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Silvicultural Treatments for Enhancing and Recruiting Spotted Owl Habitat in British Columbia

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Cover photo: Adult Spotted Owl with juvenile at nest.
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EXECUTIVE SUMMARY

British Columbia forms the northern periphery of the Northern Spotted Owl's habitat *(Strix occidentalis caurina)*; this owl is an endangered species that depends on old-growth forest for its survival and reproduction. Stand-level definitions, which are based on Washington State research, describe two classes of Spotted Owl habitat: superior quality habitat (Type A) which is appropriate for nesting, foraging, roosting, and dispersing; and moderate quality habitat (Type B) which is unsuitable for nesting but appropriate for other owl activities. Spotted Owl Management Plans have identified the need to create new suitable habitats and enhance existing ones within permanent Special Reserve Management Zones.

This report reviews how forest structure in British Columbia provides habitat for the Spotted Owl and its primary prey. It also reviews the harvesting systems that are proposed for creating stands containing Spotted Owl habitat, and it summarizes field reviews of partial harvesting and heavy volume removal approaches that would integrate timber harvesting opportunities while meeting objectives for owl habitat. Preliminary TASS modelling was used to project outcomes of harvesting and silvicultural practices on indicators of owl habitat quality, and results are provided. This report identifies opportunities to improve development of harvest systems and silvicultural treatments for developing Spotted Owl habitat.

KEYWORDS

Northern Spotted Owl, *Strix occidentalis caurina,* habitat, habitat quality, habitat recruitment, old-growth forest, timber harvesting, silviculture, silvicultural treatment, forestry, British Columbia

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INTRODUCTION

The only existence of the Northern Spotted Owl (*Strix occidentalis caurina*) in Canada is in British Columbia, which is the northern periphery of the Spotted Owl's overall range. With the total population in British Columbia estimated at <50 pairs (Blackburn et al. 2002), the Spotted Owl is an endangered species that faces imminent extirpation from the province (Committee on the Status of Endangered Wildlife in Canada 2001; Blackburn et al. 2002). Spotted Owls depend on old-growth forest attributes for reproduction and survival (e.g., Forsman et al. 1984; Carey et al. 1992; Lehmkuhl and Raphael 1993). The United States Forest Service identified the need to study creation of habitat and/or acceleration of the development of old-growth attributes to manage the Spotted Owl population in the United States (Gutiérrez and Carey 1985 [technical editors]). In British Columbia, the Spotted Owl Management Plan (Spotted Owl Management Inter-Agency Team 1997a, 1997b) relies on the creation and enhancement of suitable habitats within permanent Special Reserve Management Zones.

In the Plan, the general definition of suitable habitat for landscape management of Spotted Owls in British Columbia is forest at elevations less than 1370–1500 m (depending on biogeoclimatic zone) comprised of trees ^{3}100 years old and >19 m tall (Spotted Owl Inter-Agency Management Team 1997a, 1997b). Definitions of suitable stand-level habitat are more detailed, and classify stands based on habitat quality (Appendix A): Type A, habitat of superior quality, is appropriate for nesting, foraging, roosting, and dispersing; and Type B, habitat of moderate quality, is unsuitable for nesting but is appropriate for other Spotted Owl activities. Type C is habitat of more marginal quality—usually younger forest stands with structural attributes resulting from windthrow or fire, or containing only some of the structural attributes preferred by the owl. These stand-level definitions are based mostly on descriptions of sites in Washington State (Hanson et al. 1993) and on expert opinion (Spotted Owl Management Inter-Agency Team 1997b). Thus, resource managers in British Columbia may need to consider the differences between the ecosystems, topography, and latitudes of Washington State and British Columbia when classifying stands and before developing or implementing habitat management plans.

Under the Spotted Owl Management Plan (Spotted Owl Management Inter-Agency Team 1997a), both Special Reserve Management Zones and non-permanent matrix activity centers are managed for Spotted Owl habitat. The Plan relies on recruitment of stands, which, under the landscape definition, currently considered unsuitable for Spotted Owl habitat (i.e., those <100 years old). To be eligible for Spotted Owl habitat recruitment, these stands require treatment to accelerate and promote development of the necessary stand characteristics. Recruitment of these stands for habitat requires treatments to accelerate and promote development of the necessary stand characteristics. As well, the Plan promotes the enhancement of stands 100 to 140 years old, so that those of moderate habitat quality (Type B) may be upgraded to superior habitat quality (Type A) with the usual treatments.

Management of future habitat supply requires that the forest area potentially available for recruitment or enhancement be quantified and identified. For example, in the Chilliwack Forest District, the Fraser Timber Supply Area contains approximately 407 300 ha of <100-year-old forest, all of which are potentially available for recruitment and subsequent enhancement. Of this area, 191 900 ha are in the Timber Harvesting Landbase (British Columbia Ministry of Forests 2003). The results of a field review within the Timber Harvesting Landbase showed that forests deemed most suitable for enhancement were those 100 to 140 years old with a high site index, high density of stems per hectare, dense overstorey canopy, and a single leading species.[1] In Special Reserve Management Zones and matrix areas in the Fraser Timber Supply Area, these types of forests are currently estimated to cover approximately 450 ha.[2] Thus, landbase enhancement will become more important as larger areas of potentially suitable habitat age to >100 years.

Management of Spotted Owl habitat faces a number of challenges. One challenge is the difficulty of isolating those individual forest attributes used by owls from the suite of characteristics that describe old-growth forest (North et al. 1999).

A second challenge is the lack of information concerning the likelihood that long-term treatments will be successful in recruiting and enhancing habitats. It may require over 200 years for the types of stand structures used by Spotted Owls (e.g., large trees with broken tops, or Douglas-fir with spreading crowns) to develop (Franklin and Spies 1991). Landscape modelling efforts (Carey et al. 1999a) suggest that simple site preservation can result in long periods of stem exclusion, and that intensive management combined with long rotations can conserve overall biodiversity.

A third challenge is the unknown response of the owl or its prey to both short- and long-term treatments. Ripple et al. (1997) cited unpublished telemetry data in southwestern Oregon that indicates Spotted Owls avoided partially cut mature conifer stands with 40–59% canopy closure. A recent case study of a male Northern Spotted Owl in Oregon demonstrated that commercial thinning in the nest area may have caused a shift in its breeding range and an increase in its overall home range (Meiman et al. 2003). The need for an increased home range may be linked to a lack of available prey. Carey (2000) reported that flying squirrels moved further distances and were at lower densities in intensively managed, thinned stands compared to passively managed, long-rotation legacy stands.

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[1] C. Rowan, Stewardship, Coast Forest Region, B.C. Ministry of Forests and Range, Nanaimo, B.C.; personal communication, January 31, 2004.

[2] Based on a crude estimate of forests 100–140 years old with a single leading species, a high site index, and conventional operability. J. Brown, Stewardship, Coast Forest Region, B.C. Ministry of Forests and Range, Nanaimo, B.C.; personal communication, January 31, 2004.

A fourth challenge is that stand-level management can be costly to implement unless it includes extraction of non-timber forest products (Thomas et al. 1990).

In spite of these challenges, other projects have demonstrated that owls use forests that are comparatively younger and that have been entered for timber harvesting purposes (e.g., Irwin et al. 1991; Buchanan et al. 1995). These studies located owls in forests with different stand histories:

- In Washington's eastern Cascade Mountains, some Spotted Owls were found nesting in stands of larger-diameter trees—often ponderosa pine—that had been selectively harvested (Buchanan et al. 1995). These extractions occurred between 5 and about 20 years prior to the known use of the stands by owls (Buchanan et al. 1995; Buchanan 1996). Dwarf mistletoe occurred in most stands and is believed to be an important habitat feature.
- Spotted Owl nesting in southwestern Washington (Irwin et al. 1991) and western Oregon (Irwin et al. 2000) was documented in stands with a more substantive harvesting and disturbance history. For the most part, these forests had been harvested during the previous rotation, but residual snags (e.g. scattered non-merchantable or seed trees >80 cm dbh; Irwin et al. 2000), live trees, and large woody debris were retained. Prescriptions were not used, but retrospective ones can likely be created through careful evaluation and stand-level modelling.

These studies are significant to silvicultural management in British Columbia because these stands were managed for timber in a way that inadvertently made them suitable for Spotted Owls years later. Clearly, the fact that owls now use such stands indicates that stand management can be successful for this species.

The various management options may result in trade-offs between providing habitat for a species and maintaining timber supply. Modelling is one way of identifying how potential changes to forest structure could affect the value of owl habitat, and quantifying timber values. Forecasts by Greenough and Kurtz (1996) using the Tree and Stand Simulator (TASS) (Mitchell 1975; Appendix B) suggest that stand-tending practices on sites that had been clearcut and then planted were not successful in recruiting owl habitat within a 150-year period because suitable canopy structure and/or production of large snags did not meet habitat requirements. However, practices have changed since this study took place. For example, the introduction of variable retention harvesting and variable density thinning of second-growth forests may prove to be effective for recruiting habitat because elements of the old forest may be retained for the next rotation (Carey 2000; Beese et al. 2003).

The objectives of this report are to review the biology of the Spotted Owl and the stand management concepts aimed at providing habitat for Spotted Owls, and how current harvesting guidelines in British Columbia are being applied to meet habitat management objectives. The information in this report can be used to further develop policy and practices, and to develop field tools for applying practices.

To address the challenges and knowledge gaps associated with recruiting and enhancing Spotted Owl habitat, we set the following specific objectives:

a. Provide a general overview of how forest structure in British Columbia provides habitat for the Spotted Owl and its primary prey (flying squirrels [*Glaucomys sabrinus*] and bushy-tailed woodrats [*Neotoma cinera occidentalis*]).

b. Review current harvesting guidelines and the research relevant to managing Spotted Owl habitat.

c. Review silvicultural methods used to recruit stands for Spotted Owl habitat, including the practices currently used in British Columbia, alternative practices in British Columbia, and those used elsewhere.

d. Demonstrate use of TASS to project effects of harvesting and silvicultural practices on indicators of quality of owl habitat.

e. Identify knowledge gaps, and identify limitations of using silvicultural methods to recruit Spotted Owl habitat.

This report forms the basis for evaluating required stand-level forest-management practices as they affect Spotted Owl habitat, but it does not replace the targets described in the Spotted Owl Management Plan (Spotted Owl Management Inter-Agency Team 1997a, 1997b).

BIOLOGY AND HABITAT OF THE SPOTTED OWL

Range and Associated Ecosystems

The range of the Spotted Owl extends along the west coast of North America from northern California to the southwestern corner of British Columbia (Figure 1).

Its known range in British Columbia is quite small and is bound by the international border in the south, Carpenter Lake in the north (approximately 51°N latitude), Howe Sound in the west, and Coquihalla summit in the east. Thus, in British Columbia, Spotted Owls are found within the southern Pacific Range (Coast Mountains) and on both the windward and leeward sides of the Skagit and Hozameen Ranges (Cascade Mountains).

The climate over this geographic range is strongly influenced by the flow of warm, moist air from the Pacific Ocean and by the mountain ranges that run northwest to southeast, which serve as a barrier to this flow. Thus a maritime influence is evident in the western part of the range, but the influence is more-or-less continental influence at the eastern limit (Figure 2).

In the maritime ecosystems[3] winters are generally mild and wet. At elevations <350 m, precipitation usually falls as rain. Summers range from cool and moist at high elevations to warm and dry in the Fraser Valley. Douglas-fir (*Pseudotsuga menziesii*), western hemlock (*Tsuga heterophylla*), amabilis fir (*Abies amabilis*), and western redcedar (*Thuja plicata*) are the

[3] Maritime biogeoclimatic subzones: CWHdm = Coastal Western Hemlock dry maritime; CWHvm = Coastal Western Hemlock very wet maritime; CWHxm = Coastal Western Hemlock very dry maritime.

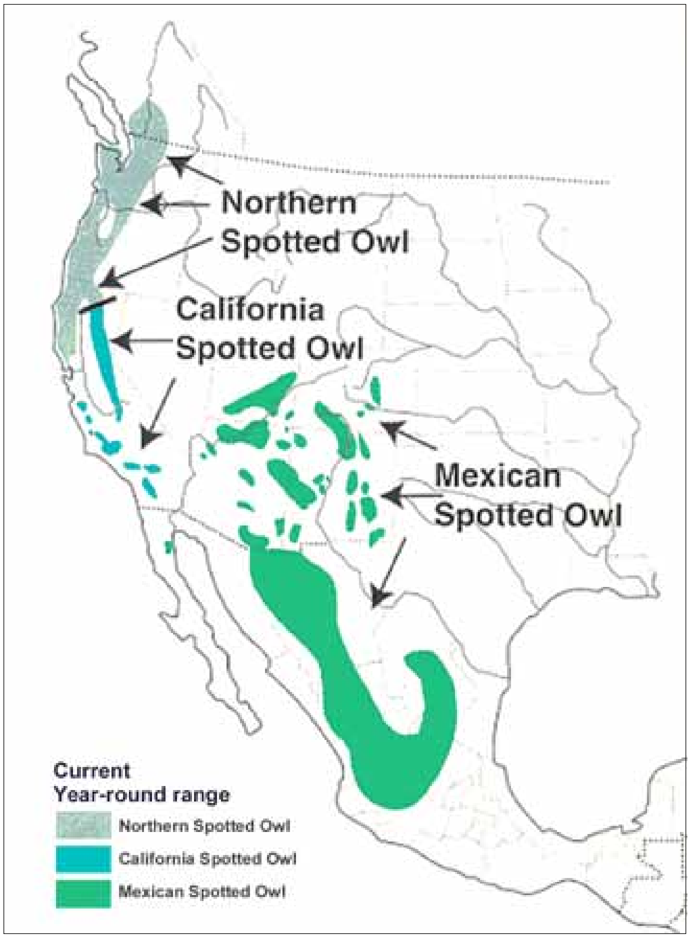

Figure 1. Current year-round range of Spotted Owls in North America (adapted from Gutiérrez et al. 1985).

major tree species. Although the Spotted Owl has been detected at high elevations in mountain hemlock (*Tsuga mertensiana*) and yellow-cedar (*Chamaecyparis nootkatensis*) forests, these areas do not likely represent suitable nesting or foraging habitat. In the submaritime and transitional ecosystems,[4] winters are cool and moist with snow accumulation dependent on elevation and topography. Summers are commonly warm and dry. Douglas-fir is generally the dominant species, and western redcedar, western hemlock, western white pine (*Pinus monticola*), ponderosa pine (*P. ponderosa*), and amabilis fir form major to minor components of the stand.

In the continental ecosystems,[5] winters are cool with low snowfall in valley bottoms and moderate snowfall at high elevations. Summers are usually warm and very dry. Douglas-fir, lodgepole pine, and ponderosa pine are the main tree species. Douglas-fir commonly occurs in pure stands or as large veterans in mixed stands containing lodgepole pine (*Pinus contorta*). Ponderosa pine is usually limited to low-elevation stands.

The Spotted Owl Management Plan (Spotted Owl Management Inter-Agency Team 1997a) considers the maritime ecosystems to be "wetter" ecosystems and the submaritime to be "drier" ecosystems. Therefore, in this Plan, data from west of the Cascade Mountains in Washington State were extrapolated to establish criteria for British Columbia's wetter ecosystems and data from the eastern Cascade Mountains in Washington extrapolated to define criteria for British Columbia's drier ecosystems group. Subsequent to implementing the Spotted Owl Management Plan, the Spotted Owl range was found to extend into the continental ecosystems; therefore, we assume the drier definition also applies to the continental group.

Forest structure depends not only on climate, physiography, and tree species composition but also on past events, especially the disturbance regime. Natural disturbance histories are often obscured and difficult to reconstruct in coastal British Columbia because of extensive timber harvesting over the past century (Wong et al. 2003); however, the disturbance regimes of maritime, sub-maritime, and continental ecosystems are quite distinct. In the maritime ecosystems, disturbances are usually small in scale; large-scale disturbances are generally considered infrequent to rare. Fire-return cycles (which usually involve stand-replacing events), based on tree rings and radiocarbon dates, have been calculated for sites in the CWHvm subzone in the Clayoquot Sound area on the west side of Vancouver Island (Gavin et al. 2003). On terraces, the median return interval was long—circa 4400 years—whereas on slopes the median was 740 years. Forests on south- and southwest-facing slopes incurred fires more frequently than those on north- or east-facing slopes. At high-elevation sites in the southern Coast Mountains and in the northern Cascade Mountains, soil charcoal was used to determine that fire was more frequent 2400 to 1300 years ago than in the last 1300 years (Hallet et al. 2003). Median fire interval was approximately 1200 years and ranged from 300 to 7030 years (Lertzman et al. 2002). The lack of large-scale fires does not preclude the occurrence of other small-to-moderate-scale disturbance events. In Cypress Park (Lertzman and Krebs 1991), and in the Capilano, Seymour, and Coquitlam river watersheds (Daniels 2003), gap-phase processes resulting from windthrow and root and stem rots were found; hemlock mistletoe also appeared to be common. Many of these small-scale openings resulted from tree mortality (Lertzman and Krebs 1991).

Studies of ecosystems similar to transitional areas in southwestern British Columbia come from Washington and

[4] Submaritime and dry transitional biogeoclimatic subzones: CWHds = Coastal Western Hemlock Dry Submaritime; CWHms = Coastal Western Hemlock Moist Submaritime; IDFww = Interior Douglas-fir Wet Warm.

[5] Continental biogeoclimatic subzones: IDFdk = Interior Douglas-fir Dry Cool; IDFxh = Interior Douglas-fir Very Dry Hot; IDFxw = Interior Douglas-fir Very Dry Warm; MSdm = Montane Spruce Dry Mild; MSdk = Montane Spruce Dry Cool; PPxh = Ponderosa Pine Very Dry Hot.

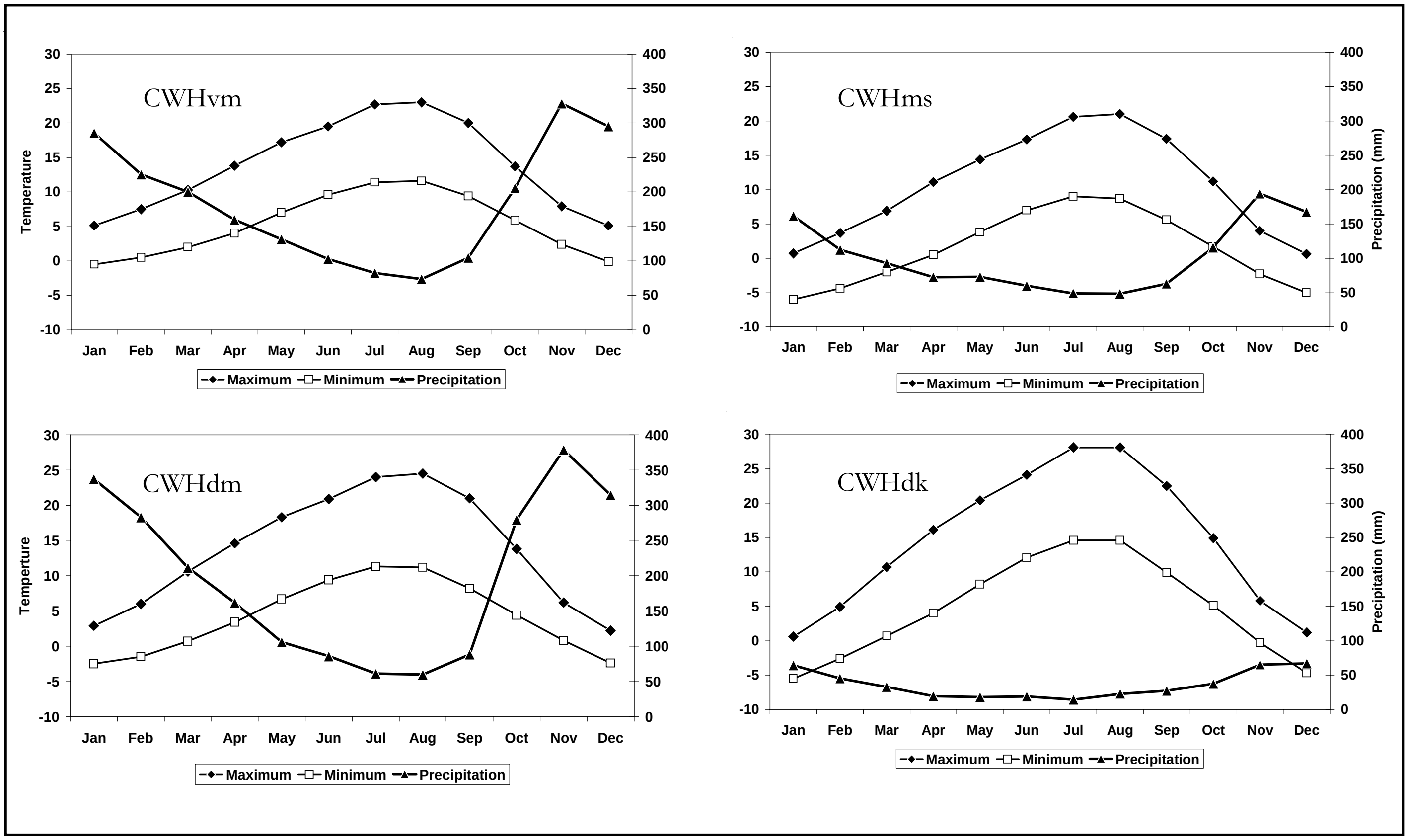

Figure 2. Representative monthly climate data: maximum and minimum temperatures and total precipitation, for wet (CWHvm, CWHdm), submaritime (CWHms), and continental (IDFdk) ecosystems, within the range of the Northern Spotted Owl.

Oregon (e.g., Helmstrom and Franklin 1982; Stewart 1986, 1989; Spies et al. 1990). These Douglas-fir-dominated ecosystems, which may be subject to summer drought, have shorter fire-return intervals than the wet maritime ecosystems. For example, at Mount Rainier, where local annual precipitation ranges from 2050 mm at low elevations to 2690 mm at high elevations, the natural fire-return interval was estimated at 434 years (Helmstrom and Franklin 1982). Within very old stands (>500 years old), the age range of shade-intolerant Douglas-fir may be wide because of episodes of partial stand destruction (Franklin and Waring 1980; Stewart 1989). The interaction of large- and small-scale disturbances produces a mosaic of variously sized patches containing regeneration of different ages (Stewart 1986).

There are surveys of dry submaritime and continental ecosystems in British Columbia, but published works are few (see Wong et al. 2003). In submaritime ecosystems, disturbances usually occur on a larger scale than in maritime ecosystems, although the frequency and severity of both stand-replacing and stand-maintaining events can vary substantially. In the Skagit area of Washington State (an area comparable to British Columbia's submaritime ecosystems), researchers calculated a mean fire-return interval of 94 years in forests of predominantly Douglas-fir (Agee et al. 1990), and >400 years for refugia where western redcedar was the leading species. In the continental ecosystems with no histories of extensive fire suppression, low-severity, stand-maintaining fires with mean return intervals of 13 to 49 years appear to be common (Wong et al. 2003). The presence of veteran Douglas-fir in these ecosystems suggests that, in these areas, the periods between major fires as stand-replacing events are long. These patches of veteran Douglas-fir suggest a mixed fire regime. In continental ecosystems in the Wenatchee Mountains in central Washington State, fire refugia comprised areas of <10 ha, but these did not form an interconnected matrix of old forest (Camp et al. 1997).

Habitat Requirements

To devise and implement practices for enhancing or recruiting habitat for Spotted Owls, foresters need a basic understanding of how these animals use forest habitat. Knowledge of the habitat requirements of both the Spotted Owl and its main prey species is fundamental to this understanding. The Spotted Owl and its prey often need similar elements of forest structure, but they use these elements differently (Table 1).

Table 1. Importance of forest structure characteristics to the Spotted Owl and its prey.

Elements			Importance: For owl	Importance: For prey [a]
Trees	Live	Trunk	Large deformed trees for nest cavities.	Large deformed trees with bole entries and scarred trees. Verical movement.
		Branches	Large branches for nest platforms. Perches for hunting and roosting. Shelter from predators Cover (sun exposure, precipitation). Lower densities for accessible flight pathways.	Connected pathways for movement in canopy. Platforms for nests. Lichen for food and nesting material.
		Roots		Hypogeous fungi for food.
		Leaves		Nesting material.
		Catkins, cones		Seed source for food, e.g., conifer, maple, arbutus.
		Bark		Nesting material (redcedar, broadleaf maple).
		Dwarf mistletoe	Nesting platform (Douglas-fir).	Nesting platform (Douglas-fir, possibly hemlock).
	Dead	Snags	Broken top trees (chimney snags) for nest structures. Perches.	Dens (heart rot, fire-created cavities, dead tops). Cover. Vertical movement.
		Coarse woody debris		Cover. Horizontal movement. Dens, middens. Crevices for stick nests or middens, or for storing winter food. Fungi for food.
Vegetation	Shrubs			Berries for food. Cover.
	Vascular plants			Food source. Nesting material. Cover.
	Moss			Nesting material.
	Fungi			Food source.

Table 1 continued on next page

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			Importance	
Elements			For owl	For prey [a]
Rock				Crevices for middens, or for storing winter food.
Stand structure	Overstorey canopy	Deep crowns	Enhance perching and cover.	Enhance movement and cover.
		Canopy (crown) closure(higher percent cover)	Maintains stand condition for thermoregulation. Reduces snow cover and thus access to prey. Reduces predation risk.	Maintains stand condition for thermoregulation. Reduced snow cover improves access to food.
		High overstorey canopy (canopy lift)	Horizontal flight paths.	Provides escape from predators.
	Spatial heterogeneity	Vertical complexity (multiple layers)	Manoeuvrability for flight paths. Vertical column for perching.	Reduces large vertical gaps between understorey and overstorey, and enhances interconnectedness for movement. Enhanced cover reduces predation risk.
		Horizontal complexity (gaps)	Helps in locating and capturing prey. Improves stand access (enter/exit canopy). Produces large branch platforms in gaps.	Provides access to open forest floor to search for food and for quick escape to cover. Provides access to enhanced patchy understorey for food production and cover.
		Stem density	Improves manoeuvrability for flight paths and stand access.	Increased subcanopy movement distances.
	Species composition	Mixed (conifer, but deciduous component not required)	Provides variation in size and structure of trees for enhancing perching, nest structures, and prey diversity.	Provides a variety of seed sources. Allows for heartrot cavity production for dens. Provides adequate snag volume. Ensures availability of mistletoe, lichen, and fungi.

[a] Prey consists mainly of flying squirrels and bushy-tailed woodrats.

Prey. Prey must be available and accessible to the Spotted Owl within its home range[6] and nesting area[7] and during dispersal.[8] In British Columbia, prey are mostly arboreal and semi-arboreal rodents (Horoupian et al. in prep.), particularly flying squirrels and bushy-tailed woodrats. Other prey species in British Columbia are unidentified squirrels (*Tamiasciurus sp*), deermice (*Peromyscus spp*.), common pika (*Ochotona princeps*), Varied Thrush (*Ixoreus naevius*), and ermine (*Mustela erminea*). In addition, research from Washington State reports that hares (*Lepus americanus*) and red-backed voles (*Clethrionomys gapperi*) are also prey (Forsman et al. 2001). The Spotted Owl is a sit-and-wait predator, which means that it perches and then launches an attack over a relatively short distance to pounce on its prey (Forsman et al. 1984).

[6] The Spotted Owl's median annual home range areas are reported as 5761 ha for the Olympic Peninsula, 3321 ha for the western Cascade Mountains, and 2675 ha for the eastern Cascade Mountains (Hanson et al. 1993). In British Columbia, under the Spotted Owl Management Plan (Spotted Owl Management Inter-Agency Team 1997a, 1997b) long-term activity centers for owls are managed as ~3200 ha.

[7] Prey may be more concentrated in the owl's nesting area, where the owl focuses its activity, i.e., within a 2.6-km radius of the nest (Forsman et al. 1984). The Spotted Owl Management Plan (Spotted Owl Management Inter-Agency Team 1997a, 1997b) recommends patches of suitable habitat, comprising, in total, a minimum of 500 ha, should be adjacent to the nest and an 80-ha no-harvest reserve should be established around a nesting or roosting site.

[8] According to the Spotted Owl Management Plan (Spotted Owl Management Inter-Agency Team 1997a, 1997b), movement corridors within long-term activity centers should be 1 km wide, and clusters of long-term activity centers—which form Spotted Owl Resource Management Zones—should be within 15 km of each other.

Therefore, to access prey, the owl must not only have space to fly and manoeuvre through the forest stand, but it must also have a variety of perches available throughout the stand and adjacent to forest openings (Forsman et al. 1984, 2001; Thomas et al. 1990; Hanson et al. 1993).

Predation. Juvenile Spotted Owls are more vulnerable to predation than adults. Common predators are Great Horned Owls (*Bubo virginianus*), Northern Goshawks (*Accipiter gentilis*), Red-tailed Hawks (*Buteo jamaicensis*), Common Ravens (*Corvus corax*), and possibly Barred Owls (*Strix varia*) (Forsman et al. 2002). Spotted Owls must have cover for security during dispersal, foraging, roosting, and nesting. A closed overstorey canopy reduces visual and physical exposure of the owl to potential predators, and dense clumps of trees and tall shrubs provide direct overhead and horizontal coverage of perches and roosts.

Nests. Nests are found in:

a. in live, deformed trees that have heart rot cavities;[9]

b. chimney snags;[10] or

c. four types of non-cavity structures including:

  i. large, wide branches with little additional structure, which apparently are rare and not yet detected in British Columbia,

  ii. old stick nests (e.g., those of the Northern Goshawk),

  iii. debris accumulations on horizontal branches, which are usually on a cluster of branches growing adventitiously in response to mistletoe infection and are not yet detected in British Columbia, and

  iv. branch clusters triggered by mistletoe infection (Forsman and Giese 1997; Manley et al. 2004).

In the CWH biogeoclimatic zone, nests are found primarily in cavities (especially side cavities), whereas in the Interior Douglas-fir zone, nests are found in cavities (especially open-top cavities in snags), abandoned Goshawk nests, and one was found in a large growth of Douglas-fir dwarf mistletoe (Manley et al. 2004).

In British Columbia, trees used for nesting ranged from 50.1 to 131 cm dbh and occurred in areas with a high density of large snags (Manley et al. 2004). Compared to random patches, nest patches had lower densities of mid-size trees (35–60 cm dbh), but higher densities of somewhat larger trees (60–85 cm dbh), and also higher basal areas of deciduous trees associated with small, colluvial disturbances (Manley et al. 2004). On the Olympic Peninsula in Washington State, nests were most often located in multi-layered stands dominated by large, old trees >100 cm dbh, and canopy closure over the nest varied from 35 to 90% (Forsman and Giese 1997). Trees with cavity nests were larger (mean dbh 142 cm) than those with platform nests (mean dbh 89 cm) (Forsman and Giese 1997).

[9] These particular nest cavities usually form in the location a live leader has snapped off and a secondary leader has taken over.
[10] A snag with its top snapped off.

In the eastern Cascade Mountains of Washington State, nests were common in mistletoe growths, on old Northern Goshawk nests, and on live Douglas-fir trees in dominant or codominant canopy positions; in addition, Spotted Owls used a small number of cavity nests (Buchanan et al. 1993). Nest trees had larger diameters than most trees in the vicinity, and those with broken tops had significantly larger diameters (94.7 cm dbh) than other trees supporting other types of nest structures (59.4 cm dbh) (Buchanan et al. 1993). Nest sites had greater basal area of live trees, greater basal area of Douglas-fir trees, and higher densities of ponderosa pine (61–84 cm dbh) than random non-nest sites. Also, the basal area of snags was greater than that of random non-nesting sites (Buchanan et al. 1995).

Climate may have an influence on the Spotted Owl's selection of nest sites and its use of nest structures. Cavity nests, particularly side cavities, provide protection in areas with frequent heavy rainfall, while platform nests suffice in climates with less rainfall (Buchanan et al. 1993; Forsman and Giese 1997; Manley et al. 2004). Large trees (dead or alive) may be thermally preferable for nesting and roosting (Thome et al. 1999). In California, nests overtopped by canopies with a high volume of foliage were also associated with high reproductive success, which suggests these nests were protected from detrimental weather conditions (North et al. 2000). Although Spotted Owls re-use their nest structures, they often change locations in successive nesting attempts (Forsman and Giese 1997); therefore, owls need a supply of available and accessible nest structures over time even if the original structures remain intact.

Roosts. Spotted Owls select roosts throughout their home range and near their nest sites. They use both trees and snags and will perch close to the trunk to take advantage of the shade and cover provided by the overhead branches (Forsman et al. 1984). In hot weather, shade cover at roosts is important for Spotted Owl thermoregulation, because, while its plumage provides protection in winter conditions, it can cause the owls to become overheated in the summer (Barrows 1981). Roosts may be lower in the understorey on warmer days and higher in the overstorey on cooler days (Forsman et al. 1984). During inclement weather, owls must be able to find sheltered roosts. Roost sites associated with breeding are described as having high vertical canopy layering (vertical diversity) (Mills et al. 1993) and are often in large snags (North et al. 1999). In the mature forests on the Olympic Peninsula, Spotted Owls used roost sites in forests with large snags (>51 cm dbh) and canopy closure >70% (Buchanan et al. 1999). On the western slopes of the Cascade Range in central Washington State, researchers found that roost sites from the non-breeding season were at lower elevations and in areas with larger diameter trees, canopy trees at lower densities, greater canopy cover, lower shrub cover, and fewer pieces of downed wood compared to random sites (Herter et al. 2002). They suggest that in winter owls may favour sites that provide ease of movement and unimpeded access to the forest floor for hunting. However, snow cover and lack of foliage on some shrubs may reduce the importance of these attributes at some sites in winter. Herter et al. (2002) also detected differences between male and female roosts and suggest that the males may be more capable of using comparatively young, denser stands because they are smaller.

Dispersal. After breeding, Spotted Owls expand their area of use. Juveniles disperse at random from nest sites and continue moving until a permanent territory is located or until they die. Spotted Owls must be able to forage and avoid predators during dispersal; therefore, poorer quality habitats, although traversed, could present high risk to survival of the birds. A study of juvenile Spotted Owls in Oregon and Washington (Forsman et al. 2002) reported a dispersal range of 0.6 to 111 km, but only 8.7% of juveniles travelled >50 km. Median distance was 14 km for males and 24 km for females.

Habitat Requirements of Prey

Characteristics of the Spotted Owl's habitat are closely linked to those of its major prey: flying squirrels and bushy-tailed woodrats.

Range and habitats of major prey species. Arboreal flying squirrels are found in forests across Canada (Banfield 1974). They are not old-growth specific (Waters and Zabel 1995), although their abundance varies with stand structure. Studies suggest that prey may be more abundant and more accessible in old-growth forests than in younger forests (e.g., 40 to 80 years old) (Carey et al. 1992; Ransome and Sullivan 2003). The semi-arboreal bushy-tailed woodrat is a subspecies native to western British Columbia (Banfield 1974). It has strong associations with rocky outcrops in Douglas-fir and pine forests and with rock talus[11] (Banfield 1974). In Oregon, woodrats are more abundant in old-growth forests (>250 years old) than in young stands (40 to 70 years old), and are often more abundant in forested riparian habitats than in rocky areas (Carey et al. 1992).

Movement. Flying squirrels are nocturnal and live mostly in the forest canopy, except when they are searching for food on the ground. Connected canopies and small gaps are important to expedite arboreal travel and minimize glide distances because the squirrels have a high surface area relative to body mass, which renders them susceptible to metabolic heat loss, particularly in winter (Carey et al. 2002). Bushy-tailed woodrats are semi-arboreal and will climb trees (Carey 1991).

Natal and resting structures. Flying squirrel dens—including natal and resting—are often constructed from lichen and plant materials in cavities of large live or dead trees, and occasionally in stump cavities and downed wood. Flying squirrels also use lichen, sticks, or leaves to construct nests on branches or mistletoe broom platforms (Bakker and Hastings 2002; Carey 2002). Flying squirrels have been observed using hemlock mistletoe platforms in British Columbia coastal forests.[12] They use communal dens, and need cavities large enough to accommodate three or more individuals (Carey et al. 1997). Multiple sites can be used in the same season. Thermoregulation in dens is important for flying squirrels; lined cavities may provide protection against inclement weather and cold temperatures (Carey 2002). Cavities in large-diameter trees and tree boles may provide thermal insulation in cold climates where snowfall occurs (Bakker and Hastings 2002). In stands without large overstorey trees, flying squirrels may use open structures for resting areas (Waters and Zabel 1995), as overhanging branches may provide sufficient protection from inclement weather (Cotton and Parker 2000). A closed overstorey canopy can provide a sheltered microclimate (Carey et al. 2002).

Bushy-tailed woodrats usually build dens in rock crevices, but they will also build stick nests under logs or in tree cavities (Carey 1991). In crevices, they will build a midden from plant material and faeces solidified by their urine; nests are found within the midden (Trapani 2003). Tree "houses" have been reported in coniferous forests, but are uncommon (Carey 1991; Trapani 2003).

Foraging. Flying squirrels and bushy-tailed woodrats commonly forage on or near the ground at night. Flying squirrels often consume truffles (*hypogeous fungi*: ascomycetes in the genus *Tuber*) and false truffles (various ascomycetes, basidiomycetes, zygomycetes, and glomeromycetes) which can occur patchily and may have low nutrient value (Carey et al. 2002; Anderson 2003). They will consume—particularly during periods of low truffle availability—a variety of lichens, seeds, berries, nuts, fruits, mushrooms, and occasionally insects. Their diet in British Columbia appears more diverse than that in Washington and Oregon (Anderson 2003). Bushy-tailed woodrats usually forage within 500 m of their dens, consuming mostly green vegetation, cambium, nuts, seeds, mushrooms, animal matter (Carey 1991; Trapani 2003), and they will build food caches for the winter (Banfield 1974).

Predation. In addition to Spotted Owls, predators of flying squirrels and bushy-tailed woodrats include other owl species, hawk species, and larger mammals (e.g., weasel and marten). Bobcats are also important predators of bushy-tailed woodrats (Carey 1991; Trapani 2003). Both prey species may search for food in exposed areas on forest floors because it takes less time to find food there. In open areas, they are likely vulnerable to predation (Carey et al. 2002), although nearby understorey vegetation could help reduce this risk (Waters and Zabel 1995). Building dens in cavities and high above the forest floor, and changing den locations often, may reduce the risk of predation (Carey 2002; Carey et al. 2002). In addition, risk is reduced when connected forest canopies provide flying squirrels with sheltered pathways (Carey 2002), and mid-storey canopies in forest openings provide cover as the flying squirrel "glides" across openings (Carey et al. 1999b).

[11] Evidence of bushy-tailed woodrat middens on talus slopes near two Northern Spotted Owl sites in British Columbia were reported. Jared Hobbs, Biodiversity Branch, B.C. Ministry of Water, Land and Air Protection, Victoria, B.C.; personal communication, April 2003.

[12] Wayne Wall, Habitat Specialist, International Forest Products, Campbell River, B.C.; personal communication, August 10, 2004.

Development of Stand Structures

Managing for Spotted Owl habitat requires that resource managers understand of natural stand development, including specific structural attributes of importance for the owl's life cycle.

Oliver and Larson's (1996) stand-development model describes Douglas-fir forest development following tree-initiating disturbances in terms of i) stand initiation, ii) stem exclusion, iii) understorey re-initiation, and iv) old-growth establishment. However, Franklin et al. (2002) summarize and propose other models of stand development. After a disturbance, regenerating stands may pass through all four stages proposed by Oliver and Larson (1996). Without density control (i.e., spacing) fully stocked stands will enter the stem exclusion phase; the typically closed stand conditions allow little understorey development to occur. These stands lack the necessary characteristics for the owl or its prey. In later stages of stand development, i.e., understorey re-initiation and old-growth stages, the necessary vertical and horizontal complexity develops and stand characteristics suitable for Spotted Owl habitat occur. Although owls have been found to forage in 60-year-old stands, in these cases the stands usually contain remnants of old stands (Thomas et al. 1990).

In maritime and submaritime ecosystems, shrub (or small tree) species such as vine maple (*Acer circinatum*) and Douglas maple (*A. glabrum*) may provide cover and seed sources for prey populations such as flying squirrels. Other plants provide berry sources for prey populations; these include Ericaceous shrubs (e.g., salal [*Gaultheria shallon*]) in maritime ecosystems and various huckleberries (*Vaccinium* spp)—which tend to produce more fruit in openings than under a closed canopy—throughout the area. Similarly, Wender et al. (2004) found increased abundance and probability of flowering/fruiting in four shrub species (including salal) after overstorey thinning.

Tree death leads to the provision of coarse woody debris in the form of snags and fallen logs. Coarse woody debris provides habitat for various organisms ranging from large (bears, small mammals) to small (arthropods) to microscopic (fungi, bacteria, phoretic mites, nematodes, and protozoans) (Parsons et al. 1991). Downed wood is also believed to provide refugia for mycorrhizal fungi, particularly in dry ecosystems and during droughts (Amaranthus et al. 1994). Stands that have regenerated naturally after fire, wind, or partial harvesting often maintain a legacy of old trees or snags as well as abundant fallen logs. These elements are usually rare in young, managed stands unless pockets of root rot are left untreated or unless silvicultural efforts are undertaken to maintain and enhance habitat attributes.

Occurrence of dwarf mistletoe brooms may enhance owl habitat by providing nest sites for the owl or its prey. In stands in the eastern Cascade Mountains, owls were found to nest in large dwarf mistletoe brooms on Douglas-fir trees (Buchanan et al. 1993); some of these mistletoe-infected trees had survived fires, or they were remnants of partial harvesting that had occurred at least 40 years ago in previously infected stands. Within the area occupied by Spotted Owls in British Columbia, Douglas-fir dwarf mistletoe is largely confined to the continental ecosystems in the Fraser River drainage near Lytton. Similar to those in the stands in the eastern Cascade Mountains, these brooms can be located in veteran trees that remain after low-to-moderate severity fires or after partial harvesting.

The presence of fungi in stands is an important habitat characteristic. Truffles, which are consumed by prey species such as flying squirrels, are formed primarily by ectomycorrhizal fungi associated with tree hosts such as western hemlock, Douglas-fir, and true fir. In autumn, edible mushrooms, primarily ectomycorrhizal basidiomycetes associated with the same tree hosts, are plentiful. Small mammals also consume some arbuscular mycorrhizal fungi (*Glomus* species) that are associates of tree species such as western redcedar and vine maple. Ericaceous shrubs, such as salal and *Vaccinium* species, however, are unlikely to host truffles because the known ericoid mycorrhizae form inedible microscopic fruit bodies (Xiao and Berch 1995).

In Washington State, researchers found that truffles and standing crop are more abundant in mature and old-growth forests than in young, managed stands; however, truffle consumption by small mammals was highest in managed stands (North et al. 1997). Highly palatable truffles are found in young stands, whereas less-palatable ones are found in mature forests, which, in part, leads to the differences in standing crop. However, mushroom abundance was similar for all forest development stages, as was the availability of the most palatable species.

APPLICATION OF TIMBER-HARVESTING GUIDELINES WITHIN SPOTTED OWL MANAGEMENT AREAS

Information is lacking about how to combine commercial timber management objectives with objectives that maintain or recruit owl habitat (Hicks et al. 1999). Recognizing the need for innovative approaches for creating stand attributes, the Spotted Owl Management Plan (Spotted Owl Management Inter-Agency Team 1997a, 1997b) developed approaches to integrate the requirements of timber harvesting and owl habitat with the stated primary objective of ". . . optimize the removal of timber resources without jeopardizing the long-term survival of the Spotted Owl" (Spotted Owl Management Inter-Agency Team 1997a, page 49). The following sections describe the Plan's guidelines for each form of harvesting, and they summarize key observations of the operational experience (with guideline implementation practices) based on the authors' recent discussions and fieldtrips (Appendix C). Relevant research, including projected outcomes following stand-level modelling of a subset of sites, is also discussed.

Heavy Volume Removal: Meeting Timber Management Objectives while Providing Potential Future Owl Habitat

Description

In forests where the primary objective is timber production—i.e., forests that exceed 67% suitable habitat targets within Special Management Resource Zones (SMRZ) and spotted owl activity centers—clearcutting with reserves is used to ensure "old forest" attributes are retained, which would allow future recruitment of owl habitat (Spotted Owl Management Inter-Agency Team 1997b) in the event that habitat elsewhere is lost due to fire or other disturbances. While "clearcut" and "clearcut with reserves" are the terms used to describe the harvesting (Spotted Owl Management Inter-Agency Team 1997b), the actual practice may be more appropriately described as a "retention harvest"[13] system (Beese et al. 2003). This report uses the generally accepted term of heavy volume removal (HVR) to describe these harvests.

Heavy volume removal prescription guidelines focus on retention of attributes that will facilitate recruitment of future owl habitat, including trees (groups and dispersed), snags, and downed woody debris. A relatively even distribution of trees throughout the cutblock is preferred unless site conditions or other management objectives (such as visual quality, topography, harvesting systems constraints, understorey tree establishment and growth, forest health factors, and windthrow risk) warrant an alternative retention pattern (Spotted Owl Management Inter-Agency Team 1999). heavy volume removal harvesting guidelines (Spotted Owl Management Inter-Agency Team 1997b) include retaining a minimum of 10–15% of the prescribed area in uncut patches. (If these patches are unsuitable for owl habitat they should be enhanced to meet qualifications.) A wildlife tree patch (WTP) is an area of trees with special characteristics that provide valuable habitat for the conservation and enhancement of wildlife (British Columbia Ministry of Forests and Range 2005a). Additional characteristics to be met either within the wildlife tree patch or cutblock include:

- Retain 2 trees/ha with broken tops.
- Maintain or create 5 dead trees (snags) or dying trees per hectare, with larger minimum diameters specified (>76 cm) in the wetter maritime ecosystems, and smaller diameters (>51 cm) in the drier submaritime and continental ecosystems.
- In the wetter ecosystems, retain at least 15 of the largest trees per hectare. In the drier ecosystems, retain 40 of the largest trees per hectare.
- Maintain existing coarse woody debris and add 25 m^3/ha of unmerchantable logs >50 cm diameter.

Meeting guidelines and objectives such as retention of large trees and trees with broken tops may be addressed in the same tree. Expectations are that where retention is contemplated outside harvesting units (wildlife tree patches, riparian reserves, and other areas) will provide additional Spotted Owl habitat.

Operational Experience

Big Silver River (Pine Creek)

A prescription for heavy volume removal was completed in the CWHds1 in Special Reserve Management Zone 12 near Harrison Lake (Block BS1408; Big Silver River) which is outside a long-term owl habitat zone.[14] The heavy volume removal comprises 8.3 ha of immature forest (age not specified) that is part of a larger 79.8-ha block for which partial harvesting was prescribed.

Stand volume was dominated by Douglas-fir (68%) with lesser amounts of western hemlock (18%) and western redcedar (14%). Deciduous was lacking. The heavy volume removal prescription described the silvicultural system as "variable retention" and incorporated a combination of ground and cable-yarding methods. Trees marked for retention were selected from the 80 largest dbh trees per hectare of all major conifer species available although the prescription did not specify species preference or composition target for residuals. Tree retention (45 stems/ha) intentionally exceeded guidelines (40 stems/ha) to provide a buffer in case of potential windthrow (estimated as 10%) or harvesting damage to retained trees. Snags, described as sometimes limited in numbers in the present stand, were supplemented by creating snags (e.g., by girdling) from residual trees to meet the target of 5 snags/ha and distribution targets. Natural regeneration complimented planting, with Douglas-fir and redcedar being the preferred planting species. Target species composition at free growing was set at Douglas-fir 70%, redcedar 20%, and western hemlock 10%.

The hoe forwarding[15] employed during ground-based yarding appeared to cause minor levels of ground disturbance. Some initial windthrow occurred but subsequent blowdown may have been curtailed by crown pruning which was accomplished with helicopters. Dispersed residual trees showed little evidence of harvesting-related stem scarring. Overall, the retention objectives were met in this prescription (Figure 3). Vegetation management is proposed in the Silviculture Prescription—including treating vegetation (birch, cherry, and maple)— could be carried out in order to meet free-growing objectives. However, a component of deciduous species should be maintained as it provides some desired stand structure for the owl (Table 1) while meeting regeneration obligations.

TASS Simulations

TASS was used to project stand development following an initial harvest similar to the Big Silver heavy volume removal harvest. TASS started with a 120-year-old forest (Douglas-fir site index 22) that regenerated naturally following harvesting. For modelling, we simplified the species composition by leaving only Douglas-fir standing, which included 40 of the largest 80

[13] Retention is used here to describe retention pattern rather than a silvicultural system.
[14] The authors conducted a field trip to this area on June 11, 2003.
[15] A hydraulic log loader lifts and swings them toward the road for loading.

Figure 3. Dispersed retention as prescribed by a heavy volume removal prescription near Harrison Lake (Block 1408).

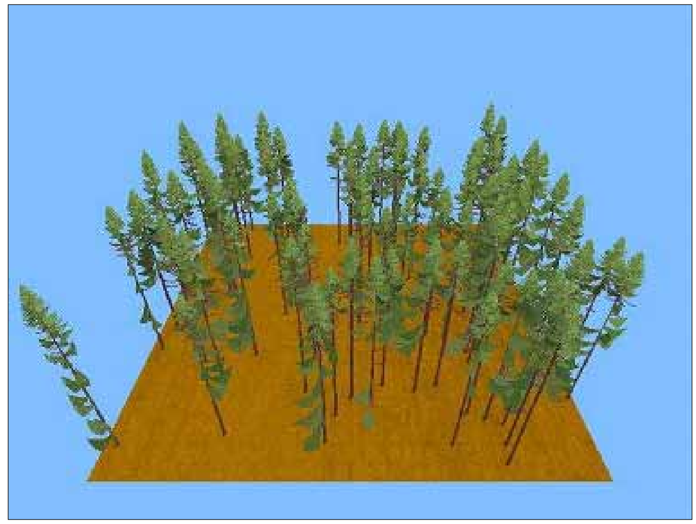

Figure 4. Representation of dispersed retention (40 Douglas-fir/ha) in a submaritime ecosystem, Year 0 (post-harvest).

Figure 5. Representation of a forest in a submaritime ecosystem 100 years after dispersed retention (40 Douglas-fir/ha) and planting with 1600 seedlings.

Douglas-fir per hectare (Figure 4). Snags were removed according to the Workers' Compensation Board[16] of British Columbia guidelines. Douglas-fir and western redcedar were planted (900 seedlings/ha) in an 80:20 ratio. The simulation was run for 100 years (Figure 5) but natural regeneration ingress was not incorporated due to lack of data regarding the development of planted seedlings and natural regeneration.

In the simulation, planted Douglas-fir displayed little mortality and all western redcedar survived in the first few decades. After 100 years, 80% (800 stems/ha of the original total 900 stems/ha) survived of which 95% were in the subcanopy stratum. This stratum was comprised of Douglas-fir and western redcedar in approximately the same ratio as at planting. About 202 stems in the subcanopy and 40 in the canopy were at least 30 cm dbh.

The Douglas-fir subcanopy was about 29 m tall with 25.3 m of clear stem, but western redcedar trees were only 21.3 m tall with 17.7 m (83%) of clear stem. Overstorey Douglas-fir did not develop into snags because growth of 120-year-old trees continues unhindered in the model unless a treatment that would cause mortality is applied.

Snags were recruited from subcanopy mortality (dbh <30 cm) and were smaller than those desired for the wetter maritime (75 cm) and drier submaritime/continental ecosystems (51 cm). More vigorous trees of at least 30 cm dbh would not be expected to die within the 100-year period. In this case, the ensuing reduction in habitat quality—because of low snag recruitment—

[16] The Workers Compensation Board is now known as WorkSafeBC.

may be mitigated by the 11.2 ha of wildlife trees and snags in the vicinity of the 8.3-ha area of heavy volume removal.

Based on expert opinion rather than empirical data, Hanson et al. (1993) suggest that stands in western Washington need to have 284–690 stems/ha (of at least 10 cm dbh) with dominant/codominant tree heights of at least 26 m to provide a canopy sufficiently open for Spotted Owls to fly beneath. TASS simulations suggest that stand density in the heavy volume removal treatment exceeds the range suggested by Hanson et al. (1993), but that sufficient height growth and crown lift, 100 years post harvest, may help to fulfil these criteria. Simulations also suggest that the Harrison Lake heavy volume removal treatment will barely achieve the of 247 stems/ha (at least 30 cm dbh) for Type B habitat. Reducing the number of planted seedlings from 900 to 500 improves the likelihood that live stem requirements will be met; i.e., the projection is for 263 trees of at least 30 cm dbh, 502 stems of at least 10 cm dbh, top heights of >34 m, and clear stems >30 m. However, the heavy volume removal portion would still rely on surrounding areas or on retained inclusions of wildlife trees for snags.

Relevant Research

Harvesting prescriptions that follow the guidelines for heavy volume removal include aspects of variable retention (VR) as defined by the Operational and Site Planning Regulation (British Columbia Ministry of Forests 1998).[17] Variable retention retains individual or groups of trees to enhance structural diversity over the cutblock for at least one rotation. While heavy volume removal guidelines allow for a range of retention patterns, in practice, the need, under the Spotted Owl Management Plan, to maintain either 15 of the largest 30 trees or 40 of the largest 80 trees forces resource managers to use dispersed patterns of tree selection in order to meet minimum diameter requirements, rather than use group patterns which retain a range of stem diameters. Established trials that use retention characteristics similar to those specified for heavy volume removal provide resource managers with guidance in applying prescriptions (Appendix D), in particular by highlighting short-term implications for forest development and management, including windthrow, snag retention, shift in composition, growth and yield, regeneration health, and long-term habitat development.

Windthrow. Dispersed trees in a post-harvest setting are subject to wind damage. Wind-thrown trees lose their habitat value as standing trees or snags because blowdown typically results from root failure rather than stem breakage. Windthrow rates of dispersed trees at initial densities equal to or greater than heavy volume removal guidelines have ranged from 22% (D'Anjou 2002), to 37%,[18] to 47% (de Montigny 2004). Relatively low rate of wind damage to a 145-year-old Douglas-fir stand (<7%) has been associated with thinning at least 15 years prior to clearcut harvesting (Buermeyer and Harrington 2002).

Windthrow has been associated with a subsequent bark beetle attack and subsequent death of other reserve trees (D'Anjou 2006). Rollerson (2002) suggests crown feathering or topping and pruning to reduce windthrow frequency; crown treatments have been found to be effective for reducing blowdown (D'Anjou 2002; de Montigny 2004).

Snag retention. A dispersed retention pattern tends to require the felling of snags in order to address issues of worker safety (Nuszdorfer and D'Anjou 2001). Retaining snags within groups or in reserves (e.g., riparian zones) is the suggested alternative. Snags created from living trees will lack the decay levels and stem forms of existing snags. Some created snags seem to decay quickly; if such snags decay and fall faster than "natural" snags, they will need to be replaced in order to ensure the necessary presence of snags in the Spotted Owl habitat.[19]

Shift in composition of regeneration. Overstorey retention may shift the understorey regeneration to more shade-tolerant species. Retrospective research in the Willamette National Forest in Oregon found greater percentages of western hemlock as remnant density increased (Traut and Muir 2000) but found decreased proportions of Douglas-fir only in remnant densities above 15 stems/ha (Rose and Muir 1997). Simulations of stand development with retention of 5 to 30 stems/ha suggest that, due to higher growth rates, regenerating western hemlock and redcedar dominated Douglas-fir (Hansen et al. 1995). In the CWHdm, D'Anjou (2002) documented increased density and greater proportion of shade-intolerant species beneath dispersed retention (initially 57 stems/ha) compared to clearcut conditions. Douglas-fir is a desirable component of Spotted Owl habitat, but dense understories impede Douglas-fir development and, without intervention, potentially extend the duration of the stem exclusion phase. Focussing on retaining the desired species of regeneration (e.g., Douglas-fir rather than western hemlock) may reduce the regeneration of more shade-tolerant species (such as hemlock) by limiting seed fall of undesired species, but the surrounding unharvested forest will remain a source of seed of all represented species.

Growth and yield. Retention has implications for stand growth and yield. Field studies in the CWHdm (D'Anjou 2002), IDFww[20], and elsewhere (Wampler 1993; Acker et al. 1998; Buermeyer and Harrington 2002), plus modelling efforts, suggest that dispersed and/or grouped retention will reduce understorey growth and yield compared with conventional clearcutting. Modelling projections[21] suggest that, compared to conventional clearcutting, variable retention reduces yields over a rotation,

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[17] Retention system means a silvicultural system that is designed to: (a) retain individual trees or groups of trees to maintain structural diversity over the area of the cutblock for at least one rotation, and (b) leave more than half the total area of the cutblock within one tree height from the base of a tree or group of trees, whether or not the tree or group of trees is inside the cutblock.
[18] Brian D'Anjou, Research Silviculturist, Coast Forest Region, British Columbia Ministry of Forests and Range, Nanaimo, B.C.; unpublished research data, circa 2004.
[19] J.B. Buchanan, Wildlife Biologist, Washington Department of Fish and Wildlife, Olympia, Washington; personal communication, June 2005.
[20] Brian D'Anjou, Research Silviculturist, Coast Forest Region, British Columbia Ministry of Forests and Range, Nanaimo, B.C.; unpublished research data.
[21] DiLucca, M.D. Yield implication of variable retention harvesting. Presentation to Western Mensurationist Meeting, July 1–3, 2003, Victoria, B.C.

and that the reduction will be proportional to the degree of stem dispersion. I.e., the aggregation of retained stems into a few groups has less impact on yield than evenly dispersed trees. These projections focused on the underplanting of Douglas-fir, which is considered moderately shade tolerant to shade intolerant within the range of ecosystems on the Coast, but projections do not account for the growth and yield of the retained overstorey. Planting of genetically improved seedlings may partially offset reductions in Douglas-fir growth because the genetically induced growth benefits associated with open-light conditions (clearcut) appear to persist in partial shade (St. Clair and Sniezko 1999). Reduced yield may also be mitigated on some sites by planting desired shade-tolerant species. While reduced growth and yield will not conflict with the primary objective of creating a stand that has the potential to develop as owl habitat, dispersed retention may lengthen the time required to meet minimum tree diameter targets.

Regeneration health. Overstorey retention has been shown to affect the health of the understorey plantation. Stem gall development (D'Anjou 2002) and budworm attack[22] have been documented on Douglas-fir regeneration beneath a dispersed Douglas-fir overstorey. Retention infected with hemlock dwarf mistletoe (*Arceuthobium tsugense*), although potentially beneficial within owl habitat (Table 1), is a source of infection to regenerating stands (Muir et al. 2004) and it can negatively affect long-term stand growth. Operational control of the disease, such as planting mistletoe-resistant species or applying potential biological control (fungi) (Deeks et al. 2000) may help reduce any conflicts between management objectives.

Long-term habitat development. While one goal of heavy volume removal is to create a structurally heterogeneous stand with the potential to provide future owl habitat Franklin et al. (2002) suggest that shelterwoods—which dispersed retention can resemble visually and structurally—spatially homogenize the treated forest rather than maintaining the spatial heterogeneity of natural stands. Aubry et al. (1999) suggest dispersed retention is most appropriate where objectives require that target structures or conditions be uniformly distributed—e.g., in downed woody material, or snags—to mitigate microclimate or hydrological impacts. While dispersed retention will provide structure throughout the stand, owl habitat development may be enhanced if retention focuses on trees with the greatest future habitat value, including wildlife trees with defects (such as mistletoe brooms) and trees suitable for snag development, regardless of spatial pattern.

Guidelines for Partial Harvesting: Maintaining or Enhancing Spotted Owl Habitat in Older Stands

Light-Volume Removal

Guidelines for partial harvesting were established with an emphasis on improving or enhancing stand conditions for the owl (Spotted Owl Management Inter-Agency Team 1997b). Partial harvesting practices are applied to upgrade habitat of moderate quality (Type B, 100-to-140-year-old trees) to superior quality (Type A), or to accelerate development of owl habitat through management of younger stands. For the following review, the former is considered "maintenance and enhancement" and the latter "recruitment". Under the Spotted Owl Management Plan, "light volume removal" is prescribed "to maintain but not degrade habitat quality" of mature timber (stand age between 80 and 110 years) within the Special Reserve Management Zones and activity centers, while providing a source of timber and economic return (Spotted Owl Management Inter-Agency Team 1997b). Commercial thinning can be considered a type of partial harvesting for habitat recruitment.

All partial harvesting prescriptions must meet specified restrictions, including the following (Spotted Owl Management Inter-Agency Team 1997b):

- Harvest, evenly over the block, up to one-third of the basal area from each 10-cm diameter class. Volume removal in excess of 33% is permitted if approved by officials.
- Patch cuts (0.05–0.5 ha) can represent no more than 5% of the prescribed area, with openings being a minimum of 100 m apart (edge to edge) from adjacent patch cuts, clearcuts, or natural openings that are at least 0.25 ha. To create openings >0.5 ha requires the approval of officials.
- Yarding corridors cannot exceed the average inter-tree spacing, based on the number of stems retained per hectare (Table 2).
- Maintain or create 5 snags/ha with >50 cm dbh in maritime ecosystems and >30 cm in submaritime and continental ones.
- Maintain a minimum crown closure: 60% in the wetter maritime ecosystems, 50% in the drier maritime.

Based on expert opinion and stand-structure stage, Spotted Owl Management Inter-Agency Team (1997b) suggests that up to four entries might be required to accelerate forest development to old-growth-type conditions.

Using Partial Harvesting for Habitat Maintenance or Enhancement: Operational Experience

The implementation of three site-specific Silviculture Prescriptions[23] following the application of partial harvesting guidelines, and subsequent field visits to these stands, are described in this section. Formal documentation regarding the ability of the post-harvest stand structure to meet structural objectives was not available for the authors to review.

Ford Mountain

A partial harvesting prescription[24] developed in 2002 was applied to a 15.8-ha block of mature (100 to 110 years old) stand of mixed Douglas-fir, western redcedar, and western hemlock near

[22] Brian D'Anjou, Research Silviculturist, Coast Forest Region, British Columbia Ministry of Forests and Range, Nanaimo, B.C.; unpublished research data.
[23] Recent changes in provincial legislation eliminate the need to prepare new Silviculture Prescriptions. Existing Silviculture Prescriptions will largely remain in effect for the duration of their terms. Silviculture Prescriptions will be replaced by sites plans that Licensees will be required to prepare, but not submit for government approval (British Columbia Ministry of Forests and Range 2005b).
[24] The authors of this report viewed these prescriptions in the summer of 2003.

Table 2. Average widths of corridors required for partial harvesting (Spotted Owl Management Inter-Agency Team 1999).

Stems retained in mature layers (no./ha)	Average corridor widths (m)
173	7.6
200	7.0
250	6.3
300	5.8
400	5.0
500	4.5
625	4.0
800	3.5
1000	3.2

Ford Mountain in the Chilliwack Forest District (CWHds1) (Figure 6). The assessment of the habitat's suitability for Spotted Owls was attached to the Silviculture Prescription (Appendix E) and it indicated the stand met either Type B or Type A habitat definitions as per the Spotted Owl Management Plan (Appendix A).

Harvesting was designed to reduce stand volume by 30%. The stated objective was to "maintain all Type B Spotted Owl habitat attributes (drier submaritime ecosystems) or meet Type A habitat criteria".[25] The Silviculture Prescription suggests all stand attributes would meet Type B criteria (forage, dispersal, roosting), of which six attributes would meet Type A. Allowing for crown closure and larger tree diameters in the future would bring the site up to the requirements for Type A habitat, although a time period was not specified. Both coarse woody debris amounts and snag densities would be elevated in order to meet the definition of Type A habitat through harvest. The Prescription did not address windthrow risk.

Harvesting was conducted by manual falling and ground-based skidding in corridors averaging 6.5 m wide. The Silviculture Prescription committed to meeting the specifications for Type A habitat by increasing the density of snags >50 cm dbh—from preharvest levels of 2 snags/ha to post-harvest levels of 5 snags/ha—through retention and/or creation.

A field visit to the site two years after the completion of harvesting revealed low harvest-related damage to the residual

Figure 6. Harvested gap in forest near Ford Mountain (Chilliwack Valley, Chilliwack Forest District) after partial harvesting prescription.

stand, little apparent windthrow, and an estimated crown closure of 50%. Understorey vegetation development (shrubs and ferns) appeared vigorous, although it is a potential short-term deterrent to the establishment of new conifer regeneration. While underplanting with shade-tolerant redcedar and western hemlock was proposed, the Silviculture Prescription does not provide density targets for lower crown classes and therefore descriptions of conditions under which planting could occur are lacking. Post-harvest sampling of coarse woody debris would determine the success of the Silviculture Prescription in meeting the criteria for Type A habitat, and determine whether further enhancement is necessary.

Big Silver River (Pine Creek)

Partial harvesting guidelines were applied in 2002 to a 55.6-ha block near Harrison Lake in Special Reserve Management Zone

[25] Silviculture Prescription Amendment No. 1, Forest License A20542, Cutting Permit 030, Block no. 2001, February 27, 2002; Chilliwack Forest District, Coast Forest Region, B.C. Ministry of Forests, Chilliwack, BC.

12 (CWHds1) in the Chilliwack Forest District.[26] The stand, composed of Douglas-fir, western hemlock, and western redcedar, was described as a mixed stand of mature and immature types, having old-growth trees ≥250 years old and up to 160 cm dbh (some with fire scars), and having younger trees (120 years old) (Figure 7). The Silviculture Prescription[27] states harvesting "strives to achieve post-harvest stands that have Type A or Type B habitat characteristics" while providing harvest opportunities. Most pre-harvest stand attributes met the specifications for Type A habitat, except snag density, which met Type B specifications, and CWD amounts, which were not reported. Utilization standards, which were the ones in effect at the time of harvesting, were expected to meet CWD objectives. Pre-harvest and expected post-harvest diameter class distributions were described, as were stocking targets by canopy layer (British Columbia Ministry of Forests 1995).[28] Three species are preferred for stocking, including Douglas-fir and redcedar—either of which may be planted—and hemlock. Two deciduous species, birch and broadleaf maple, are considered acceptable.

A windthrow assessment suggested the windthrow hazard rating was moderate to high. Harvesting was therefore designed to limit windthrow, which included selection of more windfirm trees. Trees were pre-marked for harvest but substitution was allowed on a tree-by-tree basis to help ensure the safety of fallers. Douglas-fir within identified root rot centers was marked for

Figure 7. Yarding corridor (ground-based) and harvested gap in partial harvesting prescription near Pine Creek (SRMZ 12). (Photo by Chuck Rowan)

[26] A portion of this block was harvested according to heavy volume removal specifications.
[27] Silviculture Prescription, F.L. A19203, Block No. BS1408, July 23, 2002; International Forest Products Ltd., Harrison Lake, B.C.
[28] Canopy layers:
1. Mature layer means the layer of trees with a stem diameter ≥12.5 cm, measured at a height of 1.3 m.
2. Pole layer means a layer of trees with a stem diameter ≥7.5 cm, but <12.5 cm, measured at a height of 1.3 m.
3. Sapling layer means the layer of trees with a stem diameter <7.5 cm, measured at a height of 1.3 m.
4. Regeneration layer means the layer of trees <1.3 m tall.

harvest, and trees were removed in a narrow (5–7 m) strip pattern. Both cable and ground-based yarding (hoe forwarding and skidders) were employed. Douglas-fir and western redcedar were planted on skid trails, yarding corridors, and rehabilitated roads. Western hemlock is expected to regenerate naturally.

During the field review of the block, which took place about two years after harvesting, little scarring or other damage were observed; some windthrow was visible but its extent was not assessed. Ground-based yarding had exposed mineral soil, but potential for soil erosion seemed minimal due to site conditions. Expectations are that most of the block would be considered fully stocked due to the remaining trees in the three top layers. The degree of success of planted regeneration, especially that of Douglas-fir, in terms of survival and ability to compete against the more shade-tolerant western hemlock will be determined through future field reviews. Vegetation management is identified as a potential treatment for ensuring the site meets free-growing obligations. However, because the primary management objective is to manage owl habitat, any vegetation treatment must consider how the removal of deciduous species would affect the quality of owl habitat.

South Anderson

A partial harvesting prescription was developed in 2003 for Special Reserve Management Zone 11D in the Anderson Drainage, which is northeast of Spuzzum, British Columbia. The block is located on the east-facing slope in the CWHms1 in a mature stand (age class 8, >140 years old) of western redcedar, Douglas-fir, western hemlock, and Engelmann spruce (*Picea engelmanni)*. The stand contained trees with a wide range of tree diameters—some exceeding 100 cm dbh—and crown gaps occurred due to group mortality attributed to attacks by western spruce budworm (*Choristoneura occidentalis*).

Harvesting was proposed to "maintain or enhance the existing habitat for the Spotted Owls and create an economic return."[29] The site plan for the block was extensive (29 pages), and it divided the 90.9-ha block into three primary site units plus nine other minor site units representing the proposed patch cuts. The overall site was evaluated as Type B habitat. The harvesting goal was to remove the maximum basal area allowed under the guidelines for light variable retention (33%). Harvesting patterns included single-tree harvesting, harvesting in narrow corridors (maximum 7.6-m width), and patch harvesting (0.1–0.5 ha). Western redcedar poles (typically in layer 2) and lesser amounts of Douglas-fir and amabilis fir, where present, were pre-marked for harvest. Most post-harvest stand attributes were expected to meet Type A criteria, except that deficiencies would occur in the density of trees >51 cm dbh because pre-harvest densities of that size class did not meet the criteria. Planting with Douglas-fir and western redcedar would be restricted to openings >25 m^2.

Trees were felled manually and yarded by a Sikorsky 61 helicopter. Harvesting activities were conducted with on-site supervision to ensure prescription specifications were met. As observed from a neighbouring road, the harvested gaps were the only apparent evidence (Figure 8) of harvesting activities. A field review was conducted within one year of the completion of harvesting. The following were observed: little site disturbance due to helicopter yarding; a range of opening sizes in overstorey crown cover; and high levels of coarse woody debris in a range of decay stages and sizes overall, and which exceeded Type A amounts in two of the three main site units. Widely distributed lower cohorts, which were lacking in the Ford Mountain and Pine Creek sites, have the potential to respond positively with the canopy cover reductions. Relatively low abundances of understorey shrub, herb, or fern were expected to be enhanced following the creation of crown openings.

Partial Harvesting in Mature Stands: Summary of Field Visits

Overall, based on walkthroughs of parts of three partially harvested blocks, harvesting in the mature stands appeared innovative due to using a range of harvesting patterns and yarding methods. Harvesting also appeared to meet the spirit of the guidelines for achieving Spotted Owl habitat objectives, while accommodating operational limitations. However, these prescriptions lack any provision for assessing the short- and long-term implications for the quality of owl habitat, nor for the responses of the owls, competitors, predators, and prey. Prescriptions could be enhanced by including more thorough, clear, and consistent descriptions of pre-harvest stand structure, by tree species. The description should incorporate both merchantable and non-merchantable data in order to identify current stand structure, and it should include a clear description of the target stand in order to assess the implications of partial

Figure 8. Aerial view of the south portion of the Anderson drainage, shortly after low volume removal.

[29] Site Plan and Attachments, License A19202, Block 37-1, dated June 12, 2003; Richard J. Anderson Forest Consulting Ltd.

harvesting to all forest layers. Long-term implications to owl habitat of felling existing snags for the reasons of protecting workers, and replacing them by creating snags from live trees, should be considered because artificially created snags have a distinctly different decay pattern than natural snags. Because prescriptions cover only the initial harvesting entry and do not refer to subsequent entries, the potential for future entries must be assessed to determine whether the stands remain in the operable landbase. Stand-growth modelling, as described in the following section, should help provide resource managers with additional information regarding the implications for Spotted Owl habitat of using different harvesting regimes according to site-specific forest conditions.

TASS Simulation: Partial Harvesting Prescription

Stand growth modelling is a tool for evaluating whether alternative harvesting can meet the stated objectives of creating stands with desired characteristics. TASS was run to explore possible outcomes of using a light variable retention type of silviculture prescription such as that used in the South Anderson block (Figure 9). The stand modelled in TASS was similar to the South Anderson block but the modelled stand was younger and more homogeneous. The harvest was set at 30% of the basal area of trees at least 30 cm dbh to be removed across 10-cm diameter classes. Trees were removed either as single trees or as patch cuts (group selection) in gaps of <0.5 ha, and at least 100 m apart, and totalling no more than 5% of the total area. While the South Anderson block is a mix of Douglas-fir, western redcedar, western hemlock, amabilis fir, and Sitka spruce, the forest was simplified to a 60-ha block of 60% Douglas-fir and 40% western hemlock to facilitate modelling. The simulated block was grown to 100 years of age before the harvesting pattern was applied. The harvesting pattern (Figure 9) was visually similar to that viewed at South Anderson. In the simulation, regeneration was left to western hemlock naturals, and existing snags were removed during harvesting, to mimic Workers' Compensation Board regulations. The simulation was run for 100 years using a site index of 35 for Douglas-fir and 31 for western hemlock.

Simulation results indicate that although the majority of snags (all mortality) would be <30 cm dbh, over 40 snags/ha would be ≥30 cm dbh, and at least one would be >50 cm dbh within 50 years of the completion of harvest. Two strata would be formed: 100 years after the completion of harvest about 320 stems/ha of the original forest would still be standing, in addition to 150–200 surviving western hemlock naturals (Figure 10). In this scenario, western hemlock regeneration would form a single post-harvest cohort, which would be about 36 m tall and have a 30-m clear stem after 100 years. The simulated stand appeared to meet Type B criteria for owl habitat in the submaritime (Spotted Owl Management Inter-Agency Team 1997a) but it would not achieve the three or more canopy layers and seven or more snags ≥50 cm dbh required for Type A habitat. The simulated stand did meet the Type A criterion of stem density ≥50 cm dbh (173–247 stems/ha) and it would meet the snag

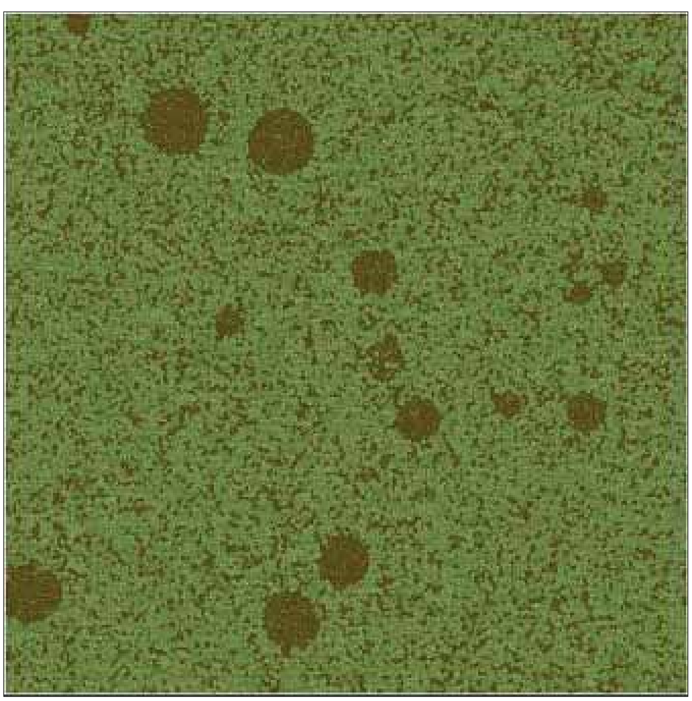

Figure 9. Representation of harvesting patterns on a 60-ha block following low volume removal.

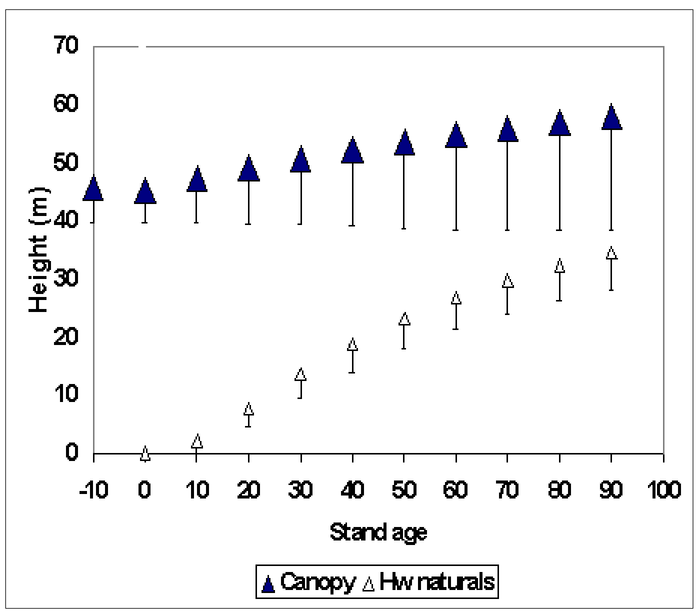

Figure 10. Simulation of the growth of a two-strata forest over a 100-year period after a low volume removal (age 0). Height of trees in the original forest are shown in black and the natural regeneration of western hemlock in the lower strata are open symbols. Length of the arrow estimates the crown length.

criterion if snags could be retained while still meeting the safety requirements of the Workers' Compensation Board. Snag requirements could also be met if clumps of trees were retained where some of the trees were ≥50 cm dbh, and preferably diseased or having other defects that hasten mortality.

Partial Harvesting in Older Stands: Relevant Research

Partial harvesting prescriptions, like other management prescriptions, are "untested hypothetical constructs" until validated by scientifically valid observations (Franklin 2005). Few well-documented examples of partial harvesting prescriptions in mature, late successional, and old-growth forests exist (Aubry et al. 1999); the long-term implications of treatments that are now being applied are therefore uncertain. Because clearcutting has been the dominant harvesting method on the coast, there are limited opportunities to do retrospective studies that are relevant to partial harvesting prescriptions. Reviews of past partial harvesting in the Pacific Northwest conducted in the 1930s in older Douglas-fir-dominated stands (150 to 600 years old) considered the practice to be "high grading" (Isaac 1956), because harvesting usually focused on removing only the largest trees. The negative effects included residual tree damage, windthrow, mortality, and conversion of the stand from desired Douglas-fir to more shade-tolerant species. In British Columbia "selective logging" first started in the Interior in "yellow pine" and southern interior "spruce" forests in the 1930s; both types of forests comprised smaller tree sizes and gentle typography suited to partial harvesting (Macbean 1948).

There is little experience to guide resource managers in developing subsequent prescriptions for older stands in order to meet the habitat requirements of Spotted Owl; harvesting in Washington and Oregon are limited to stands <80 years old (Interagency SEIS Team1994). Owl nesting sites are found in stands with a history of partial harvesting on the eastern edge of the Cascade Mountains in Washington (Buchanan et al. 1993) and in the western Cascade Mountains in Oregon (Irwin et al. 2000). Irwin et al. described features that silviculturists may be able to control in order to develop future owl habitat. These include control of tree density and form, woody debris, understorey vegetation (foraging site), and legacy retention trees (nesting site). However, rather than relying on research from Washington State, having local data will help re-evaluate whether or not existing guidelines are appropriate for our ecosystems.

Recently established trials in the CWHdm[30] have some relevance to partial harvesting and Spotted Owl habitat management (D'Anjou 2002). Prescriptions described as "extended rotations with commercial thinning" have been designed to accelerate the development of old-growth attributes in a mature Douglas-fir forest (120 to 130 years old). The prescriptions involve multiple harvesting entries over several decades. In two trials, the first harvesting entries used cable harvesting and narrow corridors to remove, respectively, 11% and 18% of the volume. Within the narrow yarding corridors, and compared to unharvested portions of the block, the number and total cover of understorey vegetation species increased,[31] natural regeneration density increased, and planted redcedar survival (>90% after five years) was enhanced. Challenges associated with these prescriptions include maintaining understorey conditions to sustain desired regeneration and vegetation development levels, as residual tree crowns expand and yarding corridors gaps close.

Flexibility in partial harvesting prescriptions may be needed to ensure that the long-term objectives for Spotted Owl habitat are met. Furthermore, designing subsequent entries (e.g., up to four, as recommended by Spotted Owl Management Inter-Agency Team 1997b) may require flexibility in applying treatments and developing approaches.

Corridors. Flexibility in width and spacing of yarding corridors was needed at implementation. Restrictive corridor widths limit operational flexibility in variable forest and site conditions. Wider corridor widths do not necessarily reduce habitat quality if corridor construction provides for the development of structurally heterogeneous characteristics of Spotted Owl habitat without degrading the overall stand. But, if a stand is currently used by owls, resource managers must be cautious not to compromise overall stand structure.

Gaps. Employing an ecosystem-based approach to designing harvest areas and patterns may be more effective for achieving operational objectives than for restricting the size and distance between gaps because the latter case usually results in removing trees in narrow strips. As suggested by Franklin et al. (2002), gap development in Douglas-fir forests enhances horizontal heterogeneity at later stages of stand development. Natural disturbances, including gap creation, provide guidance for designing prescriptions to sustain biodiversity (Coates and Burton 1997; Mitchell et al. 2003). Small-scale trials could be applied in less contentious areas to assess implications of harvesting in gaps. Partial harvesting in gaps may consider using "standing-stem harvesting," whereby a tree is cut almost completely through, but some connecting wood is left in the center, supported by wedges. A helicopter, specially equipped with a grapple and cable, then snaps and removes the stem. Standing-stem harvesting can reduce damage to existing understorey regeneration that would, potentially, otherwise be damaged during manual falling and mechanical yarding.

Establish alternatives. Uncertainty exists over the effectiveness of current partial harvesting prescriptions. Bormann and Kiester (2004) proposed using "options forestry" in cases where the outcomes of forestry practices are uncertain. Alternative management approaches can be established to achieve defined objectives, and periodic monitoring can assess if alternative approaches are successful in meeting specific long-term objectives, thus providing opportunities for learning and integrating results into subsequent prescriptions. Block et al.

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[30] See http://www.for.gov.bc.ca/rco/research/projects/RCSF/RCSF.htm for information about the Roberts Creek Study Forest.

[31] Brian D'Anjou, Research Silviculturalist, Coast Forest Region, B.C. Ministry of Forests, Nanaimo, B.C.; unpublished data.

(2001) provide guidelines for scientifically monitoring the effects of treatments on wildlife. Monitoring could include the following activities.

- Monitor regeneration development within openings (corridors and gaps), to determine conditions suitable for the survival and growth of desired species and for the development of lower crown classes.
- Monitor residual stand growth response, including lower crown classes, to develop time estimates for meeting the desired structural objectives, e.g., multi-storey stand structure, large-diameter trees, and snags.
- Monitor development of other attributes important to the owl and its prey; for example, vertical and horizontal complexity, dead wood, and lower vegetation.
- Assess the effects of stand entries on competitors and predators, and the occurrence of owls or prey species, to learn how the stand is used.

Predictive stand modelling—e.g., using TASS, ZELIG, ORGANON—will be a vital tool for projecting long-term stand structure after partial harvesting and other forest treatments. Verifying model results with field sampling will confirm the effects of forest stand enhancement.

Recruiting Owl Habitat in Young Stands

Recruitment Rationale

The development of younger plantations can be different than that of naturally disturbed stands because of differences in the patterns of regeneration and species composition (Poage and Tappeiner 2002), which in turn affect the potential for recruiting owl habitat. Greenough and Kurtz (1996) simulated stand-tending practices in clearcut and planted sites using TASS, but found no scenarios that successfully predicted recruitment of Spotted Owl habitat meeting the Type A or B requirements within 150 years of treatment. Similarly, Andrews et al. (2005) found young stands (age class 50), without incurring silvicultural intervention or natural disturbance, did not develop features associated with owl nest sites within 160 years total stand age.

The potential for silviculture practices to accelerate the development of owl habitat was recognized early on in the development of the Pacific Northwest owl conservation strategy (Thomas et al. 1990) and was supported through the establishment of local operational guidelines (Spotted Owl Management Inter-Agency Team 1997b) for enhancing owl habitat in younger stands. Andrews et al. (2005), utilizing the ORGANON growth model, found multiple thinnings of a younger Douglas-fir stand, combined with underplanting, leads to forests structurally similar to sampled owl nest sites in the Central coast of Oregon. Modelling of young Douglas-fir forest development has shown that silvicultural treatments promote the development of structurally complex stands that reflect late successional conditions (Garman et al. 2003, using ZELIG.PNW 3.0). Silvicultural treatments can promote the development of multi-storey structures and large-diameter trees (Barbour et al. 1997, using ORGANON). Modelled simulations of various thinning regimes in 40-year-old Douglas-fir stands (Garman et al. 2003) and 15-to-30-year-old stands (Barbour et al. 1997) support the notion that silvicultural interventions hold promise for accelerating stand development.

Operational Experience

Local experience in recruiting Spotted Owl habitat in younger stands is limited. One example is a commercial thinning applied in a structurally uniform 35-to-40-year-old Douglas-fir plantation in a Forest Management Agreement near Slollicum Creek (CWHdm) (Figure 11). The area was planted after being disturbed by wildfire. Subsequent juvenile spacing and fertilizing resulted in uniform diameter and spacing with limited habitat attributes for owls. The site was assessed as unsuitable Spotted Owl habitat (i.e., Type C: marginal).

The commercial thinning was developed in 2002 to "provide for the maintenance of Spotted Owl and wildlife attributes"[32] plus provide merchantable timber, a stated objective in the Forest Management Agreement. Harvesting was described as "a low thinning". Basal area retention was set at ±50% (270 stems/ha, ranging from 150 to 370, or 25 m^2 basal area), and included harvesting of root rot zones (*Phellinus weirii)*. Root rot centers were replanted with root rot resistant species—including deciduous trees—which are expected to improve various stand values including "biodiversity and stand-level variability". Understorey vegetation vigour and diversity are expected to increase after harvesting, including development of western hemlock and redcedar understorey. The post-harvest stand remains graded as Type C (marginal) habitat. It will require

Figure 11. Commercial thinning at Slollicum Creek (CWHdm) for future development of owl habitat.

[32] Silviculture Prescription, License A56389, Small Business Forest Enterprise Program, dated August 6th, 2002. east side of Harrison Lake (Sasquatch Spotted Owl SRMZ #5).

additional treatments to elevate it to suitable owl habitat. Thinning at 20 to 30 years post-harvest, and fertilization 5 to 7 years after thinning, may be required to encourage understorey tree and vegetation development.

A field review of the block revealed a more open overstorey crown compared to that in unthinned portions of the block. Harvesting-related damage to the residual stand appeared low. Enhanced development of shrub, fern, and deciduous trees (including vine maple) was also observed. Because snags were lacking, five limby trees (wolf trees) were selected for retention to provide future snags, and any trees scarred during harvesting are expected to also contribute to future snag and wildlife tree development. The amount of coarse woody debris was low, which was a result of past fire and high utilization factors, but it was expected to be recruited from windfall and tree mortality related to root rot.

There are some alternative approaches that could be used in younger, structurally simple stands to create desired owl habitat attributes.

- Vary residual stand spacing to create greater heterogeneity in understorey conditions. This should develop desired complexity than that which results from the uniform spacing that is typically applied for timber-management objectives. Armleder (1999) discusses the benefits and the application of clumpy spacing (less uniform) in the dry belt Douglas-fir forests.
- Plant desired species (e.g., redcedar) immediately, which, in combination with natural regeneration, will hasten the development of lower canopy layers to initiate multi-storey stand structure.
- Leave woody material (thin to waste) on site during thinning as a means of contributing to CWD abundance. This will provide woody material with advanced decay when the future stand begins to meet habitat requirements.

Relevant Research

Recruiting owl habitat in younger stands through silviculture has been explored in the U.S. Pacific Northwest. The following are potential sources of guidance for designing prescriptions.

- *Northwest Forest Plan (NFP).* The Northwest Forest Plan set aside large portions of U.S. federal land, including plantations between 10 and 50 years of age, for late successional reserves. The Northwest Forest Plan suggested the application of intermediate treatments (thinning, underplanting, snag development, reforestation, and fire) on these plantations could assist development of late successional characteristics in young stands. The Tioga Creek Subwatershed Density Management Plan (Bureau of Land Management 2002), which was one outcome of the Northwest Forest plan, was prepared for a late successional reserve in Oregon. It provides specific thinning prescriptions for a range of stand types with some relevance to local ecosystems.
- *Habitat Conservation Plans (HCP).* Habitat Conservation Plans were developed in Washington State to increase the amount of late successional habitat on trust lands. These plans address the management of younger stands to create complex owl habitats. The Habitat Conservation Plans developed for the 36 640-ha Cedar River watershed near Seattle has relevance to management of lower elevation forests of Douglas-fir and western hemlock.
- *Research trials.* Researchers in Washington and Oregon are evaluating treatments and silvicultural systems relevant to developing Spotted Owl habitat in younger stands (Appendix F). The Forest Ecosystem Study in Washington State (Carey et al. 1999c) is assessing variable density thinning, underplanting, and den augmentation for developing Spotted Owl habitat in 60-to-70-year-old managed stands. The Olympic Habitat Development Study (Olympic National Forest 1995) is evaluating the potential for accelerating development of late-successional (old-growth) attributes in relatively uniform 40-to-70-year-old conifer stands. The effects of variable density thinning (Harrington et al. 2005), coarse woody debris arrangement, and supplemental planting on stand structure and future development stands are being evaluated. Locally, studies designed with other objectives—e.g., thinning on visually sensitive sites (Phillips 2001)—demonstrate treatments in younger stands where harvesting entries may develop desired structural attributes. Thinning research trials have been established in younger stands (approximately 12 years old) in Washington State (Reutebuch et al. 2004), and plans are being established for thinning younger stands (10 to 12 years old) within the Roberts Creek Study Forest because excessive natural regeneration development beneath dispersed overstorey may hasten and extend the stem-exclusion phase of stand development. The stand currently lacks structural attributes for managing a wider range of non-timber objectives.

Potential Treatments

Treatments for creating or promoting Spotted Owl habitat are listed in Table 3, along with the structural attributes that will be enhanced. Some treatments would be applied simultaneously, and others independently, depending on stand conditions and objectives. Thinning for the purpose of developing specific stand-structural attributes has been extensively reported (Franklin and Spies 1991; DeBell et al. 1997; Hayes et al. 1997; Tappeiner et al. 1997). Thinning benefits include promoting establishment of shade-tolerant conifers (Del Rio and Berg 1979), hardwoods (Fried et al. 1988), and shrubs (Tappeiner and Zasada 1993; Huffman et al. 1994), and improved habitat quality for small forest-floor mammals (Larson 2001; Block et al. 2005).

The design of thinning regimes to promote spatial diversity will differ from that of prescriptions aimed at creating uniform stand conditions. Both residual densities and scale of treatment are factors to consider. Thinning densities can range, and may include:

- removal of all trees for larger gap creation (RD < 3.25)[33],
- densities simulating smaller gaps that have occurred due to natural disturbances,

[33] Relative density (RD) expresses the actual density of trees in a stand relative to the theoretical maximum density (Curtis 1982).

Table 3. Treatments for creating specific stand structural attributes relevant to Spotted Owl habitat. Selection of treatments and application methods depend on phase of stand development.

Treatments	Desired stand structural attributes: Increase tree species diversity	Create large-diameter trees with full crowns and large branches (future snags)	Enhance understorey vegetation abundance/diversity	Develop multi-storey canopy structure	Develop canopy lift
Plant	Plant to desired species mixture based on site ecology, canopy overstorey, and shade tolerance.	Wide spacing enhances development of trees with large branches.	Plant with variable spacing such that a portion of block is unplanted.	If required, plant shade-tolerant species if understorey conditions are suitable.	Underplant with shade-tolerant species, thus lifting the crowns of more shade-intolerant species.
Thin	Control species composition to meet goals.	Conduct wide spacing on a portion of the block.	Create gaps or utilize natural gaps (root rot) to sustain existing understorey vegetation.	Increase understorey light for development of lower canopy.	n.a.
In-fill/ underplant	In-fill with under-represented species.	n.a.	n.a.	Plant shade-tolerant species.	Underplant with shade-tolerant species, thus lifting the crowns of more shade-intolerant species.
Fertilize post-planting	n.a.	Accelerate development of larger trees.	n.a.	n.a.	n.a.
Prune	Allow greater understorey light for lower tree development	n.a.	Allow greater understorey light for lower vegetation development	n.a.	Prune lower branches where required.
Retain unharvested trees and patches	Provide seed source for range of tree species	Unharvested trees will continue to grow and perhaps re-establish larger crown through epicormic branching	Preserves species on site for future distribution.	n.a.	n.a.

- densities where timber management is an objective (RD 4.75 to 6.75), and
- densities where severe crowding is reducing tree growth with sparse understorey (RD > 6.75).

Wide spacing allows maximum growth of Douglas-fir (development of full crown, large branches, etc.). While Tappeiner et al. (1997) suggest densities of about 100 to 120 trees/ha produce growth rates in young stands comparable to those in the old stands, experience with wide spacing is limited in the Pacific Northwest. Widely spaced Douglas-fir canopies may close faster than expected and this in turn can challenge the maintenance of a second canopy layer.

Area over which a thinning treatment is applied is another factor to consider. Carey (2002) suggests that, in the Pacific Northwest, treatment areas that range from 0.25 to 1.0 acre (0.1 to 0.4 ha; average 0.5 acre, or 0.2 ha) are ecologically appropriate for variable density thinning. Application of variable density thinning can be simplified, e.g., alternate 0.5-acre sections (0.2 ha = 2000 m^2 = 45 x 45 m) to accommodate heavily thinned, moderately thinned, and unthinned areas; alternate treatments in strips; or alternate treatments between gaps free of trees and areas left unthinned. The guidelines for using juvenile spacing[34] to maintain biodiversity (Park 1993) may assist achievement of long-term goals for recruiting owl habitat. There remains uncertainty about how specific stands will respond to untested thinning prescriptions, which justifies using a range of approaches rather than relying on a single approach (Garman et al. 2003).

CONCLUSIONS

Prescriptions designed to meet Spotted Owl habitat objectives have highly increased levels of management complexity compared to those designed to establish even-aged plantations for meeting timber objectives. Furthermore, while prescriptions have employed a range of cutting patterns and yarding systems, the designs and their implementation followed untested guidelines. Subsequent prescription design will be improved as we gain greater knowledge of the implications of specific treatments on long-term stand structure and attributes. A monitoring program can provide this knowledge, as well as verify that standards and guidelines are being followed, determine whether the desired results are achieved, and evaluate whether underlying assumptions of guidelines are sound (Interagency SEIS Team 1994). The Northwest Forest Plan emphasizes the importance of such monitoring. Standardizing data collection will permit pooling of the results from the monitoring program, thus enhancing the opportunity to increase understanding of the implications of treatments.

In addition to monitoring, utilizing and updating computer models, as data become available, will improve assessment and comparison of implications to stand structure from specific treatments, and it will assist with selection of the most effective prescriptions. This knowledge will assist with developing and completing multi-entry prescriptions for the recruitment of owl habitat over an extended time period. There remains a lack of knowledge concerning how owls and their prey will use these transitional stands. Managing stands for owl habitat will require operational foresters to link knowledge of owl habitat use to site-specific ecology in a defensible prescription. No single prescription will likely apply to all sites.

Ensuring that Spotted Owl habitat enhancement is applied to sites with existing biological legacies (i.e., with large-diameter trees and snags, and higher levels of coarse woody debris) may provide better opportunities to recruit suitable habitat for nesting and foraging. For stands without these attributes, it may take many decades before the desired results emerge. Concerns about entering existing habitat—such as unknowingly removing habitat elements and/or degrading habitat quality, and the potential for a low return on high cost for given market conditions—have made the enhancement of mature stands a low priority. Costs of stand-level management are a driving factor in terms of the type, number, and extent of treatments that should be completed. Latta and Montgomery (2004) provide some initial guidance for minimizing the costs of management; i.e., older stands with high site quality and well-stocked stands will be better candidates for treatments than stands with lower site quality and poor stocking. Co-ordinating stand-level management within landscape planning that provides for owl dispersal, roosting, and nesting habitat will assist in selecting appropriate sites and setting priorities for applying silvicultural activities for enhancing owl habitat.

[34] Juvenile spacing is a silvicultural treatment that reduces the number of trees in young stands. It is often carried out before the target stems are large enough to have commercial value.

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APPENDIX A. CHARACTERISTICS OF SUITABLE SPOTTED OWL HABITAT IN BRITISH COLUMBIA (SPOTTED OWL MANAGEMENT INTER-AGENCY TEAM 1997A)

		Habitat type[a]	
Ecosystems	Natural disturbances	Type A, superior habitat (nest, roost, forage, and dispersal)	Type B, moderate habitat (roost, forage, and dispersal)
Wet: maritime Coastal Western Hemlock and Mountain Hemlock biogeoclimatic zones	Ranging from rare to infrequent stand-initiating events.	Three or more canopy layers. Multi-species canopy dominated by large (>75 cm dbh) overstorey trees (typically 37-185 stems/ha). Moderate to high (60-80%) canopy closure. Five or more large (>50 cm dbh) trees/ha with various deformities (e.g., large cavities, broken tops, dwarf mistletoe infections). Five or more large (>75 cm dbh) snags/ha. Accumulations (>268 m^3/ha) of fallen trees and other coarse woody debris on the ground.	Two or more canopy layers. Multi-species canopy dominated by large (>50 cm dbh) overstorey trees (typically 247-457 stems/ha, although densities as low as 86 stems/ha are possible where large-diameter trees are present). Moderate to high (60-80%) canopy closure. Five or more (>50 cm dbh) large trees/ha with various deformities (e.g., large cavities, broken tops, dwarf mistletoe infections). Five or more large (>50 cm dbh) snags/ha. Accumulations (>100 m^3/ha) of fallen trees and other coarse woody debris on the ground.
Dry: sub-maritime Coastal Western Hemlock and Mountain Hemlock; and Interior Douglas-fir and Engelmann Spruce-Sub-Alpine Fir biogeoclimatic zones	Ranging from infrequent stand-initiating events to frequent stand-maintaining fires; however, fire suppression has increased frequency of stand-initiating events.	Three or more canopy layers. Multi-species canopy dominated by large (>50 cm dbh) over-storey trees (typically 173-247 stems/ha, although densities as low as 86 stems/ha are possible where large-diameter trees are present). Moderate to high (60-85%) canopy closure. Five or more large (>30 cm dbh) trees/ha with various deformities (e.g., large cavities, broken tops, dwarf mistletoe infections). Seven or more large (>50 cm dbh) snags/ha. Accumulations (>268 m^3/ha) of fallen trees and other coarse woody debris on the ground.	Two or more canopy layers. Multi-species canopy dominated by large (>30 cm dbh) overstorey trees (typically >247 stems/ha). Overstorey stands must contain 20% Douglas-fir and/or western hemlock. >50% canopy closure. Five or more large (>30 cm dbh) trees/ha with various deformities (e.g., large cavities, broken tops, dwarf mistletoe infections). Five or more large (>30 cm dbh) snags/ha. Accumulations (>100 m^3/ha) of fallen trees and other coarse woody debris on the ground.

[a] In general, stands ~100 to 140 years old and with tree heights >19 m are considered Type B, but they must be evaluated for other stand characteristics. In general, stands >140 years old and >19 m tall are Type A, but they must be evaluated for other stand characteristics.

APPENDIX B. TASS DESCRIPTION (ADAPTED FROM DI LUCCA 1999)

The Tree and Stand Simulator (TASS) is a biologically oriented, spatially explicit, individual tree model. It was designed to produce potential growth and yield tables for even-aged, managed stands. It is calibrated for four coastal and four interior species in British Columbia. TASS is driven by the height growth (i.e., it uses the B.C. Ministry of Forests recommended site index or height-age curves), branch extension, and crown expansion of competing trees. The model grows trees and simulates crown competition in a three-dimensional growing space. The crowns of individual trees add a shell of foliage each year and either expand or contract asymmetrically in response to internal growth processes, physical restrictions imposed by the crowns of competitors, environmental factors, and cultural practices. The volume increment produced by the foliage is distributed over the bole annually, and is accumulated to provide tree and stand statistics. More information about TASS can be found in the publications by Mitchell (1975) and Mitchell and Cameron (1985).

TASS generates growth and yield information for even-aged stands of pure coniferous species of commercial importance in coastal and interior forests of British Columbia. It is mainly used for:

- stand-level crop planning;
- stand-level silvicultural treatment decision-making (e.g., espacement, fertilization, pruning, pre-commercial, and commercial thinning);
- forest-level planning including long-term timber supply projections for managed second-growth stands;
- predicting impacts of pest and disease yield (e.g., laminated root rot and spruce weevil);
- predicting height-growth repression in lodgepole pine stands;
- investigating tree growth and stand dynamics;
- teaching growth and yield, and stand dynamics;
- generating stand density management diagrams; and
- predicting wood quality (i.e., size and distribution of branch knots and juvenile-mature wood distribution) used by SYLVER (Silvicultural treatments on Yield, Lumber Value, and Economic Return) to determine product value and economic return.

The main limitation of TASS is that it does not predict the yield of complex stands (i.e., mixed-species and/or uneven-aged stands).

TASS is calibrated to conform with data derived from research trials and remeasured plots located in managed and unmanaged stands. Most of the biological growth relationships in TASS are derived from detailed stem analysis of tree boles, branches, and foliage. A total of 11 989 permanent plots (i.e., comprised of 43 799 plot measurements)—established for local species growing within British Columbia, Alberta, the Pacific Northwest region of the United States, Europe, and New Zealand—have been consistently summarized and classified by species and treatments including control, thinned, and fertilized (Goudie 1980).

APPENDIX C. STUDY BLOCKS WITH SPOTTED OWL HABITAT MANAGEMENT OBJECTIVES: SUMMARIES OF SITES AND PRESCRIPTIONS

	Type of management, and location				
	Heavy volume removal (HVR)	Light volume removal (LVR)			
	Pine Creek, Big Silver River	Pine Creek, Big Silver River	Ford Mountain, Chilliwack Forest District	Anderson River, Chilliwack Forest District	Harrison Lake Block 152, Chilliwack Forest District
SRMZ (activity center)	12	12	2 C	11 D	12
Year of prescription	2002 (July)	2002 (July)	2002 (Mar)	2003 (June)	2001 (Oct)
Area	8.3	55.6	15.8	90.9	43.8
Ecosystem	CWHds1	CWHds1	CWHds1	CWHms1	CWHds1
Forest type	Mature (110-120 years)	Mature/old-growth mixture	100-110 years	Mature/old-growth mixture	Mature/old-growth mixture
Species	Cw Hw Fd Mb	Cw Hw Fd Mb	Fd Hw Cw	Cw Fd Hw Ss	Fd Cw Mb Hw
Habitat assessment	Not suitable habitat	Most Type A, others Type B	All Type B, and some Type A	Yes for each of three units	All Type B, and some Type A
Yarding method	Ground-based and cable	Ground-based and cable	Ground-based	Helicopter	Cable and ground-based
Planting prescribed	FD, Cw (resistant species in root rot)	Skid and yarding trails, Cw, natural Hw	If required	Only in patches	Patches and single-tree
Snag development	Possible creation if required	Post-harvest densities meet targets	Post-harvest densities meet targets (may create)	Post-harvest densities meet targets	Post-harvest densities meet targets
Deciduous management	No	No	No	No	Yes
Root rot management	Yes	Yes	Not required	Not present	Not required
Windthrow management	Tree-top pruning, anticipate 10% loss	No	No	No	Not required

APPENDIX D. HARVESTING STUDIES EVALUATING ALTERNATIVE SYSTEMS AND WITH POTENTIAL RELEVANCE TO RECRUITMENT OF SPOTTED OWL HABITAT, LISTED BY YEAR OF ESTABLISHMENT

Study	Objective	Treatments	Location
Boston Bar Partial Harvesting Study (D'Anjou 1997)	Demonstrate and evaluate the effects of a range of dispersed retention densities on regeneration, micro-climate, and vegetation.	Dispersed retention	Boston Bar (IDFww)
Roberts Creek Study Forest (D'Anjou 2002)	Demonstrate, evaluate, and develop silvicultural systems to meet a variety of biological, social, and economic objectives.	Aggregated retention Dispersed retention Extended rotation	Sunshine Coast (CWHdm)
Montane Alternative Silvicultural Systems (MASS) (Arnott et al. [editors] 1995)	Study the biological and silvicultural impacts of alternative silvicultural systems for coastal montane forests.	Clearcut Patch cut Green tree retention Shelterwood	Montane Forest south of Campbell River (CWHmm2)
Silvicultural Options for Harvesting Young-Growth Production Forests (Reutebuch 2001; de Montigny 2004; Curtis et al. 2004)	Evaluate forestry practices and silvicultural systems that can be used to reduce visual impacts of harvesting operations while maintaining a productive forest.	Aggregated retention Dispersed retention Extended rotation	Campbell River, Vancouver Island (CWHxm); Capitol State Forest, near Olympia Washington
Forest Project: Weyerhaeuser (Weyerhaeuser 2002)	An adaptive management program designed to examine the effectiveness of retention systems and stewardship zoning in maintaining those forest attributes necessary to sustain biodiversity and essential ecosystem functions.	Dispersed and group retention Group selection Clearcut	Multiple sites in coastal B.C., including Vancouver Island
Overstorey Density Study (Capitol Forest) (Brodie 2006)	Growth of planted regeneration (Douglas-fir, western hemlock, and redcedar) evaluated under six levels of overstorey retention.	Dispersed retention	Capitol State Forest near Olympia, Washington

APPENDIX E. EXAMPLE OF A COMPLETED SPOTTED OWL HABITAT SUITABILITY ASSESSMENT FORM, WITH CURRENT AND POST-HARVEST LEVELS OF STRUCTURAL ATTRIBUTES MANAGED FOR SPOTTED OWL HABITAT

Spotted Owl Habitat Suitability Assessment: Dryer Submaritime Ecosystems

Location: Ford Mountain . **License #/Block:** FL A20542 C.P. 30 . **Standards Unit #:** 1 .

Habitat Type	Type B – Moderate Quality (forage, dispersal, roosting)	Type A – Superior Quality (nesting, roosting, foraging, dispersal)	Current Stand Attributes	Post-treatment Condition
1. Stand Age	Mature and Old	Old	130 – 140 years	130 – 140 years
2. Biogeoclimatic Zone	CWHds1, CWHms1, CWHms2, MHmm2, ESSFmw, IDFww	CWHds1, CWHms1, CWHms2, MHmm2, ESSFmw, IDFww	CWHds1	CWHds1
3. Number of Canopy Layers	≥2	≥3	≥3	≥3
4. Crown Closure	≥50%, 5m open canopy above ground	60-85%, 5m open canopy above ground	73.8%	≥50%
5. Tree Species	≥2 tree species	≥2 tree species	5	5
6. Large Trees	≥30 cm dbh overstory	≥51 cm dbh overstory of 173-247 stems/ha	≥30 cm dbh - 329 ≥51 cm dbh - 159	≥30 cm dbh - 230 ≥51 cm dbh - 111
7. Deformities/ damage (Wildlife trees)	n/a	≥5 trees/ha with deformities/damage	≥5 trees/ha with deformities/damage	≥5 trees/ha with deformities/damage
8. Snags	≥5 snags/ha>30 cm dbh	≥5 snags/ha>51 cm dbh	≥30 cm dbh - 54 ≥51 cm dbh - 2	≥51 cm dbh - ≥5
9. Coarse Woody Debris	≥100 m³/ha large CWD,>10 cm dbh at various stages of decomposition	≥268 m³/ha large CWD,>10 cm dbh at various stages of decomposition	172.7 m³/ha (per MOF summary attached)	≥268 m³/ha
10. Understory Vegetation (species & abundance)			See Plant Indicator Summary and field cards for Plots 2 and 3 attached to silviculture prescription.	

Description of projected future habitat conditions (Type A or Type B): All Type B attributes for forage, dispersal and roosting, with canopy layers, number of species, wildlife trees, snags, coarse woody debris, and understory vegetation meeting Type A habitat criteria; Type A habitat when stand age, crown closure and tree diameter criteria are achieved.

APPENDIX F. STAND-MANAGEMENT STUDIES WITH RELEVANCE TO SPOTTED OWL HABITAT ENHANCEMENT

Study	Objective	Forest type	Treatment
Forest Ecosystem Study (Carey et al. 1999c)	Developing Spotted Owl habitat in 60-to-70-year-old second-growth stands.	60-to-70-year-old second growth.	Variable density thinning (3 densities) and underplanting. Den augmentation.
Olympic Habitat Development Study (Olympic National Forest 1995)	In uniform stands, accelerate development of habitat conditions that are similar to those in late successional ("old-growth") stands.	Range of west coast forests between 40 and 70 years old, Olympic Adaptive Management Area (AMA), Washington.	Retention of uncut patches, creation of small openings, and removal of 30% of basal area. Coarse woody debris manipulations. Seeding or planting to accelerate establishment of other plant species.
H.J. Andrews Experimental Forest, Western Cascade Range, Oregon, uneven-aged management (Tucker 1999)	Develop alternative approaches to initiate uneven-aged/multi-cohort stand structure.	30-to-40-year-old plantations, Blue River Ranger District of theWillamette National Forest, Oregon.	Thinning to maintain multi-storied stand (relative density of 20-40). Thinning by single-tree selection to maintain the stand at a relative density of 30-50. Group selection through small gaps of varying size and age.
Young stand thinning and diversity study (Cascade Centre for Ecosystem Management 2001)	Accelerate development of late successional habitat.	35-to-50-year-old Douglas-fir (90%) plantation, near Blue River Ranger Station, Oregon.	Four treatments: light thin (~100-120 trees/acre), heavy thin (~50-60 trees/acre), light thin with gaps (~0.5-acre gaps over 20% of the stand), uncut control, underplanting, and snag creation treatments.