Ecological effects of variable-retention harvests in the north-western United States: the DEMO study*

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Abstract
The retention of trees in harvest units is an integral part of forest management practices on federal lands in the northwestern United States (U.S.), yet the ecological benefits that result from various levels or patterns of retained trees remain speculative. Large-scale and long-term silvicultural experiments are needed to evaluate the effects of alternative forest management strategies on biological diversity, yet they are rarely undertaken due to the substantial commitments of time and resources required. The Demonstration of Ecosystem Management Options (DEMO) study was initiated by U.S. Congressional mandate in 1993 and is unique in the northwestern U.S. in its geographic scope, experimental design, and collaboration between research and management. The experimental design consists of six harvest treatments, each 13 ha in size, replicated at six locations (blocks). Treatments represent strong contrasts in the level (15–100%) and pattern (dispersed or aggregated) of retention in mature Douglas-fir forests. Data were collected from 1994 to 1996 prior to harvest, experimental harvests were implemented in 1997 and 1998, and initial post-treatment sampling was completed in 2001. A variety of ecological responses were measured and public perceptions of visual quality were evaluated. We discuss the objectives and experimental and sampling designs for the DEMO study, and present brief summaries of the results of component studies. Early results have provided important insights into response mechanisms, but the most significant and useful results will be obtained as experimental stands reach maturity in the coming decades.

Keywords: Aggregated retention, biological diversity, dispersed retention, ecological responses, silviculture, forest structure, variable-retention harvest, visual quality

1 Introduction

Forests dominated by Douglas-fir *(Pseudotsuga menziesii)* in the western hemlock *(Tsuga heterophylla)* zone of the northwestern United States are among the most productive and commercially valuable forests in the world (FRANKLIN and DYRNESS 1973). Clearcutting followed by broadcast burning and planting were the standard harvest and regeneration

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practices used in the Douglas-fir region from the 1950s through the early 1990s. In the process, much of the area was converted from structurally diverse and ecologically complex old-growth forests to short-rotation, even-aged plantations. These forests could be managed more efficiently than mixed-age or mixed-species stands, and were thought to mimic the stands that regenerate after catastrophic wildfires and other stand-replacing disturbances in that region. Throughout most of the 20th century, the primary value of forests was to provide wood, water, grazing, recreation, and other commodities; there was little concern about the potential loss of ecological diversity from intensive forest management. In fact, old-growth forests were considered by many foresters to be unproductive and in need of active management. In particular, decadent trees and standing dead and down wood, and the pathogens and insects that create or utilize these structures, were considered undesirable components of a well-managed forest. With the exception of snag management for cavity-nesting birds, which was initiated during the 1970s (e.g., BALDA 1975; THOMAS *et al.* 1979), neither the ecological value of late-successional forest structures, nor the many organisms that depend on them for survival and reproduction, was given much consideration by forest managers.

Societal values and forest management objectives have changed substantially in the Pacific Northwest during the last few decades (THOMAS *et al.* 1990; USDA and USDI 1994; TUCHMANN *et al.* 1996). Intensive management designed to maximize wood production has largely been replaced by a new paradigm of "ecosystem management" based on the concept of sustainable use for multiple forest values (CHRISTENSEN *et al.* 1996; BOYCE and HANEY 1997). Increased societal concerns about the detrimental effects of clearcutting on aesthetic quality and ecological integrity have led resource managers to develop new strategies to retain or restore many of the biotic components and abiotic processes that play key roles in the functioning of forest ecosystems, especially those associated with old-growth conditions (FRANKLIN *et al.* 1981). The challenge now is to design silvicultural prescriptions that will provide a sustainable supply of timber while retaining a variety of species, structures, and processes associated with natural disturbance and successional recovery in these systems, including some found only in late-seral stages (ARNOTT and BEESE 1997; BERGERON and HARVEY 1997; COATES *et al.* 1997; FRIES *et al.* 1997; FRANKLIN *et al.* 2002; PALIK *et al.* 2002). This change in management objectives has led to a variety of silvicultural prescriptions that preserve or create snags and down woody debris after regeneration harvests, and retain live trees in both riparian areas and upland sites. The densities of live (or green), residual trees may range from a few "wildlife" trees (5–12 per ha), to a residual stand density typical of a shelterwood regeneration cut (25–75 per ha), to fairly large (up to 1 ha) undisturbed patches (aggregates) within a harvested unit.

In 1990, the U.S. Fish and Wildlife Service concluded that the northern spotted owl *(Strix occidentalis caurina)* was threatened with extinction due primarily to habitat loss from the widespread conversion of old-growth Douglas-fir forests to young, second-growth stands (THOMAS *et al.* 1990). As a result of this decision, all resource management plans and timber harvest prescriptions on lands administered by the USDA Forest Service and USDI Bureau of Land Management (federal lands) in the Douglas-fir region were combined into a single comprehensive plan for ecosystem management known as the Northwest Forest Plan (USDA and USDI 1994; TUCHMANN *et al.* 1996). With the implementation of the Northwest Forest Plan in 1994, clearcutting of harvest units was no longer allowed on federal lands within the range of the owl. Instead, variable-retention harvests that leave live trees in at least 15% of the area in each harvest unit are now required. In addition, (1) 70% of this retention must be in aggregates 0.2–1.0 ha or larger, with the remainder dispersed either as single trees or in small clumps <0.2 ha in size; (2) to the extent possible, retention should include the largest and oldest live trees, decadent or leaning trees, and hard snags; and (3) aggregates are to be retained indefinitely. These standards and guidelines reflect the collective knowledge and professional judgements of biologists who have studied the organisms and ecological processes in these forests; however, these prescriptions have not been evaluated empirically. Although insights gained from monitoring the effects of these new harvest regulations will play an important role in shaping the future of forest management in the Pacific Northwest through "adaptive management" (WALTERS 1986; BORMANN *et al.* 1994), knowledge gained by this process is often site-specific and may be of limited value. To ensure that management prescriptions provide intended ecological and social benefits, they must be evaluated experimentally at a regional scale.

Research is being conducted in the Douglas-fir region that will provide information for designing silvicultural strategies to accelerate the development of late-successional forest characteristics in young, managed stands (e.g., TAPPEINER 1992; HARRINGTON and CAREY 1997; CAREY *et al.* 1999; LINDH and MUIR 2004), and several operational studies were implemented in the 1990s that depart from the even-aged management approach (PETERSON and MONSERUD 2002). However, no large-scale harvest experiments have been conducted that will provide information needed by forest managers to develop effective strategies for balancing timber production with the maintenance of biodiversity in mature Douglas-fir forests. Lands available for timber harvest under the Northwest Forest Plan encompass 1 610 000 ha; 42% (680 000 ha) support mature forests dominated by conifers >53 cm dbh (USDA and USDI 1994). Although previous studies indicate that preserving large live trees, snags, and down wood during harvest will help to maintain ecosystem function and stability (FRANKLIN *et al.* 1997), little information is available on the effects of various levels or patterns of green-tree retention on ecosystem composition and structure or visual quality.

The appropriate design for variable-retention harvests in a given locality will depend upon management objectives; no single configuration or amount of retention will meet all objectives equally well. For example, at a given level of retention, green trees left in either dispersed or aggregated patterns are expected to have contrasting effects on many physical, ecological, and economic objectives (Table 1). However, these predictions are largely conjectural; no controlled experimental studies have been conducted to test their validity. Although data are available on the ecological characteristics of unmanaged forests and clearcuts in the Douglas-fir region, there is little quantitative information on how forest ecosystems will respond along a gradient of retention levels (FRANKLIN *et al.* 1997). Thus, reliable and broadly applicable information on the ecological effects and public responses to variable-retention harvests is needed if forest managers are to achieve the objectives of ecosystem management.

The large-scale and long-term experiments that are required to provide this information are extremely challenging to establish and maintain. For statistically valid replication, they require large tracts of intact forest, which are becoming increasingly scarce in the Douglas-fir region and elsewhere. Numerous obstacles also must be overcome to obtain regulatory exemptions to test novel silvicultural strategies on public lands or to apply rigorous experimental designs that conflict with standard operational practices. In addition, the resources required to conduct such studies are daunting; they include designating large areas of productive timberland for research purposes, a commitment from forest managers to select and designate research sites that will be protected from other activities until study completion, and the funding required to conduct large-scale interdisciplinary studies, among others. Furthermore, because the most valuable and useful results of harvest experiments will not be available until experimentally treated stands have reached maturity, these commitments must remain in place for decades through numerous personnel changes.

Table 1. Hypothesized contrasts between dispersed and aggregated green-tree retention, assuming an equal level of retention (reproduced from FRANKLIN *et al.* 1997).

	Pattern of retention	
Objective on harvest unit	Dispersed	Aggregated
Microclimate modification	Less, but generalized over harvest area	More, but on localized portions of harvest area
Influence on geohydrological processes	Same as above	Same as above
Maintenance of root strength	Same as above	Same as above
Retain diversity of tree sizes, species, and conditions	Low probability	High probability
Retain large-diameter trees	More emphasis	Less emphasis
Retain multiple vegetation (including tree) canopy layers	Low probability	High probability
Retain snags	Difficult, especially for soft snags	Readily accomplished, even for soft snags
Retain areas of undisturbed forest floor and intact understory community	Limited possibilities	Yes, can be extensive as aggregates
Retain structurally intact forest habitat patches	Not possible	Possible
Distributed source of coarse woody debris (snags and logs)	Yes	No
Distributed source of arboreal energy to maintain below-ground processes and organisms	Yes	No
Carrying capacity for territorial snag- and/or log-dwelling species	More	Less
Windthrow hazard for residual trees	Average wind firmness greater (strong dominants), but trees are isolated	Average wind firmness less, but the trees have mutual support
Management flexibility in treating young stands	Less	More
Harvest (e.g., logging) costs	Greater increase over clearcutting	Less increase over clearcutting
Safety issues	More	Less
Impacts on growth of regenerated stand	More, generalized over harvest area	Less, impacts are localized

1.1 The Demonstration of Ecosystem Management Options (DEMO) Study

In 1991, intensive planning for a large-scale study to critically evaluate the efficacy of alternative harvest strategies was initiated by partners in private industry, academia, and public research and management agencies. Planners effectively communicated the need for such research to several members of the U.S. Congress, which resulted in a substantial allocation of new funds in 1993 to initiate a large-scale study and demonstration of the biological, social, and economic consequences of diverse silvicultural strategies in the northwestern U.S. As described in detail by FRANKLIN *et al.* (1999), initial efforts by those charged with designing the study were hampered by competing research objectives, disagreements over experimental design, changes in leadership and other personnel, and various administrative impediments. In 1996, after several years of planning, pilot studies, anonymous peer review, and reconciliation of peer-review comments, the final design of the DEMO study was completed (AUBRY *et al.* 1999). DEMO is the first large-scale, replicated experiment to study the ecological and social effects of variable-retention harvests in Douglas-fir forests of the northwestern U.S. (FRANKLIN *et al.* 1999). The study design allows us to address the following general questions: (1) Does the level of green-tree retention influence various ecological attributes, physical processes, and public perceptions of visual quality? (2) At a given level of retention, do effects vary with the pattern of residual trees? (3) Are short-term responses maintained over time as stands develop?

Large-scale harvest experiments cannot succeed without a close partnership between research and management. Researchers must understand the regulatory constraints that public land managers face and be prepared to accommodate those constraints within the limits of a sound experimental design. Similarly, managers must have a clear understanding of the need for rigorous experimental design, especially treatment implementation, and must take responsibility for ensuring that research sites are protected from potentially confounding activities (FRANKLIN *et al.* 1999). The extent to which this partnership has provided benefits to all participants in DEMO is one of the primary reasons for the success of this study. HALPERN *et al.* (1999) and ABBOTT *et al.* (1999) describe the challenges and rewards of collaboration between scientists and managers from both perspectives, and share some of the lessons learned by those who participated in site selection, installation of sampling grids, experimental harvests, post-harvest silvicultural treatments, and public involvement.

2 Methods and materials

In this section, we provide an overview of the research methodologies used in DEMO. AUBRY *et al.* (1999), HALPERN *et al.* (1999), and other papers in HALPERN and RAPHAEL (1999) present more comprehensive descriptions of the experimental design, treatment prescriptions, and sampling protocols. Additional information, including photographs of research sites, can be found at the DEMO website (http://www.cfr.washington.edu/research.demo).

2.1 Experimental design and treatment prescriptions

The DEMO study consists of six treatments that represent strongly contrasting levels (percentage of area or basal area) and patterns (dispersed or aggregated) of green-tree retention in a randomized complete block design (Fig. 1). Treatment units are 13 ha in size and square or slightly rectangular in shape. Harvest treatments, which involve creation of gaps, retention of intact forest aggregates, or thinning to create an evenly dispersed overstory, were designed to represent a diversity of residual forest structures and levels of disturbance. Although a variety of forest types are represented, Douglas-fir is the dominant tree species in all blocks. Stand ages range from 65 to 170 years (Table 2). Past management activities varied among blocks; three had no previous activity, one was salvage-logged (1970–1978), one was thinned (1986), and one was a second-growth stand that regenerated naturally. Treatment units were located in upland areas of relatively homogeneous mature forest; large streams, wetlands, roads, and existing harvest units were avoided.

The six treatments were randomly assigned within each of six geographic locations (blocks): four in southwestern Washington and two in southwestern Oregon (Fig. 1). Experimental harvests were completed in each block within a period of 3–7 months in 1997

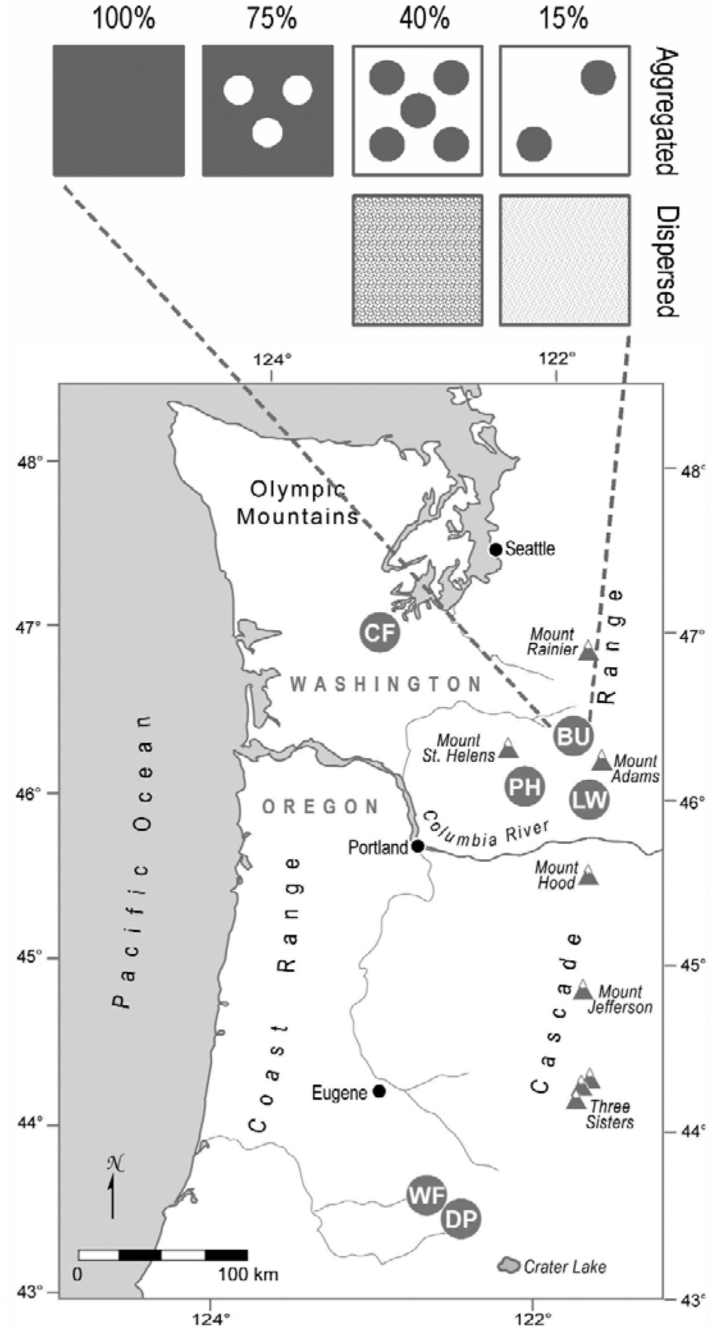

Fig. 1. Locations of the six experimental blocks (CF = Capitol Forest, BU = Butte, PH = Paradise Hills, LW = Little White Salmon, WF = Watson Falls, DP = Dog Prairie) and a schematic representation of the harvest treatments implemented at each block (dark gray areas represent uncut forest [100 and 75% treatments] or 1-ha forest aggregates [A0 and 14% aggregated]).

or 1998. Local forest managers determined the most appropriate harvesting system for each block (Table 2). Yarding was done with helicopters in three blocks (Butte, Little White Salmon, and Dog Prairie), shovel-loaders and/or rubber-tired skidders in two (Paradise Hills and Watson Falls), and primarily by suspension cables in one (Capitol Forest) (HALPERN and MCKENZIE 2001). To minimize extraneous within-block variation, all treatment prescriptions (e.g., harvest system, slash treatment, site preparation, planting) were applied consistently among the six treatments within each block.

Table 2. Environmental features, stand characteristics, and yarding methods used in the six experimental blocks of the DEMO study. Ranges are based on mean values for each of the six treatment units in each block.

Location/block	Elevation (m)	Slope (%)	Aspect	Stand age (years)	Management history	Yarding method
Capitol Forest	210–275	28–52	varied	65	second-growth/ natural regeneration	suspension cables[1]
Butte	975–1280	40–53	E-SE	70–80	none	helicopter[2]
Paradise Hills	850–1035	9–33	varied	110–140	none	shovel loader/ rubber-tired skidder
Little White Salmon	825–975	40–66	NW-NE	140–170	none	helicopter[2]
Watson Falls	945–1310	4–7	flat	110–130	salvage logged (1970–1978)	shovel loader
Dog Prairie	1460–1710	34–62	SW	165	thinned (1986)	helicopter[2]

[1] Small portions (0.8–2.4 ha) of the 15% dispersed and both 40% treatments were yarded with a shovel loader where cables could not be used.

[2] Tree canopies were yarded with the upper bole to reduce slash loadings.

The six treatments include:

100% retention (no harvest)
This treatment provides a baseline for assessing the effects of harvest treatments on ecosystem composition, structure, and function.

75% aggregated retention
All merchantable trees in three 1-ha circles (56.4-m radius) were harvested (25% of the treatment unit).

40% aggregated retention
Five 1-ha circles were retained (40% of the treatment unit); all merchantable trees in the surrounding matrix were harvested.

40% dispersed retention
Dominant and co-dominant trees were retained in an even distribution throughout the treatment unit. In each block, the basal area retained was equal to that retained in the five patches of the corresponding 40% aggregated-retention treatment.

15% aggregated retention
Two 1-ha circles were retained (15% of the treatment unit); all merchantable trees in the surrounding matrix were harvested.

15% dispersed retention
Dominant and co-dominant trees were retained in an even distribution throughout the treatment unit. In each block, the basal area retained was equal to that retained in the two patches of the corresponding 15% aggregated-retention treatment.

2.2 The systematic sampling grid

We established a grid in each treatment unit to sample a variety of ecological response variables, including levels of ground disturbance and slash accumulation, and abundance and species composition of overstory and understory vegetation, amphibians, forest-floor small mammals, arboreal rodents, bats, and breeding birds (details on sampling methods are presented below). Several other response variables, including abundance and species composition of fungi and canopy invertebrates, were sampled in other locations within each treatment unit. To provide forest managers with flexibility in unit placement, we used either an 8 x 8 or 7 x 9 sampling grid with 40-m spacing (Fig. 2). Each sampling point is permanently marked with a steel reinforcing bar covered by a 1.5 m-tall PVC (polyvinyl chloride) pipe affixed with a row and column identifier. Corner points of all grids were permanently referenced at sub-meter accuracy using a GPS (global positioning system). The permanent grid enables researchers to sample response variables at the same locations in perpetuity and, for some attributes, the grid permits point-by-point correlation (e.g., relations between overstory and understory characteristics [McKenzie *et al.* 2000]). In addition, the grid provides a consistent and systematic framework for assessing within-treatment variation in responses; this is particularly important in the 15, 40, and 75% aggregated-retention treatments that contain two distinct post-harvest environments (clearcut and intact forest; Figs. 1 and 2). Permanent photo locations were established at 3–6 grid points within each treatment unit to document effects of harvest and future stand development (see http://www.cfr.washington.edu/research.demo/photogallery/index.htm).

2.3 Post-harvest treatments

As with the harvest system used, all post-harvest treatments were applied consistently within each block. To provide snags for future stands and to meet minimum snag requirements specified in the Northwest Forest Plan, 6.5 snags/ha were created in all harvested areas by girdling or removing the tops of dominant or co-dominant green trees within one growing season of harvest. To the extent possible, decadent or broken-top trees were selected for snag creation. Pre-existing down woody debris was retained during harvest, but no prescriptions were implemented to create additional material. Local forest managers evaluated slash loadings after harvest to assess potential fire hazards and constraints on planting and post-harvest sampling (e.g., access to the ground surface). If treatment of slash was required, methods were developed jointly by forest managers and researchers. Submerchantable trees (<18 cm dbh) were left standing in harvested areas of treatment units except at Paradise Hills, where they were felled, and at Watson Falls, where trees damaged during harvest operations were felled. To ensure adequate reforestation of harvested areas, seedlings (typically a mix of species that varied among blocks; see HALPERN *et al.,* in press for details) were planted at densities needed to achieve minimum stocking of 312 trees/ha five years after harvest; this target included both planted seedlings and advanced regeneration. The use of fertilizers, herbicides, and seeding for erosion control is prohibited on all DEMO sites.

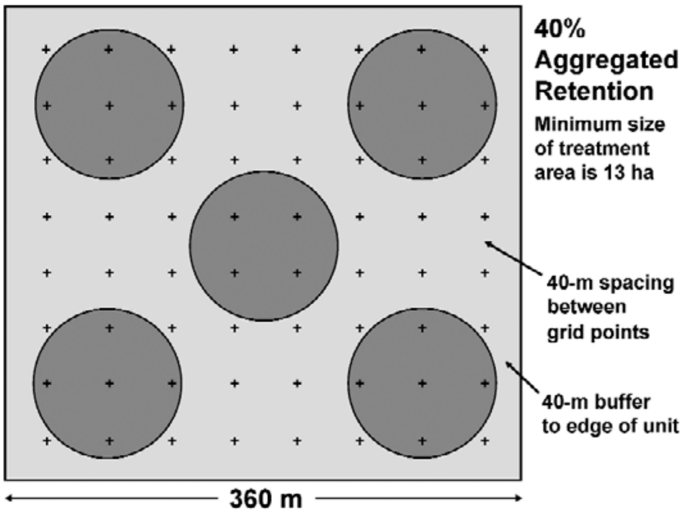

Fig. 2. Schematic representation of the DEMO sampling grid configured for an 8 x 8 square grid in a 40% aggregated-retention treatment unit.

2.4 Sampling of response variables

2.4.1 Overstory and understory vegetation

Vegetation studies in DEMO were designed to address two fundamental objectives: (1) to elucidate the effects of level and pattern of green-tree retention on key elements of forest structure and composition (and to suggest possible mechanisms for these effects), and (2) to quantify changes in vegetation to aid interpretation of responses of associated organisms and processes (see below). Two basic designs have been employed. First, a series of permanent vegetation plots was established within each treatment unit prior to harvest. Plots were systematically arrayed at a subset of grid points, with the number and spatial distribution of plots varying by treatment (HALPERN *et al.* 1999; HALPERN *et al.*, in press). In aggregated-retention treatments, treatment-level responses represent weighted averages of responses within the two contrasting environments: forest aggregates and adjacent harvested areas.

Each plot contains a series of nested subplots and transects for quantifying harvest-related disturbance and various measures of structural and compositional change. Research interests are diverse and include patterns and amounts of ground disturbance (HALPERN and MCKENZIE 2001); overstory growth, mortality, and stem damage (MOORE *et al.* 2002); dynamics of snags and coarse woody debris; growth, mortality, and recruitment of understory trees (including planted and natural regeneration); and changes in the abundance and diversity of vascular plants and ground-layer bryophytes (HALPERN *et al.*, in press). Some of these variables were sampled multiple times after harvest (e.g., tree mortality), but others have been sampled less frequently.

A second sampling design explores spatial gradients in vegetation response within the aggregated-retention treatments (NELSON and HALPERN, in press). Of interest was the extent to which forest aggregates retain components of the original flora, and how understory responses vary with proximity to the forest edge (both within and adjacent to the aggregates). Sampling was limited to the 40% aggregated-retention treatment at two blocks, Butte and Paradise Hills. Bands of sample plots are arrayed along orthogonal transects 81 m in length that span harvested, ecotonal, and forest environments (HALPERN *et al.* 1999; NELSON and HALPERN, in press). Measurements were taken prior to harvest and for two years after treatment.

2.4.2 Ectomycorrhizal fungi

Ectomycorrhizal fungi (EMF) play an important role in maintaining forest productivity and recovery from disturbance (AMARANTHUS 1998); thus, the effects of variable-retention harvests on abundance and diversity of EMF is a key consideration for forest managers. Fungal sporocarps were sampled in three of the six DEMO blocks during peak spring and fall fruiting seasons. Pre-treatment data were collected for two to three years between 1993 and 1997 and post-treatment data for three years between 1998 and 2001. A combination of fixed and temporary strip plots (2 x 50 m) was established in each treatment unit within which both epigeous (mushroom) and hypogeous (truffle) sporocarps were sampled (CAZARES *et al.* 1999). Fresh specimens were identified to the lowest taxonomic level possible using a stereo microscope, then dried for 8–18 hours at 63 °C in a portable dehydrator until crisp-dry. Analyses were conducted separately for mushrooms and truffles based on total sporocarp standing-crop biomass (g/ha dry weight). Consideration of treatment effects at lower taxonomic levels is in progress.

2.4.3 Canopy arthropods

Canopy arthropods represent a diverse and functionally important component of the forest ecosystem, and their responses to disturbance or major changes in forest structure are not well understood. Arthropods were sampled in the DEMO study from foliated branches (0.5 m in length, 30–50 g dry weight) at upper-, mid-, and lower-crown levels of one overstory Douglas-fir, and from three understory vine maples *(Acer circinatum)*. Sampling was conducted one year before (1996) and two years after harvest (1999 and 2000); samples were collected in early (June) and late summer (August) to examine seasonal variation in community composition. Samples representing aggregated-retention treatments were selected from the center of a planned aggregate (or distant from the edge of a gap in the 75% aggregated treatment). A second set of samples contrasted responses of arthropods in edge vs. interior environments within the aggregated treatments. Here, one additional Douglas-fir and three vine maples were selected from the edge of the forest aggregate (15 and 40% retention) or gap (75% retention) for comparison with the interior samples. The abundance of taxa (number/kg dry weight) was summarized by functional group (e.g., folivores, sap-suckers, gall-formers, predators, and detritivores); individual species were considered when they were widely distributed and sufficiently abundant.

2.4.4 Amphibians and forest-floor small mammals

Much is known about wildlife habitat associations in unmanaged Douglas-fir forests (RUGGIERO *et al.* 1991), but no large-scale experimental studies have been conducted on wildlife responses to variable-retention harvests. Due to the limited vagility and narrow habitat associations of many species, populations of amphibians (particularly terrestrial salamanders) and forest-floor small mammals may be strongly influenced by the effects of variable-retention harvests on habitat conditions and microclimatic regimes (LEHMKUHL *et al.* 1999). Arrays of pitfall traps were used to sample amphibians and small mammals concurrently in the DEMO study. In each treatment unit, one pitfall trap was buried flush with the ground at each point in the sampling grid. The trap was constructed by taping two #10 cans together to create a cylinder 72-cm tall and 15-cm wide; a snug-fitting conical plastic sleeve with the bottom cut out was placed on the lip of the trap to limit escapes (CORN and BURY 1990). Each block was sampled for two years before (1995 and 1996) and two years after harvest (between 1998 and 2000). During each sampling year, traps were opened for approximately four weeks during October and early November, between the onset of fall rains and the beginning of snow accumulation. Traps were checked weekly; all mammals captured were collected, whereas live amphibians were either marked and released on site or kept in captivity and returned to the site at the end of each trapping session. Collected specimens were examined in the laboratory to confirm species identification, take standard measurements, and determine sex and reproductive status. Data analyses were based on indices of relative abundance (captures per unit number of trap-nights).

2.4.5 Bats

There is growing concern that bat populations may decline in intensively managed forest landscapes due to the loss of large snags and decadent trees that are used for day roosts, and the effects that timber harvest may have on prey populations and foraging spaces (LEHMKUHL *et al.* 1999). Bat activity was monitored in the DEMO study with ultrasonic detectors for two years before (between 1994 and 1996) and two years after harvest (between 1998 and 2000). Each treatment was surveyed for two consecutive nights on at least three occasions per field season (late June through early September). During pre-harvest sampling, one monitoring station was placed in each treatment unit. After harvest, one station was used in control and dispersed treatments and two stations were used in aggregated treatments (one detector in undisturbed forest and one in a harvested area). Detectors were placed 1 m from the ground, oriented 30º from horizontal, and set to record for 8–9 hours beginning at dusk. For data analyses, bats were grouped into two categories based on similar echolocation call characteristics: small-bodied *Myotis* bats and larger non-*Myotis* bats.

2.4.6 Breeding birds

Although forest birds are associated with a variety of stand conditions (e.g., early successional vs. late-successional species), avian community responses to variable-retention harvests, especially among birds associated with closed-canopy conditions, are largely unknown (LEHMKUHL *et al.* 1999). Bird populations were sampled in DEMO using a combination of point counts and territory mapping two years and one year before harvest, respectively (between 1994 and 1997), and two years after harvest (between 1998 and 2001). Four point-count stations were established in each treatment unit >160 m apart and >80 m from the treatment boundary. Each unit was surveyed six times during the breeding season (May through mid-July). For point counts, all birds within 50 m were tallied by species for eight minutes at each station; surveys were completed within three hours of dawn. Spot-mapping took place while observers walked between point-count stations and after point counts were completed. Pairing success was determined by observing females in territories, pairing and nesting behavior, and changes in male song types. For data analyses, indices of relative abundance were calculated as the mean number of detections per species, visit, and treatment; pairing success was the number of territories in each unit where males successfully paired.

2.4.7 Public perceptions of visual quality

Public perceptions of forest management in the northwestern U.S. are complex. However, a critical dimension of social acceptability is how recent timber harvests are perceived visually by the public (RIBE 1999). In recent decades, public concern about forest management practices on federal lands has centered on negative perceptions of clearcutting. In the context of variable-retention harvests, three major factors (or attributes) of harvest units can be varied to reduce visual impacts: amount of green-tree retention, pattern or spatial distribution of retention (e.g., dispersed vs. aggregated), and the shape of harvest units and retained aggregates (e.g., geometric vs. more "natural"). In this study, DEMO harvest units were photographed in foreground vista views. Additional photo simulations were produced to represent the DEMO treatments with more natural harvest shapes. The result was 15 scenes exhibiting possible combinations of retention pattern and harvest shape at five levels of basal-area retention: 0, 15, 40, 75, and 100%. A printed mail survey was then developed that included these 15 color scenes and nine additional color vista photos of national forests in the Cascade Range (to capture a broader range of scenic quality than the study images). Respondents completing the survey were asked to rate each image for scenic beauty on a scale of –5 to +5, with 0 representing a neutral response. A random sample of 835 residents of western Washington and Oregon were sent letters requesting participation in the survey; 353 volunteered and 331 completed the survey.

2.5 Data management and archiving

To ensure the quality and long-term availability of ecological information collected in the DEMO study, we have invested considerable resources in data management and documentation. Database management is centralized in the Forest Science Data Bank at Oregon State University, which houses data sets from more than 200 ecological studies, including those of the Andrews Long-Term Ecological Research (LTER) Program (http://www.fsl.orst.edu/lter/data.cfm?topnav=8). The Forest Science Data Bank supports data collection, data entry, quality assurance and control, archiving, and cross-disciplinary access. Data are subjected to double-entry, verification, and quality-assurance procedures that include both generic validation and rules specific to particular data types and study designs.

3 Results and discussion

Pre-publication summaries of initial post-treatment results from the DEMO study were provided by the following researchers: Charles B. Halpern, Douglas A. Maguire, and Cara R. Nelson, overstory and understory vegetation; Daniel L. Luoma, ectomycorrhizal fungi; Timothy D. Schowalter, canopy arthropods; Christine C. Maguire, salamanders; Stephen D. West, forest-floor small mammals; Janet L. Erickson, bats; David A. Manuwal, breeding birds; and Robert Ribe, public perceptions of visual quality.

3.1 Overstory and understory vegetation

Vegetation studies in DEMO have provided a comprehensive view of how forest structure, composition, and species diversity respond in the short-term to varying levels and spatial patterns of retention. As expected, level and pattern of retention had strong and predictable effects on overstory structure (e.g., density, basal area, quadratic mean diameter, and canopy cover). However, considerable variation among blocks in initial forest structure resulted in substantial variability in post-harvest structure among replicates of the same treatment. For this reason, initial and residual stand structures have been characterized in detail, and comprehensive analyses have attempted to distinguish how well responses relate to residual stand structure vs. intensity of disturbance (D. Maguire, unpubl. data).

Patterns of tree bole damage and mortality were strikingly different among treatments. A significantly greater proportion of trees were damaged in dispersed- than in aggregated-retention treatments, reflecting the wider dispersion of felling and yarding activity (MOORE *et al.* 2002); future incidence of stem rot and growth reduction may be greater in these treatments. Cumulative mortality over three years of post-harvest observation was also greater in dispersed treatments and at lower levels of retention (15%), reflecting greater rates of stem breakage and uprooting under these conditions. As a result, short-term cumulative mortality exceeded 8% on average in the 15% dispersed treatments.

For most groups of forest understory plants, declines in abundance and richness were significantly greater at 15 than at 40% retention (HALPERN *et al.,* in press). However, pattern of overstory retention had surprisingly little effect on treatment-level responses. Although changes within the 1-ha aggregates were small on average, declines in adjacent harvested areas were greater than those in the corresponding dispersed treatments. In addition, forest aggregates were not immune to edge effects: over two years of observation, one third of the understory herbs examined showed significant declines in cover with proximity to the forest edge (NELSON and HALPERN, in press). Late-seral herbs were particularly sensitive to pattern of retention, showing more frequent extirpations from harvested plots in the aggregated treatments than from plots in the dispersed treatments. Ground-layer bryophytes showed similar patterns of response as did vascular plants, although for a number of variables (changes in cover, richness, or species frequency), declines were similar at 15 and 40% retention, suggesting a threshold response to harvest. We suspect that early responses in the understory were mediated, in large part, by soil disturbance and slash accumulation that varied significantly with level and pattern of retention (HALPERN and MCKENZIE 2001). Longer-term sampling will be necessary to document the longevity of these effects; with time, distinct differences in overstory structure may play an increasingly important role in understory response.

3.2 Ectomycorrhizal fungi

A total of 150 mushroom and 58 truffle taxa were collected during the course of the study. Effects of treatments on the taxonomic diversity of EMF were generally proportional to the level of retention: compared to controls, the number of sporocarp-producing taxa was reduced most in the 15% aggregated and dispersed treatments, and least in the 75% aggregated treatment. Higher levels of retention generally maintained higher levels of sporocarp production, but results varied by type of sporocarp and by season. Mushroom biomass was reduced in four of five harvested treatments in fall, but in only one of five treatments in spring. Truffle biomass was significantly reduced in three of five treatments in fall and in all harvested treatments in spring. These results suggest that, in a given harvest unit, a combination of aggregated and dispersed retention may be most effective at maintaining the EMF community. It is likely that dispersed retention ameliorates the detrimental effect of clearcutting on fungal diversity, and that forest aggregates embedded in dispersed retention will maintain sporocarp production due to reduced edge effects.

3.3 Canopy arthropods

Over 200 arthropod taxa were collected during this study (158 on Douglas-fir and 90 on vine maple), of which 57 occurred in at least 5% of samples. Despite strong contrasts in post-harvest stand structure, functional groups showed surprisingly few differences in response among treatments or to position within aggregated-retention treatments (edge vs. interior locations). Considerable variation in abundance was observed among blocks (reflecting regional gradients in environment; PROGAR and SCHOWALTER 2002). However changes in composition over time in control treatments were comparable to those in harvested treatments, suggesting that arthropods are more sensitive to temporal variation in weather than to disturbance or changes in forest structure at this spatial scale. Future sampling will be necessary to determine whether effects of level and/or pattern of retention are manifested more gradually and over longer periods of time.

3.4 Salamanders

A total of 3657 salamanders was captured during the course of the study, including three woodland-breeding and five pond- and stream-breeding species. Four species were captured in sufficiently high numbers for statistical analyses. Little evidence was found that level or pattern of retention strongly influenced salamander populations during the first few years after harvest. Mean weights, lengths, and sex and age ratios showed little change from pre-harvest conditions. However, within aggregated-retention treatments, salamanders were captured more frequently in uncut than in cut areas. Although strong effects of variable-retention harvests on populations of forest-dwelling salamanders were not detected, these findings may change over time. Due to the longevity and high site-tenacity of terrestrial salamanders, population-level responses may not become apparent for many years after disturbance. However, salamanders were most abundant in areas where coarse woody debris volume and/or herbaceous cover were high, suggesting that these stand attributes could be manipulated by forest managers to provide short- and, possibly, long-term benefits to salamanders, regardless of silvicultural treatment.

3.5 Forest-floor small mammals

Altogether, 21 351 small mammals were captured representing 32 species; eight species (three shrews and five rodents) made up 91% of total captures. During the first two years after harvest, the pattern of retention did not have consistently strong effects on small mammal abundance or community composition at the spatial scale of this study. Two community metrics, richness and evenness, showed little change after harvest. However, the similarity of small mammal communities between control and harvested units declined at lower levels of retention, reflecting the response of early successional species to canopy removal. Initial results indicate that 1-ha aggregates may function as short-term refuges or "lifeboats" (FRANKLIN *et al.* 1997) for several small mammals that are associated with interior forest conditions. For two species of forest voles (*Clethrionomys californicus* and *C. gapperi*), the majority of captures (90 and 70%, respectively) in the aggregated-retention treatments were in the forest aggregates.

Threshold responses to harvest were found for some small mammal species; i.e., similar abundances were found in all harvest treatments or in all treatments below 75% retention. For other species, abundance increased or decreased along the gradient of harvest intensity. Finally, several species showed differential responses to harvest among blocks. This latter finding may reflect the sensitivity of small mammals to different harvest methods, regional variation in environmental conditions, or differential availability of forest-floor resources after harvest. Because small mammal populations may change dramatically in the first few years after harvest, additional assessments will be necessary to elucidate the long-term influences of the DEMO harvests on small mammals.

3.6 Bats

Members of the *Myotis* group generally are small, slow flying, agile bats, whereas the larger bodied non-*Myotis* bats typically are faster but less maneuverable. Not surprisingly, we found low detection rates for non-*Myotis* bats in undisturbed forest compared with harvested areas, reflecting the association of these larger bats with open habitats. Our results suggest that variable-retention harvests that create forest openings or reduce the density of forest canopies increase use by some species of forest-dwelling bats. However, increased bat activity does not necessarily reflect an increase in abundance. If canopy gaps attract and concentrate bats that use openings and edges for feeding, measured responses may simply reflect a spatial shift in bat activity. Although variable-retention harvests may affect foraging habitat for bats, their greatest impact on bat populations is probably from the loss of large trees and snags that provide roosting habitat. Thus, forest managers must also consider the potential reduction or loss of suitable day roosts from timber-harvest activities.

3.7 Breeding birds

Based on relative abundance data from point-count surveys, no bird species responded significantly to the DEMO treatments; however, seven species increased and one decreased in abundance on all treatments (including controls) after harvest. Territory mapping showed that five species responded to the treatments: three had fewer territories in the 15% retention treatments compared to all other treatments, one late-seral species had fewer territories in all harvest treatments compared to the control, and one early seral species had more territories in the 15% dispersed-retention treatment than in other treatments. Pairing success for two late-seral species was lower in the 15% retention treatments than in other treatments. In general, birds that feed or nest in the tree canopy or that feed in the bark decreased at greater harvest levels, whereas species associated with forest-edge or open habitats increased in response to all harvest treatments. In summary, green-tree retention has varying effects on bird communities; some species increase, whereas others decrease and may become less successful at reproducing. Although these results only reflect initial post-harvest responses to the DEMO treatments, it appears that forest songbirds respond primarily to the level of retention, rather than to pattern.

3.8 Public perceptions of visual quality

Based on average ratings of visual quality obtained from the mail survey, public perceptions of variable-retention harvests appear to be strongly influenced by both pattern and amount of retention. Dispersed treatments have greater perceived visual quality than aggregated treatments, but only if the amount of retention substantially exceeds current minimum standards in the Northwest Forest Plan (15%). These findings contrast with current guidelines that emphasize retention in forest aggregates. Survey results also indicate that if retention is aggregated, increases in the amount of retention result in only slight increases in perceived visual quality. In contrast, if retention is dispersed, increases in the amount of retention are effective at increasing perceived scenic beauty. Non-geometric boundaries of harvest units and/or aggregates yield small but significant increases in visual quality perceptions only at low retention levels (0 and 15%), irrespective of retention pattern. For examples of simulated photos used in the survey and additional results see (http://www.cfr.washington.edu/research.demo/research/social_perceptions/social_perceptions.htm).

4 Future research and technology transfer

A second round of post-treatment vegetation sampling is scheduled for the summers of 2003 and 2004. Six- and seven-year responses of the forest understory will be interpreted in light of immediate post-harvest responses. Overstory tree growth and survival will be related to silvicultural treatments and the stand structures created by each treatment. Likewise, clear differences in the response of both advanced regeneration and planted seedlings are expected to emerge by the second round of sampling.

Several ancillary studies have been initiated this past year, including responses of litter-dwelling arthropods (see: http://www.cfr.washington.edu/research.demo/research/arthropods/Litter_inv.htm), effects of level and pattern of retention on the nature of trophic interactions between bark-dwelling arthropods and cavity-nesting birds (see: http://www.cfr.washington.edu/research.demo/research/arthropods/Bark_inv.htm), and characterization of microclimate in dispersed- and aggregated-retention treatments. Microclimatic studies may provide mechanistic explanations for some of the patterns observed to date, and may indicate where additional efforts should be focused to understand future responses to stand structure.

DEMO scientists are reporting results in a variety of formats including journal publications, symposium presentations and proceedings, and website reports (for summary reports from individual studies see: http://www.cfr.washington.edu/research.demo/research/r_invest.htm). An IUFRO meeting on Innovative Experiments for Sustainable Forestry is planned for August 2004 in Portland, Oregon, USA. This will be the second meeting of the new working party on Applied Forest Ecological Experiments and will be open to both scientists and forest managers. Concurrent sessions will provide an opportunity for discussions between scientists and managers about the challenge of simultaneously managing forests for timber production and biological diversity. Opportunities will also exist at the meeting to critique the scientific merit of DEMO and similar studies throughout the world, particularly in regard to experimental design, treatment implementation, response monitoring, statistical analysis, and ecological interpretation. Themes gleaned from that meeting will be taken forward to the IUFRO World Congress in Brisbane, Australia in 2005.

As part of local technology transfer in the northwestern U.S., DEMO scientists will be working with federal land managers to further interpret results and to design future treatments that are both operationally sound and scientifically rigorous. Computer projections of stand development will aid the design and scheduling of subsequent treatments, and participation by managers will ensure that treatments can be implemented under current administrative guidelines and constraints. Interactions among scientists and managers will take place primarily in the form of workshops that emphasize the collaborative nature of this research.

5 References

ABBOTT, R.S.; WHITE, J.D.; WOODARD, B.L., 1999: The benefits and challenges of large-scale silvicultural experiments: perspectives from forest managers on the Demonstration of Ecosystem Management Options (DEMO) study. Northwest Sci. 73 (Special Issue): 118–125.

AMARANTHUS, M.P., 1998: The importance and conservation of ectomycorrhizal fungal diversity in forest ecosystems: lessons from Europe and the Pacific Northwest. Portland, OR, USA, USDA For. Serv., Gen. Tech. Rep. PNW-GTR-431: 15 pp.

ARNOTT, J.T.; BEESE, W.J., 1997: Alternatives to clearcutting in BC coastal montane forests. For. Chron. 73: 670–678.

AUBRY, K.B.; AMARANTHUS, M.P.; HALPERN, C.B.; WHITE, J.D.; WOODARD, B.L.; PETERSON, C.E.; LAGOUDAKIS, C.A.; HORTON, A.J., 1999: Experimental design of the DEMO study: evaluating the ecological and social effects of different levels and patterns of green-tree retention in harvest units. Northwest Sci. 73 (Special Issue): 12–26.

BALDA, R.P., 1975: The relationship of secondary cavity nesters to snag densities in western coniferous forests. Albuquerque, NM, USA, USDA Forest Service, Technical Bulletin 1: 37 pp.

BERGERON, Y.; HARVEY, B., 1997: Basing silviculture on natural ecosystem dynamics: an approach applied to the southern boreal mixedwood forest of Quebec. For. Ecol. Manage. 92: 235–242.

BORMANN, B.T.; CUNNINGHAM, P.G.; BROOKES, M.H.; MANNING, V.W.; COLLOPY, M.W., 1994: Adaptive ecosystem management in the Pacific Northwest. Portland, OR, USA, USDA For. Serv., Gen. Tech. Rep. PNW-GTR-341. 22 pp.

BOYCE, M.S.; HANEY, A. (eds), 1997: Ecosystem management: applications for sustainable forest and wildlife resources. New Haven, CT, USA, Yale University Press. 361 pp.

CAREY, A.B.; THYSELL, D.R.; BRODIE, A.W., 1999: The Forest Ecosystem Study: background, rationale, implementation, baseline conditions, and silvicultural assessment. Portland, OR, USA, USDA For. Serv., Gen. Tech. Rep. PNW-GTR-457. 129 pp.

CAZARES, E.; LUOMA, D.L.; AMARANTHUS, M.P.; CHAMBERS, C.L.; LEHMKUHL, J.F., 1999: Interaction of fungal sporocarp production with small mammal abundance and diet in Douglas-fir stands of the southern Cascade Range. Northwest Sci. 73 (Special Issue): 64–76.

CHRISTENSEN, N.L.; BARTUSKA, A.M.; BROWN, J.H.; CARPENTER, S.; D'ANTONIO, C.; FRANCIS, R.; FRANKLIN, J.F.; MACMAHON, J.A.; NOSS, R.F.; PARSONS, D.J.; PETERSON, C.H.; TURNER, M.G.; WOODMANSEE, R.G., 1996: The report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. Ecol. Appl. 6: 665–691.

COATES, K.D.; BANNER, A.; STEVENTON, J.D.; LEPAGE, P.; BARTEMUCCI, P., 1997: The Date Creek silvicultural systems study in the interior cedar-hemlock forests of northwestern British Columbia: overview and treatment summaries. Victoria, British Columbia, Canada, Land Management Handbook 38, BC Ministry of Forests.

CORN, P.S.; BURY, R.B., 1990: Sampling methods for terrestrial amphibians and reptiles. Portland, OR, USA, USDA For. Serv., Gen. Tech. Rep. PNW-GTR-256: 34 pp.

FRANKLIN, J.F.; BERG, D.R.; THORNBURGH, D.A.; TAPPEINER, J.C., 1997: Alternative silvicultural approaches to timber harvesting: variable retention systems. In: KOHM, K.A.; FRANKLIN, J.F. (eds) Creating a Forestry for the 21st Century: The Science of Ecosystem Management. Washington, DC, USA, Island Press. 111–139.

FRANKLIN, J.F.; CROMACK, JR., K.; DENISON, W.; MCKEE, A.; MASER, C.; SEDELL, J.; SWANSON, F.; JUDAY, G., 1981: Ecological characteristics of old-growth Douglas-fir forests. Portland, OR, USA, USDA For. Serv., Gen. Tech. Rep. PNW-GTR-118. 48 pp.

FRANKLIN, J.; DYRNESS, C.T., 1973: Natural vegetation of Oregon and Washington. Portland, OR, USA, USDA For. Serv., Gen. Tech. Rep. PNW-GTR-8. 417 pp.

FRANKLIN, J.F.; NORRIS, L.A.; BERG, D.R.; SMITH, G.R., 1999: The history of an experiment in regeneration harvest of northwestern forest ecosystems. Northwest Sci. 73 (Special Issue): 3–11.

FRANKLIN, J.F.; SPIES, T.A.; VAN PELT, R.; CAREY, A.B.; THORNBURGH, D.A.; BERG, D.R.; LINDENMAYER, D.B.; HARMON, M.E.; KEETON, W.S.; SHAW, D.C.; BIBLE, K.; CHEN, J., 2002: Disturbances and structural development of natural forest ecosystems with silvicultural implications, using Douglas-fir forests as an example. For. Ecol. Manage. 155: 399–423.

FRIES, C.; JOHANSSON, O.; PETTERSSON, B.; SIMONSSON, P., 1997: Silvicultural models to maintain and restore natural stand structures in Swedish boreal forests. For. Ecol. Manage. 94: 89–103.

HALPERN, C.B.; EVANS, S.A.; NELSON, C.R.; MCKENZIE, D.; LIGUORI, D.A.; HIBBS, D.E.; HALAJ, M.G., 1999: Response of forest vegetation to varying levels and patterns of green-tree retention: an overview of a long-term experiment. Northwest Sci. 73 (Special Issue): 27–44.

HALPERN, C.B.; MCKENZIE, D., 2001: Disturbance and post-harvest ground conditions in a structural retention experiment. For. Ecol. Manage. 154: 215–225.

HALPERN, C.B.; MCKENZIE, D.; EVANS, S. A.; MAGUIRE, D. A.,: Early responses of forest understories to timber harvest with varying levels and patterns of green-tree retention. Ecol. Appl. In press.

HALPERN, C.B.; RAPHAEL, M.G. (eds) 1999: Retention harvests in northwestern forest ecosystems: the Demonstration of Ecosystem Management Options (DEMO) Study. Northwest Sci. 73 (Special Issue): 125 pp.

HARRINGTON, C.A.; CAREY, A.B., 1997: The Olympic Habitat Development Study: effects of thinning, manipulation of coarse woody debris and understory management on stand structure and composition of understory plants and forest-floor small mammals. Olympia, WA, USA, Unpublished study plan on file at USDA Forest Service, Pacific Northwest Research Station. 38 pp.

LEHMKUHL, J.F.; WEST, S.D.; CHAMBERS, C.L.; MCCOMB, W.C.; MANUWAL, D.A.; AUBRY, K.B.; ERICKSON, J.L.; GITZEN, R.A.; LEU, M., 1999: An experiment for assessing wildlife response to varying levels and patterns of green-tree retention. Northwest Sci. 73 (Special Issue): 45–63.

LINDH, B.C.; MUIR, P.S., 2004: Understory vegetation in young Douglas-fir forests: does thinning help restore old-growth composition? For. Ecol. Manage. 192: 285–296.

MCKENZIE, D.; HALPERN, C.B.; NELSON, C.R., 2000: Overstory influences on herb and shrub communities in mature forests of western Washington, USA. Can. J. For. Res. 30: 1655–1666.

MOORE, J.R.; MAGUIRE, D.A.; PHILLIPS, D.L.; HALPERN, C.B., 2002: Effects of varying levels and patterns of green-tree retention on amount of harvesting damage. Western J. Appl. For. 17: 202–206.

NELSON, C.R.; HALPERN, C.B.: Edge-related responses of understory plants to aggregated retention harvest in the Pacific Northwest. Ecol. Appl. In press.

PALIK, B.J.; MITCHELL, R.J.; HIERS, J.K., 2002: Modeling silviculture after natural disturbance to sustain biodiversity in the longleaf pine *(Pinus palustris)* ecosystem: balancing complexity and implementation. For. Ecol. Manage. 155: 347–356.

PETERSON, C.E.; MONSERUD, R.A., 2002: Compatibility between wood production and other values and uses on forested lands: a problem analysis. Portland, OR, USA, USDA For. Serv., Gen. Tech. Rep. PNW-GTR-564. 51 pp.

PROGAR, R.D.; SCHOWALTER, T.D., 2002: Canopy arthropod assemblages along a precipitation and latitudinal gradient among Douglas-fir *(Pseudotsuga menziesii)* forests in the Pacific Northwest of the United States. Ecography 25: 129–138.

RIBE, R., 1999: Regeneration harvests versus clearcuts: public views of the acceptability and aesthetics of Northwest Forest Plan harvests. Northwest Sci. 73 (Special Issue): 102–117.

RUGGIERO, L.F.; AUBRY, K.B.; CAREY, A.B.; HUFF, M.H. (tech coords), 1991: Wildlife and vegetation of unmanaged Douglas-fir forests. Portland, OR, USA, USDA For. Serv., Gen. Tech. Rep. PNW-GTR-285. 533 pp.

TAPPEINER, J.C., 1992: Managing stands for northern spotted owl habitat – Appendix F. In Volume II: Appendixes, Final Draft Recovery Plan for the Northern Spotted Owl. Portland, OR, USA, USDI Fish and Wildlife Service. 245–289.

THOMAS, J.W.; ANDERSON, R.G.; MASER, C.; BULL, E.L., 1979: Snags. In: THOMAS, J.W. (ed) Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. Washington, DC, USA, USDA Forest Service, Agricultural Handbook 553: 60–77.

THOMAS, J.W.; FORSMAN, E.D.; LINT, J.B.; MESLOW, E.C.; NOON, B.R.; VERNER, J., 1990: A conservation strategy for the northern spotted owl: report of the Interagency Scientific Committee to Address the Conservation of the Northern Spotted Owl. Portland, OR, USA, USDA Forest Service, USDI Bureau of Land Management, USDI Fish and Wildlife Service, and USDI National Park Service. 427 pp.

TUCHMANN, E.T.; CONNAUGHTON, K.P.; FREEDMAN, L.E.; MORIWAKI, C.B., 1996: The Northwest Forest Plan: a report to the President and Congress. Portland, OR, USA, USDA Forest Service, Pacific Northwest Research Station. 253 pp.

USDA and USDI, 1994: Record of decision for amendments to Forest Service and Bureau of Land Management planning documents within the range of the northern spotted owl. Portland, OR, USA, USDA Forest Service, irregular pagination.

WALTERS, C., 1986: Adaptive management of renewable resources. New York, NY, USA, Macmillan Publishing Company. 374 pp.

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