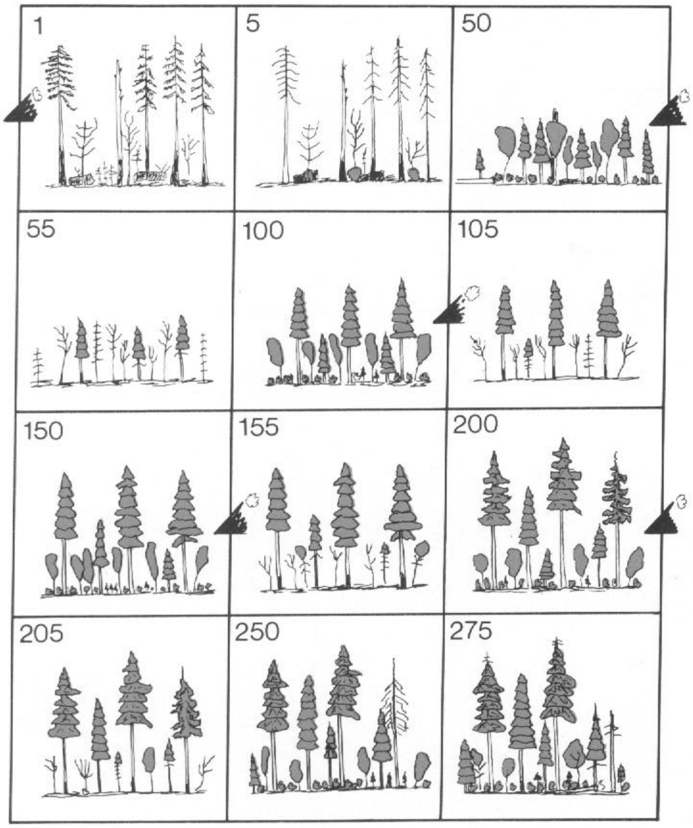

Figure 9—Stand development sequence for dry Douglas-fir forest. Fire return interval is about 50 years. Old-growth character is found in those stands that burn with low-to-moderate severity over several fires, allowing the development of large residual Douglas-fir. The minimum criteria for old growth are met through a much different developmental sequence than shown for wet-site Douglas-fir forest in figure 8.

Discussion

The historic role of fire in Pacific Northwest forests is critical in understanding how these Douglas-fir forests developed, and to what extent they provide habitat for wildlife. The extent to which such patterns and processes provide a blueprint for future management is less clear. No areas are large enough to allow totally free-ranging fire; few areas have management objectives that will allow prescribed natural fire (lightning ignitions allowed to burn under certain conditions in certain zones). Logging followed by slash burning has sometimes been called a mimic of natural process (Agee 1989). Although some aspects (for example, smoke production; Fahnestock and Agee 1983) may be similar, the functional result in the past has been quite different: no snags are left (shade, woodpeckers) and much more soil disturbance is present after logging, which may redirect postdisturbance plant succession (Scott 1980).

Historic fire patterns have several implications for remaining old-growth forests. Today's old growth tends to be fragmented—that is, broken into small units—as a result of harvest. Based on historic patterns of fire, increased fragmentation compared to natural conditions should be more significant to the north, which apparently had larger blocks of single-aged stands. The increasingly smaller size of old-growth stands will create a drier, windier microclimate along stand edges, accelerating both windthrow and potential fire behavior. Slash burns may increase the risk of fire escape to neighboring stands (Agee 1989). Such units will also be easier to reach and protect from fire, however, if that is the appropriate management strategy.

To suggest that fire is an appropriate process in the preservation of old-growth forest seems paradoxical. Yet it is apparent that almost all of our Douglas-fir old-growth forest resource consists of first- or multi-generation forests born of fire. Fire is responsible for their destruction; yet it is also responsible for their creation and maintenance. Without fire, the old-growth forests of the Pacific Northwest would have significantly different species composition and structure, and would likely function quite differently as wildlife habitat.

In the short term, management plans to perpetuate old-growth forest can ignore fire. So many other disturbances are reducing the area of old growth that short-term management should be oriented to a preservation- rather than a process-oriented approach: preserve what we have without regard to its long-term maintenance. Eventually, we must come to grips with the realization that these living systems will change, even with complete protection from disturbance. The proportion of Douglas-fir will decline, particularly on more mesic sites, with attendant changes in wildlife habitat. In the long run, we will be forced to recognize a more dynamic management strategy, sensitive not only to historic fire regimes, but also to the new fire regimes expected with global climate change.

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Forest Fragmentation in the Pacific Northwest and its Potential Effects on Wildlife

John F. Lehmkuhl and Leonard F. Ruggiero

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Abstract

Fragmentation is the creation of a complex mosaic of spatial and successional habitats from formerly contiguous habitat. Loss of habitat and the less obvious phenomenon of habitat-patch isolation are aspects ‘of fragmentation that threaten the viability of wildlife populations, the components of biotic diversity. Fragmentation of forests on Federal lands in the Pacific Northwest is the product of staggered-set clearcutting of late-successional forest. Large-scale block clearcutting on private lands has minimized fragmentation simply by leaving few or no fragments. Less than 20 percent of the original old-growth forest remains, and the fragmentation of remaining old-growth stands may degrade the quality of these areas for plants and wildlife. Analysis of population vulnerability suggests that life-history characteristics, along with biotic and physical environmental factors, influence population structure and individual fitness. These factors determine the risk of local population extinction. We compiled a list of 93 species associated with late-successional Douglas-fir forests in the Northwest and rated the risk for each species of local extinction from fragmentation on a scale of 1 to 10 based on the frequency of occurrence, abundance, and variation in abundance data from the old-growth community studies (this volume), and on body size, vagility, and migratory status information from the literature. Over 80 percent of the listed species had high to moderately high risk scores (7 to 10); risk for these species was a function of the low frequency and abundance associated with three combinations of body size and vagility. Clearcutting in patterns that minimize fragmentation would reduce the impact of isolation and small patch size for 27 species, likely benefit another 20 species, but probably have little impact on 46 species.

Introduction

Forest fragmentation and its effects on biotic diversity have been recognized during the last decade as one of the most pressing problems faced by conservation biologists. Particular attention has been given to the relatively undeveloped and unstudied tropical region (Soul) and Wilcox 1980). Recent planning activities of Federal land-management agencies and issues related to the conservation of old-growth forest ecosystems, however, have brought forest fragmentation to the forefront of domestic conservation biology (Harris 1984, Harris and others 1982, Lehmkuhl 1984, Lumen and Nietro 1980, Meslow and others 1981, Salwasser and Samson 1985).

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Forest fragmentation typically is the creation of a complex spatial and temporal mosaic of forest patches by staggered-set clearcutting, in which small (<20 ha) clearcuts are scattered over the landscape. Aside from the loss of old-growth forest habitats that results from this practice, the remaining forest patches become smaller and more isolated as logging continues. Nowhere is this problem more evident or controversial than in the old-growth forests administered for multiple use by public land-management agencies in the Pacific Northwest (Franklin and Forman 1987, Meslow and others 1981). The problem is made urgent by the planned harvest of 50 percent of the old-growth remaining on National Forest lands in western Oregon and Washington over the next 5 years, at a rate of more than 75,000 ha per year (Marcot and others, this volume; Ohman and others 1988), and by the planned liquidation of old growth remaining on Bureau of Land Management (BLM) lands in southern Oregon over the next 10 to 20 years (Lumen and Nietro 1980).

A substantial literature documents the effects of forest fragmentation on birds in agricultural landscapes of Eastern North America and Europe (for example, Forman and others 1976, Freemark and Merriam 1986, Galli and others 1976, Van Dorp and Opdam 1987, Whitcomb and others 1981). These studies have generally found that the presence or abundance of forest-interior birds declines with decreasing size and increasing isolation of forest patches. A few studies have analyzed changes in the general abundance of forest birds (Raphael and others 1988), and small mammals and amphibians (Raphael 1988c) as the result of logging in Western forests. Little is known, however, about the specific effects of fragmentation caused by clearcutting formerly extensive old-growth forests in Western North America. In contrast to Eastern forests, studies in Western forests (Lehmkuhl and others, this volume; Raphael 1984; Rosenberg and Raphael 1986) have found vertebrate richness or abundance only weakly related to stand size and isolation, although some negative effects were suggested for particular species. Isolation and small-area effects were suggested by Newmark (1987) as the cause of local extinction for 43 percent of the medium and large mammal species in National Parks of the Western United States. A comparison of the western forest situation with that in eastern forests, however, is weak.

Eastern forests have experienced extensive fragmentation (Whitcomb and others 1981), providing relatively static and simple systems with woodlot patches in an agricultural-land matrix. The relatively static dynamics and high contrast between patch and matrix are ideal for studying the effects of habitat patch size and isolation. Western forests managed for timber production, however, are at an early stage of fragmentation with a dynamic and complex pattern that is more difficult to study. Old growth in a managed landscape forms the matrix, rather than the patch as with woodlots (Harris and others 1982, Vemer 1986), until a threshold is reached where cutover forest area exceeds pristine forest area (Franklin and Forman 1987). Boundaries between old growth and cleat-cuts, although initially distinct, are dynamic and become increasingly ambiguous with secondary succession of clearcuts (Rosenberg and Raphael 1986), whereas woodlot boundaries remain distinct and both boundary and habitat matrix are relatively static.

The incipient nature of Western forest fragmentation nevertheless allows us the opportunity to study and manage forest landscapes to prevent or ameliorate the impacts of timber harvesting on wildlife populations. Our goal in this paper is to assess the state of old-growth forest fragmentation in the Pacific Northwest, and the potential effects of that process on wildlife. Our objectives are to briefly describe the loss and fragmentation of old-growth forests in the Pacific Northwest, to review concepts for assessing the effects of forest fragmentation on wildlife population persistence and diversity and describe the characteristics of species vulnerable to extinction, to compile a list of Pacific Northwest species associated with old-growth forests and rate their vulnerability to fragmentation, and to examine timber harvest alternatives that may minimize the effects of fragmentation on wildlife populations. We will primarily discuss the fragmentation of old-growth, or late-successional forests (synonymous in view of problems in defining the old-growth condition; see Marcot and others, this volume), because they are least likely to be present in managed forest landscapes. The discussion will be oriented to public land management, as opposed to private industrial forest land where old growth has been largely eliminated (Harris 1984, Ohman and others 1988, Spies and Franklin 1988) and where wildlife values are incidental (Hicks 1985) to timber production.

Forest Fragmentation in the Pacific Northwest

Two issues are associated with current harvest patterns of old growth: quantitative loss of habitat for associated species, and qualitative loss of habitat resulting from the reduced capacity of remaining patches to support old-growth conditions and wildlife communities. Assessing the quantitative loss of old growth is problematic because estimates of the area of old-growth forest remaining on public lands vary with the definition of the old-growth condition (Marcot and others, this volume). We are not prepared to defend any particular definition, but we present estimates from the literature to provide order-of-magnitude information.

Estimates of old-growth forest remaining in Oregon and Washington range from 1 to 2.5 million ha, representing 10 to 25 percent of a base 10 million ha of commercial forest land. Spies and Franklin (1988) estimated that 1 million ha of old-growth forest (17 percent) remains from the 6 million ha of commercial forest land that occurred before settlement. The Pacific Northwest Region of the USDA Forest Service estimates that remaining old-growth on National Forests in Oregon and Washington are 2.5 million ha (USFS 1988). More in line with Spies and Franklin, Morrison (1988) reinterpreted Regional data with a stricter definition of old-growth and estimated that little more than 1 million ha remains. Northern California appears to have retained a much larger percentage (50 percent or 400 000 ha) of its original 810 000 ha of old-growth forest (Raphael and others 1988) from a base of 1.1 million ha of commercial forest land.

The qualitative loss of old-growth habitat by the creation of many small fragments in formerly contiguous forest is the second issue associated with forest management. The viability of remnant patches as wildlife habitat is a function of myriad edge effects that depend on patch size and isolation. Some research suggests that a fundamental change in microclimate occurs within 160 m of the forest edge, which creates conditions different from the patch interior (Franklin and Forman 1987, Harris 1984). Patches 10 ha are effectively all edge and have lost the essential attributes of the old-growth condition. This, and other edge effects, which we will discuss later in detail, act to reduce the effective size and functional viability of patches for plant and animal communities.

Forty years of staggered-set clearcutting on National Forest (Harris 1984, Spies and Franklin 1988) and BLM lands (Lumen and Nietro 1980, Monthey 1984) has resulted in various stages of fragmentation of the remaining forest. Data on the patch-size distribution of forest fragments are available for only a few areas. Harris (1984) presented data from the Siuslaw National Forest in the Oregon Coast Range indicating that 3 to 6 percent of the forest area remained in old growth, depending on the definition used; 34 percent of the old-growth stands were smaller than 8 ha and 61 percent of the patches were smaller than 16 ha, accounting for 8 and 21 percent of the total old-growth area. If stands less than 8 ha are not functional as old growth and are subtracted from the old-growth area of the Siuslaw National Forest, only 2 percent of the Forest area remains as functional old-growth, even assuming a total area of 6 percent old growth. The isolation of forest fragments with distances up to 7 km (Harris and others 1982) between patches further limits the functioning of old-growth patches as wildlife habitat.

Monthey (1984) reported a similar patch-size distribution for BLM lands in Oregon: about 50 percent of the patches were less than 12 ha, and most were less than 4 (Lehmkuhl and others, this volume) on 48 2025-ha landscapes on National Forest and National Park lands in the southern Washington Cascade Range indicated that about. 31 percent of the area was old growth; 39 percent of the patches were 110 ha, but they represented only 4 percent of the total old-growth area. Excluding study landscapes in Mount Rainier National Park yielded only a slightly larger percentage (5 percent), of old-growth stands 10 ha, which suggests that much of the remaining old-growth in the southern Washington Cascades may still be in large enough patches to be considered functional. Those study landscapes, however, may be biased for relatively high old-growth area because selection of study landscapes was based on the requirement that stands be >40 ha for the original stand-scale studies. The study landscapes may nevertheless represent the general area as indicated by the similar percentages of clearcut area (16 percent) for study landscapes and the Gifford Pinchot National Forest in general (G. Gruelich, unpubl. data).

Assessing Fragmentation Effects on Wildlife

Species Diversity and Population Persistence

Maintaining species diversity is the ultimate goal of current conservation efforts. Species diversity as an operational goal for management, however, is not always desirable (Anderson 1979; Askins and others 1987; Murphy 1989; Raphael, this volume; Van Home 1983; Vemer 1986). Conventional methods for measuring species diversity do not distinguish between species and do not account for their special ecological and management importance. Clearly, we need to be concerned with individual species, while diversity should be a conceptual goal for conserving regional biota (Anderson 1979, Askins and others 1987, Murphy 1989, Noss and Harris 1986, Van Home 1983, Wilcox and Murphy 1985). To manage for species, we must understand the processes affecting the persistence and stability of populations of individual species as components of species richness.

The persistence of a population is primarily a function of its size, with extinction (local or global) invariably preceded by reduced population size (Gilpin and Soul) 1986, Goodman 1987a,b, Newmark 1987, Pimm and others 1988, Soul) and others 1988, Wilcox 1980). The reduction may result from natural or human-caused disturbance; in our case, smaller populations are a consequence of a quantitative or qualitative loss of habitat. In circumstances where population size is reduced below a threshold number for recovery, the subsequent extinction of the reduced population may be deterministic and unavoidable. More often, extinction depends on the interplay of stochastic (random) factors with population and environmental factors (Gilpin and Soul) 1986, Shaffer 1981). Shaffer (198 1) described four primary stochastic forces of extinction:

- Stochastic demographic changes in small populations, such as variation in birth and death rates and sex or age anomalies randomly affect individuals in a manner that increases the variance in reproductive rate and increases the probability of extinction from a chance reproductive failure (Goodman 1987a, Lande 1988);

- Environmental stochasticity, random temporal changes in environmental quality or interspecific interactions, affect individuals equally in a manner that increases variation in abundance and has proportionately large effects on small populations (Goodman 1987a, Lande 1988);

- Catastrophes may occur at random intervals through time and can arguably be called intense, punctuated cases of environmental stochasticity; and

- Genetic stochasticity arises from a reduction in the effective population size with consequential deleterious short-term effects of inbreeding on reproductive success, and long-term losses of genetic variation (heterozygosity) and adaptability to environmental change from genetic drift (Frankel and Soule 1981, Schonewald-Cox and others 1983).

In general, the probability of extinction for small populations is highest from environmental effects, followed by demographic stochasticity, long-term genetic effects, and lastly catastrophes (Gilpin and Soule 1986, Lande 1988). The importance of stochastic extinction forces is largely determined by the interaction between the particular characteristics of a species, the population, and the environment. An appropriate framework for assessing the strength of this interaction is population vulnerability analysis.

Population Vulnerability Analysis

Population vulnerability analysis as proposed by Gilpin and Soule) (1986) has three aspects: the physical and biotic environment of the individual and population; the population phenotype, or the species life history and habitat requirements; and the expression of the first two aspects in population structure and individual fitness.

The environment-Fragmentation affects the environment by reducing the availability and heterogeneity of original habitats. Forest remaining after logging is a subset of the original area, and it usually represents a less heterogeneous array of habitats. The loss of habitat heterogeneity takes two forms (Goodman 1987a): loss of regional heterogeneity reduces the ability of populations to average effects over their geographic range; and loss of resource hot spots, or locations of stable resource availability, eliminates refugia in which populations can persist under periodic severe environmental conditions and from which they can later recolonize formerly occupied areas.

Fragmentation also alters the context and configuration of a stand by exposing remnant forest patches to edge effects. The present connotation of edge effect differs from conventional usage (Leopold 1933), which suggests that more species diversity occurs on the ecotone of two habitat types. Edge effect here means deleterious effects of ecotones on plant and animal populations (Harris 1989, Laudenslayer 1986, Reese and Ratti 1988, Soule) 1986, Yahner 1989). Many forest-edge effects have been detailed in the literature, particularly for eastern U.S. Forests, but each situation has unique problems (Janzen 1986). Some environmental and edge effects are described below.

- Competition between interior and edge species may occur when edge species that colonize the early-successional habitats and forest edges created by logging (Anderson 1979; Askins and others 1987; Lehmkuhl and others, this volume; Rosenberg and Raphael 1986) also use the interior of remaining forest (Kendeigh 1944, Reese and Ratti 1988, Wilcove and others 1986, Yahner 1989). Competition may ultimately reduce the viability of interior species' populations.

- Generalist species occurring in the forest at the time of fragmentation may benefit from environmental changes outside the forest, receiving a cross-boundary subsidy (Janzne 1986). Consequent increases in generalist species' vigor or populations may alter community interactions, and result, for example, in greater competition with other animal species or altered plant-animal interactions (Janzen 1986). Alverson and others (1988) described how a cross-boundary subsidy from abundant early-successional habitat in logged areas of Wisconsin maintains a high white-tailed deer population, which has a major impact on the composition and regeneration of remnant old forest. Elk likewise receive a subsidy from early-successional habitat on recently logged sites (Hett and others 1978, Raedeke and Lehmkuhl 1986) and can markedly depress understory regeneration of hemlock in Pacific Northwest forests (Harmon and Franklin 1983).

- Nest predation and parasitism have been shown to increase in eastern forests along edges up to 600 m inside the patch, which is nearly four times the distance of microclimatic effects in Pacific Northwest forests (Reese and Ratti 1988, Wilcove and others 1986, Yahner 1989). Corvids and small mammalian omnivores are usually implicated as the most serious nest predators (Reese and Ratti 1988).

- The patch boundary may be a unidirectional filter through which animals pass out of the patch and cannot return (Janzen 1986). Game animals, for example, are most vulnerable to hunting mortality when they venture from the cover of forest patches into large open clearcuts.

- Secondary extinctions may result from the elimination of keystone species (Paine 1969, Soule 1986, Wilcove and others 1986) or altered community processes (Terborgh 1988). Gilbert (1980b) and Terborgh (1988) described situations in the tropics where the elimination of top predators could have cascading effects through the community by changing the size or structure of prey populations, which in turn influence plant-community dynamics through seed dispersal and predation. Soul) and others (1988) described a meso-predator release effect on chaparral birds in which the local extinction of a large predator (coyote) allowed small predators (fox and domestic cats) to increase, decimating prey species that formerly persisted with low populations of the small predators. Maser and Maser (1988) suggested that timber harvest practices that preclude viable populations of mycophagous forest-dwelling squirrels may alter fungal spore dispersal and eliminate a critical link in the symbiosis between hypogeous mycorrhizal fungi and coniferous trees which improves tree productivity.

- Edge creep occurs when extrinsic processes act on patch edges to progressively decrease patch area or quality (Soul) 1986). Ground fires along patch edges, for example, may penetrate only a short distance inside the patch, but they initiate a positive feedback loop of increasing fire effects. The growth of herbaceous vegetation responding to increased light and release from shrub competition after a fire may provide abundant fuel for subsequent fires that creep further into the patch and renew the cycle (Janzen 1986). Other examples are firewood cutters who penetrate progressively deeper into a patch to cut snags for wood, and chronic windthrow and subsequent salvage that progressively decreases patch area.

- Microclimatic changes along patch edges alter the conditions for interior plant and animal species and usually result in drier conditions with more available light (Bond 1957, Harris 1984, Ranney and others 1981). The current estimate suggested for the Pacific Northwest is that microclimatic effects extend up to two tree lengths (about 160 m) inside a patch (Franklin and Forman 1987, Harris 1984), which is tentatively supported by ongoing research (T. Spies, pers. comm.). Seral plants become more vigorous or abundant at edges in response to microclimatic changes, leading to greater abundance of seral plants in the seed pool and a higher probability of their establishment in patch interiors or colonization of gap disturbances (Janzen 1986, Ranney and others 1981).

The dynamics of forest habitat and environmental change with fragmentation are poorly understood. Are there thresholds of change in habitat attributes, or are the changes continuous? Franklin and For-man's (1987) simple checkerboard model with 10-ha patches suggests several patterns and thresholds of change: as the forest matrix becomes smaller with an increasing number of Clearcut patches, the edge length peaks at 50 percent cutover, but then the relation reverses and clearcuts become the matrix with forest patches; total area of forest interior habitat declines linearly to zero at 50 percent cutover, assuming that edge microclimatic effects occur within 160 m from the edge; and patch size does not decline until a threshold of 30 percent cutover when forest patch size drops precipitously until the 50 percent cut level, after which patch size remains steady.

Research data from Lehmkuhl and others (this volume) contradict the Franklin and Forman patch-size model, however, indicating that forest patch size declines linearly between 0 and 50 percent cutover. They support Franklin and Forman's (1987) 50 percent edge threshold when late-successional forests become the patches in a clearcut matrix. The threshold for more strictly defined old-growth forest, however, was lower, near 30 percent cutover. Wilcove and others (1986) suggest that patch numbers increase exponentially with time under a steady rate of fragmentation. Burgess and Sharpe (1981) presented data from southern Wisconsin landscapes that indicated mean distance between patches increased exponentially until about 10 percent of the forest remained.

Population phenotype-The life history characteristics of species are probably the most important aspect of the population phenotype for population vulnerability analysis (Margules and others 1982, McCoy 1982, Shaffer and Samson 1985, Simberloff and Abele 1982). The probability that a population will persist with habitat loss, which is one aspect of fragmentation, is largely a function of population density or abundance: the greater the abundance or density, the lower the risk of local extinction (Diamond 1984, Diamond and others 1987, Newmark 1987, Pimm and others 1988, Soul) and others 1988, Terborgh and Winter 1980, Wilcox 1980). Vulnerability to extinction in isolated habitat patches may also increase with large body size (Diamond 1984, Diamond and others 1987, Pimm and others 1988); low fecundity (Pimm and others 1988); specialization on patchy resources (Karr 1982a, Terborgh and Winter 1980); behavioral patterns requiring the formation of large groups and thus concentrated resources, dependence on keystone or link species, or occurrence at the edge of a species' range (Terborgh and Winter 1980); temporal variation in population size (Diamond 1984, Goodman 1987a,b, Karr 1982b); and metabolic rate (Wilcox 1980).

Persistence despite isolation of habitat patches, the second aspect of fragmentation, is a function of the dispersal abilities of the species (for example, Harris 1984, Soule and others 1988, Wilcox 1980). Dispersing individuals may rescue populations dwindling to extinction (Brown and Kodric-Brown 1977), or found new populations where they have become locally extinct. Species with poor dispersal capabilities, especially those with low powers of persistence, have a high risk of extinction in fragmented landscapes.

Population structure-We have discussed the increased probability of stochastic extinction from a reduction in population size brought on by the loss of forest habitat. Fragmentation also breaks the population into small subunits, each with dynamics different from the original contiguous population and each with a greater chance than the whole of local extinction from stochastic factors. Such fragmented populations are metapopulations, in which the subunits are interconnected through patterns of gene flow, extinction, and recolonization (Gill 1978, Lande and Barrowclough 1987, Levins 1970).

Determining the viability of the subpopulations of a metapopulation in fragmented landscapes is difficult. Long-term study is necessary because extinctions may be highly stochastic or observable effects after fragmentation may be delayed until populations reach an equilibrium with the changed availability of resources (Shaffer 1981). A "source-sink' effect may occur, whereby animals dispersing from undisturbed source areas colonize sink habitat patches that would otherwise not support populations (Pulliam 1988, Wiens 1976). Animals may breed in low-quality sink patches but have a negative reproductive rate, while the appearance of a viable population is maintained by immigration (Pulliam 1988). Then, interpatch distances are important determinants of population persistence, and they interact with species mobility and life-history characteristics to determine the rate at which immigration is effective in maintaining population size and genetic diversity.

The dynamics of population response to various amounts of fragmentation are essentially unknown: is population response gradual or continuous, or is the response nonlinear with thresholds? Several models predict response thresholds. Franklin and Forman's (1987) model predicts that forest-interior species richness declines slowly until 30 percent cutover, then rapidly declines to 50 percent cutover in response to rapidly decreasing patch sizes. Total species diversity increases rapidly up to 30 percent forest removal as edge species colonize in response to increasing edge length, but then declines slowly with the loss of interior species and declining edge. Game species, which are mainly edge species, follow a similar trend. A model by McLellan and others (1986) indicates a threshold of population decline at 50 percent habitat loss for species susceptible to fragmentation (low vagility, small populations). A population persists longer when patches of the same habitat are larger and closer. Less susceptible species begin to decline when 75 percent of the habitat is removed.

The Pacific Northwest Vertebrate Community

The forests of the Pacific Northwest support a large and diverse fauna of over 400 species (Brown 1985), of which 58 percent are bird species, 30 percent mammals, 7 percent amphibians, and 5 percent reptiles (Harris 1984). In a review of the literature, Harris (1984) concluded that species diversity declines with elevation, increases with moisture, and increases with the structural diversity associated with increasing stand age, which mainly consists of the vertical structure afforded by large, living trees; dead, standing trees (snags); and logs on land and in streams. Recent, extensive, field studies have shown forest-bird community richness to be positively associated with increasing temperature, which is a negative function of elevation and distance from the ocean (Huff and Raley, this volume). Concurrent studies of small mammal and amphibian communities indicated richness to be primarily a function of zoogeographic barriers to dispersal (mainly the Columbia River and the Willamette Valley) and localized geographic distributions, especially for amphibians (Aubry and others, this volume; Bury and others, this volume a).

Vulnerability Analysis

Assessing the effects of forest fragmentation from timber harvest on wildlife diversity and population viability raises several basic questions: "What species are associated with late-successional forest landscapes?" "What species are at greatest risk as assessed from an examination of the structural and life-history characteristics of species' populations that influence their persistence in forest landscapes altered by timber harvest?" and "What are the options for timber management to manipulate forest stand- and landscape-scale characteristics to minimize the risks of local extinction?"

To answer the first question, we used the list of species associated with late-successional forest from the summary paper of this symposium (Ruggiero and others, this volume). Other species were added from the wildlife-habitat relationships tables in Brown (1985) to include species that use late-successional stages (large sawtimber and old growth) of the temperate coniferous forest and were not sampled by the old-growth community studies (this volume). The list was edited to exclude species taken from Brown that are not found primarily in temperate coniferous forests. We concentrated on species associated with late-successional forest because this is the stage of forest development least likely to be represented in managed forest landscapes of the future. The list of 93 species is not complete (appendix table 2), but reflects current knowledge of habitat relationships. Earlier lists based on literature reviews are similar in the total number of species listed. Harris (1984) proposed late-successional forest as primary habitat for 118 species, with 40 species dependent on old growth. Brown (1985) described 76 species that use old-growth forest as primary breeding habitat and 65 species that use it as primary feeding habitat.

The vulnerability of listed species was assessed by compiling research data and general information about the abundance, life history, and habitat relationships of species, and then determining the risk of local extinction associated with each variable. Field data on the frequency of occurrence, abundance, and coefficient of variation in abundance among stands from the old-growth community studies (Lehmkuhl and others, this volume) were assembled for 64 of 93 listed species. The values of those variables for each species were converted to percentages of the maximum value for species in the same taxon, and then grouped into three classes: 0 to 33 percent, 34 to 66 percent, and >66 percent of maximum. Risks associated with the percentile classes were scored from low (1) to high (3) depending on the variable. Risk scores declined with increasing frequency of occurrence and abundance, but scores increased with increasing variation in abundance. Scores were estimated for 29 species (for which abundance data were not available from the community studies) by examining scores for similar species and consulting the general literature.

Risks associated with the life-history parameters of body size, vagility, and migratory status were similarly rated as low, moderate, or high. Risk scores increased with increasing body size under the premise that small-bodied species have smaller home ranges and higher densities than larger species, and may persist longer in small patches than large species. Risk decreased with increasing vagility because high vagility enables dispersing individuals to rescue failing subpopulations in isolated habitat patches, or to recolonize patches with locally extinct subpopulations. Risk associated with migratory status was scored low (1) for resident species, moderate (2) for short-distance migrants, and high (3) for long-distance migrants. Robbins and others (1989) showed that long-distance migrants were more susceptible to stand-area effects than short-distance migrants or residents. Pimm and others (1988) found migrants to have a higher risk of extinction than residents, probably because of greater migration risk and variability in population size. The intermediate risk we assigned to short-distance migrants is not clearly supported by the literature, but was inferred from the arguments of Pimm and others (1988) concerning migration risk. Ancillary data on the strength of association with late-successional forest, and use of structural and special habitats, were compiled to further assess risk and aid in habitat management.

A cumulative risk rating was calculated for each species as the weighted sum of risk scores for individual variables, by means of the following formula:

Cumulative risk = 3 * (frequency score + abundance score) + 2 * (body size score + vagility score) + migratory status + variance in abundance.

Weights were assigned to reflect the relative importance of variables that affect persistence in fragmented landscapes. Frequency and abundance were weighted by 3 to account for the primary importance of population size and density. Body size and vagility were weighted by 2 to reflect the lesser, but still vital, importance of body size for persistence in isolated patches, and vagility in the rescue and recolonization of isolated populations. Variation in abundance and migratory status scores were unweighted to indicate their relatively lesser importance for persistence. Cumulative scores were recalculated according to a scale of 1 to 10 to simplify ranking of risk.

Eighty percent of the species fell into moderately high (score 7.8) and high-risk categories (scores 9, 10) (fig. 1). The 20 high-risk species have low frequency and abundance, and one of three body size-vagility combinations (appendix table 2). Small size and low vagility characterized 12 species of amphibians and small mammals. Their persistence in isolated patches of a highly fragmented landscape is problematic because of low frequency and abundance, and poor probability that subpopulations could be rescued or patches recolonized because of limited vagility. The limitation of poor vagility depends on the varying porosity of adjacent altered habitats to movement of dispersing animals. An additional consideration is the very limited geographic distributions of three amphibians.

These species may persist in relatively smaller patches than large species, however, because of their small size and relatively higher potential density. Amphibians may have an additional advantage relative to small mammals because their lower metabolism and energy requirements presume smaller ranges and higher densities. Small patches of late-successional forest are often regarded as poor habitat because of microclimatic and other edge effects, but the impact of edge effects on amphibians and small mammals remains to be shown. Small patches may **be adequate** to support viable populations of amphibians and perhaps small mammals, and may be important sources for recolonization of adjacent altered stands made suitable with time by succession. The elimination of small old-growth patches as poor habitat, therefore, may be imprudent unless they are imminently threatened by blowdown.

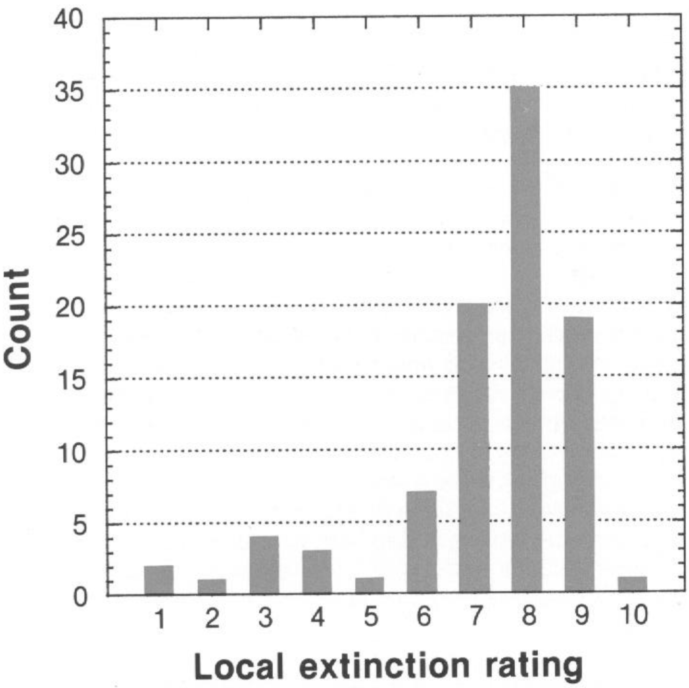

Figure 1—Frequency distribution of weighted risk of local extinction. Scores were calculated as the ranked, weighted sum of population distribution and life-history characteristics as determined by the old-growth community studies (dataset from Lehmkuhl and others, this volume). See appendix table 2 and text for methods.

Another high-risk group includes three squirrel species of small to medium size and moderate vagility. Because of their higher mobility, animals with medium size and moderate vagility are less at risk than smaller species from the isolation of habitat patches and subpopulations. The risk is greater, however, from diminishing patch sizes because of the greater energy demands of larger body size. Persistence for these species is a balance between decreasing patch sizes and increasing isolation.

The third high-risk group is composed of five species of birds and mammals with large size and high vagility. High vagility usually enables these species to overcome patch isolation. Large body size, however, implies greater energy needs and larger home ranges than smaller species have, and consequently, total available habitat and patch size are most important. These species are generalists (elk, mule deer) or tied to special features (for example, bald eagles need tall trees or snags near water), and arguably do not specifically require extensive late-successional forests. Elk and mule deer, however, require some old forest for thermal and hiding cover, and they require winter feeding areas during years of heavy snow. This need is particularly important for deer in areas with snowfall down to sea level, such as southern Alaska and British Columbia (see papers in Meehan and others 1984). Regardless of specific cases, the risk analysis is significant because it indicates the vulnerability of large animals.

Nearly 60 percent of the rated species have moderately high risk scores (7-8) with only slightly less than high risk of local extinction. The large number of species in the group mitigates the lower score, making it perhaps the most important group for management. In common with high-risk species, these animals have low frequency and abundance, but with various combinations of body size and vagility. Combinations of body size and vagility range from small size with low vagility for amphibians and small mammals to small- and medium-size birds and mammals with high vagility. An important group is comprised of medium-size birds and mammals, which include the spotted owl, northern goshawk, pileated woodpecker, marten, and fisher. The vulnerability of the birds primarily is a function of habitat loss and the requirements of medium body size, and secondarily of isolation and vagility. The vulnerability of the marten and fisher, by contrast, is a function of both habitat loss and medium body size, and habitat-population isolation with only moderate vagility.

Timber Harvest Alternatives

A foremost consideration in formulating an adequate answer to the question of alternative timber-harvest strategies is the fact that populations of species closely associated with late-successional forest will always experience some detrimental impacts from loss of habitat. Minimum-fragmentation alternatives do not reduce the impact of lost habitat, but primarily attempt to minimize the additional negative impacts that small habitat patch-sizes, edge effects, and isolation of remaining forest patches have on the forest environment and metapopulation structure. The value of a given timber-management alternative therefore depends on how species respond to changes in patch size and isolation. Animals respond to increasing patch size as a function of their body size: large species with large ranges and low density benefit from larger patches that allow for larger, more persistent populations. Response to declining isolation is a function of vagility: animals with low vagility have greater access to other habitat patches as isolation decreases. We cross-tabulated vagility and body size for the species in our data set to examine how the impact of timber harvest may be reduced by a minimum fragmentation scheme (table 1).

Increasing the patch size and decreasing the isolation of habitat patches reduces impacts on at least 27 species (score 4), probably helps another 20 species (score 3), and likely has little impact on 46 species (table 1). This analysis does not consider qualitative habitat loss through edge effects. Those species that can be identified as interior species may benefit from the reduction of edge through minimum fragmentation practices. Some preliminary evidence from ongoing research indicates that the abundance of a few birds (winter wren, Swainson's thrush, and varied thrush) is higher in patch interiors (A. Hansen and J. Peterson, pers. comm.).

Table 1—Species groups and number of species associated with late-successional forest that are likely to sustain fewer impacts from a minimum-fragmentation clearcutting alternative relative to current maximum-fragmentation practices

Vagility scores	Body-size scores[a]		
	Large - 3	Medium - 2	Small - 1
Low - 3	6 (0)[b]	5 (0)	4 (21)
Moderate - 2	5 (0)	4 (2)	3 (5)
High - 1	4 (4)	3 (15)	2 (46)

[a] Column scores are the sums of vagility and body-size scores (see text) and indicate the relative impact of the alternative, with higher numbers indicating more favorable response of the species group.
[b] The number in parentheses indicates the number of species (from appendix table 2) in that category.

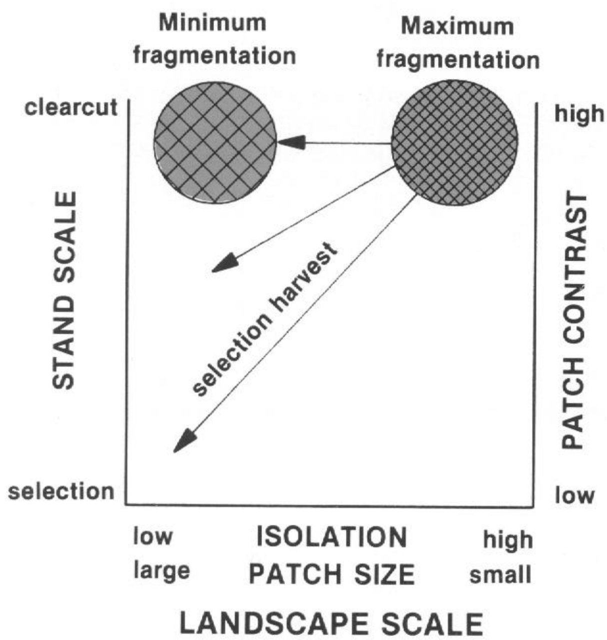

Figure 2—Hypothetical "management space" for appraising the impacts of alternative timber-harvest methods on landscape pattern. The horizontal axis represents a landscape scale of management, where timber harvest determines the size and isolation of remaining forest patches. The vertical axis represents the contrast between forest and harvested areas, which is at a stand scale of management. Current staggered-set clearcutting and minimum fragmentation alternatives act along the horizontal axis (top of figure), whereas selection harvest tends to act at both landscape and stand scales by minimizing the contrast between forest patches and the altered matrix, and thus minimizes the isolation and increases the functional size of patches (diagonal arrows).

Other management options may reduce the impacts of timber harvest. Alternatives such as minimum fragmentation alter the juxtaposition of clearcut units at a landscape scale to alter the size and isolation of remaining forest patches (fig. 2). Management, however, can also act at a stand scale along which selection harvest and clearcutting lie at the extremes. Current staggered-set clearcutting is in the area of greatest impact at the extremes of both stand- and landscape-scale modification (top right of fig. 2). Minimum fragmentation alternatives move management to the left along the landscape axis, and stand-scale impacts and patch contrast remain constant. As harvest changes from clearcut to selection methods, or as other means of maintaining the structural and functional characteristics of harvested stands are used (Harris and others 1982, Nyberg and others 1987), the contrast and edge effects between altered and remnant patches and landscape fragmentation decrease concurrently as shown by the arrows in figure 2.

Conclusions

Reducing timber harvest will always increase the probabilities of persistence for vulnerable wildlife species. Viable populations may exist with some timber harvest, however, especially if harvest practices are modified to minimize the effects of logging at landscape and stand scales. Alternative plans for arranging clearcut units to minimize landscape-scale impacts have been suggested by Franklin and Forman (1987) and are being planned for some National Forests in the Pacific Northwest. Alternative stand-scale practices, such as retaining green trees and coarse woody debris, are only recently being explored. Other beneficial practices include the use of corridors that maintain habitat connectivity across the landscape and facilitate wildlife movement from wilderness or between forest patches across managed landscapes (Harris 1984, Noss 1987, Noss and Harris 1986, Simberloff and Cox 1987). Population viability will also be enhanced if the location of cutting units does not remove habitat refugia or decrease the habitat heterogeneity across the landscape that animal populations depend on during periods of environmental stress. Planning for the replacement over time of late-successional forest patches or structural attributes like snags will ensure the viability of species requiring these key habitats.

We need more research to give managers better information and tools. Verner (1986) gave a good prescription for research into fragmentation effects: emphasis has been on birds for several reasons, but we need more research on mammals, reptiles, and amphibians; more research is needed on the processes affecting wildlife persistence in fragmented landscapes, rather than patterns related to area alone; we need to determine population parameters and model population responses to examine the consequences of fragmentation over space and time, which is not feasible without long-term research; and more emphasis should be placed on the spatial dynamics of fragmentation from a landscape perspective.

We suggest several additional research issues: more emphasis is needed on habitat relationships in managed forests, and the interaction of remnant forest patches and the managed habitat matrix; continued research is needed into the value of late-successional forests for wildlife to assess long-term trends; examination of habitat relationships from a landscape-scale perspective is needed to account for processes working above the stand or patch scale: and study is needed of the ecology of species and species groups that current research has shown to be clearly associated with late-successional forests.

We have used facts and speculation to assess the impacts of timber harvest on the vertebrate community. We can say definitely that the old axiom good timber management is good wildlife management does not apply to species associated with late-successional forest. These species will always sustain some negative impact from logging. Given that logging will continue and wildlife populations will continue to be affected, a larger question is "At what point will forest fragmentation from logging endanger the viability of wildlife populations on public lands?" Models (Franklin and Forman 1987; McLellan and others 1986; B. Noon, pers. comm.) and some field data (Lehmkuhl and others, this volume; Rosenberg and Raphael 1986) suggest that, for most species, we have not yet reached a threshold of fragmentation on most public lands beyond which local population viability is doubtful and management options are few. This is very good news. Nevertheless, some species, such as the spotted owl, will always be exceptionally vulnerable no matter how viable the majority of species remain. The viability of populations of those vulnerable species will be the touchstone of our commitment to maintaining biotic diversity on public forest lands.

Acknowledgments

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Appendix

Table 2—Risk of local extinction for species associated with late-successional temperate coniferous forest [the species list was modified from Ruggiero and others (this volume) and Brown (1985)]

	Variables[a]										
	Management score										
Species	DE	ST	SP	FR	AB	BO	VA	MI	VR	RISK[b]	RANK
Clouded salamander	2	1	0	3	3	1	3	1	3	30	10
Oregon slender salamander	1	1	0	3	3	1	3	1	1	28	9
Pacific giant salamander	1	1	0	3	3	1	3	1	2	29	9
Larch Mountain salamander	1	1	2	3	3	1	3	1	1	28	9
Siskiyou Mountains salamander	1	1	2	3	3	1	3	1	1	28	9
Van Dyke's salamander	1	1	2	3	3	1	3	1	1	28	9
Olympic salamander	1	1	0	3	3	1	3	1	2	28	9
Bald eagle	1	2	1	3	3	3	1	2	1	29	9
Band-tailed pigeon	2	2	0	3	3	2	1	2	2	28	9
Common raven	1	2	0	3	3	3	1	1	1	28	9
Red tree vole	1	2	0	3	3	1	3	1	1	28	9
White-footed vole	1	1	0	3	3	1	3	1	1	28	9
Elk	2	3	0	3	3	3	1	1	1	28	9
Northern flying squirrel	1	3	1	3	3	1	2	1	3	28	9
Mule deer	2	3	0	3	3	3	1	1	1	28	9
Coast mole	2	1	0	3	3	1	3	1	2	29	9
Western gray squirrel	2	2	0	3	3	2	2	1	1	28	9
Marsh shrew	2	1	0	3	3	1	3	1	1	28	9
Pacific shrew	2	1	0	3	3	1	3	1	1	28	9
Douglas' squirrel	2	2	0	3	3	2	2	1	1	28	9
Western redback salamander	1	1	0	3	2	1	3	1	2	26	8
Cascades frog	1	1	0	3	3	1	2	2	1	27	8
Red-legged frog	1	1	0	2	3	1	2	2	3	26	8
American robin	2	3	0	3	3	1	1	2	2	26	8
Bufflehead	1	2	1	3	3	2	1	2	1	27	8
Blue grouse	2	2	0	3	3	2	1	1	1	26	8
Barrow's goldeneye	2	2	1	3	3	2	1	2	1	27	8
Black-throated gray warbler	2	2	0	3	3	1	1	3	2	27	8
Black-headed grosbeak	2	2	0	3	3	1	1	3	2	27	8
Common merganser	1	2	1	3	3	2	1	2	1	27	8
Cooper's hawk	1	2	0	3	3	2	1	2	1	27	8
Evening grosbeak	1	2	0	3	3	1	1	2	2	26	8
Hutton's vireo	2	2	0	3	3	1	1	2	2	26	8
Hooded merganser	2	2	1	3	3	2	1	2	1	27	8
Northern goshawk	1	2	0	3	3	2	1	1	1	26	8
Nashville warbler	2	2	0	3	3	1	1	3	1	26	8
Olive-sided flycatcher	1	2	0	3	3	1	1	3	1	26	8
Pine siskin	1	2	0	3	3	1	1	2	2	26	8
Pileated woodpecker	1	3	1	3	3	2	1	1	2	27	8
Red-breasted sapsucker	2	2	1	3	3	1	1	2	2	26	8
Swainson's thrush	1	3	0	3	3	1	1	3	2	27	8
Sharp-shinned hawk	1	2	0	3	3	2	1	2	1	27	8
Northern spotted owl	1	3	0	3	3	2	1	1	1	26	8
Townsend's warbler	2	2	0	3	3	1	1	3	2	27	8
Vaux's swift	1	2	1	3	3	1	1	3	2	27	8
Western tanager	1	2	0	3	3	1	1	3	2	27	8
Western screech-owl	2	2	1	3	3	2	1	1	1	26	8
Wood duck	2	2	1	3	3	2	1	2	1	27	8
White-winged crossbill	2	2	0	3	3	1	1	2	3	27	8
Yellow-rumped warbler	1	2	0	3	3	1	1	2	2	26	8
Fisher	1	3	0	3	3	2	1	1	1	26	8

See footnotes on next page.

Table 2—continued

Species	Variables[a]										
	Management score										
	DE	ST	SP	FR	AB	BO	VA	MI	VR	RISK[b]	RANK
Marten	1	3	0	3	3	2	1	1	1	26	8
Shrew-mole	1	1	0	2	3	1	3	1	2	26	8
Forest deer mouse	1	1	0	2	3	1	3	1	3	27	8
Water shrew	2	1	0	2	3	1	3	1	3	27	8
Tailed frog	1	1	0	2	2	1	3	1	3	24	7
Dunn's salamander	1	1	0	2	2	1	3	1	3	24	7
Hammond's flycatcher	1	2	0	2	3	1	1	3	3	25	7
Marbled murrelet	1	2	0	3	3	1	1	1	1	24	7
Northern pygmy-owl	1	2	1	3	3	1	1	1	1	24	7
Northern flicker	1	3	1	3	3	1	1	1	1	24	7
Northern saw-whet owl	1	2	1	3	3	1	1	1	1	24	7
Purple finch	1	2	0	3	3	1	1	1	1	24	7
Rufous hummingbird	1	2	0	2	3	1	1	3	2	24	7
Townsend's solitaire	1	2	0	3	3	1	1	2	1	25	7
Wilson's warbler	2	2	0	2	3	1	1	3	2	24	7
Big brown bat	1	2	1	3	3	1	1	1	2	25	7
Silver-haired bat	1	2	1	3	3	1	1	1	2	25	7
Keen's myotis	1	2	1	3	3	1	1	1	2	25	7
Yuma myotis	1	2	1	3	3	1	1	1	2	25	7
California myotis	1	2	1	3	3	1	1	1	2	25	7
Long-eared myotis	1	2	1	3	3	1	1	1	2	25	7
Long-legged myotis	1	2	1	3	3	1	1	1	2	25	7
Little brown myotis	1	2	1	3	3	1	1	1	2	25	7
Fringed myotis	1	2	1	3	3	1	1	1	2	25	7
Northwestern salamander	1	1	0	2	2	1	2	2	3	23	6
Roughskin newt	1	1	0	2	2	1	2	2	3	23	6
Gray jay	1	2	0	2	3	1	1	1	2	22	6
Hairy woodpecker	1	2	1	2	3	1	1	1	2	22	6
Hermit thrush	1	2	0	2	3	1	1	2	2	23	6
Red crossbill	1	2	0	3	2	1	1	2	2	23	6
Steller's jay	2	3	0	2	3	1	1	1	3	23	6
Western red-backed vole	1	1	0	1	2	1	3	1	3	21	5
Brown creeper	1	2	1	1	3	1	1	1	2	19	4
Red-breasted nuthatch	1	2	1	1	3	1	1	1	2	19	4
Varied thrush	1	3	0	1	3	1	1	2	2	20	4
Ensatina	2	1	0	1	1	1	3	1	2	17	3
Southern red-backed vole	1	1	0	1	1	1	3	1	3	18	3
Hermit & Townsend's warblers	1	2	0	1	2	1	1	3	2	18	3
Western flycatcher	1	2	0	1	2	1	1	3	2	18	3
Golden-crowned kinglet	1	2	0	1	2	1	1	1	2	16	2
Chestnut-backed chickadee	1	2	1	1	1	1	1	1	2	13	1
Winter wren	1	3	0	1	1	1	1	2	2	14	1

[a] DEpendency on late-successional forest: 1 = primary; 2 = secondary. STructural layer used: 1 = horizontal; 2 = vertical (foliage); 3 = both. SPecial management: 0 = none; 1 = snags; 3 = limited distribution. MIgratory status scored as 1 = resident; 2 = short-distance migrant; 3 = long-distance migrant. Other life history variables were scored as 1 = low, 2 = moderate, 3 = high risk.
[b] Risk = 3* (FRequency + ABundance) + 2* (BOdy size + VAgility) + MIgratory status + VaRiance in abundance. Scores for frequency, abundance, and variation were assessed from data presented by Lehmkuhl and others (this volume). Total risk was calculated as the weighted sum.

Old-Growth Inventories: Status, Definitions, and Visions for the Future

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Abstract

Inventories of old-growth forests require a classification system for identifying and arraying forest conditions for a variety of interests. Old growth has value as fish and wildlife habitat, as a timber stratum, as an economic resource, and as a component of biological diversity. It is needed for scientific study, for long-term forest productivity, for recreation, for aesthetics, for spiritual interests, and for watershed protection. Several authors have defined old growth. Their definitions have similar but not identical components, and none suffices for all forest types, nor do they meet the intent of all interests. Recent estimates of known and candidate old growth in Washington, Oregon, and California total to 3.6 million ha. This sum, however, is based on a variety of definitions, forest types, and recency of data. Estimates based on consistent definitions and data sources are not available. Differences between estimates made by the Forest Service and The Wilderness Society of the amount of old growth on National Forests in Washington and Oregon can be partially explained by the stringency of their definitions of old growth and the methods they used to identify old-growth stands. The amount and distribution of old growth on National Forests in the Pacific Northwest in the future will depend on management allocations in reserved (for example, wilderness) and non-reserved (for example, timber production) status.

Current information needs relative to inventories of old-growth forest include descriptions of successional and developmental stages of old-growth forests and criteria for defining old growth for each forest type in the Pacific Northwest. At present, the Forest Service is conducting a regional inventory in the Pacific Northwest, using an attribute-driven approach. This work will provide the most complete inventory to date on National Forest lands. Other recommendations for old-growth inventories include: taking an attribute-based rather than a definition-based approach; developing a map-based rather than just numerical-based product to address the scale, context, and size of old-growth stands; and integrating any adopted definition of old-growth as part of a system for describing the amounts and distributional patterns of older forest.

Introduction-What Constitutes an Old-Growth Inventory?

Without adequate inventories and without a clear understanding of the amount and distribution of old growth it is difficult for the decision maker to determine what is practical or feasible (Ham 1984:69).

Conducting inventories of a natural system across a broad geographic area is a difficult task. Attempting to inventory old-growth forests throughout the Western United States and beyond is challenging because of the large size and great diversity of the area. An old-growth inventory requires an explicit and quantitative classification system to identify and array candidate areas. Potential old-growth stands are first identified by a set of general criteria, and finally classified according to a precise set of stand structural attributes.

This paper was prompted by the need to review existing definitions and inventory estimates of old-growth forests in the Western United States, and to help resolve controversies over old-growth inventories on National Forests by describing the bases of the estimates. Specifically, the objectives of this paper are to describe the proposed definitions that have guided estimates of the amount and distribution of old-growth forests, to review estimates of the amount and distribution of old-growth forests in the Pacific Northwest, to describe the bases for estimates of the amount of old-growth forests on selected National Forests in Washington and Oregon, and to propose methods for improving the reliability of those inventories. This paper is not intended to represent official Forest Service policy on old growth, nor to present a new inventory of old growth. The geographic scope of this paper includes Washington, Oregon, and California for tallying existing inventories; and Washington and Oregon only (the Pacific Northwest Region of USDA Forest Service) for describing definitions of old growth on National Forest land.

Important Considerations for Old-Growth Definitions and Inventories

In current planning and management activities on National Forests, old growth has several values (Sirmon 1985). and one of them is its importance as wildlife habitat (Meehan and others 1984, Meslow and others 1981, Raphael and Barrett 1984, Thomas and others 1988). Old growth provides optimal habitat for some management indicator species, including spotted owl, pileated woodpecker, and marten, and for many other species of plants, fish, amphibians, reptiles, birds, and small mammals (Harris and others 1982, Meslow and others 1981, Raphael 1988c, Raphael and Barrett 1984). It also provides thermal and hiding cover for ungulates, especially in winter (Schoen and others 1984, Wallmo and Schoen 1980). Old growth, therefore, plays an important role in providing for productive populations of some species of special ecological and administrative interest. For some of these species, old growth may be a key factor in providing for continued population viability.

Old growth also has value as a source of timber. It has been defined as forested areas that are past mean annual increment of wood-volume production (DeBell and Franklin 1987). Silviculturally, the structure and age-classes of old-growth forests, with large diameter boles, presence of snags, and less than ideal stocking, represent less than optimal use of growing space for trees. Economically, old-growth stands are valuable as timber because of the large volume and high quality of wood they contain (Society of American Foresters 1984).

Additional values of old growth are as natural research areas for scientific study (Greene 1988, Sheppard and Cook 1988) and its ecological role in providing long-term forest productivity (Franklin and others 1981, Perry and others 1988). Other interests in old growth include its recreational, aesthetic, and spiritual significance (Anderson 1988), its contribution to watershed protection (Sedell and Swanson 1984), and its importance as a contributor to biological diversity (Harris 1984, Luman and Neitro 1980, Norse and others 1986).

Addressing each of these values requires different concepts and definitions of old growth. The wide variety of interests in old growth also requires consideration of several spatial scales for inventories: stand, watershed, province, and State or regional scales. Inventories are the basis for describing the present and future distribution and amount of old growth, and for evaluating management alternatives and options available over time.

Review of Old-Growth Definitions

Several definitions of old growth have been proposed or used for Pacific Northwest forests. Few definitions have been developed independently. In particular, definitions by the Old-Growth Definition Task Group (1986) refined earlier definitions by Franklin and Spies (1984) and Society of American Foresters (1984), which in turn were based on Franklin and others (1981). Most of the Forest Service definitions and those of The Wilderness Society were based on these definitions in detail or in concept. Definitions are of two kinds: those based on timber production criteria, and “ecological definitions” (those based on field observations of vegetational structure and composition rather than on economic value, timber age, or stocking-classes).

Existing Definitions of Old-Growth Forests in the Pacific Northwest

Society of American Foresters-The Society of American Foresters (1984) defined old-growth Douglas-fir forests of western Oregon and Washington as stands that have two or (commonly) more tree species with a range in tree sizes and ages and often including a long-lived dominant (such as Douglas-fir) and a shade-tolerant associate (such as western hemlock); a deep, multilayered canopy; some individual live trees (greater than 25 per ha) either more than 200 years old or greater than about 100 cm in d.b.h.; significant coarse woody debris, including more than 25 snags per ha greater than 6 m tall and more than about 45 metric tons/ha of down wood, and at least 10 snags and logs per ha over 64 cm in diameter and 15 m long. SAP did not provide a definition for other forest types.

Old-Growth Definition Task Group-This task group provided interim, working definitions of old growth in four Douglas-fir and mixed-conifer forest types in the Cascade Range of Washington and Oregon, in northwestern California, and in the Sierra Nevada of California (Old-Growth Definition Task Group 1986). Their definitions (table 1) included criteria for live-tree size, age, density, and associates; canopy structure; snag size and density; and log size and density. Different criteria were developed for the four forest types to reflect differences in moisture regimes and expected site potential Collectively, these definitions are commonly referred to as ecological definitions.

USDA Forest Service-The Forest Service has published old-growth definitions for Washington, Oregon, and California in two regional guides to support the planning process for the management of forest land (table 2). For Washington and Oregon, the Pacific Northwest Regional Guide defined old growth with qualitative criteria (table 2) as well as with quantitative, Forest-specific criteria (as in table 3). In addition to the regional definitions, the draft Forest plans for most National Forests quantified structural parameters for stands of specific forest types. Many of these definitions varied by National Forest.

In the Pacific Northwest Region, a minimum tract size of 4 ha was established as a regional standard, and qualitative guidelines were presented for optimal tract size to support functional patches of old growth:

> Optimum tract size will be related to the needs of dependent wildlife species, such as northern spotted owls or pileated woodpeckers, and the ability to insulate part of the stand from the edge effects in created openings.

In California, the Pacific Southwest Forest Service Regional Guide used qualitative criteria to define old growth (table 2).

The Wilderness Society-The inventory assessment conducted by Morrison (1988) for The Wilderness Society used the ecological old-growth definition of the Old-Growth Definition Task Group (1986). Where inventory data were unavailable, log and snag criteria were not used. Morrison also defined several additional classes and subclasses of old growth (Morrison 1988:10). “Classic” old-growth stands meet all minimum criteria of the Old-Growth Definition Task Group (1986) and contain at least 20 trees per ha that exceed 300 years in age or 100 cm in d.b.h. A subclass of classic old growth is “super” old growth, with trees exceeding 700 years old or 180 cm in d.b.h. Stands meeting the definition of the Old-Growth Definition Task Group (1986), including where inventory data on logs and snags were not available, were termed “early” old growth, and contain at least 20 trees per ha over 200 years old or 80 cm in d.b.h. Such stands may include some older trees but they are in low numbers. “Mature” stands contain more than 50 trees per ha exceeding 80 years old or 53 cm in d.b.h. Such stands fail to meet one or more of the minimum old-growth criteria. Morrison also summarized old-growth tracts more than 122 m from roads or clearcuts.

Old-Growth Research Studies-Stands classified as mature and old growth in the studies by the Old-Growth Forest Wildlife Habitat Program were selected to represent the full range of conditions in Douglas-fir forests more than 200 years old (T. Spies, pers. comm.). They were selected before the criteria used by the Old-Growth Definition Task Group were developed. As a result, not all old-growth stands studied in this research fully meet the criteria established by the Task Group.

Comparison of Four Existing Definitions-The three key definitions outlined above (Old-Growth Definition Task Group, Pacific Northwest Regional Guide, and Society of American Foresters (1984)) describe old growth in Douglas-fir/western hemlock forests in Washington and Oregon (table 4). Only the Pacific Northwest Regional Guide describes old growth for true fir/mountain hemlock forests. In the Douglas-fir/western hemlock type, all three definitions call for live trees of two or more species with a variety of sizes and ages. The Society of American Foresters’ (1984) definition is most stringent on tree density and size. The Pacific Northwest Regional Guide does not specify age. All other definitions allow >200 years old as an alternative to tree diameter. Criteria for shade-tolerant associates also vary among definitions. All three definitions agree on qualitative canopy characteristics. Quantitative criteria for snags and logs vary widely, however, with the Society of American Foresters’ definition calling for the greatest densities and largest diameters.

Table l-Interim minimum standards for old-growth Douglas-fir and mixed-conifer forests in western Washington and Oregon and in California (from Old-Growth Definition Task Group 1986:4)

Stand characteristic	**Douglas-fir** on western hemlock sites (western hemlock, Pacific silver fii)	Douglas-fir on mixed conifer sites **(white fir,** Douglas-fir)	Douglas-fir on mixed **evergreen** sites **(tanoak,** Douglas-fir)	Sierra mixed-conifer forests (white fir)
Live trees	Two or more species with wide range of ages and tree sizes	Two or more species with wide age range and full range of tree sizes	Douglas-fir and evergreen hardwood species **(tanoak,** Pacific **madrone,** and canyon live oak) associates (40 to 60% of canopy)	Two or more with wide age range **and** full range of **tree** sizes
	Douglas-fir **≥20** per ha of trees **>81** cm in diameter or **>** 200 years old	Douglas-fir, ponderosa **pine,** or sugar pine **≥20** per ha of trees **>76** cm in diameter or **>200** years old	Douglas-fir or sugar pine **≥15 per ha of trees** **78** 1 cm in diameter or **>200** years old	Douglas-fir, sugar pine, or ponderosa pine **≥20** per ha of trees **781** cm in diameter or 7200 years old
	Tolerant associates (western hemlock. western **redcedar,** Pacific silver fir, grand fii, or **bigleaf** maple) 130 per ha or trees >41 cm in diameter	Intermediate and small size-classes are typically white **fir,** Douglas-fir, **and incense-cedar. singly or in mixture**	Intermediate and small size-classes may be evergreen hardwoods or include a component of conifers (e.g., Douglas-fir or white fir)	Intermediate and small size-classes are typically white fir with **incense-**cedar or both in some stands
Canopy	Deep, multilayered **canopy**	Multilayered canopy	Douglas-fii emergent above evergreen hardwood canopy	Multilayered canopy
Snags	Conifer snags 110 per ha that are >51 cm in diameter and **>4.6 m** tall	**Conifer snags 23.7** per ha that are >51 cm in diameter and **>4.6** m tall	Conifer snags **≥3.7** per ha that are >51 cm in diameter and **>4.6** m tall	Conifer snags **≥7.4** per ha that are >51 cm in diameter and 74.6 m **tall**
Logs	Logs **≥34** metric tons per ha including 10 pieces per ha **≥61** cm in diameter and **>15** m long	Logs **≥22** metric tons per bit including 5 pieces per ha >61 cm in diameter and 715 m long	Logs **≥22** metric tons per ha including 5 pieces per ha >61 cm in diameter and **>15** m long	Logs **≥22** tons per ha including 5 pieces per ha **≥61** cm in diameter and **>15** m long

Table 2-Old-growth definitions from USDA Forest Service Pacific Northwest and Pacific Southwest Regional Guides (units converted to metric)

Pacific Northwest Region (Region 6)-Washington and Oregon
For all National Forests in the Pacific Northwest Region, an old-growth stand is defined as any stand of trees 4 ha or greater generally with the following characteristics:

(a) Stands contain **mature and overmature trees in** the overstory and are well into the mature growth stage
(b) Stands usually contain a **multilayered canopy** and trees of several age-classes
(c) Standing **dead trees and down material** are present; and,
(d) Evidence of **human activities** may be present but may not significantly alter the other characteristics and would be a subordinate factor in a description of such a stand

Pacific Southwest Region (Region 5) -California
Old growth is a stand that is past full maturity and showing signs of decadence, the last stage in forest succession. The definition of old growth by tree age, size, height or density varies by timber type. Among the components of old growth that may be of importance to wildlife species and that may be affected by land-management practices are large trees, old trees, decadence of standing vegetation, much dead and down woody material, uneven-aged vegetation, multi-layered vegetation, moderate foliar-height diversity, and mesic micro-habitats afforded by high canopy closure. High canopy closure does not always correspond to decadence.

Efficacy of Existing Definitions

Society of American Foresters (1984), the Old-Growth Definition Task Group (1986)) Morrison (1988), and Forest Service definitions all describe old-forest conditions as an "old-growth ecological type" with varying degrees of stringency. Thomas and others (1988:253) recommended that old growth be ecologically defined on the basis of the composition of plant and animal species, and the vegetative structure (including sizes and densities of live trees, snags, and down wood, and the number and nature of canopy layers) of stands. Minimum stand size and its effect on specific ecological functions is another critical characteristic, especially as related to providing fish and wildlife habitat. The Forest Service, Pacific Northwest Region, established 4 ha as a criterion for minimum stand size, and alluded to optimal sizes for conserving wildlife species and habitats. Morrison (1988) summarized inventories by two stand size-classes and by degree of isolation from other old-growth stands. The Old-Growth Definition Task Group (1986) cautioned that stands of less than about 32 ha are fully influenced by edge conditions, and should not be expected to provide interior forest conditions.

As Should be expected, none of the definitions suffices for defining, locating, and analyzing old-growth forests for the full variety of resource interests. Nor do any of the definitions cover all forest types in the Pacific Northwest. None of the definitions is part of a classification scheme for describing the full sere of development of old-forest conditions. Information based on successional development and structural changes will be most useful in developing an understanding of the status of old forests and in making future projections of old forests. Any single definition should only be part of a whole system for classifying old forests in a scheme that recognizes the range of young through old-growth and climax forest conditions.

Table 3-SpecifIc definitions of old growth as used in the USDA Forest Service Pacific Northwest Regional Guide for Cedar-Hemlock-Douglas-fir Forest Type (units converted to metric)

- At least **60 percent of the overstory canopy is dominated by large individual trees** in some combination of shade-tolerant and shade-intolerant species.
- The stand contains some **trees** with **stem diameters 81 cm or greater,** an average of **five snags per ha,** and **67 metric tons of logs per ha.**
- Trees have **mature bark characteristics;** for example, Douglas-fir has to have deeply furrowed bark.
- **Crown-height growth has slowed,** giving the tops a more rounded shape; tops may be broken.
- **Limbs are usually heavy and gnarled,** often with **mosses and lichens** present.
- Stands in these forest types will be considered old growth until fewer **than 12 overmature trees remain per ha.**

A Review of Old-Growth Inventories in the Western United States

Amounts of Old Growth

The following discussion reviews old-growth and old-forest inventories in Washington, Oregon, and California. Substantial amounts also occur in Alaska and British Columbia throughout coastal and interior environments, including stands dominated by Douglas-fir, western hemlock, and western redcedar. Much of this additional old-forest area, however, occurs in Sitka spruce and high boreal forest types, including black spruce and white spruce. These forests are ecologically much different than the lower elevation and more coastal forest types dominated by Douglas-fir, Sitka spruce, and western hemlock in Washington, Oregon, and California. Inventory amounts from Alaska and British Columbia are therefore excluded from the summary that follows.

Washington and Oregon-Franklin and Spies (1984) and the Society of American Foresters (1984) estimated nearly 6 million ha of old growth on commercial forest land in the

Table 4-Three old-growth definitions[a]

Stand characteristic	Old-Growth Definition Task Group	Pacific Northwest Regional Guide	Society of American Foresters
Douglas-fir on Western Hemlock Sites			
Live trees	Two or more species; wide range of age & size	Two or more species of several age-classes	Two or more species; wide range of age & size
	Douglas-fir ≥20 per ha of trees d.b.h. >81 cm or >200 yrs	Overmature trees 212 per ha with at least some Douglas-fir with d.b.h. ≥81 cm	≥ 25 trees Per ha with d.b.h. >102 cm or or >200 yrs old
	Tolerant associates ≥30 Per ha	No specific standard	No specific standard
Canopy	Deep, multilayered	Multilayered	Multilayered
Snags	Conifer snags ≥10/ha >51 cm in diameter and >4.6-m tall	≥5/ha	>25/ha >6 m tall and some >64 cm in diameter
Logs	Logs 234 metric tons/ha including 10 pieces/ha ≥6 1 cm in diameter and >15 m long	Logs ≥67 metric tons per ha	>45 metric tons/ha and some >64 cm in diameter and >15 m long'
Fir-Mountain Hemlock			
Live trees	Not addressed	Two or more species of several age-classes	Not addressed
		Dominant trees >12/ha	
		No specific standard	
Canopy		Multilayered	
snags		≥12/ha	
Logs		≥45 metric tons/ha	

[a] To develop their estimates, The Wilderness Society (Morrison 1988) defined "early old growth" with the old-growth criteria of the Old-Growth Definition Task Group (1986). One deviation was that age data in timber-inventory plots were not quantified precisely enough to use stand age (>200 years) as a criterion, as with the Old-Growth Definition Task Group (1986) definition. The Society also established definitions for "classic old growth" and "super old growth."

Douglas-fir region in the mid-1800s, and at present nearly 4 million ha have been harvested. More recently, Spies and Franklin (1988) estimated that about 17 percent of old growth existing in the early 1800s remains in the Douglas-fir region of the Pacific Northwest. In an independent estimate, Norse (1990) suggested that as much as 7.7 million ha of old growth may have been present in western Washington and Oregon before Euro-American settlement, although he acknowledged that this estimate may be high. Because of the absence of historic field inventories, these figures are approximate, and definitions applied to forest conditions are imprecise.

According to draft Forest plans, some 2.5 million ha of forests classified as old growth remain on National Forests in Washington and Oregon both east and west of the Cascade Crest. This estimate was based on the definition of old growth from the Pacific Northwest Regional Guide (table 2), and interpreted in the draft Forest plan by each National Forest. The draft plans were published between 1986 and 1988. The old-growth figures were generally updated to 1985, but some were based on earlier inventories that had not been updated. No information is available on historic amounts of old growth on these National Forests.

The reported 2.5 million ha represent about 25 percent of the total area of National Forest land in these two States. An estimated 1.2 million ha of that area occurs on the 10 National Forests that are located either wholly or predominantly east of the Cascade Crest, and 1.3 million ha occur on the 9 National Forests' located either wholly or predominantly west of the Cascade Crest.

About 0.30 million ha of the 2.5million ha total occur in areas reserved from timber harvest by decrees of Congress, such as in wilderness, Research Natural Areas, and other special reserves, and of that 0.30 million ha, about 0.11 million ha occur in the 10 National Forests east of the crest and 0.19 million ha occur in the 9 forests west of the crest. This leaves a reported 2.2 million ha of old growth on National Forests throughout Washington and Oregon that are not in such reserved lands.

The Wilderness Society (Morrison 1988) also estimated old growth in Oregon and Washington. This estimate, however, covered only six of the nine west-side National Forests in Oregon and Washington, and it used the definition produced by the Old-Growth Definition Task Group (1986). According to Morrison (1988), only 45 percent of the area inventoried as old growth by the Forest Service actually met all criteria set forth by the Old-Growth Definition Task Group.

Haynes (1986) estimated, based on data from the 1970s, that about 1.3 million ha of forest stands more than 250 years old remained on all land (regardless of ownership) in the Douglas-fir region of western Washington and western Oregon. Of this remaining old growth, about 0.4 million ha are protected, mostly in National Parks in Washington. Haynes' estimates were substantially lower than Forest Service estimates. Haynes' definition of old growth included forests older, and thus more scarce, than did the Forest Service definition, and he estimated old growth from stand-age data (Morrison 1988). The precision of estimates made by Haynes and by the Forest Service was not reported.

More recently, Greene (1988) reported that 0.3 1 million ha of old-growth forest stands more than 200 years old occur in North Cascades, Mount Rainier, Olympic, and Crater Lake National Parks. Franklin and others (1988) estimated that 60 percent of the 97 000 ha within Mount Rainier National Park in the central Washington Cascades are forested, and most forests are at least 200 years old.

The Bureau of Land Management (BLM) has defined old growth as stands 4 ha or larger with trees more than 200 years old (R. Metzgar, pers. comm.;[2] 1987 BLM Spotted Owl Environmental Assessment, cited in Greene 1988). In April 1987, the BLM in western Oregon had 0.19 million ha of unsold old growth remaining, with a projected 0.17 million ha remaining by 1990 (Greene 1988). In April 1988, they had 0.19 million ha of old growth on commercial forest land, 0.06 million ha protected by current plans, and 0.13 million ha subject to harvest (R. Metzgar, pers. comm.[2]). The 0.13 million ha were estimated by expanding permanent plot information, not by mapping stands in place, although BLM plans to incorporate all old-growth stands in their geographic information systems during their 1990s inventory. Based on BLM Timber Management Plans implemented from 1980 through 1984, Ohmann and others (1988) reported 0.17 million ha of old growth 200 years old on BLM land in western Oregon. BLM land in western Washington adds a negligible amount, if any, to these old-growth amounts,

Ohmann and others (1988) also reported 2800 ha of old growth on other public lands and 17 000 ha of old growth on forest-industry lands in western Oregon. In these estimates, old growth was defined according to the Old-Growth Definition Task Group (1986).

California--Currently, California has 8.0 million ha of forest land (U.S. Department of Agriculture, Forest Service 1986); 39 percent is in National Forests, 53 percent in private ownership, and 8 percent in other ownerships. In the mid-1800s, 5.1 million ha of the 8.0 million ha were thought to be old growth. About half of these occurred in the Sierra Nevada, a fourth in the North Coast, and the remainder in northeastern California with less than 3 percent in the mountains of southem California (Laudenslayer 1985).

Based on inventories from an earlier date (dates vary, depending on National Forest), Laudenslayer (1985) estimated that about 0.9 million ha of forest stands qualified as candidate old growth on National Forests in California around 1980. This amount was about 17 percent of estimated historic old growth. Candidate old growth was defined as all stands that might meet or do meet structural criteria for old growth as presented in the Pacific Southwest Regional Guide (table 2). On National Forests in California, old growth had not been defined for most forest types and the only data available were by timber-type strata. Even if old growth was defined by forest type, existing inventories would not likely be able

[1] The nine west-side National Forests are the Olympic, Mount Baker-Snoqualmie, Gifford Pinchot, Mount Hood, Willamette, Deschutes, Umpqua, Siskiyou, and Siuslaw.

[2] On file with Bruce Marcot

and overmature timber-type-strata and stocking-classes. Laudenslayer also estimated that, in the future under Forest Service plans, the 0.9 million ha will decrease to about 0.7 million ha, or about 14 percent of historic amounts. Virtually all old growth on private lands in California may be harvested in the next 30 to 50 years (F. Samson and others, unpubl. manuscript).

In California, Resources Planning Act (RPA) Timber and Wildlife Narratives provide a more recent estimate of candidate old growth. In the Timber Narratives, old growth was defined under the general regional definition (table 2), and in the Wildlife Narratives, overmature forest was based on the definition of old-growth habitat for management indicator species. In 1987, 0.6 million ha of candidate stands qualified as old growth on National Forests in California, with 0.4 million ha on land suitable for timber production (RPA Timber Narrative, Pacific Southwest Region). These candidate stands included forests typed by the Forest Service as containing overstory trees with crown diameters of >7 m and with canopy closure >40 percent (Forest Service stand classes 4N and 4G). Another Forest Service summary reported about 0.8 million ha of overmature forest on National Forests in California in 1985, 0.2 million ha of which occur in wilderness (RPA Wildlife Narrative, Pacific Southwest Region).

Summary-The most extensive estimates of old growth suggest that amounts of old growth and other old forests on National Forests in Pacific States total about 3.6 million ha (table 5). This tally uses the Forest Service's estimate of old-growth amounts in Washington and Oregon. If the more stringent definition and estimate by Morrison (1988) is used, total amounts would be lower.

This tally of current inventories is very approximate. It combines many forest types, including upper elevation, true fii forests in the Washington and Oregon Cascade Range; namely, Pacific silver fir, grand fir, and ponderosa pine forests in eastern Washington and Oregon; mixed-conifer and Jeffrey pine forests in northern California and the Sierra Nevada, and other forest types. The estimate combines data from different years and is based on a variety of definitions of old growth. It includes candidate old-growth forests, an unknown but significant proportion of which would not qualify as ecological old growth (Old-Growth Definition Task Group 1986). The estimate, however, does not include amounts of old growth that may exist on lands of other Federal, Provincial, State, local, commercial, and private administration and ownership throughout the geographic area considered.

Size of Old-Growth Stands

Past clearcutting of old growth has fragmented remaining stands into smaller patches with greater interpatch distance. Fragmentation also alters stand shapes. An unknown proportion of existing old-growth forests occur in relatively inaccessible or unproductive areas, such as in canyon bottoms or along ridges. Such old-growth stands are often linear and narrow. Most or all of such stands may be influenced by edge conditions. Effects of small patch-size, increasing isolation, and edge conditions may adversely affect the persistence of some wildlife populations in old-growth areas.

Harris (1984) summarized the sizes of 319 old-growth stands from 1981 Total Resource Inventory System (TRI) data from the Siuslaw National Forest in the Oregon Coast Range. He noted that 61 percent of the stands were less than 16 ha, the average stand was 28 ha, and the median was 13 ha.

Laudenslayer (1985) noted that on National Forests in California, candidate old-growth stands of all forest types averaged about 16 ha, ranging from an average of 7 ha in the red fir forest type in the north coast to an average of 235 ha in the Jeffrey pine forest type in the Sierra Nevada. Few data are available on the distances between old-growth patches, but old-growth patches are probably becoming increasingly smaller and isolated over time (Harris 1984).

Old-Growth Inventory and Management Direction on National Forest Land in Western Washington and Oregon

Forest Service and The Wilderness Society Estimates

The Wilderness Society estimates of the amount of old growth remaining in Washington and Oregon (tables 6,7; Morrison 1988) and estimates by the Forest Service (table 7; draft Forest plans) differed substantially. Both estimates were derived from Forest Service timber inventories, but these inventories were not designed to measure all characteristics of importance in distinguishing old-growth stands. Both estimates, therefore, required extrapolation from the inventory values.

The two estimates were produced for different purposes with different techniques. The Forest Service estimate was derived from a mapped inventory of old growth for Forest planning, and therefore relied heavily on photo-interpretation, The Wilderness Society estimate was intended to be only a numerical estimate. Although Morrison (1988) did use photo-interpretation, he depended more heavily on plot data from the Forest Service timber-inventory process.

Table S-Estimated current amounts (in millions of hectares) of old growth and candidate old growth on selected lands in the Pacific States of the United States

Area	Estimate	Definition	Reference
Washington and Oregon:			
Forest Service	2.5 (1.3 west-side only)	Old growth variously defined in plans and Regional Guide	Draft National Forest Plans
National Park Service	0.31	Forests >2OO yrs old	Green 1988
Bureau of Land Management-Oregon	0.19	Stands of 4+ ha, trees >200 yrs old	R. Metxgar, pers. comm.
Other public lands and forest industry, western Oregon only	0.019	Old-Growth Definition Task Group	Ohmann and others 1988
California:			
Forest Service	0.60	Stands with trees >7.3 m crown diam. and canopy closure >40 Percent	RPA Timber Narrative, Pacific Southwest Region
Total	3.6	Includes all candidate old-growth and excludes old growth on some lands other than National Forests)	

The two estimates were based on different years and on different definitions of old growth. The Forest Service estimates were generally current for 1985, although several estimates were based on older data. Morrison's estimate was based on data updated to 1988. Morrison adhered to the definition proposed by the Old-Growth Definition Task Group (1986), except for down wood and snag density criteria. Morrison also applied the Task Group definition to forest types for which it was not developed. The National Forests used the less restrictive definition published in the Regional Guide, which was modified to reflect conditions specific to each forest type and each National Forest.

The draft Environmental Impact Statements for the Forest Plans show that the operational definitions used by National Forests actually varied from the definition presented in the Regional Guide. These operational definitions generally focused on characteristics for which data were more readily available. Definitions used by the nine west-side National Forests in Washington and Oregon require fewer large trees, large snags, or trees of shade-tolerant species than do either the Old-Growth Task Group or the Regional Guide definitions (see table 4; The Wilderness Society 1988).

Data published by Morrison (1988) allowed us to estimate inventory results by using the less restrictive definitions that the Forest Service used on six National Forests in western Oregon and Washington (table 6). In addition to areas that met all the old-growth criteria of the Old-Growth Definition Task Group (1986), Morrison listed areas that had some old-growth characteristics but failed to meet individual criteria (table 6) Most of these areas would likely meet the less restrictive definition generally used by the Forest Service. All of these areas have developed beyond a mature stage marked only by the presence of trees >53 cm d.b.h., and all contain at least some trees >80 cm d.b.h. These areas were summed and compared to Forest Service old-growth estimates in table 7. This table also shows the sampling error calculated by Morrison for his old-growth estimates. Sampling error (table 7) for the sum of these four, less restrictive old-growth classes would actually be greater than the sampling error calculated only for the old-growth class.

Predictably, these adjustments bring the two estimates closer together. Figures taken from The Wilderness Society report total to 0.8 million ha or 80 percent of the Forest Service estimate of 1.0 million ha (table 7). This compares to The Wilderness Society estimate of 0.4 million ha of old growth on the six National Forests, which represented 45 percent of the Forest Service estimate. When sampling error is taken into account, estimates overlap on two of the six forests. If the 3 years of harvest between 1985 and 1988 were taken into account, the two estimates on the Willamette National Forest would probably also overlap.

Table 6—The Wilderness Society area-estimates in thousands of hectares of old-growth forest and forest conditions that fail to meet one or more old-growth criteria (*sensu* Old-Growth Definition Task Group 1986) as listed in table 4, on 6 National Forests in western Washington and Oregon

National Forest	(1) Old growth[a]	(2) Fails late-seral tree-criterion	(3) Fails snag criterion	(4) Fails large-tree criterion	(1-4) Total[b]	(5) Fails multilayer-canopy criterion	(6) Meets mature-forest criterion	(1-6) Total with mature
Mount Baker-Snoqualmie	120	3	40	29	192	3	41	236
Olympic	43	1	0	21	64	1	8	74
Gifford Pinchot	48	1	23	31	104	0	80	183
Mount Hood	72	0	27	39	138	0	35	173
Willamette	121	29	36	35	221	0	93	314
Siskiyou	57	0	18	34	109	0	7	117
Total	461				829			1097

Source: Morrison (1988).

[a] Includes old growth on all land allocations, including wilderness. Other columns do not include wilderness lands established before the date of the inventory data available from the National Forests.

[b] Columns 1 to 5 all contain stands with at least some trees >80-cm in d.b.h. Column 6 does not.

Table 7-Estimates of old growth in thousands of hectares by the Forest Service and The Wilderness Society (Morrison 1988) including areas that fail to meet one or more old-growth criteria

National Forest	The Wilderness Society old-growth plus other old-forest stands (from table 6)	Forest Service[a] old-growth estimate	Difference	Sampling error (Morrison 1988)
Mount Baker-Snoqualmie	192	270	76	8
Olympic	64	88	23	2
Gifford Pinchot	104	93	10	17
Mount Hood	138	140	2	13
Willamette	221	259	37	25
Siskiyou	109	179	70	19
Total	829	1029		

[a] Derived from draft Forest Plans.

This comparison is not intended to show that both inventories are really the same. Significant differences clearly exist. The comparison indicates that old-growth estimates are sensitive to the definitions on which they are based. This emphasizes the need for a commonly accepted definition of old growth, a better understanding of important old-growth characteristics, and better inventories intended to quantify those characteristics. Inventories must be designed to provide information on individual characteristics rather than to accommodate one fixed definition of old growth. The importance of such an inventory design is highlighted by the fact that the stands classified as "old growth" in the Old-Growth Program research studies (this volume) did not actually meet, nor were they designed to meet, all criteria from the Old-Growth Definition Task Group. An inventory designed around this single definition would fail to inform us about a large amount of forest land that is important wildlife habitat. Improved inventories must be completed soon if we are to make use of information from research (this volume).

Current Management of Old Growth and Old-Growth Allocations in National Forest Plans

What will be the fate of the 1.3 million ha of old growth on the nine National Forests in western Washington and Oregon? Forest-planning alternatives propose the retention of about 0.6 to 1.2 million ha over time. Preferred alternatives of the nine draft Forest plans called for a total of 0.8 million ha of reported old growth to be retained over time, which is about 57 percent of currently inventoried amounts. The proportion of total historic old growth represented by this amount is substantially less and is not quantified.

In current planning and management activities on National Forests, old growth appears as an issue derived from various interests, including recreation, fish and wildlife habitat, timber supply, long-term forest productivity, scientific research areas, and aesthetics. Management-area direction established in Forest plans will determine the future amount and distribution of forest habitat, including some old growth, for wildlife species, and particularly management indicator species on National Forests. In addition, management requirements for standing and fallen dead trees in all areas address a vital component of old-growth forests that also may be found in younger stands. Those snags will probably be smaller, however, and may not persist as long as in old-growth stands.

Actual amounts and distributions of old growth for wildlife species is currently decided by each National Forest through Forest plans. Amounts and distributions result from applying regional standards ("minimum requirements") for maintaining old-forest habitats for spotted owls, marten, pileated woodpeckers, a variety of other primary excavators, and some additional key vulnerable species identified in each of several provinces in the Pacific Northwest Region. Forest plans establish final allocations, but they must meet or exceed the regional standards.

Habitat-management areas for old-growth management indicator species provide one type of allocation where old growth may occur. Other allocations will also contain old growth. As an example, the draft Forest plan on the Willamette National Forest lists the following land allocation-classes that may contain old-growth forest (other National Forests will retain old growth under similar allocations):

Congressionally withdrawn-no harvest
- Wilderness
- National Recreation Areas
- Experimental Forests
- Research Natural Areas

Administratively withdrawn-no harvest
- Proposed Research Natural Areas
- Old-Growth Groves
- Threatened or Endangered Species Habitats (such as for bald eagle)
- Other Special Wildlife Habitats and Habitat Protection areas
  - Spotted Owl Habitat Areas
  - Pileated Woodpecker Habitat Areas
  - Marten Habitat Areas
  - Deer and Elk Thermal Cover
  - Other Special Habitat (Protection and Enhancement)
- Semiprimitive (Roadless) Areas
- Recreation Sites (Existing and Proposed)
- Mining Claims
- Lands Technically Unsuited for Timber Production

Partial Harvest Categories
- Visual Retention Areas
- Semiprimitive (Roadless) Areas
- Riparian

Full Harvest Categories
- General Forest

Old growth occurring in the full harvest allocation and several other allocations (such as mining claims) would be retained only until the time of harvest or management activity.

Under the Preferred Alternative in the Willamette National Forest draft plan, 52 percent of old growth will be retained through time. This totals about 0.18 million ha (table 8). The remaining 48 percent or 0.17 million ha is planned to be harvested over the next five decades. According to the draft Forest plan, old growth on the Willamette National Forest was defined according to the Old-Growth Definition Task Group (1986; see table 1) with specifications that vary by forest type. Like most of the other draft Forest plans in the region, the Willamette National Forest draft plan quantified and analyzed the effects of land-allocation decisions on the distribution of old-growth forest-stands for specific management indicator species (spotted owls, marten, pileated woodpeckers, and primary cavity excavators). Outside of such management requirements, however, the effects of land-allocation decisions on the size and context of old-growth stands were not analyzed.

Old-Growth Habitat Characteristics of Importance to Wildlife: A Key to Future Inventories

Some wildlife species may have co-evolved with, and depend on, specific amounts and conditions of old-growth forests. Specific kinds, sizes, and patterns of old-growth environments are, therefore, keys to the long-term survival of these species. Land allocations affect the distribution of old growth across

Table 8—Allocation of mature and old-growth forest under the preferred alternative in the draft Forest plan, Willamette National Forest

Category	Area	Percentage
	Hectares	
Withdrawn		
Wilderness	93 600	—
Unsuited for timber production	45 000	—
Minimum management requirement wildlife habitats	27 700	—
No harvest	18 000	—
Subtotal	184 200	52
Harvestable		
Timber harvest areas	167 200	48
Total	351 400	100

Note: On a forest-wide average, about 75 percent of all mature and old-growth areas actually meet the old-growth criteria of the Old-Growth Definition Task Group (1986). This error rate varies slightly by forest type. For example, in the Douglas-fir/western hemlock forest type, 50 percent of the mature ("large sawtimber") stage is old growth and 87 percent of the old-growth stage is actually old growth (J. Mayo, pers. comm., on file with B. Marcot).

the landscape over time and the effectiveness of old growth as habitat for wildlife. Resulting spatial patterns of old growth influence the viability of many wildlife species that depend on the ecological conditions of old forests. Old growth may provide population "reservoirs" for species that find early successional stages of second-growth conifer stands marginal habitat.

What attributes of old growth affect the perpetuation of these old-growth wildlife species? Attributes may be characterized at stand and landscape scales. Attributes at each scale may be useful for guiding future inventories of old growth as wildlife habitat.

At the stand scale, important vegetational structures include the presence of key substrates, food, and resources, especially epiphytic mosses and lichens, which are important as winter food for ungulates and rodents; and the presence of specific thermal and moisture conditions. Other stand characteristics important to old-growth-dependent wildlife are related to long-term productivity of the forest environment. These characteristics include the presence of dead and decaying, standing and down wood as habitat for breeding, feeding, hiding, and other needs; and the presence and density of hypogeous fungi, which are important as food sources for the co-evolved mycophagous small mammals that disperse the mychorrizal fungi needed for conifer growth.

Landscape attributes affecting the perpetuation of old-growth dependent and associated wildlife include the spatial distribution of old growth; the size of stands; the presence of habitat corridors between old-growth or old-forest stands; proximity to other stands of various successional stages and especially for well-developed mature-forest stages and species with different seasonal uses of habitats; and the susceptibility of the old-growth habitat to catastrophic loss (such as wildfire, insects, disease, wind and ice storms, and volcanic eruptions).

Stand size, in combination with its landscape context (the condition, activities, or both on the adjacent landscape that affect the stand), is of major significance in perpetuating old-growth resources and can have a major effect on their use by wildlife. Wide-ranging species may be able to use stands of various structural- , size- , and age-classes. If such stands are separated by unsuitable habitat or disruptive activities, however, the remaining old-growth stands become smaller in effective (interior) size, more fragmented, and possibly not suitable for occupancy or for successful reproduction. An old-growth inventory that quantifies such stand and landscape attributes is a prerequisite for evaluating possible context and landscape effects on species' presence.

The Mature and Overmature (MOM) Forest Inventory on National Forest Land

Rationale for an Old-Forest Inventory

An old-growth inventory must respond to a set of clearly stated goals and objectives (Thomas and others 1988). These goals directly determine the classification schemes, parameters to be gauged, spatial scale of resolution for the inventory, and acceptable scales for the reliability of the information. They also help guide how the inventory process and its results are integrated into other resource information needs (see Davis and Henderson 1977). At present, goals and objectives for conducting an inventory of old-growth forests in the Pacific Northwest vary among groups with different interests in how the old-growth resource is managed.

An old-growth inventory can be category driven or attribute driven. With a category-driven inventory, old-forest stands are tallied into one or more classes, which are defined *a priori*. By contrast, in an attribute-driven approach, the classifier describes forest stands by a set of structural characteristics deemed pertinent to old-forest conditions. These stands are then classified *a posteriori* based on a specified set of stand attributes. The utility of both approaches depends on the purpose of the inventory. For old-growth inventories, the attribute-driven approach—when used with a classification of seral stages of old forests—is more flexible than a category-driven approach. As Smith (1982a:1) observed, It is better to invent additional patterns than to warp those observed to fit preconceived ones.

With either approach, we must specify what is being inventoried. Inventories of old-growth forests include the presence or amount of various stand characteristics, and distributions of old growth at different scales of resolution and geographic areas. Amounts should be displayed as totals by State, by Federal and State agency jurisdiction, by administrative unit within agencies, by individual and corporate ownership, by ecophysiographic province, or by other geographic divisions. Size and context should include contiguous sizes and the shapes of old-growth stands and their relation to adjacent landscape conditions and activities, including the proximity of other old-growth stands. Distribution includes defining the spatial scale at which an old-growth inventory should be conducted. This scale greatly affects the kinds of stand attributes that can be used as inventory criteria and the resolution at which such attributes should be known.

For example, a stand-by-stand inventory could include a complete census of appropriate characteristics for each vegetative unit. By contrast, a forest-wide inventory may use a stratified sampling approach to provide reliable information at the scale of vegetation types. Then, some of the characteristics of any given stand are known only as a probability-that is, an estimate of the proportion of all stands in a stratum that have particular structural characteristics.

An old-growth inventory must be designed with a specified degree of reliability. The degree of error and confidence in the statements of amount and distribution should be known, at least qualitatively. The reliability of an inventory is a function of many factors. These include the correctness and usefulness of the classification scheme used; the quality of the sampling design by which remote-sensing images are interpreted and vegetation surveys in the field are conducted; the consistency with which inventory criteria are applied across various land units, taking into account the need to vary criteria by forest type and land form; the availability and quality of remotely sensed images: the expense and training involved in having people interpret the remotely sensed images; the experience and training of field crews; and the sample sizes used in field verification testing and from which subsequent classification strata are derived.

Inventory of Mature and Overmature Forest

A large-scale, attribute-driven inventory of mature and overmature forests has been instituted on National Forests in Washington and Oregon as part of an inventory of all vegetation stands. The main objective of the inventory of mature and overmature forest is to provide a set of data to which a solid, basic set of definitions of the developmental stages of old forests can be applied. This inventory will provide an accurate inventory of old-growth stands; allow for the use of multiple definitions of old-growth forest conditions; and be accessible on a geographic information system (GE) for analysis of distributional conditions. Plans also call for a periodic update of the inventory with remote imagery, although this technology needs further testing.

The inventory of mature and overmature forest was designed to enhance the existing Vegetative Resource Survey, which is the standard inventory of all vegetation stands on National Forests in the Pacific Northwest Region. This enhancement resulted in a redefinition of mapping criteria and a greater emphasis on sampling stand attributes that are considered to be of importance in old forests. These attributes include the size, shape, and location of stands; the multicanopy structure of the stands: mixes of tree, shrub, and herbaceous species; the diameters and heights of live trees; canopy closure within each canopy layer and for the stand as a whole; the size, distribution, and decay states of standing and down dead trees; and heterogeneous characteristics of stands with small canopy openings.

Information about these attributes will allow interpretations about the values of stands from several different viewpoints. One interpretation that could be made would be whether stands meet a specific definition of old growth. This interpretation, however, would be an outcome of the basic information that was collected, rather than being the driving force for the design of the inventory.

The Mature and Overmature (MOM) Inventory follows the two-stage design of the existing Vegetative Resource Survey. The first stage is done by photo-interpretation. In this step, each forest stand is delineated on photos and maps. For each delineated stand, information is recorded on the number of canopy layers (up to three); canopy closure of the entire stand; the presence of snags; clumpiness of the canopy; the presence of large, remnant trees from stands that previously occupied the site; and volume. In addition, for each of the canopy layers, information is recorded on tree species, canopy closure, crown diameter of dominant trees, clumpiness, and visible snags. All of this information is derived from photo-interpretation and is ground verified on about 10 percent of all stands.

After the photo-interpretation is completed, stands are arrayed according to their attributes to determine an appropriate distribution for additional, detailed ground plots. The ground plots are the second stage of the inventory. In other inventories, the standard design calls for lumping the stands into defined strata to develop a sampling strategy. With the MOM Inventory, strata are avoided so that plot data can later be combined in several different ways to address various concerns. Instead of developing strata, the sample plots are distributed so that the full array of stand conditions are sampled. This process involves arraying the stands according to species composition, number of canopy layers, tree density or stocking, canopy closure, and crown diameters. The ground plots follow a IO-point design and include detailed information on live-tree species including height, density, diameter, and form by canopy layer; snag density, diameter, height, and decay state; diameter, length, and decay state of logs; and the presence of indicator plant species in the understory. This last category is used to classify the stand by plant association.

Because this plot information can be collected only for a sample of stands, it will not be available for all the stands that are photo-interpreted. Data from the MOM Inventory can be analyzed in two different ways to draw inferences about stands that were not sampled. First, a collection of stands can be defined based on any combination of the photo-interpreted characteristics. Plot data can then be summarized for all stands in this collection that were ground sampled. Because these collections of stands are not being defined as a priori strata, the values of attributes for such a summary could vary widely.

The second analysis opportunity is to develop correlations between characteristics that were photo-interpreted and characteristics that were measured in plots. For each stand, this comparison would allow us to identify photo-interpreted characteristics with some degree of certainty, and to identify ground-sampled characteristics with some known degree of reliability. Currently, the ability to correlate ground-sampled characteristics with photo-interpreted characteristics is the largest unknown in the inventory design, and the reliability of inferences about these ground-sampled characteristics is also unknown.

The combined MOM and Vegetative Resource Inventories will result in five products:

- A stand map for each forest stored on a GIS.
- A data card for each stand containing the photo-interpreted data for that stand. This information will be stored in the attribute file of the GIS.
- A database containing all plot data.
- Summarized plot data for collections of stands defined according to any combination of the photo-interpreted characteristics.
- Statistical correlations between photo-interpreted characteristics and plot-sampled characteristics.

The MOM-Inventory process is currently being implemented on the Siuslaw and Willamette National Forests as part of the Vegetative Resource Inventory. It is expected to be completed on all nine of the west-side forests in Oregon and Washington by 1994.

Recommendations for Old-Growth Inventories

We offer the following recommendations for developing a multipurpose, old-growth inventory. First, an old-growth inventory should be attribute-based rather than definition-based. An example is the inventory of mature and overmature forests currently being conducted by the Pacific Northwest Region of the Forest Service.

Second, an old-growth inventory should be map-based to address landscape issues, including that of scale. Map-unit sizes should be small enough to identify old growth where edge effects eliminate interior habitat. A map-based approach would also benefit from further exploring the use of Landsat as a tool for updating inventories over time. In addition, a map-based inventory would benefit from the application of a geographic information system for evaluating the data, especially the landscape and spatial conditions of stand size, shape, and context. The MOM Inventory is currently being installed on GIS to facilitate the evaluation of spatial components.

Third, any adopted definition of old growth should be part of a system of describing the amount and distribution of various stages of forests, especially older ones. The full classification system would include descriptions of the total vegetation inventory from seedling to old-growth successional stages, including noncommercial forest lands and nonforest vegetation. Specifically, the Old-Growth Task Group definitions should be the basis for ecological definitions used in a broader framework. In this manner, a consistent definition can be applied to the attribute-based data and also allow analyses of stand conditions that meet various other definitions.

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Ecological Definitions of Old-Growth Douglas-Fir Forests

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Abstract

We examined the potential for definitional and indexing approaches to identifying old-growth Douglas-fir stands. An interim definition created by the Old-Growth Definition Task Group uses multiple structural characteristics of forest stands-specific levels of large or old live trees, snags, logs, and foliage canopy layers. This definition and numerous variants with different parameters and parameter values were tested for their ability to discriminate old growth from young and mature natural forests with an independently collected data set. The criteria used in the definitions appear appropriate but variants of the definition differ significantly in their ability to distinguish old-growth in particular geographic areas. Definitions that used density of all large (>lOO cm in diameter at breast height) trees, rather than just Douglas-fir, performed best. Further refinement of definitions should probably be site specific. Developing approaches that recognize the continuous variability in old-growth stands are recommended for the whole region. These approaches could be simple indices based on multiple structural characteristics or using discriminant analysis; examples are provided to demonstrate the merits of both concepts. Maintaining a holistic perspective on old-growth forest ecosystems is critical in these and other current efforts to characterize old growth by individual attributes.

Introduction

Old-growth forest is a biological or ecological concept that presumes ecosystems systematically change as they persist over long periods. An ecosystem has, in effect, a series of linked life stages, progressing from origin (birth) to old age (senescence), which vary in composition, function, and structure. Such progressions can take a very long time in forests because the dominant organisms, trees, typically live very long.

Characterizing old-growth forests is possible based on these concepts. Obviously, a series of ecological attributes must be considered because of the many relevant compositional, functional, and structural features. For practical reasons, however, a working definition-one for everyday use in gathering stand data-emphasizes structural and compositional rather than the conceptually important functional features that are difficult to measure.

A generic definition of old-growth forests, applicable to most temperate and subalpine forests, is possible. Old-growth forests are later stages in forest development that are often compositionally and always structurally distinct from earlier successional stages. For example, forests at low to moderate elevations in western Washington and Oregon often shift from strong dominance by Douglas-fir in early stages of succession to mixed stands with large amounts of western hemlock and other tolerant species at mid to late stages in succession (Franklin and Hemstrom 1981). Even where both early- and late-successional forests are composed of the same species, such as many sites with ponderosa or lodgepole pine, the old stands differ from young stands in structure; for example, old stands have a much larger range in tree sixes. The age at which forests become old growth varies widely with forest type or species, site conditions, and stand history.

Structurally, old-growth stands are characterized by a wide within-stand range of tree sizes and spacing and include trees that are large for the particular species and site combination. Decadence is often evident in larger and older trees. Multiple canopy layers are generally present. Total organic matter accumulations are high relative to other developmental stages. Functionally, old-growth forests are characterized by slow growth of the dominant trees and stable biomass accumulations that are constant over long periods. Respiration reduces net annual additions of living organic matter to low amounts relative to earlier successional stages, despite high gross primary productivity in old-growth stands. All climax forests" forests that appear to have stable composition and structure in the absence of a major disturbance"qualify as old growth, although most old-growth forests are not climax; that is, they still contain seral species and are undergoing slow directional changes in composition and structure. Not all virgin or primeval forests are old growth and not all old-growth stands are totally free of human disturbance. Old-growth forests could theoretically originate after either human or natural disturbance because they are defined by composition, structure, and function and not by origin or naturalness.

General characterizations of old-growth forest are conceptually important, but specific definitions are essential to forest-land management. Inventories to identify the quantity and location of old-growth forests require such specificity. Forest policy, including the allocation of forest lands to various uses, are partially based on these inventories. Old-growth forests need to be characterized so that important attributes can be retained and attempts made to create similar forests. Characterizations are also needed by scientific researchers.

In this paper, we will consider the state and future of old growth in the Pacific Northwest. Our primary focus is on the mesic temperate forests dominated by Douglas-fir and located west of the crest of the Cascade Range in Washington, Oregon, and northern California. We review the history and adequacy of the existing old-growth definition and explore directions for future development of such characterizations including local refinement and extension to other forest types, developing indices with continuous scales of variation, and using statistical methods, such as discriminant analysis.

Old-growth forests in our study area vary widely in their age and ecological state (for example, in composition and structure), which reflects a similar wide variability in their history and physical environments. Old-growth Douglas-fir forests are from about 200 to over 1000 years old, they undergo gradual but significant autogenic change during those centuries of existence and may also be subjected to varying numbers and intensities of disturbance events, such as windstorms. As a consequence, old-growth Douglas-fir forests can differ substantially in their degree of "oldgrowthness"-that is, in the degree to which they express the various structural and functional features associated with these forests; this variability must be considered in efforts to define and manage old growth.

Current Definition of Old-Growth Douglas-Fir Forests

Historical Development of the Interim Definition

The history of the interim definition of old-growth Douglas fir forests (Old-Growth Definition Task Group 1986) is discussed in detail by Marcot and others (this volume). It began with National Science Foundation funding of the Coniferous Forest Biome in 1969, as part of the International Biological Program (Edmonds 1982), and of subsequent ecosystem studies, particularly at the H. J. Andrews Experimental Forest. The USDA Forest Service also contributed to this research. These studies provided a wealth of data and concepts on the nature of old-growth forests and associated streams (see Blinn and others 1988, McKee and others 1987).

In 1976 the research group associated with this work received a request from a National Forest planner for assistance in characterizing old-growth forests; as he put it, "We know that old-growth forests are more than just some big old trees, but we don't know how else to describe them. Could your group provide us with a more complete characterization?" A workshop, convened at Wind River, Washington, in 1977, produced the synthesis entitled, "Ecological Characteristics of Old-Growth Douglas-Fir Forests" (Franklin and others 1981).

All current attempts at ecological definitions of old-growth Douglas-fir are based on the 1977 synthesis and subsequent research, much of it under the auspices of the Forest Service's Old-Growth Forest Wildlife Habitat Program. These studies clarify the distinctiveness of old-growth forests in composition, structure, and function and, perhaps even more important, the complexity of most naturally regenerated forests developing after wildfire, windstorm, or other catastrophic events in the Pacific Northwest, regardless of successional stage. For example, the structural complexity of young natural forests is high because of the carryover of large snags,, logs, and even large live trees from the predisturbance stand; conditions in these natural stands obviously contrast with the simplified structure of most young forests managed for timber production. Past old-growth studies also illustrate the need to use multiple attributes to characterize old-growth forests and the value and validity of emphasizing structure in working definitions. Among the first iterations of old-growth definitions based on these ecosystem concepts are those by the Society of American Foresters (1984) and Franklin and Spies (1984).

In 1985, an interagency group-the Old-Growth Wildlife Habitat Research and Development Program Steering Committee-created the Old-Growth Definition Task Group to develop an interim definition of old-growth Douglas-fir forests. The group was composed of technical experts from the USDI Bureau of Land Management, Oregon State University, and National Forest and Research branches of the Forest Service. The draft reports they wrote were extensively reviewed by management groups and scientists and revised before the interim definitions were published (Old-Growth Definition Task Group 1986).

The Interim Definition and Its Adequacy

The interim definition consist of separate definitions for old-growth Douglas-fir forests under three broad environmental conditions indexed by plant series (table 1). The three definitions are based on multiple structural criteria: density of live trees of large or old Douglas-firs and of associated medium- to large shade-tolerant tree species; multiple canopy layers; standing dead tree (snag) densities, including larger sizes; and logs, including total weight and a minimum number of large pieces. The rationale for selection of specific characteristics is discussed in the original publication (Old-Growth Definition Task Group 1986).

Although the definitions have been cussed and discussed since their publication, no data have been available to test their adequacy in discriminating old-growth from young and mature forests. Forest-inventory procedures usually do not collect data on all of the characteristics used in the definitions; however, Morrison (1989) was able to effectively use USDA Forest Service inventory plot data by adapting the definitions to the more limited set of parameters that were included in the inventories.

Spies and his associates have provided the first complete and independent data set (Spies and others 1988; Spies and others, in press; Spies and Franklin, this volume) appropriate for testing the performance of one of the interim definitions-the definition developed for stands on western hemlock and mid-elevation Pacific silver fir sites (table 1). This interim definition is the only one subsequently addressed in this paper. The data are from 196 young, mature, and old-growth stands in the Oregon and southern Washington Cascade Range and Oregon Coast Ranges (Spies and others 1988; Spies and others, in press; Spies and Franklin, this volume). Stands were selected that contained Douglas-fir and appeared to have originated after a high-intensity or stand-regenerating wildfire. None of the stands were selected according to any preconceived set of old-growth criteria. Five systematically spaced plots were used to characterize each of the selected stands. Stands were classified as young (<80 years old), mature (80-199 years old), and old (>200 years old), according to the ages of the dominant Douglas-fir trees. The 85 age-defined old-growth stands from this data set are the standard against which the performance of the various definitions and other discriminating procedures are tested.

Table 1-Interim minimum standards for old-growth Douglas-fir forests in western Washington and Oregon[a]

Stand characteristic	Douglas-fin on western hemlock sites (western hemlock, Pacific silver fir)	Douglas-fir on mixed-conifer sites (white fir, Douglas-fir	Douglas-fir on mixed-evergreen sites (tanoak, Douglas-fir)
Live trees	Two or more species with wide range of ages and tree sizes	Two or more species with wide age range and full range of tree sizes	Douglas-fir and evergreen hardwood (tanoak, Pacific madrone, and canyon live oak associates (40 to 60 percent of canopy)
	Douglas-fir ≥ 20 per ha of trees > 81 cm diameter or > 200 years old	Douglas-fir, ponderosa pine, or sugar pine ≥ 20 per ha of trees >76 cm diameter or >200 years old	Douglas-fir or sugar pine ≥ 15 per ha of trees > 81 cm diameter or > 200 years old
	Tolerant associates (western hemlock, western redcedar, Pacific silver fir, grand fii, or bigleaf maple) ≥ 30 per ha of trees >41 cm diameter	Intermediate and small size-classes are typically white fir, Douglas-fir, and incense-cedar, singly or in mixture	Intermediate and small size-classes may be evergreen hardwoods or include a component of conifers (e.g., Douglas-fii or white fir)

See footnote on next page.

Table l-continued"

Stand characteristic	Douglas-fir on western hemlock sites (western hemlock, Pacific silver fii)	Douglas-fir on mixed-conifer sites (white fir, Douglas-fir	Douglas-fir on mixed-evergreen sites (tanoak, Douglas-fir)
Canopy	Deep, multilayered Canopy	Multilayered Canopy	Douglas-fir emergent above evergreen hardwood Canopy
Snags	Conifer snags ≥ 10 per ha which are >51 cm diameter and >4.6 m tall	Conifer snags ≥ 3.7 Per ha that are >51 cm diameter and >4.6 m tall	Conifer snags ≥ 3.7 per acre that are>51 cm diameter and >4.6 m tall
Logs	Logs ≥34 metric tons Per acre including 10 pieces Per ha >61 cm diameter and >15 m long	Logs 222 metric tons per acre including 5 pieces per acre ≥61 cm diameter and >15 m long	Logs ≥ 22 metric tons per acre including 5 pieces per acre ≥ 61 cm diameter and >15 m long

[a] From Old-Growth Definition Task Group (1986). Plant series are shown in parentheses.

The selection of attributes used in the interim definition generally appear appropriate; that is, they are important features of old-growth forest (Spies and others 1986, Spies and others 1989) and several discriminate old-growth from younger forest stages (Spies and Franklin, this volume). Analyses (Spies, this volume; Spies and Franklin, this volume) have identified other features that distinguish old-growth forests, such as coverage of western yew, coverage of herb and deciduous shrub species, and measures of crown decadence in overstory trees.

The parameter values chosen in the interim definition were intended as "minimum standards," and they do fall well below average or characteristic values for measured stands. The values were, in fact, selected as a "lowest common denominator," with the intent that most old-growth stands would meet the criteria and most young or mature forests would not. As an example, the 85 old-growth stands sampled by Spies and his associates average 66 tons per ha of logs (Spies and others 1988), and the minimum standards call for only 35 tons per ha on western hemlock sites (Old-Growth Definition Task Group 1986). Similarly, large snags averaged about 12 per ha in the old-growth samples versus the task group requirement for 10 per ha.

Table 2-Performance of the interim definition for Western Hemloc kSeries

Parameter and minimum standard	Province: Oregon coast Ranges	Oregon Cascade Range	Southern Washington Cascade Range	All
Douglas-fir > 80 cm in d.b.h. (> 20 Per ha)	96	94	77	89
Shade associates > 40 cm in d.b.h. (2 30 Per ha)	72	76	97	83
Snags > 50 cm in d.b.h. >5 m tall(>10 per ha)	68	74	92	79
Log biomass (34 tons per ha)	92	88	97	92
All criteria	52	56	70	60

[a] Performance is the percentage of old-growth stands fulfilling individual and collective minimal standards based on stand means ± standard deviation. 15 percent of mature stands also fulfilled all criteria.
[b] From Old-Growth Definition Task Group (1986).

The interim definition does not perform as well as expected in distinguishing this set of old-growth stands, however, even though parameter values are well below mean measured values for old-growth stands (table 2). For example, only 70 percent of the 24 old-growth (>200-year-old) stands sampled by Spies and his associates in the Washington Cascade Range met all minimum criteria, even when 1 standard deviation around the mean stand value is allowed. Percentages were even lower for the Oregon Coast (52 percent) and Cascade (56 percent) Ranges (table 2). Furthermore, the interim definition did not completely exclude mature and young stands; discrimination was poorest in the Coast Range, where 30 percent of the mature (80- to 199-year-old) stands also met the minimum standards for old growth.

The mediocre performance of the interim definition results from at least two factors. First, the statistical distribution of measured stand attributes, such as number of large snags, are skewed so that the median values lie well below the means. Hence, many stands fail to fulfill minimum values even though average values for old-growth stands indicate that a higher percentage should meet them. Second, a higher percentage of stands fulfill individual criteria than can fulfill all of the criteria (table 2). For example, old-growth stands measured in the southern Washington Cascade Range meet the four criteria 77, 92, 97, and 97 percent of the time, but only 70 percent of the stands meet all four criteria simultaneously.

Revising the Interim Definition

Several approaches are possible for modifying the interim definition: adjust the values in the interim definition so that it does a better job of either characterizing or distinguishing old-growth Douglas-fir stands, developing more site-specific versions of the definition, such as for individual habitat types or restricted geographic regions; or a combination of the two approaches.

Fifteen iterations of a revised interim definition for old-growth Douglas-fir forests on western hemlock sites were developed by using different variables and parameter values as minimum standards. The selection of variables and range of values were based on conditions encountered in the old (>200-year-old) stands sampled by Spies and his associates. Four different large-tree variables were tried: Douglas-firs >80 cm in d.b.h. and >100 cm in d.b.h. and density of all trees >80 cm in d.b.h. and >100 cm in d.b.h. The range of values used in the 15 definitions are

Douglas-fir >80 cm in d.b.h.	10-20 per ha
Douglas-fir >lOO cm in d.b.h.	l10-20 per ha
All trees >80 cm in d.b.h.	20 per ha
All trees >lOO cm in d.b.h.	10-15 per ha
Shade-tolerant trees >40 cm in d.b.h.	10-30 per ha
Snags >50 cm in d.b.h. and >5 m tall	4-10 per ha
Log biomass	30-34 tons per ha

The definitions were tested by determining the proportion of stands in the old-growth data set that they correctly identified based on having values within 1 standard deviation of the mean stand value. Generally, definitions were judged by their ability to identify old-growth stands (minimize Type I error), although their ability to exclude mature and young stands (minimize Type II error) were also considered.

The best revised definition correctly identifies 82 percent of the old-growth (>200-year-old) stands sampled by Spies and his associates (table 3). This definition uses density of large trees of all species rather than just Douglas-fir. It also uses much lower parameter values than those used in the original definition: all trees >100 cm in d.b.h. 10 per ha; shade-tolerant trees >40 cm in d.b.h., 10 per ha; large snags, 4 per ha; and log biomass, 30 tons per ha. These substantially lower values relax the criteria to the point where 24 percent of the mature stands also meet the old-growth criteria. A definition that uses a value of 15 per ha for all trees >lOO cm in d.b.h. performs almost as well in identifying old growth but does much better at discriminating against mature stands. Old-growth stands in the Oregon Coast Ranges were the most difficult to distinguish correctly under any of the definitions, including the original.

Among individual attributes, density of large trees best differentiates old growth from young and mature stands of natural origin; coarse woody debris (snags and logs) does poorest. This is true of all versions of the definition and reflects the substantial similarities between natural stands of all age-classes. It is also consistent with the finding of Spies and

Table 3-Performance[a] of the "best-performing" revision of the interim definition of old growth for the Western Hemlock Series

Parameter and minimum standard	Province: Oregon Coast Ranges	Oregon Cascade Range	Southern Washington Cascade Range	All
All species > 100 cm in d.b.h. (≥ 10 per ha)	96	96	92	95
Shade associates > 40 cm in d.b.h. (≥ 10 per ha)	88	88	100	92
Snags > 50 cm in d.b.h. >5 m tall (≥4 per ha)	84	94	100	94’
Log biomass (30 tons per ha)	92	92	100	95
All criteria	76	80	92	82’

[a] Performance is the percentage of old-growth stands fulfilling individual and collective minimal standards based on stand means ±1 standard deviation. 24 percent of mature stands also fulfilled all criteria.
[b] From Old-Growth Definition Task Group (1986).

Franklin (this volume) that the best classification success in discriminant analyses is achieved using an equation based on overstory attributes.

The revised definition continues to focus on minimum standards, with the objective of improving its ability to distinguish old from young and mature stands. An alternative approach would be to use mean values and associated variances for characterizing old-growth stands. By replacing the minimum standards or values with mean or median values, the definition would provide a much better perspective on what an average old-growth stand is like. Obviously, such a definition would do much more poorly than one based on minimum standards at distinguishing old-growth stands from other stages in forest succession. It would decrease the probability of "poor quality" stands-stands with few old-growth structural features-being included in an old-growth pool.

Substantial efforts to further refine one general definition of old-growth forests for the Western Hemlock Series is probably not warranted at this time. First, appropriate data sets are not available for old-growth stands over large geographic areas-for example, old-growth Douglas-fir forests on Western Hemlock Series sites in the central and northern Washington Cascade Range, Olympic Mountains, British Columbia, and the northern Oregon Coast Ranges. Data sets are very limited for old-growth Douglas-fir on other series or habitat types in southwestern Oregon or in eastern Washington and Oregon. Even within geographic areas that have been sampled, sampling has avoided old-growth stands of species other than Douglas-fir, such as western redcedar or western hemlock. Further development of general definitions seem pointless until such data are available.

A second and perhaps more important reason for suspending efforts at further refinement of a general definition is the large variability in old-growth stands apparent from the existing data sets. We infer from this high variability that regional variations in environment and disturbances (stand ages and disturbance histories) are very important (Spies and Franklin, this volume). As data are added from additional geographic areas, the range of variability known for old-growth forests can only be expected to increase. A definition that attempts to encompass these increasing amounts of variability becomes less and less valuable as a tool for identifying and characterizing old-growth stands in specific locales.

Further development of old-growth definitions should probably be directed toward developing more site-specific definitions, such as for specific habitat types, geographic locales, or both.

We believe that all classificatory work, whether as discrete types or along gradients, should be locally fine-tuned for maximum value. An example might be to define old-growth on the Western Hemlock/Swordfern and closely related habitat types in the northern Oregon Cascade Range. The Area Ecology program of the Forest Service's Pacific Northwest Region (6) provides an excellent opportunity to carry out locale-specific efforts of this type-that is, quantifying more specifically the characteristics of old growth with much more intensive sampling.

The interim Douglas-fir definition can be effectively extended to other forest types. Because the definition was. by direction, for old-growth Douglas-fir and not for old-growth conifer forests in general, Douglas-fir had to be a component of all of the stands, but most other temperate and subalpine old-growth stands in the Douglas-fir region follow a similar pattern in stand structural attributes. As suggested in the interim definition, The Douglas-fir old-growth criteria in table 1 can be modified for use with other species or types. The major change is replacement of Douglas-fir as the dominant species...Sitka spruce or western redcedar can be substituted... [and] In old-growth western hemlock or Pacific silver **fir** forests, these species would dominate all size classes including the [larger trees]. (Old-Growth Definition Task Group 1986). The revised definition, which uses density of large trees of all species rather than just Douglas-fir, is already better adapted for use in these other forest types than was the original interim definition. Obviously, data would have to be gathered to provide parameter values for these forest types because very little currently exists; such stands were excluded from the Old-Growth Forest Wildlife Habitat Program.

Characterizations by Using Continuous Scales

The problem with these categorical approaches to old-growth characterization is that they attempt to pigeon-hole old-growth forests, which exhibit continuous temporal and spatial variability. Systems of characterization based on continuous scales of variability avoid this problem and allow us to recognize varying degrees of old-growthness. They also mesh well with the approach to old-growth inventory recently suggested by a multi-interest consensus group facilitated by the Pacific Northwest Region of the Forest Service; this group agreed that stands should be characterized in terms of structural attributes rather than simply identified as falling in or out of a specific old-growth definition (Marcot and others, this volume). Alternative approaches to old-growth identification include developing indices based on multiple characteristics and discriminant analysis. Our explorations of indices follow; results of discriminant analysis are mainly reported elsewhere (Spies and Franklin, this volume).

Indices to successional stage are probably best comprised of characteristics that are ecologically important, such as providing wildlife habitat, and functional features of the ecosystem as well as those strongly related to forest age. Many stand-structure attributes exhibit one of two typical patterns of change (table 4, fig. 1): a U-shaped curve, such as is typical of the amount of coarse woody debris with highest amounts early and late in succession; and an S-shaped curve rising to an asymptote from low values early in succession, which is typical of average tree size. As discussed by Spies and Franklin (1988), these two general patterns of development are useful in constructing an old-growth index by simply summing absolute or transformed values of characteristics, so that the highest index numbers occur in the later stages of stand development (fig. 2). We illustrated this scheme with three stands (Spies and Franklin 1988): a stand with high densities of large trees and large amounts of coarse woody debris has an index value of more than 0.75; a young stand with high amounts of woody debris inherited from the previous old stand is indexed at 0.5; and a young stand lacking both woody debris and large trees has an index value below 0.25.

We constructed and tested four versions of a more complex structural index by using both pooled and province-specific data sets. Attributes used in this index are amount of crown decadence of Douglas-fir (broken tops, dead tops, broken tops with upturned leaders, and multiple tops); density of large trees defined in the four versions as Douglas-firs >80 cm in d.b.h., Douglas-firs >100 cm in d.b.h., all trees >80 cm in d.b.h., and all trees > 100 cm in d.b.h. density of shade-tolerant associates either >25 cm or >40 cm in d.b.h.; density of large snags; and log biomass, using 60 tons per ha as the base value. Two versions of each index were constructed and tested for each province: one based on mean values for that province and another using means for the pooled (multiple province) data set.

Table 4—Classification[a] of ecosystem characteristics according to their expected pattern of change during succession in Douglas-fir forests

Characteristics following a U-shaped curve (curve 1)	Characteristics following an S-shaped curve (curve 2)
Amount of coarse woody debris	Average tree size
Number of large snags	Diversity of tree sizes
Coarse woody debris as percentage of total ecosystem biomass	Incidence of broken tops
	Forest floor depth
Heterogeneity of understory	Surface area of boles and branches
Plant species diversity	
Mammal diversity	Wood biomass

[a] From Spies and Franklin 1988

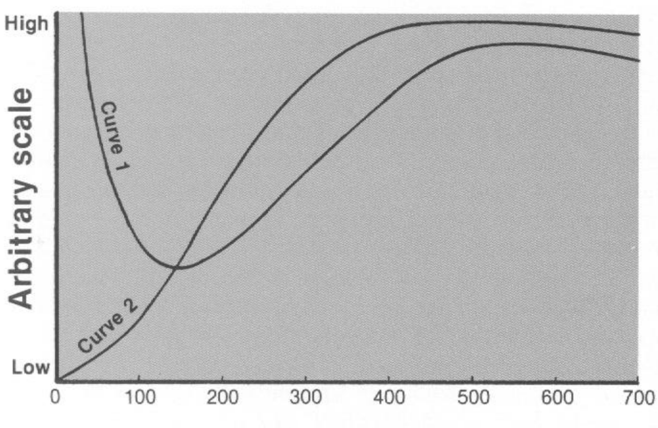

Figure 1—Generalized curves of change in ecosystem attributes with long developmental periods in a Douglas-fir forest sere (from Spies and Franklin 1988).

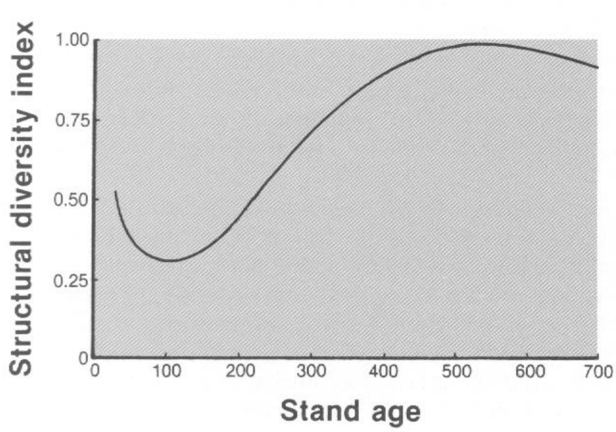

Figure 2—Hypothetical index of structural diversity in relation to stand age in a Douglas-fir forest sere (from Spies and Franklin 1988).

This set of five structural attributes works well at indexing forest stands along an age gradient in most of its forms (see, for example, figs. 3, 4). One version performs particularly well with the complete set of stands, as well as the stands in both the Oregon and southern Washington Cascade Range (figs. 3, 4). This version uses density of all trees >80 cm in d.b.h. and of shade-tolerant trees >40 cm in d.b.h., along with the measures of Douglas-fir crown decadence, large-snag density, and log biomass. Other versions also work well, however—particularly in specific provinces. We infer from the variability in performance among versions that fine-tuning indices for more limited geographic areas is needed, just as with the definition. The high degree of overlap between natural young, mature, and old stands using these indices (fig. 3, 4), is important to note, however.

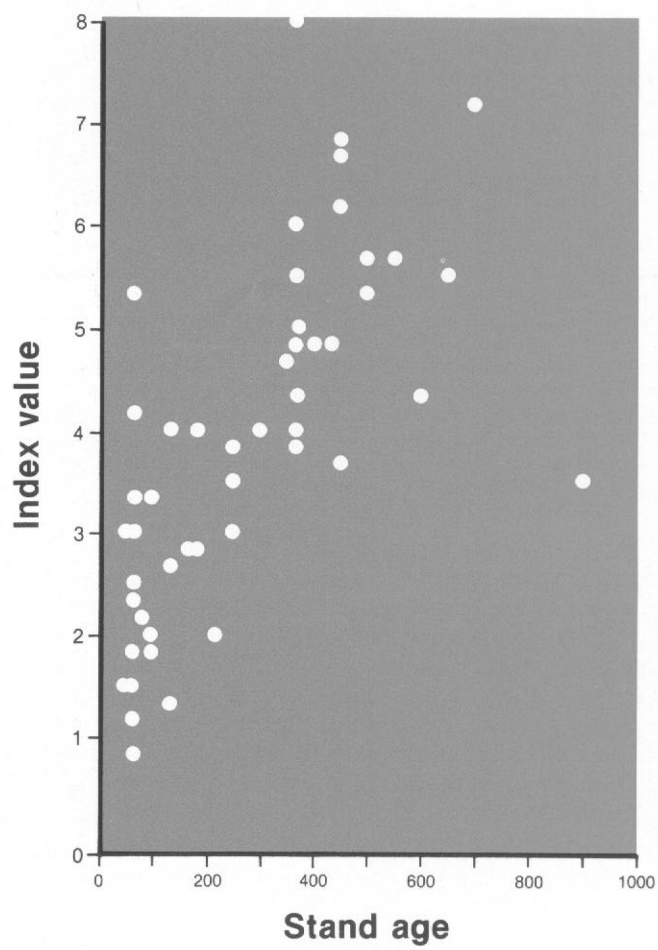

Figure 3—Test of a forest structure index to degree of old-growth development by using data from a set of natural forest stands in the southern Washington Cascade Range. This index uses Douglas-fir crown decadence, density of all trees > 80 cm d.b.h., density of shade-tolerant trees > 40 cm d.b.h., density of large snags, and log biomass (tons/ha); it was constructed with data only from the southern Washington Cascade Range.

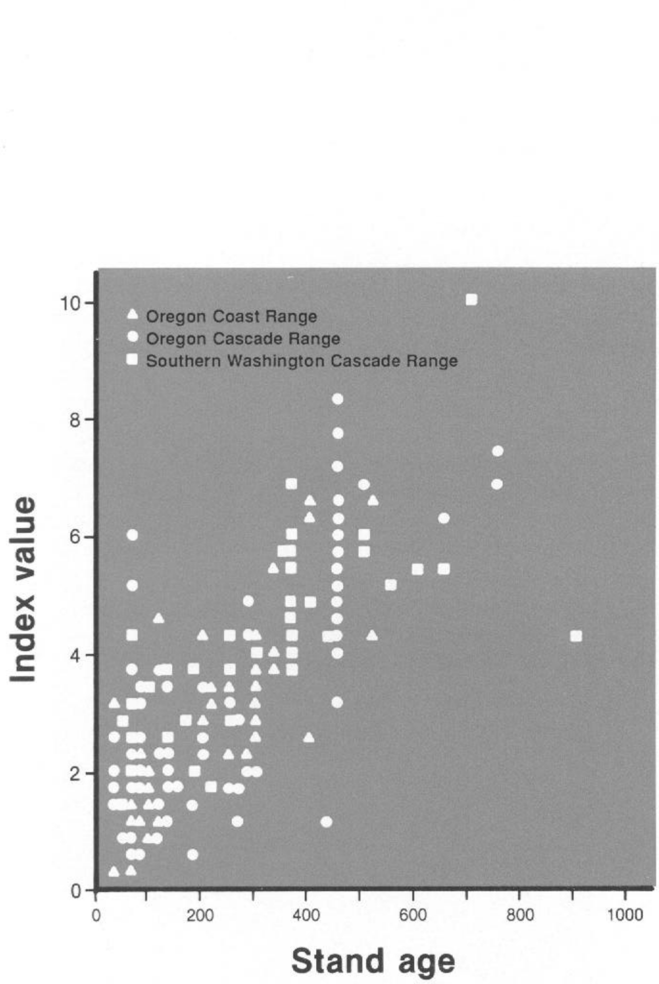

Figure 4—Test of a forest structure index to degree of old-growth development with data from natural forest stands in the Oregon and Washington Cascade Range and the Oregon Coast Range. The index uses Douglas-fir crown decadence, density of Douglas-fir >100 cm d.b.h., density of shade-tolerant trees >25 cm d.b.h., density of large snags, and log biomass (tons/ha); it was constructed with data from all provinces.

The best approach to accurately identifying old-growth stands and assigning them to a successional stage appears to be discriminant analysis (Spies and Franklin, this volume). Although this procedure is not actually indexing, it is based on multiple structural attributes (as we have applied it) and deals statistically with the wide variability in old-growth forests. Numerous equations have been developed and tested by using various combinations of attributes as reported elsewhere (Spies and Franklin, this volume). The equation that has the best classification success (94 percent of the old-growth stands accurately identified) uses an overstory attribute set: standard deviation d.b.h., mean tree diameter, density of Douglas-firs >100 cm in d.b.h., and total tree density.

Conclusions

The interim definition has worked well in identifying the essential characteristics of old-growth Douglas-fir forests. It has provided a basis for considering issues of inventory and allocation. Perhaps our current understanding of old-growth forests is now sufficient to allow interested parties to discuss the nature of this highly variable phenomenon objectively.

The merit and utility of using multiple ecological attributes and of the specific variables selected in the interim definition has been demonstrated. A version with different parameters of the definition is proposed based on existing data sets, but generic definitions will always be less useful than those developed for a more limited geographic area. Hence, further improvements in the definition should be its refinement for specific habitat types and geographic locales and extension to other forest types.

Indices and discriminant analyses are superior to general definitions in distinguishing old-growth Douglas-fir forests where that is the objective. Such approaches more easily incorporate the wide variability in old-growth forests in time and space and fit well with current concepts of forest inventory based on ecological attributes. Indexing allows recognition of various degrees of "old-growthness," as well as consideration of variability in individual attributes, such as snags or large trees, that may be important in management.

All three approaches—definition, indexing, and discriminant analysis—have merit and specific applications in considering policy, management, and research issues associated with old-growth Douglas-fir forests.

We hypothesize, based on the high structural variability in old-growth Douglas-fir forests, multiple developmental or successional routes to old-growth-like forests. If this hypothesis proves correct, it could have important management implications. Specifically, stands appear to differ widely in density and other structural features as a consequence of varied histories. Hence, developing multi-aged and multi-sized stands through partial cutting may be one alternative to long rotations in re-creating stands that resemble existing old-growth forests functionally and structurally. These stands could be created by retaining selected green trees, as well as large snags and logs, at the end of each harvest cycle.

Much additional research on old-growth forests is urgently needed. Although millions of research dollars have been directed to northern spotted owls and other vertebrates (as demonstrated by this volume), almost no funds are being expended on studies of old-growth forests as ecosystems. This lack is true for Douglas-fir forests and even more so for other coniferous forests on both sides and at the summit of the Cascade Range.

Our failure to study old-growth forests as ecosystems is increasingly serious in considerations of old-growth issues. Without adequate basic knowledge of the ecosystem, we risk losing track of its totality in our preoccupation with individual attributes or species. Definitional approaches to old growth based on attributes, including those that we have presented here, predispose us to such myopia. The values and services represented by old-growth ecosystems will he placed at ever greater risk if we perpetuate our current ignorance about these ecosystems. It will also increase doubts about our ability to manage for either old-growth ecosystems or individual attributes (for example, species and structures) associated with old growth. We must increase ecosystem understanding and management emphasis on holistic perspectives as we plan for replacement of old-growth forests. How can we presume to maintain or re-create what we do not understand? Some may presume that ignorance (on ecological values of old growth) is bliss, but this attitude creates high risk that we will continue to be blindsided by subsequent discoveries.

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