereas others find desirable habitat in relatively closed-canopy forests. Take into account habitat features, such as remnant old trees, and hardwood trees and shrubs, such as vine maple, bigleaf maple, oceanspray, and chinquapin. In particular, consider protecting the following:
   - Large (>50 centimeters in diameter) dead wood on the forest floor that may be present from the previous stand.[15]
   - Remnant old trees that provide important substrate for epiphytes and habitat for other organisms as well.
   - Hardwood trees and shrub species that provide important substrate for epiphytes, food for arthropods that are prey for birds, and cavities for cavity-nesting birds.
3. Pay attention to exotic species that may enter stands after thinning has taken place.
4. Adapt thinning prescriptions, including variable-density thinning, to individual site and stand conditions (e.g., the current stand structure and species composition, and the vulnerability of the site to wind and root disease) and specific management objectives.[16]
5. Consider multiple thinning entries over time in some stands, because the canopy may close quickly in young Douglas-fir forests located on highly productive sites.

[14] Variable-density thinning is likely to be important for other organisms as well. See “Epiphytic Lichens and Bryophytes,” “Moths,” and “Birds” in the Study Objectives, Results, and Recommendations for Management section of this report. Also see Carey and Wilson (2001) and Colgan et al. (1999).

[15] This wood provides valuable substrate for forest floor bryophytes (e.g., see Rambo and Muir 1998), and habitat for a variety of animals (see related papers in Ruggiero et al. 1991).

[16] For example, the density of stands might vary from about 50 trees per hectare to grow large trees quickly to much higher densities to maintain habitat for wildlife associated with relatively high canopy cover.

Epiphytic Lichens and Bryophytes

Macrolichens on Trees and Shrubs

Researcher: Eric Peterson[17]

Study Objectives

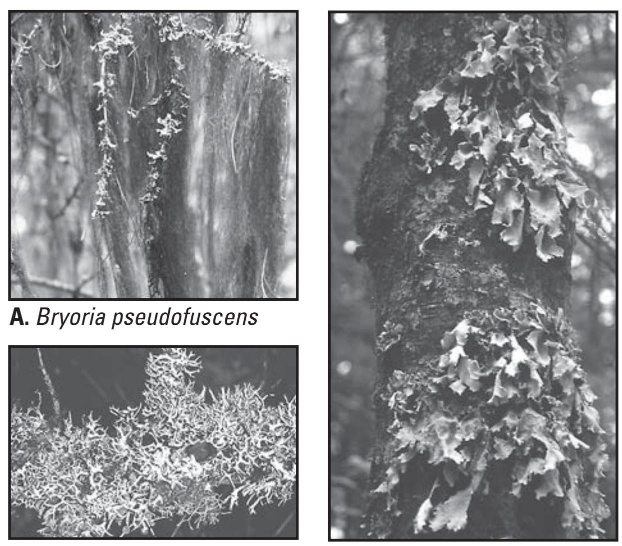
This portion of the project examined species richness, overall abundance,[18] and community composition of macrolichens in unthinned and thinned young-growth stands, old-growth stands, and landscape-level diversity hotspots. The primary objectives were to: (1) characterize the epiphytic macrolichen communities, (2) assess whether or not the communities differed among stand types, (3) determine whether or not thinned stands supported species or communities that were more similar to those in old-growth stands than were those in unthinned young-growth stands, and (4) examine whether or not particular habitat features (within-stand features and landscape-level hotspots) supported unusual species or abundances of epiphytic macrolichens on trees and shrubs.

Major Findings

A total of 117 macrolichen species (Figure 21) were collected, 26 of which were indicators for (associated mostly with) landscape-level hotspots (e.g., riparian areas, hardwood gaps, and rocky outcrops). Eleven species were indicators for old-growth stands or old remnant trees in young-growth stands, one species was an indicator for thinned, and no species were indicators for unthinned young-growth stands (Table 5). In addition to the 26 species that indicated landscape-level hotspots in general, 2 additional species were associated mostly with riparian areas, thus bringing the total number of riparian indicators to 28 species. Of the remaining macrolichen species, approximately 65 species, mostly foliose lichens, were generalists, and approximately 20 species, mostly nitrogen-fixing species, were rare—i.e., found only once or twice.

Species richness ranged from 14 to 51 species per plot, and the average number of species per stand differed little among the four stand types. However, species richness in hotspots was slightly higher (by an average of five species per stand) in hotspots than in the other stand types, as expected. Macrolichen community composition differed strongly among stand types, particularly for ecologically important species groups (Table 6). In general, old-growth stands and old remnant trees in young-growth stands supported more forage lichens and cyanolichens than did young forests. Thinned stands had a slightly greater abundance of forage lichens and *Hypogymnia imshaugii* than did unthinned stands. Richness of macrolichen species summed across all stands of a given type, however, was lower for thinned than for unthinned stands, because thinned stands lacked many species that occurred infrequently in unthinned young-growth stands. Lower richness in these thinned young-growth stands may be a consequence of the homogenization of habitat that often results from traditional thinning practices, and would not necessarily result from alternative thinning practices described in this report.

Hotspots, particularly hardwood gaps, contained a high diversity of macrolichens. Gaps increase the availability of sunlight, particularly during the period of fall through spring when leaves have fallen and macrolichens are often wetted and, thus, most active physiologically. During this time, the surrounding forest probably helps them maintain moisture. Hotspots, especially those with riparian areas and hardwood gaps, also hosted a large number of epiphytic macrolichens not well represented in upland forests. These macrolichen species included many that are able to fix nitrogen. In fact, most cyanolichens inhabited



A. *Bryoria pseudofuscens*

B. *Hypogymnia inactiva*

C. *Pseudocyphellaria rainierensis*

Figure 21. Macrolichens were grouped into three functional groups: (A) forage lichens, (B) matrix lichens, and (C) cyanolichens. Photographs by Bruce McCune (A–B) and Jim Riley (C).

[17] Research reported here is based on Peterson and McCune (2000a–b, 2001), and Peterson et al. (2000).

[18] Abundance is based on the abundance-class ratings defined in “Study Methods” in the Materials and Methods section of this report, and is not to be interpreted to represent biomass. These abundance-class ratings also apply to “Macrolichens and Bryophytes on Shrubs” in the Study Objectives, Results, and Recommendations for Management section of this report.

Table 5. Tree and shrub macrolichen species strongly associated with (indicators for) thinned young-growth, old-growth, and hotspot stands in western Oregon.[a]

Habitat	Species	Habitat	Species
Thinned young-growth stand		Hotspot (continued)	
	Hypogymnia imshaugii		*Hypogymnia occidentalis*
Old-growth stand			*Hypotrachyna sinuosa*
	Alectoria imshaugii		*Leptogium corniculatum*
	Alectoria sarmentosa		*Leptogium polycarpum*
	Alectoria vancouverensis		*Lobaria pulmonaria*
	Hypocenomyce anthracophila		*Lobaria scrobiculata*
	Lobaria oregana		*Melanelia subaurifera*
	Nodobryoria oregana		*Menegazzia terebrata*
	Platismatia herrei		*Nephroma bellum*
Old tree[b]			*Nephroma helveticum*
	Alectoria imshaugii		*Nephroma laevigatum*
	Alectoria sarmentosa		*Nephroma resupinatum*
	Alectoria vancouverensis		*Normandina pulchella*
	Cetraria pallidula		*Peltigera collina*
	Hypocenomyce anthracophila		*Pseudocyphellaria anomala*
	Hypocenomyce friesii		*Pseudocyphellaria anthraspis*
	Hypocenomyce scalaris		*Pseudocyphellaria crocata*
	Letharia vulpina		*Ramalina dilacerata*
	Lobaria oregana		*Ramalina farinacea*
	Nodobryoria oregana		*Sticta fuliginosa*
Hotspot			*Sticta limbata*
	Cladonia fimbriata		*Usnea glabrata*
	Cladonia transcendens		*Usnea wirthii*
	Fuscopannaria leucostictoides		

[a] No macrolichens were indicators for unthinned young-growth stands.
[b] Old tree refers both to trees in old-growth stands and to old remnant trees in young-growth stands.

hardwoods or riparian sites. The most notable exception to this finding was the nitrogen-fixer, *Lobaria oregana,* which was associated with old-growth stands and remnant old trees in young-growth stands.

Although communities in old-growth and hotspot stands showed distinct differences from those in other stand types, macrolichen community composition was quite similar in young-growth stands, whether the stand was unthinned or thinned. Patterns in macrolichen community composition were correlated strongly with climatic gradients. The greatest variation in composition occurred between stands in the Coast Range versus the Cascades. These differences between mountain ranges were greater among young-growth stands than among old-growth stands, which suggests that successional dynamics of these epiphytes may differ between the two ranges.

Conclusions

1. Thinned stands supported a slightly higher abundance of forage lichens (some of which are considered to be associated with old-growth stands) than did unthinned young-growth stands. In contrast, total species richness summed across all thinned stands was lower than that summed across all unthinned stands.
2. Although average species richness per stand differed little among stand types, the communities (i.e., the particular species occurring and relative abundances of each) differed greatly among stand types. Thus, comparisons of this type should include community analyses, in addition to simple measures such as species richness.[19] Macrolichen communities in thinned stands generally were similar to those in unthinned young-growth stands, but differed from those in old-growth stands and landscape-level hotspots.

[19] A similar conclusion was reached for shrub epiphytes, moths, and birds. See "Epiphytic Lichens and Bryophytes," "Moths," and "Birds" in the Study Objectives, Results, and Recommendations for Management section of this report.

Table 6. Relative abundance and/or species richness of tree and shrub macrolichens in unthinned young-growth stands compared to thinned young-growth, old-growth, and hotspot stands in the Coast Range and Cascade mountains of western Oregon. Abundance and/or species richness in the given stand type is noted as approximately equal to (=), higher than (+), or lower than (-) that found in unthinned young-growth stands.

Species group	Relative abundance and/or species richness				
	Young-growth stands			Old-growth stands	Hotspots
	Unthinned	Thinned			
		Conventional	Variable[a]		
Hardwood associates[b]	low	-/=	+	+	+
Old-growth associates[c]					
Dispersal-limited[d]	low	-/=	+	+/=	=
Substrate-limited[e]	low	-/=	+	+/=	=
Weedy[f]	intermediate	=	=	=	=
Generalists[g]	high	=	+	=	+
Riparian[h]	low	-/=	=	=	+

NOTE: Information in this table has been compiled from this study (see Peterson and McCune 2000a–b, 2001), as well as from Neitlich and McCune (1997), Ruchty (2000), and Sillett et al. (2000).

[a] Thinned leaving remnant trees, small gaps, and islands of unthinned vegetation. Comparisons in this column are presumed from this study and studies listed above, and have not been tested specifically.

[b] For example, *Leptogium polycarpum*, *Nephroma laevigatum*, and *Peltigera collina*.

[c] Lichen diversity increases if the forest includes structural diversity provided by older or larger trees.

[d] For example, *Alectoria sarmentosa* and *Lobaria oregana*.

[e] For example, *Hypocenomyce scalaris*, and several species, such as *Calicium glaucellum*, *Chaenotheca laevigata*, and *Microcalicium disseminatum,* not included in this study.

[f] Pollution-tolerant/fertilization-responsive, e.g., *Physcia aipolia*, *Physconia* spp., *Xanthoria fallax*, and *Xanthoria polycarpa*.

[g] Good dispersers, occur in both upland and riparian habitats, and are substrate generalists. Species include *Cetraria chlorophylla*, most *Hypogymnia* spp., and most *Platismatia* spp.

[h] For example, *Cetrelia cetrarioides*, *Platismatia lacunosa*, and *Ramalina thrausta*.

3. Old-growth stands supported higher species diversity and abundance of forage lichens and a higher abundance of *Lobaria oregana* than did other stand types.
4. Hotspots supported more rare or unusual macrolichens, and a higher diversity and abundance of cyanolichens, than did other stand types.

Recommendations for Management

1. Retain old and relatively mature or structurally developed trees in young-growth stands. These trees provide a means to retain and promote the growth and reinvasion of **dispersal**- and substrate-limited macrolichen species.
2. Allow some young trees to remain on-site for the long term (e.g., for centuries), where they can acquire characteristics of old trees. Strong evidence exists that certain types of macrolichens, particularly those that are dispersal-limited, simply need time to colonize, rather than require specific late-successional stand characteristics. Allowing some trees to age on the site also will help provide adequate habitat for certain types of lichens that depend on particular bark and tree characteristics.[20]
3. Protect landscape-level hotspots. These areas provide habitat for, and may help sustain, many sensitive species, which often are associated with these unusual forest structures.
4. Retain a legacy of hardwoods and shrubs, and favor the old shrubs on a site. Hardwoods provide important habitat for macrolichens, possibly because macrolichens grow during the wet season, when hardwood leaves are not present. In particular, many nitrogen-fixing species are hardwood-associated, for reasons that are not yet well understood.[21]
5. Focus on increasing structural diversity in managed forests by providing both gaps and dense areas. Such diversity should foster the development of diverse macrolichen communities.[22]

[20] These include some pin lichens (see Peterson and McCune 2000b).

[21] Hardwoods are important for moths and birds also. See “Moths” and “Birds” in the Study Objectives, Results, and Recommendations for Management section of this report.

[22] Variable-density thinning also should foster diverse herb, moth, and bird communities. See similar recommendations for other organisms studied as part of this project. See also Colgan et al. (1999), Traut and Muir (2000), and Carey and Wilson (2001).

Macrolichens and Bryophytes on Shrubs

Researcher: Abbey Rosso[23]

Study Objectives

This study focused on epiphytes on shrubs, because common field observations indicate that epiphytes can differ markedly between relatively open areas with an abundance of shrubs and more closed-canopy areas within young forests. These observations suggest that relatively open areas with hardwood shrubs and trees tend to have higher species richness and greater numbers of species typically associated with old-growth stands than do more closed-canopy areas within the same young-growth stand. Central questions were as follows: (1) Do shrubs in young-growth stands with a canopy opened by conventional thinning have higher species richness or support different communities of epiphytic lichens and bryophytes than shrubs in unthinned young-growth stands? If so, (2) does diversity or abundance of old-growth-associated species differ between unthinned and thinned young-growth stands? In addition, (3) do landscape-level hotspots support unique species, or an unusual abundance of species, and should they be viewed as important areas to protect for conserving epiphyte biodiversity (and other ecosystem attributes)?

Major Findings

A total of 139 epiphyte species , 92 macrolichens (Figure 21) and 47 bryophytes (Figure 22), were found on tall shrubs in the 68 forest stands surveyed. Epiphyte species richness and abundance differed between sites in the Coast Range and those in the Cascades (see Figure 12), as well as among the four stand types—unthinned and thinned young-growth, old-growth, and hotspot (Table 7). Overall, differences in epiphyte communities were greater between mountain ranges than among stand types. In addition, epiphytic macrolichens appeared to respond differently to thinning than did bryophytes; their abundance and/or species richness showed different patterns with regard to stand type.

Several species were associated with (indicator species for) particular stand types (Table 8) in that they exhibited greater frequency and/or abundance in those stand types. This was true particularly for landscape-level hotspots, as anticipated. The list of macrolichen indicators of stand types based on shrub surveys differs somewhat from that based on surveys of trees and shrubs (Table 5), because different hosts were included when trees were sampled. Most similar are lists of indicators for landscape-level hotspots (compare Table 8 with Table 5).

In the Coast Range, where often relatively few macrolichens occurred in the understory of unthinned stands, species richness and abundance (cover) of macrolichens on shrubs generally were greater in thinned and old-growth than in unthinned young-growth stands. Further, species richness and abundance of macrolichens in thinned stands did not differ significantly from that in old-growth stands. No

Table 7. Relative abundance and/or species richness of shrub epiphytes in unthinned young-growth stands compared to thinned young-growth, old-growth, and hotspot stands in western Oregon. Abundance and/or species richness in the given stand type is noted as approximately equal to (=), higher than (+), or lower than (-) that found in unthinned young-growth stands.

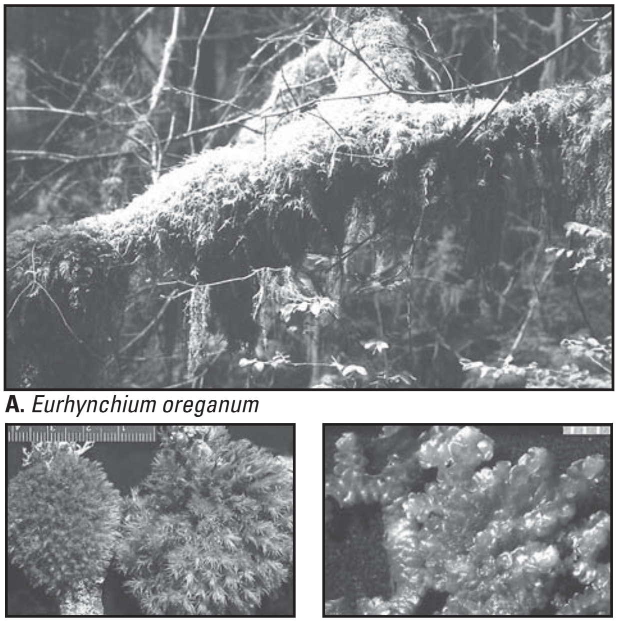
Species group[a]	Relative abundance and/or species richness				
	Young-growth stands			Old-growth stands	Hotspots
	Unthinned	Thinned+[b]	Thinned-[b]		
Macrolichens					
Forage lichens	low	+	+	+	+
Cyanolichens	low	=	=/-	+	++
Matrix lichens	low	+	+	+	+
Bryophytes					
Mosses					
Mats	medium	=	-	+	+
Tufts	low	=/+	-	+	+
Liverworts	medium	=	-	+	+

NOTE: Relative abundance ratings are based on abundance classes used in ocular surveys and on cover classes from stem microplots.

[a] Species groups are defined in "Study Organisms" in the Materials and Methods section of this report.

[b] Thinned+ is without loss of older shrub stems; Thinned- is with loss of older shrub stems.

[23] Research reported here is based on Rosso (2000).



A. *Eurhynchium oreganum*

B. *Orthotrichum lyellii* **C.** *Porella navicularis*

Figure 22. Bryophytes surveyed on shrubs included: (A) moss mats, (B) moss tufts, and (C) liverworts. Ruler measurements are in centimeters. Photographs by Bruce McCune.

difference in bryophyte species richness was apparent between unthinned and thinned young-growth stands, and both stand types supported fewer species than did old-growth stands.

Bryophyte cover on shrubs in the Coast Range was often lower in thinned than in unthinned young-growth stands. Bryophyte cover on shrubs in thinned stands in the Coast Range was significantly lower than in old-growth stands, whereas cover in unthinned stands did not differ significantly from that in old-growth stands. The thinned stands in the Coast Range supported fewer relatively old shrub stems than did unthinned young- and old-growth stands, and, because bryophyte cover was generally greatest on old shrub stems, damage to shrubs during thinning may have adversely affected shrub bryophytes.

In the Cascades, total species richness of macrolichens across all stands was greater than in the Coast Range. This difference between mountain ranges may have occurred, at least partly, because Cascades stands, both unthinned and thinned, supported higher densities of relatively old shrub stems than did Coast Range stands. Further, several Coast Range stands supported too few shrub stems for stem-microplot sampling. Although ocular surveys were conducted in these stands (when shrubs were present), epiphyte species richness would tend to be reduced, simply because shrub substrate was lacking.

Thinned young-growth stands in the Cascade mountains did not have greater macrolichen species richness or cover than did unthinned stands, possibly because species richness was relatively high in the young-growth stands in the Cascades before they were thinned. Macrolichen species richness and cover did not differ significantly between young- and old-growth stands in the Cascades. Further, thinning in young Cascades stands was not associated with a lower density of relatively old shrub stems, and bryophyte species richness and cover in these thinned stands were not lower than in unthinned stands. Bryophyte species richness did not differ between young- and old-growth stands; however, old-growth stands tended to have higher bryophyte cover (although this difference was not significant statistically).

Hotspots generally had the greatest species richness of both macrolichens and bryophytes on shrubs. Richness of cyanolichens was particularly high in hotspots, and hotspots hosted a relatively large number of species not found in other stand types (similar to findings for macrolichens on trees and shrubs). Most hotspots, especially those with relatively large abundances of bryophytes and cyanolichens, were located in riparian zones.

The high species richness and unique composition of epiphytes on shrubs in riparian areas may be the result of several factors. Riparian areas typically were undisturbed relative to other areas within the managed forests, and relatively undisturbed conditions provide time for diverse and lush epiphyte communities to develop. In addition, the microclimate in riparian areas is often cooler and moister than that in nearby upland areas, and these conditions favor many epiphytes. Further, structural features positively associated with epiphyte species richness, such as hardwoods and remnant old trees, often are relatively common in riparian areas. Hardwood trees may influence shrub epiphytes, particularly by increasing availability of light during the cool and moist seasons when many epiphytes are most active physiologically. Remnant old trees also may contribute species through litterfall or by propagule dispersal.

Influences of stand age and structure on shrub epiphytes were assessed by comparing communities with multivariate tools, which can detect differences in community composition, and can be used to test for correlations of environmental factors with those differences. In general, communities differed more between mountain ranges than among stand types. The differences in species composition of macrolichens and bryophytes between the two ranges may be related, at least in part, to the age of shrubs, which generally were older in the Cascades, as well as to climatic and other

Table 8. Tall-shrub epiphytes in the Coast Range and Cascade mountains of western Oregon strongly associated with[a] (indicators for) unthinned and thinned young-growth, old-growth, and hotspot stands.

Species group Species	Coast Range	Cascades	Species group Species	Coast Range	Cascades
Unthinned young-growth stands[b]			*Hotspots (continued)*		
Bryophytes			*Leptogium polycarpum*	X	X
Frullania californica	(X)		*Menegazzia terebrata*	X	
Radula complanata	(X)		*Nephroma laevigatum*	X	
			Nephroma resupinatum	X	X
Thinned young-growth stands[c]			*Normandina pulchella*		X
Macrolichen			*Peltigera collina*	(X)	X
Usnea cornuta	(X)		*Pseudocyphellaria anthraspis*	X	(X)
			Sticta fuliginosa	(X)	(X)
Old-growth stands			*Sticta limbata*	X	(X)
Macrolichens			*Usnea fulvoreagens*		X
Alectoria sarmentosa	X		*Usnea wirthii*	X	
Parmelia pseudosulcata	X		Bryophytes		
Sphaerphorus globosus	X		*Claopodium crispifolium*	X	(X)
Usnea filipendula group	X		*Dicranum fuscescens*	X	
Bryophytes			*Dicranum howellii*	X	
Antitrichia curtipendula	(X)		*Homalothecium fulgescens*	X	X
Isothecium myosuroides	X		*Homalothecium nuttallii*	X	X
Scapania bolanderi	X		*Hypnum subimponens*	X	X
			Leucolepis acanthoneuron	X	X
Hotspots			*Orthotrichum pulchellum*	X	
Macrolichens			*Plagiomnium venustum*	X	
Cladonia fimbriata		X	*Porella navicularis*	(X)	
Cladonia ochrochlora	X	(X)	*Rhytidiadelphus triquetrus*	X	

NOTE: X = $p < 0.05$; (X) = $0.1 > p > 0.05$, where p = the probability that positive association is by chance.
[a] Those epiphytes that occur with greater abundance or frequency in the given stand type than in other stand types.
[b] No macrolichens were indicators for unthinned young-growth stands.
[c] No bryophytes were indicators for thinned young-growth stands.

differences between the Cascades and the Coast Range. In the Coast Range, shrub macrolichen communities in thinned stands were more similar to those in old-growth stands than were communities in unthinned stands, whereas shrub bryophyte communities in unthinned stands were more similar to those in old-growth stands. In the Cascades, shrub epiphyte communities differed more by stand location than by stand type, and distinctions among communities across all unthinned and thinned young-growth and old-growth stands were not strong. In general, differences in shrub epiphyte communities among sites and stands were most strongly related to shrub characteristics (e.g., age and stem density), tree characteristics (e.g., percentage basal area in hardwoods versus conifers, and total tree basal area), and abiotic site characteristics (e.g., distance from water and, in the Cascades, elevation).

Conclusions

1. In dense young-growth stands with few epiphytes in the understory, thinning may have led to increased diversity and cover (abundance) of macrolichens on shrubs, and to increases in the similarity of macrolichen communities on shrubs between young- and old-growth stands.
2. Macrolichens and bryophytes on shrubs appeared to respond differently to thinning of the types used in these stands. Macrolichen species richness may have increased in response to thinning, whereas richness of bryophytes was not greater in thinned than in unthinned young-growth stands.
3. Thinning associated with a loss of old shrub stems may have had negative effects on some shrub epiphytes, particularly on the abundance of mat-forming bryophytes and macrolichens associated with relatively old shrub stems.

4. Landscape-level hotspots (e.g., riparian areas and hardwood gaps) were rich in shrub epiphytes, and supported communities that were distinctly different from those in surrounding forest areas (similar to findings for epiphytic macrolichens on trees and shrubs).
5. In addition to stand structure, the age of shrubs and stands had important relationships to shrub epiphyte communities.
6. Community composition, which focuses on which species are present and their relative abundances, was important for distinguishing differences in shrub epiphytes among stand types. Species richness alone tells only part of the story.[24]

Recommendations for Management

1. Incorporate variable-density thinning prescriptions that leave both gaps and dense areas. Variability in overstory density is likely to promote variability in shrub epiphyte communities.[25]
2. Minimize impacts of thinning on shrubs, particularly old shrubs with well-developed epiphyte cover. Leave a legacy of old shrubs available on a site. The age of shrub stems is an important consideration for shrub epiphytes, and for functions and species that depend on them.[26]
3. Protect a variety of landscape-level hotspots, both riparian and upslope, such as rocky outcrops and hardwood gaps.
4. Collect epiphyte species-abundance data during studies describing and documenting the condition of epiphyte communities, and in situations in which epiphyte communities are to be monitored. Note that time and funding constraints generally make it impractical to collect abundance data during routine predisturbance surveys.

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[24] These results are similar to findings for macrolichens on trees and shrubs, moths, and birds. See these respective portions of the Study Objectives, Results, and Recommendations for Management section of this report.

[25] Variable-density thinning is recommended for all other organisms studied as part of this project.

[26] Shrub age may not be as important for other species as it is for epiphytes. See “Moths” in the Study Objectives, Results, and Recommendations for Management section of this report.

Moths

Researcher: Jeff Miller

Study Objectives

In this study, abundance, species richness, and functional groupings of moths were examined to determine the potential effects of thinning in young-growth stands of Douglas-fir. In particular, this study sought to: (1) measure moth abundance and species richness in four stand types (unthinned and thinned young-growth, old-growth, and clearcut), (2) compare moth populations and communities among the stand types, in part to assess apparent effects of thinning on these organisms in young-growth stands, (3) establish baseline data for bioinventory protocol, and (4) determine whether or not moths have the potential to serve as a taxonomic/ecological indicator for assessing forest-management practices, such as thinning.

Major Findings

Most of the 500 species of moths collected (a total of nearly 15,000 specimens) were uncommon (Table 9; Figure 23). Singleton and doublet moths[27] made up over half of the total species list. Geometrids (see Appendix D[28]) and noctuids were the most frequently collected moth families, and these families were the most important taxa for ecological comparisons based on moth abundance (number of specimens collected) and species-richness values (Figure 24). Expertise in identification of these species is critical[29] for the success of programs using moths to make ecological comparisons among various stand types in forests of western Oregon.

Old-growth stands supported higher moth abundances (summed across all five old-growth stands) than did other stand types, and the lowest summed abundances occurred in clearcuts (Table 9). Summed abundances were slightly higher in unthinned than in thinned young-growth stands, although this difference probably was not statistically significant. Although old-growth stands differed from unthinned and thinned young-growth stands in terms of total moth abundance and the particular species present, they did not differ in species richness (number of species collected). Mean species richness values (and standard errors) were: 217 (22) in unthinned young-growth, 221 (20) in thinned young-growth, 227 (18) in old-growth, and 196 (33) in clearcut stands. Unthinned and thinned young-growth stands also supported nearly equal species richness. The

Table 9. Abundance of moths by family in unthinned and thinned young-growth, old-growth, and clearcut stands in Douglas-fir forests in western Oregon.

Moth family	Abundance (number of moths captured)				
	Young-growth stands		Old-growth stands	Clearcuts	Total
	Unthinned	Thinned			
Geometers	2,827	2,414	3,439	1,636	10,316
Noctuids	753	713	915	1,030	3,411
Prominents	31	59	228	7	325
Tigers	11	55	109	147	322
Tent caterpillars and lappets	29	60	65	40	194
Tortricids	18	43	41	19	121
Pyralids	15	23	37	16	91
Tussocks	9	13	24	0	46
Thyatirids	7	9	14	7	37
Slug caterpillars	2	2	22	0	26
Oecophorids	4	7	0	13	24
Giant silkworms	2	4	1	2	9
Hook-tips	2	2	4	0	8
Plumes	0	1	0	6	7
Epiplemids	0	3	2	0	5
Hawks	0	1	0	4	5
Swifts	0	1	0	0	1
Total	3,710	3,410	4,901	2,927	14,948

[27] Singleton and doublet moths are those for which only one or two, respectively, of a particular moth species is present in the sample.

[28] Common and scientific names of moth families are provided in Appendix D.

[29] This expertise is essential for all organisms studied during this project.

Figure 23. A representative sample of the species collected during one trap night at Honey Creek (site 20, Figure 12). Approximately 500 species (nearly 15,000 specimens) were collected during the moth study. Photograph by Jeff Miller.

widest range in species richness across stands of a given type occurred in clearcuts, and richness depended on the age and location of the clearcut. Heterogeneity in the landscape provided by different forest structures and plant communities was important in enhancing moth species richness at the site level, because different stand types supported many different moth species.

Hardwoods were responsible for most of the species richness in every stand type (Table 10; Figure 25). In fact, 46 percent of the species collected across all stand types were associated with hardwoods. Some hardwoods were associated with a large proportion of the moth species, whereas others were associated with relatively few. For example, caterpillars of many species feed on blueberry, chinquapin, manzanita, oceanspray, snowbrush, and willow. Oak and alder are important food sources also. Conversely, relatively few species of caterpillars feed on the foliage of dogwood and maple. The quantification of the importance of hardwoods for moth species richness is a novel finding of this study.

Although unthinned and thinned young-growth stands did not differ in moth abundance or species richness, they did exhibit differences in the relative importance of various moth functional groups (Tables 10–11). Unthinned stands supported the lowest abundance (percentage of moths from a given functional group in a given stand type) of hardwood-tree-and-shrub-feeders (Table 11). Percentages of species richness in the hardwood-feeding functional group in unthinned stands and clearcuts also were slightly lower than in thinned young- and old-growth stands, although these differences among stand types probably were not significant statistically. Conifer-feeders dominated unthinned young-growth stands (i.e., made up the highest percentage of total individuals captured), whereas hardwood-feeders dominated thinned young-growth and old-growth stands (Table 11). Herb-and-grass-feeding species had higher percentages of total abundance and species richness in clearcuts than in other stand types.

Regardless of treatment, species functional groups based on host-plant category, including those for whom host plants are not known (Figure 26),[30] indicated the following:

- Only 11 percent of moth species depended on conifers in the Douglas-fir coniferous biome (see Table 10).
- An average of 46 percent (as high as 75 percent in individual stands) of moth species depended on hardwoods.
- An average of 19 percent (up to 25 percent in individual stands) of moth species depended on herbaceous plants.

Thus, in a given stand, ~300 of 400 moths may feed on hardwoods, and only ~40 are likely to feed on conifers.

Table 10. Species richness of moths by functional group in unthinned and thinned young-growth, old-growth, and clearcut stands in western Oregon.

Functional group	Species richness[a] (% of species captured in stand type)				
	Young-growth stands		Old-growth stands	Clearcuts	Total
	Unthinned	Thinned			
Hardwood-tree-and-shrub-feeder	48	51	50	47	46
Conifer-feeder	17	17	15	11	11
Unknown	13	17	14	15	17
Herb-and-grass-feeder	10	10	14	20	19
Mixed-conifer-hardwood-feeder	9	7	7	6	6
Detritus-feeder	1	1	1	1	1

[a] Percentages do not always sum to 100 percent for a given stand type, because data were rounded.

[30] The host plant or plants are not known for every species. In fact, as much as 25–30 percent of species can have unknown host plants. This number was 40 percent 10 years ago, so research is improving the situation. Nevertheless, information on dietary habits of moths for which host plants remain unknown would contribute to interpretation of data on species richness and abundance.

Typically, around 324–400 species were collected during 1 year across all treatments in a given study area. These high numbers of species allowed for assessments of moth presence, absence, and abundance across many taxa. In addition, differences among stand types in any single taxon did not overweight statistical analyses. These high numbers also indicate very high rates of species turnover. In other words, individuals of a given species may occur in a few samples, but then are no longer present as a result of their seasonal biology. Different species were collected during different sampling events and seasons.

Relatively few moth species were indicators for (strongly associated with, by virtue of abundance, frequency, or both) particular stand types.[31] One species (*Zosteropoda hirtipes*) was an indicator for clearcuts across four of the sites (site 16, Figure 12, was excluded, because it was drier than other areas and supported many different species than did the other areas). Another species (*Feltia herilis*) was an indicator for clearcuts across three of the sites, and one species (*Cyclophora dataria*) was an indicator for old-growth stands, also across three sites. Eleven other species were identified as indicator species for various stand types at two sites.

Moth communities differed more among sites than among stand types across all sites.[32] However, when communities were contrasted among stand types within a given site, differences in moth communities among stand types were significant. As was found for epiphytes, analyses that focus on the entire moth community (i.e., that take into account species composition and relative abundance of species) can be useful in revealing differences that might be missed by comparisons of relatively simple measures, such as species richness.

A. *Pero mizon*

B. *Aseptis binotata*

Figure 24. (A) Geometrid and (B) noctuid moths, which belong to the most abundant moth families collected during the moth study. These two families were the most important taxa for ecological comparisons based on abundance and species richness. Both species are generalists on hardwoods. Photographs by Jeff Miller.

Conclusions

1. Geometrids and noctuids were the most numerous moth taxa collected, and thus were the most important moth taxa for ecological comparisons based on abundance and species-richness indices.
2. Thinned young-growth stands did not have lower species richness than did unthinned stands. However, the functional group composition of moths did differ between unthinned and thinned young-growth stands. This difference suggests that compositional changes took place after thinning, probably in response to a change in availability of host plants, particularly of hardwoods.
3. Both abundance and species richness of moths exhibited seasonal trends. Thus, sampling must occur frequently throughout the flight season.

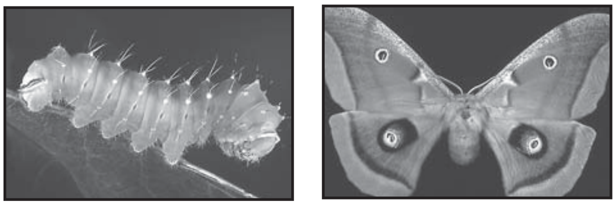
Table 11. Abundance of moths by functional group in unthinned and thinned young-growth, old-growth, and clearcut stands in western Oregon.

Functional group[a]	Abundance[b] (% total number captured)				
	Young-growth stands		Old-growth stands	Clearcuts	Total
	Unthinned	Thinned			
Hardwood-tree-and-shrub-feeder	40	47	54	56	49
Conifer-feeder	45	31	32	12	31
Unknown	9	11	7	11	9
Herb-and-grass-feeder	3	4	3	18	6
Mixed-conifer-hardwood-feeder	4	6	4	4	4

[a] Very few moths (<1 percent) belonging to the detritus feeding group were collected.
[b] Percentages do not always sum to 100 percent for a given stand type, because data were rounded.

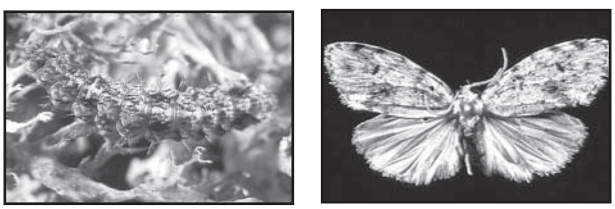
[31] Numbers of indicator species were higher for epiphytes. See "Epiphytic Lichens and Bryophytes" in the Study Objectives, Results, and Recommendations for Management section of this report.
[32] These results are similar to findings for epiphytes.

A. *Lophocampa argentata*



B. *Antheraea polyphemus*

C. *Neoalcis californiaria*



D. *Clemensia albata*

E. *Peridroma saucia*

Figure 25. Moths were classified into functional groups based on food source. Members of these groups included moths feeding on: (A) conifers, (B) hardwoods, (C) mixed conifers and hardwoods, (D) detritus, and (E) herbs and grasses. Although adult moths were captured in the traps for identification, moths in the larval stage do the feeding. Photographs by Jeff Miller.

4. Hardwood shrub densities often were higher in thinned than in unthinned young-growth stands, and these hardwoods were important food sources for moths. Caterpillars prefer to feed on fresh foliage, irrespective of stem age.[33]
5. Sampling moths in forest ecosystems required the use of specialized equipment and protocols, such as frequency of sampling and expertise in the taxonomy of this relatively less well-studied group of animals.

Recommendations for Management

1. Maintain a variety of stand types and densities across the landscape to promote a diversity of plant species and associated fauna.
2. Ensure taxonomic expertise when dealing with moth species (e.g., issue contracts for moth work only to persons known to be competent in moth taxonomy).[34] Also, when designing sampling protocols for moths, be aware of strong seasonal trends in moth abundance. Half of all the species present over a year can be collected from the end of July through August.
3. Categorize moths by functional groups in addition to species-based categorizations. Grouping by host-plant categories provides ecologically useful information, because such groupings are tied directly to the structure and composition of forests.
4. During thinning and other forest-management activities, favor plants that support a high number of caterpillars, e.g., chinquapin and oceanspray, as well as members of the genera *Alnus*, *Arctostaphylos*, *Ceanothus*, *Quercus*, *Salix*, and *Vaccinium*.[35] This can be accomplished by protecting established individuals during thinning or other forest-management activities. Although it is not possible to identify a set number of plants to retain per unit area, any removal of these species likely will have a corresponding effect on moth populations and communities.
5. Be aware that a high frequency of uncommon species in a stand might be a positive indicator of forest health.

[33] Major findings for moths appear to complement results for vegetation, epiphytes, and birds. For example, hardwoods were important for epiphytic lichens and bryophytes (as substrate and probably through influences on light or moisture regimes), moths (as food sources), and birds (as hosts for arthropods eaten by birds and as habitat). Results for moths did differ from those for epiphytes in that the age of the tree or stem did not seem important for moths, whereas older stems were important for epiphytes.

[34] Note that this holds true for other taxa as well.

[35] Additional species that are important for epiphytes include vine and bigleaf maple and California hazel. Several of these species, along with bracken fern, sword fern, salal, and salmonberry, also appear to be important for birds, in part because they are hosts for arthropods eaten by birds.

Birds

Researchers: Joan Hagar and Ed Starkey[36]

Study Objectives

This portion of the project assessed diversity (species richness) and abundance of forest birds in unthinned and thinned young-, and old-growth stands. Relationships of bird abundance to both the abundance and composition of arthropod prey (including moths) and the structure and composition of understory vegetation, particularly shrubs, also were examined. Arthropods have many important functions in forest ecosystems, including being a significant food resource for birds.[37] Many arthropods depend on hardwood shrubs for food and habitat.[38] Thus, forest-management activities that affect shrub communities, such as thinning, may alter the abundance and species composition of arthropods, which may, in turn, influence the distribution and abundance of birds that prey on arthropods.[39] Primary objectives for this study were to: (1) characterize the forest bird communities in three types of stands (unthinned and thinned young-growth and old-growth), (2) assess whether or not bird communities differ among the stand types, (3) identify the arthropod taxa that are food for shrub-associated birds, (4) describe associations between these arthropod taxa and plant species (i.e., define which plant species support which arthropod taxa), and (5) relate these findings to forest-management practices that modify forest structure and composition, and hence availability of food for forest birds.

Major Findings

A total of 57 forest bird species were observed in unthinned and thinned young-growth, and old-growth stands in the Coast Range during this study (Appendix E; e.g., Figure 26). Total abundance of birds (total number of counts per stand per year across all species) and abundances of 12 individual species differed among old-growth and unthinned and thinned young-growth stands (Table 12). Patterns of abundance in relation to stand type were highly variable among species. In comparisons of abundance among the three stand types, more species (six) had peak abundance in old-growth than in other stand types, whereas none were most abundant in unthinned, and three species were most abundant in thinned young-growth stands (Table 12). Total abundance of birds across species was greater in both thinned young- and old-growth stands than in unthinned young-growth stands.

The abundance of Swainson's thrushes was highest in both thinned young- and old-growth stands, and did not differ between these stand types. Hermit warblers and western tanagers were more abundant in both types of young-growth than in old-growth stands, and their abundance did not differ between unthinned and thinned young-growth stands. The Pacific-slope flycatcher was the only species with a significantly greater abundance in unthinned than in thinned young-growth stands, although peak abundance occurred in old-growth stands. Hairy woodpeckers, which have been reported to be associated with old-growth forests (Carey et al. 1991), actually were more abundant in thinned young-growth stands than in either old-growth or unthinned

A. *Catharus ustulatus* **B.** *Wilsonia pusilla* **C.** *Piranga rubra*

Figure 26. Three of the bird species surveyed during the *Managing for Biodiversity in Young Forests Project*: (A) Swainson's thrush, (B) Wilson's warbler, and (C) western tanager. Photographs by Bill Dyer, Cornell Laboratory of Ornithology (A), Joan Hagar (B), and U.S. Geological Survey (C).

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[36] Research reported here is based on Hagar et al. (1996).

[37] Described in the Moths portion of "Study Organisms" in the Materials and Methods section of this report.

[38] See the Major Findings portion of "Moths" in the Study Objectives, Results, and Recommendations for Management section of this report.

[39] See results related to shrubs in "Trees, Shrubs, and Herbaceous Vegetation" and "Macrolichens and Bryophytes on Shrubs" in the Study Objectives, Results, and Recommendations for Management section of this report.

Table 12. Bird abundance in unthinned and thinned young-growth stands and old-growth stands in the Oregon Coast Range between May and June, 1995 through 1997. Different letters for a given species indicate that means differ significantly ($P \leq 0.05$, ANOVA) between or among the stand types (least squares means test).

Species	Abundance (counts per stand per year)						P[a]
	Young-growth stands				Old-growth stands		
	Unthinned		Thinned				
	Mean	SE	Mean	SE	Mean	SE	
Most abundant in old-growth stands							
Brown creeper	1.3	0.29B	1.9	0.25B	2.8	0.32A	0.008
Chestnut-backed chickadee	2.9	0.29B	3.7	0.41B	5.6	0.44A	0.001
Pacific-slope flycatcher	5.4	0.77B	3.4	0.48C	8.1	0.86A	0.001
Varied thrush	0.9	0.27B	0.7	0.20B	3.3	0.61A	0.011
Winter wren	5.9	0.63B	6.1	0.64B	7.9	0.55A	0.080
Red-breasted nuthatch	1.1	0.27C	2.0	0.38B	2.9	0.43A	0.008
More abundant in thinned and old-growth than in unthinned young-growth stands							
Swainson's thrush	1.5	0.20B	4.4	0.62A	3.1	0.45A	0.004
Total	35.3	2.25B	47.5	2.74A	46.2	0.27A	<0.001
Most abundant in thinned young-growth stands							
Wilson's warbler	0.7	0.17C	4.9	1.10A	1.6	0.29B	<0.001
Hammond's flycatcher	0.8	0.20B	1.9	0.35A	0.2	0.08B	0.002
Hairy woodpecker	0.2	0.07B	0.8	0.16A	0.4	0.09B	0.011
Most abundant in young-growth stands							
Hermit warbler	7.0	0.95A	6.6	0.56A	4.2	0.86B	0.049
Western tanager	1.1	0.23A	1.8	0.31A	0.4	0.18B	0.015
No difference in abundance							
Hutton's vireo	1.0	0.22	1.0	0.31	0.4	0.14	0.131
Steller's jay	1.1	0.23	1.8	0.35	1.5	0.27	0.280
Golden-crowned kinglet	1.9	0.40	1.5	0.36	2.8	0.56	0.139

[a] The probability (P) associated with the test of the hypothesis that abundance does not differ among stand conditions is based on repeated measures analysis of variance.

young-growth stands. Only three of the species that were counted frequently enough for statistical comparisons showed no differences in abundance among stand types sampled (Table 12).

A reference collection of arthropods taken from nine dominant shrub and understory tree species indicated that arthropod abundance and species composition varied among shrub species (Table 13). Bracken fern appeared to support a greater abundance of arthropods than did other shrub species, and was more abundant (had higher cover) in thinned young-growth stands than in other stand types (see Table 4). In general, arthropods tended to be most numerous in thinned young-growth stands, though the differences among stand types may not be significant statistically.

The abundance of Wilson's warblers, an insectivorous species that forages in the forest understory, was strongly and positively associated with cover of tall hardwood shrubs. Preliminary data indicate that their abundance also was correlated positively with arthropod abundance on shrubs. Shrubs are, therefore, important in providing both cover and food for this species. The insect parts (e.g., Figure 27) identified in 85 fecal samples indicate that the diet of Wilson's warbler comprises primarily flies (Diptera), spiders, aphids (Homoptera), beetles (Coleoptera), and caterpillars (Lepidoptera). The taxa found most frequently in fecal samples from this species were also the taxa found most frequently on several species of tall hardwood shrubs and on bracken fern. Bracken fern and some of the tall shrubs (e.g., vine maple, California hazel, and oceanspray) were species that apparently responded positively to thinning (i.e., had higher density or cover in thinned than in unthinned young-growth stands).[40] Some of these tall-shrub species were identified as important substrate for shrub epiphytes and as food sources for moths. Thus, thinning young forests, in part by providing conditions that support understory plant species, may be important in fostering biodiversity of epiphytes, moths, and birds in young forests of western Oregon.

These findings suggest that plant species composition, presence of a shrub layer, epiphyte cover, and snag density influence the abundance of some bird species. Species richness, total abundance of birds, and the abundance of eight individual bird species were positively related to the abundance of hardwood trees and shrubs. In addition, the abundances of golden-crowned kinglet, red-breasted nuthatch, and chestnut-backed chickadee were positively related to variables describing epiphytes on shrubs (bryophyte cover, abundance of macrolichens, and species richness of macrolichens and bryophytes, respectively). Differences among stands in the abundances of chestnut-backed chickadee, Swainson's thrush, and black-headed grosbeak were related to variables describing amounts of dead, woody debris (including snags and large downed logs); the first two species were positively associated with soft (decay class V) snags, whereas black-headed grosbeak abundance was positively associated with soft logs.

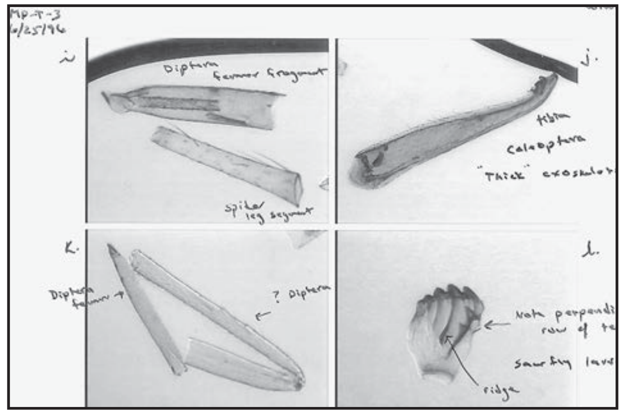

Figure 27. Fragments of arthropods fed on by Wilson's warbler. Photograph by Robert Peck.

Conclusions

1. The total abundance of birds was greater in thinned young- and old-growth stands than in unthinned stands. The relatively well-developed understory vegetation in both thinned and old-growth stands (Bailey 1997) provided vertical heterogeneity that probably best explains this finding.
2. Habitat conditions for most bird species in thinned young-growth stands differed from conditions in old-growth stands. Thus, a diversity of stand types and conditions across the landscape is necessary to provide habitat for all bird species.
3. Bird species richness was positively associated with hardwood components of stand structure, which indicates the important contribution of hardwoods to stand-level diversity.[41]

Table 13. Arthropod abundance on understory plant species in unthinned and thinned young-growth stands and old-growth stands in the Oregon Coast Range, averaged across collections from 1996 and 1997. Dashes indicate that no sample was taken from that species in the stand type indicated.

Understory plant species	Arthropod abundance (number per 100 grams dried plant material)		
	Young-growth stands		Old-growth stands
	Unthinned	Thinned	
Bracken fern	--	106	34
California hazel	--	--	48
Douglas-fir	--	--	4
Oceanspray	51	38	--
Salal	39	44	34
Salmonberry	--	--	58
Sword fern	68	56	50
Vine maple	32	34	22
Western hemlock	22	30	34
Mean	42	51	36

[40] See "Trees, Shrubs, and Herbaceous Vegetation" in the Study Objectives, Results, and Recommendations for Management section of this report, as well as Bailey (1997).

[41] The importance of hardwoods for various organisms has been described in other portions of this report.

4. Wilson's warblers were more abundant in thinned than in unthinned young- or old-growth stands. Bracken fern supported a high abundance and diversity of arthropods, including those found to be part of the diet of Wilson's warblers, as did several tall-shrub species.[42]
5. The relationship between abundance and habitat quality is unclear for many species. Preliminary evidence indicates that the abundance of some birds may be an indicator of habitat quality, because bird abundance was correlated positively with the abundance of food (arthropods).

Recommendations for Management

1. Use thinning as a tool to manage young forests to improve habitat for some bird species, but leave some unthinned areas for species associated with dense conifer canopies.[43] The size of unthinned and thinned areas depends on management goals and objectives, and on the overall landscape context. Because breeding bird territories often encompass 5–10 hectares, management at this scale, or larger, likely will be beneficial when providing habitat for birds is a consideration.
2. Retain and promote the growth of understory and midstory vegetation, particularly tall shrubs and other hardwoods. Relatively heavy thinnings and irregular spacing of residual trees should help encourage understory development.[44]
3. Maintain a diversity of stand types and conditions across the landscape. Results from this study indicate clearly that no one kind of stand condition is optimal for all species.[45]

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[42] Cover or density of bracken fern and tall shrubs tended to be higher in thinned than in unthinned stands. See "Trees, Shrubs, and Herbaceous Vegetation" in the Study Objectives, Results, and Recommendations for Management section of this report, as well as Bailey and Tappeiner (1998).

[43] Note that variable-density thinning has been suggested as a tool to enhance biodiversity of other forest organisms studied as part of this project. See the Recommendations for Management portions of other studies in the Study Objectives, Results, and Recommendations for Management section of this report.

[44] This recommendation to promote the growth of understory vegetation also has been made for epiphytes and moths. See "Epiphytic Lichens and Bryophytes" and "Moths" in the Study Objectives, Results, and Recommendations for Management section of this report.

[45] A diversity of stand conditions should foster not only diverse bird communities but also diverse communities of other forest organisms.

Project Conclusions

Common Themes

The *Managing for Biodiversity in Young Forests Project* was established in recognition of the need to understand the probable consequences for forest biodiversity of contemporary shifts in the goals and objectives of forest management, and specifically to explore the contribution of thinning to management of forests for biodiversity. As noted by Hayes et al. (1997), "Thinning has traditionally been used to maximize wood production; incorporating objectives for wildlife is a relatively new approach in forest management—one with a great deal of promise but many unanswered questions." Thinning young-growth stands in an effort to promote native biodiversity of all types of organisms over the long term raises additional questions. The effectiveness of thinning (of various types) in promoting the development of understory vegetation, tree growth and regeneration, and biodiversity of associated and interdependent organisms must be evaluated over the long term to provide answers to these questions. Fortunately, several such long-term studies are in progress (e.g., Harrington and Carey 1997; Carey et al. 1999b; Franklin et al. 1999; Carey and Harrington 2001; Reutebuch et al. 2002).

Young-growth stands vary in structure, composition, and tree density. When young forests are thinned, the resulting stand structure and composition depend on past and current tree density, the thinning treatments used, site conditions, volume of coarse woody debris, and other factors. Thinning prescriptions vary widely: some thinnings are heavy, some are light, and some are variable-density; some retain remnant trees and shrubs, whereas others do not; and some call for removal of downed wood, whereas others do not. Interpretation of studies involving thinned young-growth stands, such as those presented in this report, is complicated by the wide range of stand conditions encompassed by the term, "thinned young-growth stands." This variability among stands and site conditions needs to be considered in evaluating results from these studies, and in making decisions about appropriate thinning prescriptions for a given forest stand.

Despite differences in the organisms and conditions of stands studied, and in the relationships of the various organisms to existing stand conditions, the conclusions of the studies that are part of the *Managing for Biodiversity in Young Forests Project* exhibit a number of common themes. Some of the most important of these common themes are listed as follows:

- Variation in stand conditions, both within stands and at the landscape level, is important in providing habitat for a diversity of forest organisms.
- Hardwoods are important for many species, whether through providing habitat substrate (e.g., for epiphytes), food sources (e.g., for moth larvae), or foraging substrate (e.g., for birds)—or other habitat conditions. Hardwood shrubs, in particular, were identified as being important contributors to forest biodiversity.
- Hardwoods, particularly shrubs, were generally more abundant in thinned than in unthinned young-growth stands 10–20 years after thinning.
- The abundance of some types of organisms, individual species, and functional groups was sometimes more similar between thinned and old-growth stands than between unthinned and old-growth stands; however, many exceptions to this pattern were found. No overall generalization can be made that thinned stands have an abundance of organisms or species richness more similar to old-growth than do unthinned young-growth stands—at least in the first 10–25 years after thinning and for the kinds of organisms studied in this project.
- Analyses of communities, which take into account species composition and relative abundance of species, often were better able to reveal differences among stand types than were comparisons of summary measures, as, for example, species richness or abundance.
- Community analyses generally indicated that communities differed more by geography (site) than by stand type.

Proposed Thinning Guidelines

Thinning of the young forests surveyed during this project was completed under forest-management protocols prevailing 20–30 years ago. At that time, managers typically made no attempt to provide for development of shrub cover or multiple layers in the canopy, and took no special measures to promote biodiversity. The primary objective was wood production. Some positive influences of thinning under these earlier protocols (as inferred retrospectively) on a variety of forest organisms are apparent, however. Because of variation in the type and degree of thinning possible and the existing condition of young-growth stands, thinning prescriptions clearly need to be developed on a case-by-case basis (Figure 28). Nonetheless, based on current understanding of young-growth Douglas-fir stands in western Oregon, the following general management guidelines[46] for thinning are proposed:

- Retain all existing old, remnant trees, snags, and large woody debris.
- Leave a legacy of large trees with large limbs extending low into the crown ("wolf trees").
- Favor hardwood trees across a range of size classes, including large trees that occupy midcanopy and higher positions.
- Protect and encourage a legacy of tall hardwood shrubs, especially those with old stems.
- Leave sufficient understory conifer regeneration, which, along with hardwoods, will provide for the development of multistoried stands.
- Create conditions that provide for the presence of herbs and grasses in forest stands.
- Use variable-density thinning, including heavy thinning (e.g., to 50 trees per hectare) in portions of young-growth stands. Heavily thinned areas will encourage understory development, as well as development of trees characteristic of those found in old-growth stands.
- Foster both within-stand and landscape-level diversity in stand densities; thus, leave some areas unthinned to provide a wide range of stand densities at both spatial scales. Studies assessing responses of biodiversity to various spatial scales of management are ongoing, and results that can inform forest management will not be available for several years. Thus, recommendations for specific sizes of areas thinned to various degrees and unthinned areas are not available. Decisions about spatial scale must be guided by management objectives and site or stand conditions.

At this time, the impacts on stand structure and forest biodiversity of thinning young Douglas-fir forests of western Oregon according to the proposed guidelines are uncertain; however, results from this project and others (see Appendixes F–G) suggest that adoption of these proposed guidelines is likely to enhance native biodiversity and encourage the development of old-growth characteristics in comparison to what is found in unthinned young-growth stands and those thinned according to conventional prescriptions.

In 1977, Marion Clawson wrote that "the importance of forests tend generally to be underestimated in the United States, but is better understood in the Pacific Northwest than almost anywhere else in the country." This understanding requires ongoing research, interpretation, application, and evaluation (i.e., adaptive management; see Figure 4) to further management goals, such as those set in managing for biodiversity in young forests. The findings of this project should assist in planning for management of western Oregon's young forests. Although the findings and guidelines from the *Managing for Biodiversity in Young Forests Project* apply specifically to young Douglas-fir forests of western Oregon, they also may help guide research direction and focus in forests elsewhere.

Figure 28. A thinned Douglas-fir stand with vine maple in the understory. Thinning prescriptions need to be developed on a site-by-site basis, with consideration of stand density, age, species composition, history, landscape context, ownership, and management objectives. Photograph by Jim Riley.

[46] These guidelines are stated with recognition that some agencies, groups, and individuals already follow similar guidelines in their management activities. Although these guidelines are based largely on findings from stands ranging from 50 to 120 years in age, the concepts likely apply to younger stands as well. The validity of extrapolating results to younger stands remains untested at this time.

Application of Research Findings

The following text paraphrases some of the dialog from the video, Managing for Biodiversity in Young Forests (Tappeiner et al. 2000). This text focuses on implications for land managers and is intended as a summary of some of the most important findings of the research described in the video and in preceding sections of this report.

Forest Manager: Joan, given the current emphasis of land-use planning on maintaining and producing late-successional forests, what implications do your findings have for managing habitat for forest bird species?

Hagar: Shrubs, hardwood shrubs in particular, seem to be a key component of forest ecosystems for several species of insectivorous birds. The vertical heterogeneity provided by well-developed understory vegetation in both thinned and old-growth stands probably best explained the greater total abundance of birds in these two stand conditions compared to unthinned stands. Shrub-associated arthropod species that are important in the diet of many forest birds also were more abundant in thinned stands than in other stand types. These findings suggest that functional vertical heterogeneity involves more than simply a multistoried conifer canopy; hardwood shrubs are an important component of this heterogeneity. Maintaining and producing late-successional forests may provide habitat for many bird species, as long as management activities encourage and maintain a significant amount of shrub cover.

Forest Manager: How important is the thinning of young-growth stands from the perspective of forest birds?

Hagar: The thinned young-growth stands in my study had greater shrub cover and greater abundance of shrub-associated arthropod prey species than did the unthinned stands, and the abundance of several shrub-associated bird species was greater also. My results, and those of others working on the *Managing for Biodiversity in Young Forests Project*, suggest that thinning can be an important way to maintain and promote shrub development in young conifer stands. Thinning that intentionally protects and promotes the growth of shrubs can be used to improve young-forest habitat for shrub-associated birds. Thinning to promote late-successional habitat also is likely to maintain shrubs in the understory, which will lead to more structurally and compositionally diverse stands in the long term.

Chronology of Forestry in Oregon [47]

Thousands of years BP—Native Americans inhabit the region now defined as Oregon.

1780s—Captain John Meares recognizes the excellence of Northwest timber for ship masts and spars.

1827—The first sawmill is built in the Pacific Northwest.

1833—The first shipment of Oregon timber is sent to China.

1850s—Four water-powered mills and the first steam-powered mill are in operation in Oregon. Lumber is traded with China, Hawaii, and Australia.

1865—The Silverton Fire burns approximately 400,000 hectares of timber.

1868—Much of the Elliott State Forest burns.

1870—There are 173 sawmills in Oregon, 138 of which use water power.

1880s—Heavy logging occurs in the Blue Mountains. Federal timber is effectively available for the "taking."

1885—The first Northwest paper mill is built on the Columbia River at Camas.

1891—The General Revision Act allows presidential withdrawal of forest reserves, but provides no funding to administer the reserves. Benjamin Harrison sets aside the first of the U.S. forest reserves.

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[47] Adapted from: Parish (1949, Historic Oregon, The MacMillan Company), Dodds (1977, Oregon: a bicentennial history, W.W. Norton and Company), Dicken and Dicken (1979, Two centuries of Oregon geography. I. The making of Oregon: a study in historical geography, Oregon Historical Society), Dicken and Dicken (1982, Two centuries of Oregon geography. II. Oregon divided: a regional geography, Oregon Historical Society), Clary (1986, Timber and the Forest Service, University Press of Kansas), O'Donnell (1988, That balance so rare: the story of Oregon, Oregon Historical Society), Warren and Ishikawa (1991, Oregon handbook, Moon Publications), Wilkinson (1992, Crossing the next meridian: land, water, and the future of the West, Island Press), Jackson and Kimerling (1993, Atlas of the Pacific Northwest, Oregon State University Press), Dietrich (1995, Northwest Passage: the great Columbia River, Simon & Schuster), and Wills (1995, A historical album of Oregon, The Millbrook Press); Mattingly (1997, The Oregon story: logging [education guide], Oregon Public Broadcasting).

Forest Manager: Can you describe specific thinning prescriptions that would be most helpful for forest birds?

Hagar: We need to remember that thinned young-growth stands do not mimic old-growth stands for most bird species, and that we still have much to learn about relationships of birds to forest conditions. The main thing we can suggest at this point is to take care to protect shrubs, particularly the tall shrubs that also support lichens and bryophytes and those that are important for moths, because many of the moth species are food for birds. Thinning that maintains the diversity of tree species, especially thinning that leaves hardwood trees, also is likely to provide habitat for birds. Fairly heavy thinning and thinning with irregular spacing of residual trees are most likely to promote the most structurally and compositionally diverse bird habitat.

Forest Manager: Jeff, from the work you have completed on moths to date, what top ten species of plants make the moth world run in these forests?

Miller: The trees and shrubs that are most important for moths in these forests include the following, all of which are hardwoods: red alder, green-leaf manzanita, common buckbrush, deerbrush, snowbrush, chinquapin, oceanspray, Oregon white oak, willow species, and red huckleberry. Each of these species supports a dozen or more species of moths. Numerous herbs and grasses are important as well.

Forest Manager: Based on your experience and findings, will thinning young Douglas-fir forests enhance habitat for moths?

Miller: That depends on the specifics of the thinning prescription used. Removing all of the hardwoods would have an immediate and detrimental impact on moth populations, because so many moth species depend on hardwoods. Removing many of the smaller conifers and leaving many of the hardwoods probably would benefit moth populations by favoring the hardwoods and increasing the amount of light that reaches the understory. This action would enhance herb and shrub growth and species diversity, and, therefore, enhance the diversity of moths. Removing many of the smaller conifers and a portion of the hardwoods would affect moth populations, but the degree of change would depend on which hardwood species—and in what proportions—were removed, and on the conditions that then existed in the understory.

Forest Manager: Should we actively consider moths when we are selecting a prescription for thinning?

Miller: Yes. Moths should be considered in management decision-making processes. Moths are diverse and fascinating members of the forest community, and also play valuable roles in forest ecosystems. They are vital as food for birds and bats, in particular, and for numerous other organisms. In addition, some moth species are important pollinators and recyclers of nutrients in forest ecosystems.

Forest Manager: Abbey, why did you study epiphytic lichens and bryophytes on shrubs in particular?

Rosso: I focused on epiphytes on shrubs for several reasons. First, areas with an abundance of shrubs can be hotspots of diversity for epiphytes and other organisms within young-growth stands. Tall shrubs have been hypothesized to be initial colonization points in young-growth stands for some old-growth-associated lichens. In addition, tall shrubs are important substrates for bryophyte mats, which provide habitat for numerous arthropod species. I also focused on shrubs, because I thought that understory communities would have a stronger response to thinning

1892—The first timberland reserve in Oregon is set aside—Bull Run Reserve near Portland.

1894—Heavy logging begins in the Columbia Basin.

1897—The Organic Act recognizes broad federal power, and allows for fire protection and limited timber sales. The Forest Reserve Act expands the national forest system.

1898—Gifford Pinchot becomes chief of the Division of Forestry.

1900—Until this time, the lumber industry in Oregon rates behind that in Washington and California, because timber is inaccessible to available modes of transportation. Most of the timber on the lower eastern slopes of the Coast Range and the lower western slopes of the Cascades is already cut. Great Lakes timber is exhausted and companies are moving to the West Coast. Demand for timber increases in the eastern states.

1900–1910—A period of large-scale logging occurs in the Columbia River Basin. In Oregon, only Gilliam, Sherman, and Malheur counties lack significant timber reserves.

1905—The USDA Forest Service is created to conserve forest resources and stabilize markets. The first plywood plant is built at St. Johns.

1913—Weyerhaeuser and the Southern Pacific Railroad combined own 22.4 percent of the standing timber located in western Oregon.

1920s—Logging with oxen is on the wane.

than would the epiphyte community overall, which includes, of course, epiphytes in trees.

Forest Manager: Abbey, on one hand, I hear that thinning is a good thing, and, on the other, that we need to be cautious about thinning. With the large areas in reserve under the Northwest Forest Plan, and the relatively small area of thinning that is planned, do we really need to be careful not to damage existing old shrubs in every thinning? How much does conservation of epiphyte species depend on thinning actions?

Rosso: The importance of shrub epiphytes to overall epiphyte diversity varies considerably from site to site, from stand to stand, and among shrub species. However, if one of the goals of thinning is to enhance old-growth characteristics in these stands, then the impacts on shrubs and their epiphyte communities should be considered during all, or certainly most, thinning operations. Effective enhancement and conservation of epiphyte biodiversity, as well as that of other types of organisms such as moths and birds, require that we not only set aside reserve areas but also change the way we manage our young forests. These changes include thinning with attention to leaving hardwood trees and shrubs, remnant trees, snags, and so on.

Forest Manager: Eric, you noted that several lichen species have limited capability to disperse over long distances. This limitation suggests that trees that host these lichen species might serve as sources of "inoculum" for young-growth stands, if the host trees are retained during thinning. Over what distance is this inoculation likely to occur? In other words, what is "long distance" to a lichen?

Peterson: For any plant, the ability to colonize a new location drops off exponentially with distance from the source plant. For many, if not most, of the lichens that are associated with relatively old stands, even seemingly short distances can provide a substantial barrier to dispersal. These lichens tend to have large, heavy propagules that do not go far as they fall. Although **dispersal distance** needs to be studied more completely, we do have some specific information already. For example, most propagules of *Lobaria oregana*, which is probably the most important nitrogen-fixer in old-growth forests, disperse over a distance of only 5–10 meters. Thus, if you want to provide remnant trees to help *Lobaria oregana* colonize a new stand, the trees need to be spaced so that their crowns are less than 10–20 meters apart. The same is probably true for the forage lichens, many of which disperse by fragmentation of relatively large pieces. In addition, dispersal of lichens between stands becomes a severe problem for many lichens associated with relatively old stands, because of their large propagules. This kind of dispersal involves much greater distances than does within-stand dispersal, and thus relies on rare events and chance. As the distance between the stands increases, the average frequency of such events easily can exceed a century.

Forest Manager: John, I always thought I was promoting diversity with standard commercial thinning prescriptions. What have you learned from the studies described here, and other work of your own, that would alter past commercial thinning prescriptions so that we can do a better job of promoting diversity?

Tappeiner: Our results suggest that commercial thinning can promote diversity in many cases, and for several kinds of organisms. Current practices do not need to be changed much. We do have some recommendations for modifications, however. The major points are that

1927—The national forests contribute about 5 percent of Oregon's lumber production. There are 608 lumber mills, 5 paper mills, 64 planing mills, and 47 furniture factories in Oregon. Distribution of mills changes from the Columbia River to the margins of the Willamette Valley, Bend, Klamath Falls, Lakeview, and LaGrande. Most lumber is marketed in rough form.

1930s–1950s—The major focus of the lumber industry moves from northwest to southwest Oregon. The Tillamook Fire (in three separate events, all caused by logging operations) destroys 140,000 hectares of Oregon's finest timber.

1933—The Tillamook Burn, one of the nation's worst, destroys nearly 100,000 hectares of Oregon's timber.

1935—The chainsaw is invented.

1937—The theory of sustained yield is applied to Oregon land-grant forests by the U.S. Department of the Interior.

1938—Oregon passes Washington as the leading timber producer in the nation (Puget Sound virgin timber already has been milled). Oregon becomes the major lumber state in the nation.

late 1930s—The first sawmill is built in the Willamette Valley.

1941—The shipbuilding boom begins in Portland. Oregon law requires reforestation after timber harvest.

mid-1940s—Conversion of the lumber industry to a diversified forest-products industry begins.

1947—Oregon records 1,573 lumber mills.

1950–late 1970s—Although the diameter of logs declines, large quantities of logs are converted to lumber, plywood, veneer, and pulp, with moderate variations in volume year to year.

1960—The Multiple-Use Sustained-Yield Act lists five basic uses of national forests: "outdoor recreation, range, timber, watershed, and wildlife and fish."

1962—The Columbus Day storm causes extensive damage to forests in Oregon.

1971—The Oregon Forest Practices Act, the first of its kind in the United States, requires resource protection during logging.

1975—No large area of timber in the state is worked on a sustained-yield basis. Western Oregon begins to consider banning exports and using special methods to encourage stand regrowth.

1976—The National Forest Management Act is passed, thus providing for harvest practices that preserve biological diversity and meet multiple-use objectives. The act restricts clearcutting, but does not prohibit it. In western Oregon, only Lane and Douglas counties show an increase in logging; they account for a third of logs produced in Oregon.

1979—The northern spotted owl is chosen as an "indicator species" for ancient forests.

we should periodically evaluate the results of various thinning prescriptions, and should pay close attention to actions that can further promote diversity. These actions include the following:

- Favor hardwood trees and shrubs.
- Leave old trees, snags, logs, and large trees that may remain from the previous stand.
- Vary tree density, and do some very heavy thinning (leave <50 trees per hectare) in portions of stands, especially in relatively young stands.
- Leave tree species in addition to Douglas-fir (both conifers and hardwoods) in both Douglas-fir-dominated stands and stands with more diverse tree-species composition.
- Release conifer and hardwood saplings present in the understory.
- Plant conifers and hardwoods in the understory after heavy thinning, or in openings when multistoried stands are desired.
- Maintain long crowns, large branches, and low height:diameter ratios by thinning.
- Leave large trees, conifers other than Douglas-fir, and hardwood trees at a variable spacing. Focus more on the characteristics and purpose of the trees being left than on achieving a regular, uniform spacing of trees.

Forest Manager: John, the researchers who studied epiphytes in this project have indicated that both hardwood trees and shrubs provide important habitat for epiphytes in our forests, and they clearly are important for birds and moths as well. What can you suggest about retaining these hardwoods during thinning operations from the silvicultural perspective? Which trees or shrubs should be left? How many per hectare? And are they likely to slow the growth of conifers in young-growth stands?

Tappeiner: We can't prescribe a set number of trees or shrubs to leave, as that will depend on what is available on the site and other management considerations. We can suggest that the hardwood trees with old stems should be left, and that a legacy of the larger shrub stems should be protected. These larger and older plants are likely to harbor relatively well-developed lichen and bryophyte communities. Douglas-fir generally overtops hardwood trees at about 40–50 years in age. So, from a wood-production point of view, leaving overtopped hardwoods, or isolated groups of them, likely will have little effect on conifer growth in young-growth stands.

Forest Manager: The potential increase in exotic species in thinned stands is of concern to managers. Will we need to initiate an exotic-species control program if we implement the thinning actions you suggest?

Tappeiner: John Bailey and colleagues found an average frequency of 0.1 percent and an average cover of 0.08 percent of exotic species in thinned stands. Thus, both frequency and cover of exotics were quite low. Exotics did occur in some old-growth stands as well, although their frequency and cover averaged nearly zero percent across the old-growth stands. So, the potential for exotics to increase in thinned stands should be considered, though the effects observed to date have been quite limited and have not warranted any kind of control programs.

Forest Manager: Although the researchers associated with this project did not focus on organisms that depend on large, dead wood on the forest floor—that is, coarse woody debris, we know that others have indicated that it is important for a variety of creatures, as well as for stabilizing the forest floor, providing nutrients to soils, and so forth. You have suggested that we maintain coarse woody debris that may be present on the forest floor from the previous stand. Would you also suggest that we create more of it in young-growth stands by cutting trees and leaving them as coarse woody debris? Because we are talking about young-growth stands, many of these trees would be <50 centimeters DBH. I wonder if we might be better off *not* cutting them now to preserve the option for a future downed-wood component? Or would it be better to cut and leave them now to boost current coarse woody debris volume?

Tappeiner: This action depends on local site conditions and needs. Thinning will enable remaining trees to grow and provide large dead wood for the future. Thinning also may reduce the amount of small, dead wood, if small trees are removed or given space in which to grow. Some logs can be left on the ground, and trees can be killed to create snags as part of the thinning process, thus increasing the amount of dead wood present. I suggest that we grow large trees to provide large logs and snags that will last, and thus have a better chance of developing habitat for amphibians, cavity-nesting birds, and so forth. In many cases, root disease and damage from wind and ice also will provide dead wood.

Forest Manager: What stand-thinning schedule and prescription would you recommend for a typical plantation stand of Douglas-fir in a Coast Range late-successional reserve, if our goal is to promote biodiversity and develop late-successional forest conditions?

Tappeiner: We need to develop thinning prescriptions on a site-by-site basis. Variations in stand density, age, species composition, history, ownership, and management objectives among and within stands need to be considered carefully for each stand and instance of thinning. General prescriptions are less likely to yield the results we desire. We also need to keep in mind that most of the information we have on thinning with biodiversity enhancement in mind comes from stands that are now 40–60 years or more in age, and were established after timber harvest. We don't have this kind of information yet from thinning very young stands, or stands that are much older. Even though it is probably reasonable to assume that the consequences of thinning will be similar in stands of those ages, that is, for the most part, an untested assumption at the present time. Nevertheless, I can offer some general comments.

Assuming the stand to be about 15 years old, I would thin some parts of the stand heavily (to approximately 50 trees per hectare) right now to favor some large trees. I would do this to ensure that a mixture of species and stand densities, as well as trees with large stems and long, full crowns with large branches—which are important for epiphytes and some other forest organisms, will be present in the future. I would leave variable distances among trees. Heavily thinning an entire stand all at once may be too extreme, and would likely foreclose too many options for the future. These kinds of stands could produce a lot of commercial wood for 80–100 years or more, while they are developing characteristics of old-growth forests. Overall, the type of thinning that we've all been describing here, thinning with consideration for biodiversity, can be used both in late-successional reserves and on matrix lands.

1986—The USDA Forest Service releases proposed management guidelines for the northern spotted owl; final guidelines are released in 1988.

1987—Fires burn 100,000 hectares of timber, worth ~$97.3 million.

1990—The U.S. Fish and Wildlife Service lists the northern spotted owl as a threatened species in Washington, Oregon, and northern California. *Northern Spotted Owl v. Lujan* holds that the U.S. Endangered Species Act requires the U.S. Fish and Wildlife Service to designate critical habitat for the owl.

1993—The Forest Conference is held in Portland, Oregon, and President Clinton issues a mandate to break the gridlock over forest management.

1995—The U.S. Fish and Wildlife Service approves the Habitat Conservation Plan proposed for the Elliott State Forest by the Oregon Department of Forestry. Such plans are developed to provide protection for the habitat of sensitive species during land use.

1996—Major fires burn tens of thousands of hectares of forest land, much of it in Oregon's national forests.

Present—The amount of timber harvested in Oregon[48] is declining, as is Asian demand for Northwest logs. Restrictions on federal land are greater than on private land. Approximately 10 percent of old-growth forests, virtually all on federal land, remain uncut. Objectives for forest management focus on adaptive management of forest ecosystems and maintenance of biodiversity and forest health.

[48] Every county in the state, except Clackamas, Gilliam, Malheur, Multnomah, and Sherman, lists lumber, forest products, or forestry as a principal industry.

The Cooperative Forest Ecosystem Research Program

The Cooperative Forest Ecosystem Research (CFER) Program works closely with resource managers, researchers, and decision-makers to develop and convey information needed to successfully implement ecosystem-based management at forest stand and watershed scales, especially on lands dominated by young forests and fragmented by multiple ownerships. Since 1995, the CFER Program has facilitated management of forest ecosystems on public lands administered by the USDI Bureau of Land Management (BLM) and other cooperators in western Oregon. Founding cooperators of the CFER Program are the U.S. Geological Survey's Forest and Rangeland Ecosystem Science Center; the BLM Oregon State Office; and Oregon State University's College of Forestry and College of Agricultural Sciences. The Oregon Department of Forestry became a member in 1998. Through team-oriented, integrated research, the CFER Program works to provide forest managers with new information to evaluate current and proposed strategies and practices associated with management of forest ecosystems, and to facilitate the development of sustainable forest practices.

Acknowledgments

This publication was produced through the Cooperative Forest Ecosystem Research Program. The first three authors contributed extensively to the compilation, synthesis, and presentation of the information contained in this report. All other authors, in addition to Pat Muir and John Tappeiner, contributed study-related information or background material. Rosanna Mattingly, a contractor with the U.S. Geological Survey's Forest and Rangeland Ecosystem Science Center, wove the material into a coherent presentation, edited the report, and conducted layout. In addition to the authors, many others contributed in notable ways to this report and the video associated with the report: Rich Bowden, Chris Cadwell, Candace Cloud, Alyssa Doolittle, Janet Erickson, Doug Ferguson, Paul Hammond, Ruth Jacobs, Jack Lattin, George Lienkaemper, Joe Lint, Betsy Littlefield, Bruce McCune, Pete Oboyski, Gary Parsons, Robert Peck, Mark Reed, Dana Ross, Abbey Rosso, Andrea Ruchty, Miranda Ruth, and Charley Thompson. We thank Bruce McCune and Abbey Rosso for contributing research findings related to epiphytes and reviewing the report. We are especially grateful to Rosanna Mattingly and Ruth Jacobs for the support, insight, and unwavering commitment that saw the project through to publication. This publication and the research reported were funded and partially conducted by the U.S. Geological Survey's Forest and Rangeland Ecosystem Science Center. Oregon State University's contribution to the research and reporting was conducted under Cooperative Agreement 1434-WR-97-AG-00017 (previously 1434-WR-98-AG-00027 and 1434-WR-98-AG-00028), Subagreements 97-017-WS-003 and 97-017-WS-004. The USDI Bureau of Land Management contributed to the project through thinning activities that established stands for comparison, help in locating sites, and feedback during the research and reporting phases. The reporting was conducted under the auspices of the U.S. Geological Survey and the Cooperative Forest Ecosystem Research Program. Impartial reviews of this report were provided by Robert Alverts, USDI Bureau of Land Management, Oregon and Washington State Office, Portland, Oregon; Andrew Carey, USDA Forest Service, Pacific Northwest Research Station, Olympia, Washington; and Nancy Wogen, USDI Bureau of Land Management, Eugene District Office, Eugene, Oregon. Data sets for Figure 1 were provided by the Forest Science Data Bank, a partnership between the Department of Forest Science, Oregon State University, and the USDA Forest Service Pacific Northwest Research Station, Corvallis, Oregon. Additional research for this project was done by Jim Boyle (soils) and R. Bruce Bury (amphibians).

Glossary of Forest Ecology and Management Terms[49]

Adaptive management—A continuing process of planning, monitoring, researching, evaluating, and adjusting action with the objective of improving the ability to achieve defined goals. (See Figure 4, page 5.)

Adaptive management areas—Lands placed in a land-use designation for which adaptive management is mandated. Although a portion of timber harvest will come from these lands, they are intended for development and testing of new management approaches to integrate ecological, economic, and other social objectives. Each area (approximately ten in the Northwest Forest Plan area) has a thinning prescription with a different emphasis. (See insert, page 6.)

Administratively withdrawn areas—Areas removed from the suitable timber base through agency direction and land-management plans.

Aspect—The direction a slope faces with respect to the cardinal compass points. For example, a hillside facing east has an eastern aspect.

Biodiversity—The number and abundance of species found within a common environment. Biodiversity also includes the variety of genes, species, ecosystems, and the ecological processes that connect them in a common environment. (See insert, page 5.)

Bryophytes—Mosses, liverworts, and hornworts. (See insert, page 17.)

Canopy—The foliar cover in a forest stand consisting of one or several layers. Canopy most often refers to the uppermost layer of foliage, but can be used to describe lower layers in a multistoried stand.

Clearcut—A stand harvest in which all or almost all of the trees are removed in a single cutting. To clear a stand by removing all or nearly all of the trees.

Coarse woody debris—The woody portion of a tree that has fallen or been cut and left in the woods. Coarse woody debris usually refers to pieces at least 50 centimeters in diameter.

Commercial thinning—Any type of thinning that produces merchantable material at least equal to the value of the direct costs of harvesting.

Communities—Assemblages of organisms living together and occupying a given area.

Congressionally reserved areas—Areas that, for various reasons, have been withdrawn from timber harvest by an act of Congress, and were withdrawn before biodiversity became a major concern. These lands include such areas as national parks and monuments, wilderness areas, wild and scenic rivers, national wildlife refuges, and U.S. Department of Defense lands. (See insert, page 6.)

Conifer—A tree belonging to the taxonomic order Gymnospermae, and comprising a wide range of trees that are mostly evergreens. Conifers bear cones and needle-shaped or scalelike leaves.

Cover—Vegetation used by wildlife as protection from predators, to mitigate weather conditions, or to reproduce. Cover also refers to the protection of the soil and the shading provided to herbs and forbs by vegetation, or to the area that is occupied by vegetation or foliage.

Crown—The upper portion of a tree or other woody plant that carries the main system of branches and the foliage.

DBH (diameter at breast height)—The diameter outside the bark of a tree, measured 1.37 meters above the ground on the uphill side of the tree.

Density—The size of a population in relation to some unit of space, e.g., the number of trees located in a given area.

Density management—The cutting of trees for the primary purpose of widening their spacing so that growth of remaining trees can be accelerated. Density management also can be used to improve forest health and accelerate the attainment of old-growth characteristics where maintenance or restoration of biodiversity is an objective.

Dispersal distance—A straight-line distance that an individual travels from its point of origin until it stops dispersing or dies.

Disperse/dispersal—The spread of a species to a new location, which often occurs at a particular stage in the life cycle.

Diversity—The number of species in a community or region; also referred to as species richness. Some definitions of diversity include a measure of species relative abundance; however, in this project, diversity is used to refer to species richness. (See insert, page 5.)

Ecosystem—A spatially explicit, relatively homogeneous unit of the Earth that includes all interacting organisms and components of the abiotic environment within its boundaries.

Ecosystem management—A strategy or plan to manage ecosystems such that their composition, structure, and function will be sustained over the

[49] Taken or adapted primarily from FEMAT (1993). In addition, some sections are from other sources, e.g., Mathews (1990), USDA and USDI (1994), and Helms (1998).

long term, as opposed to a strategy or plan for managing individual species or commodities.

Endangered species—Any species of plant or animal defined through the U.S. Endangered Species Act as being in danger of extinction throughout all or a significant portion of its range.

Epiphytes—Nonparasitic organisms that grow on plants. (See insert, page 17.)

Exotic plants—Plants that are not native to an area.

Food web—The interlocking pattern of feeding relationships in a biological community. The interactions connect the various members of an ecosystem, and describe how energy passes from one organism to another.

Forest lands—Lands that are now, or are capable of becoming, at least 10 percent stocked with forest trees and that have not been developed for nontimber use.

Forest management—The practical application of biological, physical, quantitative, managerial, economic, social, and policy principles to the regeneration, management, utilization, and conservation of forests to meet specified goals and objectives while also maintaining the productivity of the forest.

Habitat—The set of environmental conditions, structure, and composition under which a specific organism can live, grow, and reproduce.

Hardwood trees—Flowering trees, belonging to the taxonomic order Angiospermae, with relatively broad, flat leaves, as compared to conifers or needle-leaved trees.

Hotspots—Within-stand or landscape-level areas with unusual structure, composition, or environment and the visual appearance of increased diversity. For epiphytes, landscape-level hotspots include relatively large hardwood gaps, riparian areas, and rocky outcrops, whereas within-stand hotspots include old remnant trees, large wolf trees, old shrubs, and hardwood trees.

Landscape—A spatial mosaic of several ecosystems, landforms, and plant communities across a defined area irrespective of ownership or other artificial boundaries, and repeated in similar form throughout.

Late-successional reserves—Forests managed to protect or foster the development of late-successional forest conditions, and to provide habitat for species that depend on late-successional habitat. (See insert, page 6.)

Lichens—Symbiotic associations between a fungus and a photosynthetic partner, i.e., green algae, cyanobacteria, or both. (See insert, page 17.)

Live-crown ratio—The ratio of a tree's crown length to the total length of the tree.

Managed forests—Forest lands treated with silvicultural practices and/or harvested.

Managed late-successional areas—Selected harvest areas and managed-pair areas. Managed-pair areas are located in some portions of the northern spotted owl's range, where it is necessary to provide additional protection in the matrix for pairs of owls and territorial singles. This consists of delineating a core habitat area, plus additional acreage of suitable habitat around the core. The acreage to be delineated around the core varies throughout the range, based on data for pairs in that area.

Matrix lands—Lands that belong to the matrix land-use allocation for federal forested lands within the area encompassed by the Northwest Forest Plan (see Figure 2, page 4). Matrix lands include federal lands outside of reserves, and are the lands from which the bulk of timber harvest will be taken. (See insert, page 6.)

Multilayered (**multistoried**) stands—Forest stands that contain trees of various heights and diameter classes, and, therefore, support foliage at various heights in the vertical profile of the stand.

Natural regeneration—Trees grown from natural seed fall or sprouting.

Nitrogen-fixing—Able to convert gaseous nitrogen into nitrogen-containing compounds that are usable by plants.

Northwest Forest Plan—A comprehensive strategy for lands managed by the USDA Forest Service and the USDI Bureau of Land Management to maintain and restore late-successional forests, with simultaneous recognition of their importance to regional economies. The Northwest Forest Plan is an outgrowth of President Clinton's 1993 conference in Portland, Oregon, to address long-standing public concern over management of forests in the Pacific Northwest. At the heart of the management issue was disagreement over the relative biodiversity of managed and old-growth forests. An interagency team of scientists, the Forest Ecosystem Management Assessment Team (FEMAT), developed and assessed a variety of forest-management alternatives, one of which was ultimately selected as the Northwest Forest Plan (USDA and USDI 1994).

Old-growth forests—Forests in the (usually) late-successional stage of forest development, with moderate-to-high canopy closure; multilayered, multispecies canopies dominated by large overstory trees; high incidences of large trees, some with broken tops and other indications of old and decaying wood (decadence); numerous large snags;

and heavy accumulations of wood, including large logs on the ground.

Overstory—That portion of the trees, in a forest of more than one story, forming the upper or uppermost canopy layer.

Public lands—Lands for which title and control rest with a government, i.e., federal, state, regional, county, or municipal.

Record of Decision—A document separate from, but associated with, an Environmental Impact Statement that states the management decision, identifies all alternatives (including both the environmentally preferable and preferred alternatives), states whether or not all practicable means to avoid environmental harm from the preferred alternative have been adopted, and, if not, why not.

Regeneration—The seedlings and saplings existing in a stand; the act of establishing young trees naturally or artificially.

Reserves—Forest areas withdrawn from acreage used for timber production. (See insert, page 6.)

Riparian—That which is related to, living or located in conjunction with, a wetland, the bank of a river or stream, or the edge of a lake or tidewater. Note that the riparian community significantly influences, and is significantly influenced by, the neighboring body of water.

Riparian reserves—Lands that are withdrawn from harvest on the basis of their distance from stream channels or standing bodies of water. They are located outside of late-successional reserves, and are managed with similar objectives, as well as aquatic-conservation objectives. (See insert, page 6.)

Seedlings—Young plants grown from seeds; for trees, often less than 2.5 centimeters DBH.

Shrubs—Plants that have persistent woody stems and a relatively low growth habit, and that generally produce several basal shoots rather than a single bole; usually less than 5 meters tall at maturity.

Silvicultural practices—A set of methods used to modify and manage a forest stand over time to meet desired conditions and objectives.

Snags—Any standing dead, partially dead, or defective trees at least 25 centimeters DBH and at least 2 meters tall.

Species—A group of related organisms having common characteristics and, for those that reproduce sexually, capable of interbreeding.

Stand—A contiguous group of trees sufficiently uniform in age-class distribution, composition, and structure, and growing on a site of sufficiently uniform quality to be a distinguishable unit.

Standards and Guidelines—The primary instructions for land managers, and the principles specifying the environmental conditions or levels to be achieved and maintained (e.g., USDA and USDI 1994, 2001). Standards address mandatory actions, whereas guidelines are recommended actions based on a land-management decision.

Structure—The arrangement of the parts of an ecosystem, both vertically and horizontally.

Successional—Of or relating to a series of dynamic changes by which one group of organisms succeeds (replaces) another through time. An example is the developmental series of plant communities, called seral stages, following a major disturbance.

Survey and manage species—Species for which survey and manage standards and guidelines are prescribed. Survey and manage guidelines are mitigation measures adopted within the Northwest Forest Plan Record of Decision (replaced with USDA and USDI 2001) that are intended to mitigate impacts of land-management efforts on those species that are closely associated with late-successional or old-growth forests and whose long-term persistence is a concern. These measures apply to all land allocations and require land managers to take certain actions relative to forest organisms that are rare or about which little is known. Actions include the following: manage known sites, survey prior to ground-disturbing activities, and conduct extensive and general regional (strategic) surveys.

Sustained yield—The yield that a forest can produce continuously at a given intensity of management. Note that sustained-yield management implies continuous production so planned as to achieve, at the earliest practical time, a balance between increment and cutting.

Thinning—See glossary entries for **commercial thinning**, **density management**.

Thinning prescription—A plan of operation that specifies the purpose for thinning, the density of trees to remain after thinning, and the kinds of trees (e.g., species, size, crown and/or stem characteristics, location) to be left or removed. The purpose of the prescription may relate to wood production, understory characteristics, riparian areas, or other considerations.

Threatened species—Any plant or animal species likely to become endangered, as defined by the U.S. Endangered Species Act, throughout all or a significant portion of its range within the foreseeable future.

Understory—All forest vegetation growing under an overstory.

Young forests—Forests that generally are <50–80 years old. (Also referred to as **young-growth forests**.)

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Appendixes

Appendix A

Researcher Biographies[50]

John D. Bailey is assistant professor of silviculture at Northern Arizona University. He received B.S. and M.S. degrees from Virginia Polytechnic Institute and State University, and his Ph.D. from Oregon State University. His major interests include silviculture and adaptive ecosystem-based management. His work with John Tappeiner on trees, shrubs, and herbaceous vegetation provides the basis for the retrospective research reported as part of the *Managing for Biodiversity in Young Forests Project.*

Joan C. Hagar is a Ph.D. student in the department of forest science at Oregon State University. She received her B.S. in biological aspects of conservation from the University of Wisconsin-Madison, and her M.S. in forest ecology from Oregon State University. Her research specialization is the ecology and management of forest birds, and she contributed that expertise to this project.

Bruce McCune is professor of botany and plant pathology at Oregon State University. He received B.S. and M.S. degrees in botany from the University of Montana at Missoula, and his Ph.D. in plant ecology from the University of Wisconsin-Madison. His research focus is the ecology of temperate forest epiphytes, particularly the ecology and taxonomy of lichens, and the development of efficient quantitative methods for their study. He also is interested in describing and understanding change in vegetation in response to disturbance and stress. He served as major and co-major professor, respectively, for the Ph.D. work of Eric Peterson and Abbey Rosso.

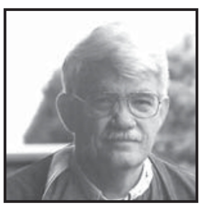
Jeffrey C. Miller is professor of entomology at Oregon State University's College of Agriculture, Agricultural Experiment Station, and College of Science. While at Oregon State University (since 1979), he has worked on insect pests of strawberry, wheat, cherry, filbert, alfalfa, peppermint, broccoli, and forests. In addition, he has studied beneficial insects (e.g., parasitic wasps and lady beetles) for use as biological control agents. His primary research interests are insect ecology and natural history, with emphases on trophic relationships, systematics, and biogeography. He studied forest moths as part of this project.

Patricia S. Muir has worked at Oregon State University since 1987, and is professor of botany and plant pathology and director of the environmental sciences undergraduate program. She received her B.S. in botany and biology from the University of Montana at Missoula, and her Ph.D. in plant ecology from the University of Wisconsin-Madison. Her major research interest focuses on effects of alternative management systems on forests and forest ecology. The effects of air pollution on vegetation have been the focus of past research. She served as co-major professor for Abbey Rosso in her Ph.D. work.

[50] Photographs in Appendix A are from U.S. Geological Survey files.

Eric B. Peterson graduated from Humboldt State University, California, with a B.S. in botany and environmental biology, and from Oregon State University with a Ph.D. in plant ecology. Much of the research for his Ph.D. dissertation on lichens was conducted as part of this project. He is currently plant ecologist for the Nevada Natural Heritage Program in Carson City, Nevada. His research interests include the biodiversity and biogeography of plants and lichens, with particular focus on modeling their occurrence and distribution.

Abbey L. Rosso received a B.A. from Cornell University; an M.S. from Scripps Institute of Oceanography, University of California, San Diego; and a Ph.D. in plant ecology from Oregon State University. Her areas of interest include lichen ecology and the effects of forest management on communities of lichens and bryophytes. Much of the research for her Ph.D. dissertation on lichens and bryophytes was conducted as part of this project.



Edward E. Starkey is research biologist for the U.S. Geological Survey's Forest and Rangeland Ecosystem Science Center, Corvallis, Oregon. He received his B.S. and M.S. from Bemidji State College and St. Cloud State College, respectively, in Minnesota. His Ph.D. is from Washington State University. He has worked on a variety of projects, including river-dependent birds of Olympic National Park, deciduous trees and shrubs as nutrient sources for aquatic organisms, and implications of forest management on forage for herbivores. He was project leader for the *Managing for Biodiversity in Young Forests Project*.

John C. Tappeiner II is a retired forest ecologist with the U.S. Geological Survey, and currently professor of forest ecology and silviculture at Oregon State University. He has taught and conducted research in silviculture and forest ecology for over 20 years. His primary research interests include the development of old-growth stands, understory establishment and growth in young-growth stands, shrub and hardwood ecology, and vegetation management for regeneration. He served as major professor for John Bailey during his Ph.D. work on vegetation, which was conducted in the project study sites.

Appendix B

Common and Scientific Names of Vegetation Referenced in Text

Common name	Scientific name
Bigleaf maple	*Acer macrophyllum*
Blackcap raspberry	*Rubus leucodermis*
Blue wildrye	*Elymus glaucus*
Blueberry	*Vaccinium* spp.
Bracken fern	*Pteridium aquilinum*
California hazel	*Corylus cornuta* var. *californica*
Chaparral willowherb	*Epilobium minutum*
Chinquapin	*Chrysolepis chrysophylla*
Coastal burnweed	*Erechtities minima*
Coastal monkey-flower	*Mimulus dentata*
Common buckbrush	*Ceanothus cuneatus*
Corn lily	*Veratrum californicum*
Deerbrush	*Ceanothus integerrimus*
Dogwood	*Cornus* spp.
Douglas-fir	*Pseudotsuga menziesii*
Elk clover	*Aralia californica*
Evergreen blackberry	*Rubus laciniatus*
Grand fir	*Abies grandis*
Green-leaf manzanita	*Arctostaphylos patula*
Groundsel	*Senecio triagularis*
Lupine	*Lupinus* spp.
Manzanita	*Arctostaphylos* spp.
Maple	*Acer* spp.
Oceanspray	*Holodiscus discolor*
Oregon white oak	*Quercus garryana*
Oregon-grape	*Berberis nervosa*
Ox-eyed daisy	*Chrysanthemum leucanthemum*
Pacific madrone	*Arbutus menziesii*
Pacific rhododendron	*Rhododendron macrophyllum*
Pacific water-parsley	*Oenanthe sarmentosa*
Pearly everlasting	*Anaphalis margaritacea*
Pinesap	*Hypopitys monotropa*
Red alder	*Alnus rubra*
Red huckleberry	*Vaccinium parvifolium*
Salal	*Gaultheria shallon*
Salmonberry	*Rubus spectabilis*
Snowbrush	*Ceanothus velutinus*
Sword fern	*Polystichum munitum*
Tanoak	*Lithocarpus densiflorus*
Vine maple	*Acer circinatum*
Western hemlock	*Tsuga heterophylla*
Western redcedar	*Thuja plicata*
Western waterleaf	*Hydrophyllum occidentalis*
Willow	*Salix* spp.

Appendix C

Taxonomy Resources

Trees and Shrubs

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McCune, B., and L. Geiser. 1997. Macrolichens of the Pacific Northwest. Oregon State University Press, Corvallis, Oregon.

Moths

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Miller, J.C., and P.C. Hammond. 2000. Macromoths of Northwest forests and woodlands. FHTET–98-18. USDA Forest Health Technology Enterprise Team, Morgantown, West Virginia.

Birds

American Ornithologists' Union. 1998. Check-list of North American birds: the species of birds of North America from the Arctic through Panama, including the West Indies and Hawaiian Islands. 7th edition. American Ornithologists' Union, Washington, D.C.

Appendix D

Common and Scientific Names of Moth Families Referenced in Text

Common name	Scientific name
Epiplemids	Epiplemidae
Geometers	Geometridae
Giant silkworms	Saturniidae
Hawks	Sphingidae
Hook-tips	Drepanidae
Noctuids	Noctuidae
Oecophorids	Oecophoridae
Plumes	Pterophoridae
Prominents	Notodontidae
Pyralids	Pyralidae
Slug caterpillars	Limacodidae
Swifts	Hepialidae
Tent caterpillars and lappets	Lasiocampidae
Thyatirids	Thyatiridae
Tigers	Arctiidae
Tortricids	Tortricidae
Tussocks	Lymantriidae

Appendix E

Common and Scientific Names of Birds Recorded During Surveys

Common name	Scientific name
American crow	*Corvus brachyrhynchos*
American goldfinch	*Carduelis tristis*
American robin	*Turdus migratorius*
Band-tailed pigeon	*Columba fasciata*
Belted kingfisher	*Ceryle alcyon*
Bewick' s wren	*Thryomanes bewickii*
Black-headed grosbeak	*Pheucticus melanocephalus*
Black-throated gray warbler	*Dendroica nigrescens*
Blue grouse	*Dendragapus obscurus*
Brown creeper	*Certhia americana*
Brown-headed cowbird	*Molothrus ater*
Bushtit	*Psaltiparus minimus*
Chestnut-backed chickadee	*Poecile rufescens*
Common nighthawk	*Chordeiles minor*
Common raven	*Corvus corax*
Dark-eyed junco	*Junco hyemalis*
Evening grosbeak	*Coccothraustes vespertinus*
Golden-crowned kinglet	*Regulus satrapa*
Gray jay	*Perisoreus canadensis*
Hairy woodpecker	*Picoides villosus*
Hammond' s flycatcher	*Empidonax hammondii*
Hermit thrush	*Catharus guttatus*
Hermit warbler	*Dendroica occidentalis*
House wren	*Troglodytes aedon*
Hutton' s vireo	*Vireo huttoni*
MacGillivray' s warbler	*Oporornis tolmiei*
Marbled murrelet	*Brachyramphus marmoratus*
Mountain quail	*Oreortyx pictus*
Mourning dove	*Zenaida macroura*
Northern flicker	*Colaptes auratus*
Northern pygmy-owl	*Glaucidium gnoma*
Olive-sided flycatcher	*Contopus cooperi*
Orange-crowned warbler	*Vermivora celata*
Pacific-slope flycatcher	*Empidonax difficilis*
Pileated woodpecker	*Dryocopus pileatus*
Pine siskin	*Carduelis pinus*
Purple finch	*Carpodacus purpureus*
Red crossbill	*Loxia curvirostra*
Red-breasted nuthatch	*Sitta canadensis*
Red-breasted sapsucker	*Sphyrapicus rubber*
Rufous hummingbird	*Selasphorus rufus*
Song sparrow	*Melospiza melodia*
Spotted towhee	*Pipilo maculatus*
Steller' s jay	*Cyanocitta stelleri*
Swainson' s thrush	*Catharus ustulatus*

Common name	Scientific name
Tree swallow	*Tachycineta bicolor*
Varied thrush	*Ixoreus naevius*
Vaux’ s swift	*Chaetura vauxi*
Warbling vireo	*Vireo gilvus*
Western screech owl	*Otus kennicottii*
Western tanager	*Piranga rubra*
Western wood-pewee	*Contopus sordidulus*
White-crowned sparrow	*Zonotrichia leucophrys*
Willow flycatcher	*Empidonax traillii*
Wilson’ s warbler	*Wilsonia pusilla*
Winter wren	*Troglodytes troglodytes*
Wrentit	*Chamaea fasciata*

Appendix F

Recommended Resources for Additional Information

Articles and Books

Assmann, E. 1970. The principles of forest yield study: studies in the organic production, structure, increment and yield of forest stands, translated by S.H. Gardiner. Pergamon Press, New York, New York. *Summarizes the European experience in forest growth and stand density.*

Bailey, J.D., and J.C. Tappeiner. 1998. Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon. Forest Ecology and Management 108:99–113. *See abstract, page 68.*

Bailey, J.D., C. Mayrsohn, P.S. Doescher, E. St. Pierre, and J.C. Tappeiner. 1998. Understory vegetation in old and young Douglas-fir forests of western Oregon. Forest Ecology and Management 112:289–302. *See abstract, page 68.*

Carey, A.B., J. Kershner, B. Biswell, and L. Dominguez de Toledo. 1999. Ecological scale and forest development: squirrels, dietary fungi, and vascular plants in managed and unmanaged forests. Wildlife Monographs 142:1–71. *Compares flying squirrels and Townsend's chipmunks in southwestern Oregon.*

Carey, A.B., B.R. Lippke, and J. Sessions. 1999. Intentional systems management: managing forests for biodiversity. Journal of Sustainable Forestry 9(3/4):83–125. *Provides a computer simulation of management strategies for Pacific Northwest western hemlock forests.*

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Colgan III, W., A.B. Carey, J.M. Trappe, R. Molina, and D. Thysell. 1999. Diversity and productivity of hypogeous fungal sporocarps in a variably thinned Douglas-fir forest. Canadian Journal of Forest Research 29(8):1259–1268. *Evaluates the use of ecosystem management techniques for truffles.*

Curtis, R.O., and D.D. Marshall. 1986. Levels-of-growing-stock cooperative study in Douglas-fir: Report No. 8—the LOGS study, twenty year results. Research Paper PNW–RP-356. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. *Summarizes Douglas-fir growth and stand development in western Oregon and Washington.*

Curtis, R.O., and D.D. Marshall. 1993. Douglas-fir rotations—time for reappraisal? Western Journal of Applied Forestry 8(3):81–85. *Discusses the growth of older Douglas-fir stands.*

Daniel, T.W., J.A. Helms, and F.S. Baker. 1979. Principles of silviculture. McGraw-Hill, New York, New York. *Serves as a textbook in silviculture and discusses stand growth.*

Dirks-Edmunds, J.C. 1999. Not just trees: the legacy of a Douglas-fir forest. Washington State University Press, Pullman, Washington. *Portrays a Douglas-fir forest in Oregon's Coast Range from the 1930s, through logging in the 1960s and clearcutting in the 1980s.*

Drew, T.J., and J.W. Flewelling. 1979. Stand density management: an alternative approach and its application to Douglas-fir plantations. Forest Science 25(3):518–532. *Reviews the development of stand-density diagrams.*

Eldredge, N. 1998. Life in the balance: humanity and the biodiversity crisis. Princeton University Press, Princeton, New Jersey. *Outlines steps to be taken as a global society to find a path away from impending extinctions.*

Hagar, J.C., W.C. McComb, and W.H. Emmingham. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands of western Oregon. Wildlife Society Bulletin 24(2):353–366. *See abstract, page 75.*

Halpern, C.B., and T.A. Spies. 1995. Plant species diversity in natural and managed forests of the Pacific Northwest. Ecological Applications 5(4):913–934. *Presents data from permanent-plot* *and chronosequence studies to describe early responses of understory communities to forest harvest and potential impacts of post-harvest practices.*

Halpern, C.B., S.A. Evans, C.R. Nelson, D. McKenzie, D.A. Liguori, D.E. Hibbs, and M.G. Halaj. 1999. Response of forest vegetation to varying levels and patterns of green-tree retention: an overview of a long-term experiment. Northwest Science 73:27–44. *Describes background vegetation studies, provides characteristics of Demonstration of Ecosystem Management Options study sites and variables, and reviews retrospective analyses and simulation models.*

Hammond, P.C., and J.C. Miller. 1998. Comparison of the biodiversity of Lepidoptera within three forested ecosystems. Annals of the Entomological Society of America 91(3):323–328. *See abstract, page 72.*

Haveri, B.A., and A.B. Carey. 2000. Forest management strategy, spatial heterogeneity, and winter birds in Washington. Wildlife Society Bulletin 28(3):643–652. *Presents the effects of management strategy and experimental variable-density thinnings on wintering birds in second-growth Douglas-fir stands.*

Hayes, J.P., S.S. Chan, W.H. Emmingham, J.C. Tappeiner, L.D. Kellogg, and J.D. Bailey. 1997. Wildlife response to thinning young forests in the Pacific Northwest. Journal of Forestry 95(8):28–33. *See abstract, page 69.*

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Marshall, D.D. 1991. The effects of thinning on stand and tree growth in a young, high site Douglas-fir stand in western Oregon. Ph.D. dissertation, Oregon State University, Corvallis, Oregon. *Synthesizes long-term stand development at the Hoskins site in western Oregon.*

McCune, B. 1994. Using epiphyte litter to estimate epiphyte biomass. The Bryologist 97(4): 396–401. *Evaluates the use of litterfall for estimating lichen biomass when large differences are expected.*

McCune, B. 2000. Lichen communities as indicators of forest health. The Bryologist 103(2):353–356. *Overviews systematic documentation of lichen communities in the United States through the Forest Health Monitoring program.*

McCune, B., K.A. Amsberry, F.J. Camacho, S. Clery, C. Cole, C. Emerson, G. Felder, P. French, D. Greene, R. Harris, M. Hutten, B. Larson, M. Lesko, S. Majors, T. Markwell, G.G. Parker, K. Pendergrass, E.B. Peterson, E.T. Peterson, J. Platt, J. Proctor, T. Rambo, A. Rosso, D. Shaw, R. Turner, and M. Widmer. 1997. Vertical profile of epiphytes in a Pacific Northwest old-growth forest. Northwest Science 71(2):145–152. *Describes vertical stratification of epiphytes by functional group in Northwest forests and evaluates methods used to estimate their abundance.*

McCune, B. 1993. Gradients in epiphyte biomass in three *Pseudotsuga–Tsuga* forests of different ages in western Oregon and Washington. The Bryologist 96(3):405–411. *See abstract, page 70.*

Miller, J.C. 2000. Monitoring the effects of *Bacillus thuringiensis kurstaki* on nontarget Lepidoptera in woodlands and forests of western Oregon. Pages 277–286 *in* P.A. Follett and J.J. Duan, editors. Nontarget effects of biological control. Kluwer Academic Publishers, Boston, Massachusetts. *Synthesizes research on nontarget Lepidoptera and provides recommendations for maintaining biodiversity.*

Miller, J.C. 1990. Field assessment of the effects of a microbial pest control agent on nontarget Lepidoptera. American Entomologist 36(2):135–139. *See abstract, page 73.*

Miller, J.C. 1990(92). Effects of a microbial insecticide, *Bacillus thuringiensis kurstaki,* on nontarget Lepidoptera in a spruce budworm-infested forest. Journal of Research on the Lepidoptera 29(4):267–276. *See abstract, page 73.*

Miller, J.C. 1993. Insect natural history, multi-species interactions and biodiversity in ecosystems. Biodiversity and Conservation 2:233–241. *See abstract, page 74.*

Miller, J.C. 1995. Caterpillars of Pacific Northwest forests and woodlands. FHM–NC-06-95. USDA Forest Service, National Center of Forest Health Management, Morgantown, West Virginia. *See abstract, page 74.*

Miller, J.C., and P.C. Hammond. 2000. Macromoths of Northwest forests and woodlands. FHTET–98-18. USDA Forest Health Technology Enterprise Team, Morgantown, West Virginia. *See abstract, page 74.*

Neitlich, P.N., and B. McCune. 1997. Hotspots of epiphytic lichen diversity in two young managed forests. Conservation Biology 11(1):172–182. *See abstract, page 71.*

Oliver, C.D., and B.C. Larson. 1996. Forest stand dynamics (update edition). John Wiley & Sons, Inc., New York, New York. *Serves as a widely recognized text on forest stand development.*

Peck, J.E., and B. McCune. 1998. Commercial moss harvest in northwestern Oregon: biomass and accumulation of epiphytes. Biological Conservation 86:299–305. *Overviews moss harvest and provides recommendations for adaptive management to protect the harvestable moss resource.*

Peck, J.E., and B. McCune. 1997. Remnant trees and canopy lichen communities in western Oregon: a retrospective approach. Ecological Applications 7(4):1181–1187. *See abstract, page 71.*

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Ruggiero, L.F., K.B. Aubry, A.B. Carey, and M.H. Huff, technical coordinators. Wildlife and vegetation of unmanaged Douglas-fir forests. General Technical Report PNW–GTR-285. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. *Presents papers on old-growth forests; Douglas-fir forests, diurnal forest birds, small mammals, and amphibians of Oregon and Washington; old-growth communities in northern California and southern Oregon; and wildlife and forest management in the Pacific Northwest.*

Sillett, S.C., B. McCune, J.E. Peck, T.R. Rambo, and A. Ruchty. 2000. Dispersal limitations of epiphytic lichens result in species dependent on old-growth forests. Ecological Applications 10(3):789–799. *See abstract, page 72.*

Tappeiner, J.C., D. Huffman, D. Marshall, T.A. Spies, and J.D. Bailey. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. Canadian Journal of Forest Research 27:638–648. *See abstract, page 69.*

Thysell, D.R., and A.B. Carey. 2000. Effects of forest management on understory and overstory vegetation: a retrospective study. General Technical Report PNW–GTR-488. USDA Forest Service, Pacific Northwest Research Station, Portland, Oregon. *Examines plant communities in Douglas-fir forests with divergent management histories.*

Thysell, D.R., and A.B. Carey. 2001. Manipulation of density of *Pseudotsuga menziesii* canopies: preliminary effects on understory vegetation. Canadian Journal of Forest Research 31(9):1513–1525. *Examines effects of inducing heterogeneity in managed forest canopies on species composition.*

Wilson, E.O. 1984. Biophilia. Harvard University Press, Cambridge, Massachusetts. *Focuses on biological diversity, its endangerment, and the need for an environmental ethic.*

Wilson, E.O., editor. 1988. Biodiversity. National Academy Press, Washington, D.C. *Reviews biodiversity, monitoring, restoration ecology, and preservation, based on the 1986 National Forum on BioDiversity.*

Wilson, S.M., and A.B. Carey. 2000. Legacy retention versus thinning: influences on small mammals. Northwest Science 74(2):131–145. *Compares effects of management strategies on small-mammal communities in western Washington.*

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Appendix G

Selected Abstracts

Researchers involved in the Managing for Biodiversity in Young Forests Project *have selected the abstracts reprinted here as representative of current understanding of phenomena and processes that contribute to biodiversity in each of their respective disciplines.*

Vegetation

Bailey, J.D., and J.C. Tappeiner. 1998. Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon. Forest Ecology and Management 108: 99–113.

We studied the composition and structure of the understory in thinned and unthinned Douglas-fir/ western hemlock stands on 32 sites in western Oregon. These stands had regenerated naturally after timber was harvested between 1880 and 1940; they were thinned between 1969 and 1984. Commercially thinned stands had 8–60% of their volume removed 10–24 years before the study. Undisturbed old-growth Douglas-fir stands were present for comparison on 20 of these paired sites. Conifer regeneration density and frequency were consistently greater in thinned than unthinned stands. For example, average seedling density in thinned stands (1433/ha) was significantly ($p \leq 0.001$) greater than in unthinned stands (233/ha), but very similar to that in old-growth stands (1010/ha). Seedling density and frequency were strongly related to the volume removed and to stand density index (and other measures of overstory density) just after thinning. In thinned stands, the density of small trees (intermediate crown class overstory trees and advanced regeneration) was 159/ha, significantly ($p \leq 0.001$) greater than in unthinned stands (90/ ha), but not significantly different from that of old-growth (204/ha). The live crown ratio of these trees in thinned stands (66%) was greater than in unthinned (44%) and old-growth (48%) stands. Cover and stem density of shrubs was variable in all three stand types. There was significantly less tall shrub cover in unthinned stands than in either thinned or old-growth stands, which did not differ. Thinned stands had the most low shrub cover. Salal and bracken fern cover was greater in thinned stands than in the other stand types, but there was no difference in sword fern and Oregongrape cover. Leaf area index in thinned stands (6.6) was not significantly different from that in unthinned (6.8) and old-growth stands (7.1); however, there was more leaf area in shrubs in the thinned stands. Thinning young Douglas-fir stands will hasten the development of multistory stands by recruitment of conifer regeneration in the understory as well as by enabling the survival of small overstory trees and growth of advanced understory regeneration. Thinning will also help develop the shrub layer by increasing tall shrub stem density and cover of some low shrubs.

Reprinted from Forest Ecology and Management, Volume 108, J.D. Bailey and J.C. Tappeiner, Effects of thinning on structural development in 40- to 100-year-old Douglas-fir stands in western Oregon, Pages 99–113, 1998, with permission from Elsevier Science.

Bailey, J.D., C. Mayrsohn, P.S. Doescher, E. St. Pierre, and J.C. Tappeiner. 1998. Understory vegetation in old and young Douglas-fir forests of western Oregon. Forest Ecology and Management 112:289–302.

We studied understory composition in thinned and unthinned Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)/western hemlock (*Tsuga heterophylla* (Raf.) Sarg.) stands on 28 sites in western Oregon. These stands had regenerated naturally after timber harvest, 40–70 years before thinning. Commercial thinning had occurred 10–24 years previously, with 8–60% of the volume removed from below with the intent to homogenize spacing among trees. Undisturbed old-growth Douglas-fir stands were present for comparison on 18 of these sites. Total herbaceous cover was greater in thinned (25% cover) stands than in unthinned (13% cover) or old-growth (15% cover) stands. Species richness was also greater in thinned (137) than in unthinned (114) and old-growth (91) stands (P=0.05). Part of the increased richness was caused by the presence of exotic species in thinned stands, but there were also more native grass and nitrogen-fixing species in thinned stands than in unthinned or old-growth stands. Groups of species differed among stand-types. For example, the frequency of tall cordate-leaved species was greater in old-growth stands (P=0.009), but their relative cover was different only between old-growth and unthinned stands (P=0.08). Both the cover and frequency of grasses and sedges in thinned stands were greater than in unthinned or old-growth stands ($P \leq 0.002$). Ordination of shrub cover showed differences among old-growth and unthinned stands compared to thinned stands, mainly because of the amount of *Gaultheria shallon* Pursh and *Polystichum munitum* (Kaulf.) Presl in heavily thinned stands. Ordination of herbaceous community data showed that there were much stronger differences among sites than among stand-types. The lack of difference among stand-types demonstrates the resiliency of herbaceous communities to disturbance associated with past and current forest management.

Reprinted from Forest Ecology and Management, Volume 112, J.D. Bailey, C. Mayrsohn, P.S. Doescher, E. St. Pierre, and J.C. Tappeiner, Understory vegetation in old and young Douglas-fir forests of western Oregon, Pages 289–302, 1998, with permission from Elsevier Science.

Hayes, J.P., S.S. Chan, W.H. Emmingham, J.C. Tappeiner, L.D. Kellogg, and J.D. Bailey. 1997. Wildlife response to thinning young forests in the Pacific Northwest. Journal of Forestry 95(8):28–33.

In western Oregon and Washington, hundreds of thousands of forested acres are in early seral stages (0 to 50 years old). Many of these stands are structurally simple, having a single canopy layer, limited number of tree species, relatively little understory, and in some cases, few standing or fallen dead trees. Management objectives for these lands vary, but whether managers want to maximize wood fiber yield or conserve biodiversity, commercial thinning may help them achieve their goals. In this article we examine the effects of thinning on wildlife and their habitat in forests of western Oregon and Washington, but many of the principles are applicable to other regions.

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Tappeiner, J.C., D. Huffman, D. Marshall, T.A. Spies, and J.D. Bailey. 1997. Density, ages, and growth rates in old-growth and young-growth forests in coastal Oregon. Canadian Journal of Forest Research 27:638–648.

We studied the ages and diameter growth rates of trees in former Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) old-growth stands on 10 sites and compared them with young-growth stands (50–70 years old, regenerated after timber harvest) in the Coast Range of western Oregon. The diameters and diameter growth rates for the first 100 years of trees in the old-g[r]owth stands were significantly greater than those in the young-growth stands. Growth rates in the old stands were comparable with those from long-term studies of young stands in which density is about

100–120 trees/ha; often young-growth stand density is well over 500 trees/ha. Ages of large trees in the old stands ranged from 100 to 420 years; ages in young stands varied by only about 5 to 10 years. Apparently, regeneration of old-growth stands on these sites occurred over a prolonged period, and trees grew at low density with little self-thinning; in contrast, after timber harvest, young stands may develop with high density of trees with similar ages and considerable self-thinning. The results suggest that thinning may be needed in dense young stands where the management objective is to speed development of old-growth characteristics.

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Epiphytic Lichens and Bryophytes

Lesica, P., B. McCune, S.V. Cooper, and W.S. Hong. 1991. Differences in lichen and bryophyte communities between old-growth and managed second-growth forests in the Swan Valley, Montana. Canadian Journal of Botany 69:1745–1755.

Lichen and bryophyte communities differed between managed second-growth and unmanaged old-growth grand fir forests in northwestern Montana in all three strata examined: lower canopy, trunk, and ground. Old-growth forests had larger trees, greater structural diversity, greater volumes of coarse woody debris, fewer species of vascular plants, more species of trunk epiphytes, higher β diversity, and higher γ diversity than second-growth forests. Although pendent fruticose lichens were common in both stand age classes, species of *Alectoria* were more abundant in old growth, while second growth was dominated by *Bryoria* spp. Nitrogen-fixing foliose lichens were more common in all strata of old growth, and *Lobaria pulmonaria,* a common N-fixing species in old growth, was absent in second growth. *Cladonia* spp. were more numerous in second-growth forests. Nearly all species of leafy liverworts were more common in old growth and typically occurred on rotting wood. Many of these liverworts were absent from second growth. Our results suggest that many species of lichens and bryophytes find optimum habitat in old-growth forests and that these species will become less common as silvicultural practices continue to convert old growth to younger aged forests.

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McCune, B. 1993. Gradients in epiphyte biomass in three *Pseudotsuga–Tsuga* forests of different ages in western Oregon and Washington. The Bryologist 96(3):405–411.

Epiphyte biomass on branches and trunks was estimated for 42 individual felled trees, distributed among three *Pseudotsuga menziesii–Tsuga heterophylla* stands aged 95, 145, and 400+ years, in the western Cascade Range of Oregon and Washington, then extrapolated to the whole stands by regression techniques. Epiphytes were sorted into four groups defined by ecological roles rather than taxonomy: cyanolichens, alectorioid lichens, other lichens, and bryophytes. In general the spatial sequence of dominance of these four groups, from upper canopy to forest floor, was: “other” lichens, alectorioid lichens, cyanolichens, and bryophytes. The zones of these functional groups of epiphytes apparently migrate upward in forests through time. For example the *Hypogymnia* and *Platismatia* that dominate throughout canopies in young forests are found primarily in the upper canopies of old forests. Similarly, bryophytes enter a stand near the forest floor and gradually expand their dominance upwards. Epiphyte biomass was greatest in the old-growth stand, with about 2.6 t/ha. In the two younger stands total epiphyte biomass was about 1 t/ha. The old-growth stand differed from the younger stands in having over 1 t/ha of cyanolichens, while this group was essentially absent from the younger stands. As a synthesis of these and previous results, a similar gradient hypothesis is proposed: epiphyte species are ordered similarly on three distinct spatial and temporal gradients: 1) vertical differences in species composition within a given stand, 2) species compositional differences among stands differing in moisture regime but of the same age, and 3) changes in species composition through time in a given stand.

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Neitlich, P.N., and B. McCune. 1997. Hotspots of epiphytic lichen diversity in two young managed forests. Conservation Biology 11(1):172–182.

Understanding within-stand variation in diversity of epiphytes will provide an improved basis for producing timber while conserving biological diversity. Two 80-ha, 50-year-old managed stands of conifers were surveyed to locate 0.4 ha putative "diversity" plots, the areas appearing most diverse in lichen epiphytes. These plots were generally located in areas made heterogeneous by canopy gaps, wolf trees (trees with large-diameter lower branches), and old-growth remnant trees. "Matrix" plots, in contrast, were chosen at random from the remaining, more homogen[e]ous forest. Diversity plots hosted from 25% to 40% more epiphytic lichen species than matrix plots in both stands. The strongest within-stand gradients in species composition were correlated with percentage of plot occupied by gaps and wolf trees. Percentage of the plot in gaps was correlated with species richness ($r = 0.79$). In the more structurally diverse stand, diversity and abundance of nitrogen-fixing "cyanolichens" were correlated with percentage of the plot occupied by gaps ($0.5 < r < 0.9$), and alectorioid lichens were correlated with percentage of the plot occupied by old-growth remnant trees ($0.5 < r < 0.6$). In the stand with more homogen[e]ous structure, percentage of the plot under gaps was correlated with regionally common species that were otherwise absent or sparse in the matrix. Protecting gaps, hardwoods, wolf trees, and old-growth remnant trees during thinning or other partial cutting is likely to promote the majority of epiphytic macrolichens in young conifer forests. Because these features are easily recognized on aerial photos and on the ground by land managers, it is practical to manage for forest structures that would promote lichen diversity.

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Peck, J.E., and B. McCune. 1997. Remnant trees and canopy lichen communities in western Oregon: a retrospective approach. Ecological Applications 7(4):1181–1187.

The "New Forestry" practice of green-tree retention is becoming an important management tool for publicly owned lands, yet few data exist to demonstrate that this tool can succeed at enhancing biodiversity. We addressed this issue by using a retrospective approach to compare canopy lichen litter in adjacent, paired stands of rotation age (55–120 yr): one with and one without old-growth (>300 yr) remnant trees. We sampled three functional groups of lichens in 17 stands in western Oregon: alectorioid lichens, cyanolichens, and green-algal foliose lichens. Thirteen stands were low elevation (520–850 m) and four were mid-elevation (1220–1340 m). Biomass of cyanolichen and green-algal foliose lichen litter was greater in low-elevation sites, whereas alectorioid lichen litter biomass was greater in mid-elevation sites. Cyanolichens were absent from all mid-elevation sites. Biomass of alectorioid lichen and cyanolichen litter was greater in low-elevation sites with remnant trees than in those without remnant trees by 86% and 233%, respectively. The biomass of green-algal foliose lichen litter was 80% greater in mid-elevation sites without remnant trees than in those with remnant trees. Total lichen litter biomass was slightly, but not significantly, greater in stands with remnant trees at both low elevations (by

23%; ~370 kg/ha standing biomass in remnant stands) and mid elevations (by 12%; ~470 kg/ha standing biomass). Cyanolichen litter biomass was positively related to the number of remnant trees present; alectorioid and green-algal lichen litter biomass were negatively correlated with the density of trees in the regeneration cohort. Because retaining live remnant trees will differentially affect these three functional groups of macrolichens, managers must be clear as to their objectives before using green-tree retention as a tool to enhance biodiversity.

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Sillett, S.C., B. McCune, J.E. Peck, T.R. Rambo, and A. Ruchty. 2000. Dispersal limitations of epiphytic lichens result in species dependent on old-growth forests. Ecological Applications 10(3):789–799.

Epiphytic lichen biomass accumulates slowly in forest canopies. We evaluated three alternative hypotheses for the slow accumulation of epiphytic lichens, using two experiments in tree crowns from 15 Douglas-fir forest stands representing three age classes: old growth, young, and recent clearcuts. The first experiment evaluated whether forest age, bark roughness, or dispersal rate limits the establishment of the dominant old-growth-associated lichen, *Lobaria oregana.* Surface-sterilized branches with either rough or smooth bark were repeatedly inoculated with propagules and compared 1 yr after the last inoculation. Dispersal affected rates of establishment: inoculated branches had 27X more newly established thalli than controls. Establishment on smooth bark was highest in clearcuts, intermediate in young forests, and lowest in old growth. There was as much or more establishment of sown propagules on smooth-barked branches as on rough-barked branches in all age classes. In the second, transplant-performance experiment, *Lobaria oregana* grew as rapidly in young forests as in old growth but lost biomass and suffered more injuries in clearcuts. In contrast, *L. pulmonaria* performed at least as well in clearcuts as in young forests and old growth. Poor dispersal and establishment limit the development of *L. oregana* populations in Douglas-fir forests. Particular substrates and microenvironments found only in old growth are not essential for *Lobaria* establishment and growth. Maximizing the number and dispersion of remnant trees in cutting units should maximize the rate of accumulation of *L. oregana* biomass in the regenerating forest. The single most important action promoting the accumulation of old-growth-associated epiphytes will be the retention of propagule sources in and near all cutting units.

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Moths[51]

Hammond, P.C., and J.C. Miller. 1998. Comparison of the biodiversity of Lepidoptera within three forested ecosystems. Annals of the Entomological Society of America 91(3):323–328.

Lepidopterans function in the dynamics of forested ecosystems by serving as defoliators, decomposers, prey or hosts to carnivores, and pollinators. The biodiversity of Lepidoptera is thus linked into the ecosystem by influencing nutrient cycling, plant population dynamics, and predator-prey population dynamics. Two important measures of biodiversity are species richness and abundance of individuals. However, values for these measures require an ecosystem context for insightful interpretation of ecological function. We propose that such an ecosystem context is

[51] These are the first studies to quantify moth species according to region and treatment. No other literature exists on this topic. The protocol and baseline data are being established for future works. The basic need is to quantify resident moth fauna. This quantification involves making checklists, being thorough in methods, and being capable in identification.

gained by an assessment of host resource requirements; in the case of Lepidoptera, this means larval host plants. The flora that contributes to the biodiversity of Lepidoptera can be grouped into 3 major vegetation types: (1) conifers, (2) hardwood trees and shrubs, and (3) herbs and grasses. We compared the macrolepidopteran biodiversity of 3 forested ecosystems: (1) western Oregon, (2) eastern Oregon, and (3) West Virginia. In respective order of the above locations, totals of 463, 385, and 475 species were found. Conifers supported 9, 10, and 1% of the species richness. By contrast, hardwoods supported 57, 45, and 61% of the species richness, whereas herbs and grasses supported 31, 42, and 31% of the species richness. The patterns in abundance of individual moths were different from species richness of moths and butterflies considered together. Comparisons of moth abundance showed conifers supported 18, 5, and 1%; hardwoods supported 69, 39, and 77%; and herbs and grasses supported 11, 55, and 8%. Practices involved in the management of forested ecosystems are discussed in the context of how Lepidoptera may be used as an indicator taxon for the assessment of land management practices, and how biodiversity of Lepidoptera could be considered in plans for habitat restoration with a specific focus on food web relationships.

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Miller, J.C. 1990. Field assessment of the effects of a microbial pest control agent on nontarget Lepidoptera. American Entomologist 36(2):135–139.

Species in a guild of nontarget leaf-feeding Lepidoptera on Garry oak, *Quercus garryana* Dougl., were monitored in the field for a period of 3 yr (1986–1988) to assess the ecological effects of three applications of the microbial pest control agent, *Bacillus thuringiensis* Berliner var. *kurstaki* within a single-season application (spring 1986). The target species for the *B. thuringiensis kurstaki* application was the gypsy moth, *Lymantria dispar* (L.), in a large-scale eradication program in Lane County, Oreg. Species richness in the guild of leaf-feeding Lepidoptera on Garry oak was significantly reduced in the treated plots during all 3 yr of the study. Also, the total number of individual nontarget Lepidoptera was significantly reduced in treated plots during the first 2 yr but not in the third. These data suggest that certain nontarget species of Lepidoptera may be ecologically “at risk” in large-scale pest control programs based on *B. thuringiensis kurstaki*. Variables such as phenology, voltinism, and plot size are discussed regarding the degrees of risk and type of species that may be most affected by large-scale microbial pest control agent control and eradication programs.

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Miller, J.C. 1990(92). Effects of a microbial insecticide, *Bacillus thuringiensis kurstaki*, on nontarget Lepidoptera in a spruce budworm-infested forest. Journal of Research on the Lepidoptera 29(4):267–276.

Species in a guild of nontarget leaf-feeding Lepidoptera on tobacco brush, *Ceanothus velutinus* Dougl. were monitored in the field to assess ecological effects of one application of the microbial pest control agent, *Bacillus thuringiensis* Berliner var. *kurstaki* [BTK]. The Lepidoptera were sampled to compare species richness, species evenness, species diversity, larval abundance, and a dominance index between an untreated and BTK treated site over a period of two years. The guild of leaf-feeding Lepidoptera on *C. velutinus* consisted of 32 species. No statistically significant differences were observed in overall species richness, although the number of species in the untreated site was 30% higher two weeks after treatment. However, species richness among uncommon species was significantly reduced in the treated site. Also, no statistically significant differences were observed in species evenness or species diversity but the indices were lower in the untreated site in three of the four post-treatment samples. A dominance index was consistently higher in the untreated site. The total number of caterpillars per 100 sec sampling was significantly higher (5.4-fold) in the untreated site in the early summer sample, two weeks after treatment. Also, larval abundance in the early summer sample was significantly higher (3.5-fold) one year later. No differences were noted in larval abundance in the late summer sample in either year.

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Miller, J.C. 1993. Insect natural history, multi-species interactions and biodiversity in ecosystems. Biodiversity and Conservation 2:233–241.

The composition and dynamics of ecosystems are influenced by insects serving as providers, eliminators and facilitators across multiple trophic levels. The role of insects in ecosystems may be documented by manipulative field studies involving exclusion techniques applied to species that are decomposers, herbivores or predators. The presence or absence of insects is important to the distribution, abundance and diversity of plants and vertebrates, which typically are the premier species in conservation efforts. Thus, policy-making in environmental management programmes should consider the role of insects in ecosystems when establishing objectives and procedures for species conservation and biodiversity.

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Miller, J.C. 1995. Caterpillars of Pacific Northwest forests and woodlands. FHM–NC-06-95. USDA Forest Service, National Center of Forest Health Management, Morgantown, West Virginia.

...Identifying field-collected caterpillars to the species level is essential to performing natural history observations and conducting detailed ecological studies on caterpillars and host plants, parasitoids and host caterpillars, and using caterpillars as indicator species in assessing environmental impacts. Diagnostic keys for identifying species of caterpillars in the Pacific Northwest are not available.... This booklet is a field guide with keys to the identification of caterpillars commonly found in forests and woodlands of the Pacific Northwest. It contains a brief section on the natural history of caterpillars and describes variations in morphology, color, and pattern that are used to identify caterpillars. It also provides details on how to collect and rear caterpillars, and how to photograph and preserve specimens. Included are a section on nomenclature and a description of the families most commonly found in the Pacific Northwest.

Miller, J.C., and P.C. Hammond. 2000. Macromoths of Northwest forests and woodlands. FHTET–98-18. USDA Forest Health Technology Enterprise Team, Morgantown, West Virginia.

...Identifying field-collected macromoths, either adults or caterpillars, to the species level is essential to performing natural history observations, accurately labelling collections, and conducting detailed ecological studies on host plants, parasitoids, and using Lepidoptera as indicator species in assessing environmental impacts. This guide to identification of the adults of macromoths of forests and woodlands with an emphasis on the fauna of the Pacific Northwest serves to complement a field guide to the caterpillars of Pacific Northwest forests and woodlands (Miller 1995). We have selected 251 species for diagnostic narratives and photographs of adults. Also, we have included discussion on over 300 additional species in diagnosing similar species to those featured with photographs. The geographical range for these species as a whole covers not just the Pacific Northwest States but also west of the Rocky Mountains and from northern California to southern British Columbia.

Birds

Chambers, C.L., W.C. McComb, and J.C. Tappeiner II. 1999. Breeding bird responses to three silvicultural treatments in the Oregon Coast Range. Ecological Applications 9(1):171–185.

Silvicultural alternatives to clear-cutting have been suggested to promote development, retention, or creation of late-successional features such as large trees, multilayered canopies, snags, and logs. We assessed bird response to three silvicultural alternatives to clear-cutting that retained structural features found in old Douglas-fir (*Pseudotsuga menziesii*) forests and that imitated natural disturbance regimes more closely than did traditional clear-cutting: (1) small-patch group selection treatment representing a low-intensity disturbance; (2) two-story treatment, representing a moderate to high-intensity disturbance; and (3) modified clear-cut treatment, representing a high-intensity disturbance. We counted diurnal breeding birds 1 yr prior to and 2 yr after harvest to estimate effects of the silvicultural treatments on bird communities compared with uncut controls. The small-patch group selection treatment was most similar in species composition to control stands. The two-story treatment was more similar to the modified clear-cut treatment. Ten bird species remained abundant following the small-patch group selection treatment. They declined in abundance in modified clearcuts and two-story stands. These species included four neotropical migratory species and five species with restricted geographic ranges and habitat associations. Nine species increased in response to moderate and/or high-intensity disturbances. This group included a larger proportion of species that were habitat generalists. Silvicultural treatments imitating low-intensity disturbances were most effective in retaining bird communities associated with mature forest; high-intensity disturbances such as the two-story and modified clear-cut treatments greatly altered bird community composition. Bird responses to the silvicultural treatments that we studied indicate that a variety of stand types is needed to meet needs of all species.

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Hagar, J.C., W.C. McComb, and W.H. Emmingham. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands of western Oregon. Wildlife Society Bulletin 24(2):353–366.

We compared abundance and diversity of breeding and winter birds between commercially thinned and unthinned 40- to 55-year-old Douglas-fir (*Pseudotsuga menziesii*) stands in the Oregon Coast Ranges. Abundance of breeding birds was greater in thinned stands. Bird species richness was correlated with habitat patchiness and densities of hardwoods, snags, and conifers. During the breeding season, Hammond’s flycatchers (*Empidonax hammondii*), hairy woodpeckers (*Picoides villosus*), red-breasted nuthatches (*Sitta canadensis*), dark-eyed juncos (*Junco hyemalis*), warbling vireos (*Vireo gilvus*), and evening grosbeaks (*Coccothraustes vespertinus*) were more abundant in thinned than unthinned stands. Pacific-slope flycatchers

(*Empidonax difficilis*) were more abundant in unthinned stands. Golden-crowned kinglets (*Regulus satrapa*), gray jays (*Perisoreus canadensis*), and black-throated gray warblers (*Dendroica nigrescens*) were more abundant in unthinned than thinned stands, but these patterns were inconsistent between seasons, regions, or years. Stand-scale habitat features were associated with the abundance of 18 bird species.

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REPORT DOCUMENTATION PAGE	Form approved OMB No. 0704-0188

Public reporting burden for this collection is estimated to average 1 hour per response, including time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.

1. AGENCY USE ONLY (Leave Blank)

2. REPORT DATE
October 2002

3. REPORT TYPE AND DATES COVERED
Biological Science Report

4. TITLE AND SUBTITLE
Managing for Biodiversity in Young Douglas-Fir Forests of Western Oregon

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESSES
U.S. Department of the Interior, U.S. Geological Survey

8. PERFORMING ORGANIZATION REPORT NUMBER
USGS/BRD/BSR–2002-0006

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESSES
U.S. Department of the Interior, U.S. Geological Survey

10. SPONSORING, MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Prepared as part of an interagency agreement between the USGS Forest and Rangeland Ecosystem Science Center and Oregon State University under the auspices of the Cooperative Forest Ecosystem Research Program.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Release unlimited. Available from the National Technical Information Service, 5825 Port Royal Road, Springfield, Virginia 22161 (800-553-6847 or 703-487-4650). Available to registered users from the Defense Technical Information Center, Attn.: Help Desk, 8725 John J Kingman Road, Suite 0944, Fort Belvoir, Virginia 22060-6218 (800-225-3842 or 703-767-9050).

12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)
This project addressed potential contributions of forest thinning to enhancing biodiversity and accelerating development of old-growth characteristics in relatively young Douglas-fir forests typical of those managed according to the Northwest Forest Plan. Studies focused primarily on 32 paired unthinned and thinned stands and 20 associated old-growth stands in the Coast Range and Cascade mountains of western Oregon. Data were collected on vascular plants in most stands surveyed, and on epiphytic lichens and bryophytes, moths, and birds in subsets of these stands. Studies assessed whether or not (1) communities of organisms differed among stand types, (2) communities in thinned stands were more similar to those in old-growth stands than were those in unthinned stands, (3) species diversity or abundance was related to specific stand features, and (4) these specific stand features were shared across taxa. Results indicated that communities differed among stand types, and that communities in thinned stands were not necessarily more similar to old-growth communities than were those in unthinned stands. Variation in stand conditions appeared to enhance biodiversity, and hardwood trees and shrubs were important for many species. These and other results form the basis for general thinning guidelines, which are presented here, and will guide future research.

14. SUBJECT TERMS (Keywords) biodiversity, bryophytes, community analysis, epiphytes, forest management, functional groups, hardwoods, lichens, moths, neotropical migratory songbirds, Northwest Forest Plan, old-growth forests, remnant trees, shrubs, thinning, variable-density thinning, vegetation

15. NUMBER OF PAGES

16. PRICE CODE
To be determined

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

USGS Forest and Rangeland Ecosystem Science Center, Cooperative Forest Ecosystem Research Program, Meta Writing and Education Services, and Ecopress.

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NOTE: The mention of trade names does not constitute endorsement or recommendation for use by the Federal Government.

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