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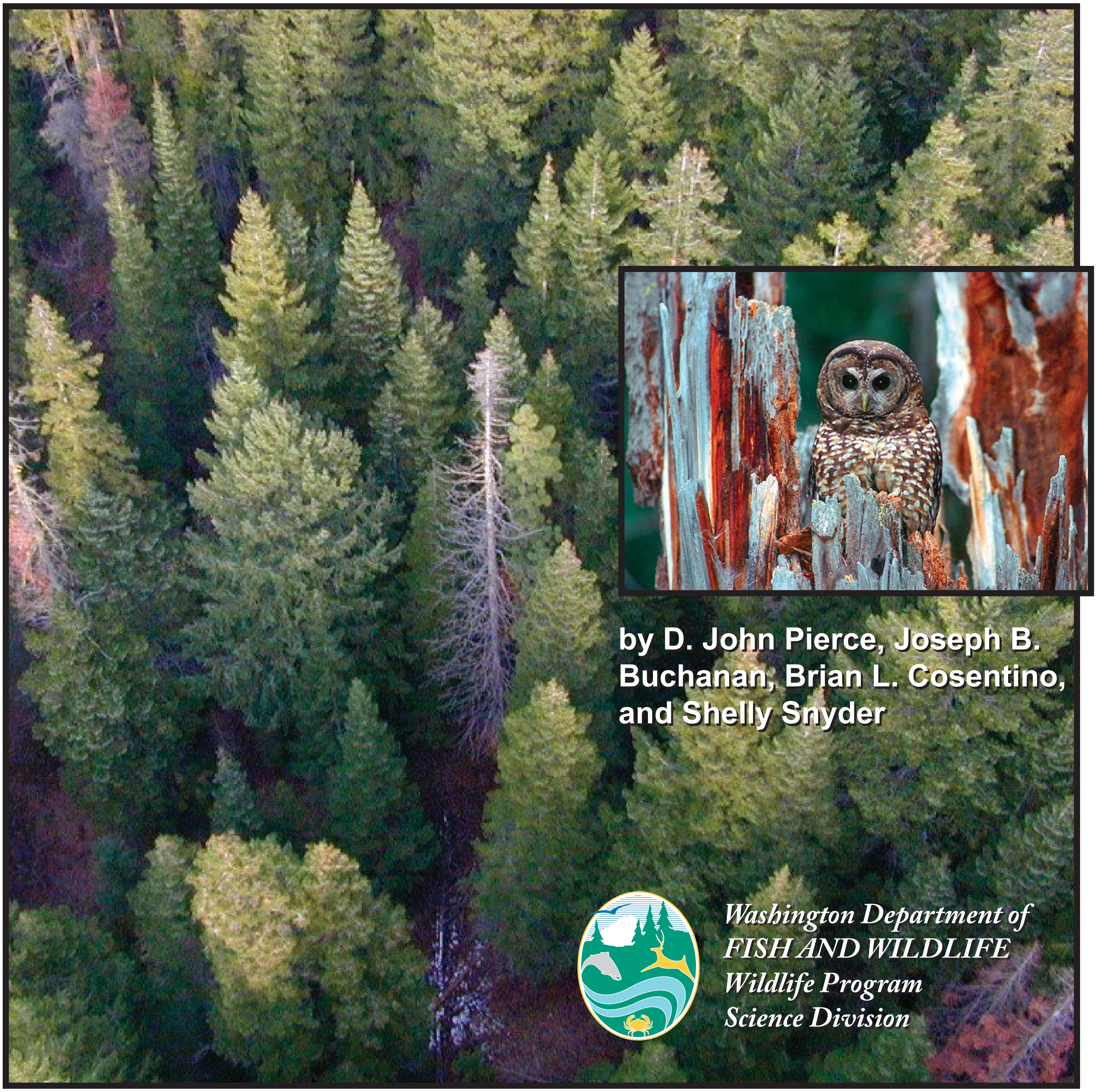
An Assessment of Spotted Owl Habitat on Non-federal Lands in Washington between 1996 and 2004



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EXECUTIVE SUMMARY

Forest Practices Rules for the Northern Spotted Owl (*Strix occidentalis caurina*) were adopted in May 1996. These rules, which apply to nonfederal lands, established 10 landscapes – known as Spotted Owl Special Emphasis Areas (SOSEAs) – wherein proposed harvest of suitable owl habitat would receive environmental review designed to provide a high level of protection. Under the rules, the level of habitat protection varied depending on whether habitat was located inside an owl management circle located inside or outside of SOSEAs or whether or not habitat lands were part of a Habitat Conservation Plan (HCP) approved by the U.S. Fish and Wildlife Service.

In 2004 the Department of Natural Resources and the Washington Department of Fish and Wildlife entered into a cooperative agreement to gather information that could be used by our agencies and the Forest Practices Board as part of a review of the Forest Practices Rules. Specific objectives of this study were to: 1) estimate the amount of suitable Spotted Owl habitat in 2004 on landscapes affected by state and private forest practices, 2) estimate the amount of Spotted Owl habitat harvested under the regulatory authority of the Forest Practices Rules between 1996 and 2004, and 3) determine the current status and net change (accounting for gains and losses) of Spotted Owl habitat on landscapes influenced by the Forest Practices Rules adopted in 1996.

The study area outside of SOSEAs included all forested lands within Status 1-3 (i.e. territorial) Spotted Owl management circles where at least 10% of the acres within a circle were under state or private ownership. In addition, all lands and all Status 1-3 owl circles inside SOSEAs were included in the study area. The study area included 450 owl circles and totaled 3,233,942 acres. The study area was divided into two sampling strata categories: 5 geographic zones (East Cascades,

North Cascades, South Cascades, Olympics, and Southwest), and an updated GIS layer that mapped seral strata (early, mid, late, and “other”).

We determined presence and absence of suitable Spotted Owl habitat at 1,514 randomly selected locations using orthophoto interpretation for early and “other” strata and helicopter reconnaissance for mid and late seral strata. Helicopter classification accuracy rates were determined by ground visits to collect quantitative stand plot data at a subset of these same plots to determine whether or not the stand met the suitable habitat definitions of the Forest Practice Rules. These accuracy classification rates were used to adjust the helicopter data to more accurately estimate the amount of Spotted Owl habitat on the landscape in 2004.

The amount of harvested habitat from 1996-2004 was estimated first by calculating the total amount of harvest that occurred during this time period regardless of Spotted Owl habitat condition. We contracted with the U.S. Forest Service Pacific Northwest Forestry Sciences Laboratory in Corvallis, Oregon (FSL), to map both clear-cut and partial harvest areas that occurred between 1996 and 2004. Using this map information, our next step was to estimate the percentage of the harvested areas that also met Spotted Owl habitat criteria in 1996 (prior to harvest) as defined by the Forest Practices rules. This was done by modeling remote sensing information collected in 1996 by the Interagency Vegetation Mapping Project team to predict Spotted Owl habitat presence within the harvested areas identified by the change map produced by the U.S. Forest Service’s lab. Stand inventory data with known Spotted Owl habitat conditions obtained from the Washington Department of Natural Resources were used to develop these models.

The ground plot data used to calibrate the helicopter predictions for 2004 conditions were used to develop accuracy classification tables for the 1996 model predictions as well. We then compared the estimates of the amount of habitat existing in 2004 with the amount of harvested habitat from 1996-2004 to calculate a Relative Change Index (RCI) to assess how the amount of harvested habitat since rule adoption in 1996 related to the total amount of habitat remaining on the landscape in 2004. Data were summarized separately for federally approved Habitat Conservation Plans (HCP) and non-HCP landscapes. Data were also summarized separately for lands within SOSEA boundaries (both inside and outside Spotted Owl management circles) and for lands outside of SOSEAs. All lands outside of SOSEA boundaries were within the boundaries of owl management circles.

Study Area Summary

We estimated that there was about 816,300 total acres of Spotted Owl habitat on all land ownership categories in our study area in 2004. Most suitable owl habitat in 2004 (56%) occurred on federal lands, and lesser amounts were present on state-local lands (21%), private lands (22%) and tribal lands (1%). Approximately 75% of the habitat in the study area occurred on non-HCP lands. Approximately 172,000 total acres of forest were harvested on the study area from 1996-2004, most of which occurred on non-HCP lands (76%). The majority of the total harvest occurred on private (79%) and state-local (14%) lands.

An estimated 33% (56,400 acres) of the harvested lands also met Spotted Owl habitat conditions as defined by the Forest Practices Rules. Approximately 71% of the harvested habitat occurred on non-HCP lands. Most of the harvested Spotted Owl habitat was on private (77%) and state-local (15%) lands. We estimated an average RCI value of 6% (95% confidence Interval (CI) = 5% - 8%) of the maximum potential amount of habitat in 2004 was harvested during the 9 years following rule adoption in 1996. RCI values on the study area ranged from 4% in the Olympics to 32% in the Southwest zone.

Changes in non-HCP Spotted Owl Special Emphasis Areas

The majority of non-HCP acres within SOSEAs were on private (55%) and federal (43%) lands. We estimated that 277,200 acres of Spotted Owl habitat existed on non-HCP lands inside of SOEAs in 2004. The majority of the habitat acres on non-HCP lands within SOSEAs were either federal (64%) or private (35%). Most of the non-HCP SOSEA Spotted Owl habitat in 2004 (59%) occurred inside of Spotted Owl management circles. The percentage of the SOSEA landscape in 2004 that met Spotted Owl habitat definitions ranged from 31% in the East Cascades to 13% in the South Cascades. Overall, the percentage of non-HCP SOSEA landscapes meeting Spotted Owl habitat criteria was higher inside of circles (28%) compared to lands outside of owl management circles (18%).

We estimated that 30% (21,000 acres) of the total harvest inside of SOSEAs on non-HCP lands was in Spotted Owl habitat. An estimated 33% of the 21,000 acres of habitat harvested during 1996-2004 occurred inside of owl management circles. Most (~19,000 acres) of the non-HCP harvested habitat inside of SOSEAs was on private land. We estimated that an average of 4% (CI = 3% - 5%) of the Spotted Owl habitat on non-HCP lands, within owl management circles in SOSEA, was harvested from 1996-2004. In contrast, an average of 11% (CI = 9% - 13%) of Spotted Owl habitat in SOSEAs outside of owl circles was harvested during this same period. Overall, RCI values on non-HCP SOSEA lands ranged from 5% in the East Cascades to 10% in each of the westside study area zones.

Changes in Habitat Conservation Plan Landscapes

Habitat conditions and levels of harvest were somewhat different on HCP compared to non-HCP lands inside of SOSEAs. Private lands made up 46% of the non-HCP lands compared to 23% of the HCP landscape. State lands made up only 1% of the non-HCP lands compared to 77% of the HCP landscape. Most of the approximately 200,500 acres of Spotted Owl habitat in 2004 on HCP lands in our study area (74%) occurred inside of SOSEAs, compared to 45% on non-HCP SOSEA lands. The average percentage of the HCP landscape in 2004 meeting Spotted Owl habitat definitions was 22%, and ranged from a high of 28% in the East Cascades to a low of 14% in Southwest zone. Overall, the relative amount of HCP landscapes that met Spotted Owl habitat criteria was higher inside of circles (24%) compared to lands outside of owl management circles (20%).

Approximately 38% (16,100 acres) of the HCP landscape that was harvested from 1996-2004 met Spotted Owl habitat definitions, compared to 31% on non-HCP SOSEA lands. The amount of Spotted Owl habitat harvested on HCP lands relative to the total habitat on HCP lands did not differ from non-HCP lands, averaging 7% (95% CI = 6% - 8%). RCI values inside of circles did not differ from RCI values outside of circles within SOSEA landscapes. Overall RCI values on HCP lands ranged from 5% in the Olympics and South Cascades to 14% in the Southwest zone.

Changes in Owl Management Circles Outside of Spotted Owl Special Emphasis Areas

The majority of the non-HCP acres outside of SOSEAs were on federal (62%) and private (35%) lands. We estimated that 338,600 acres of Spotted Owl habitat existed inside Spotted Owl management circles on non-HCP lands outside of SOEAS in 2004. The majority of the non-HCP habitat outside of SOSEAs were on federal (83%) and private (14%) lands. The relative amount of Spotted Owl habitat in owl management circles outside of SOSEAs on non-HCP lands averaged 31% (CI = 27% - 34%) and ranged from 37% in the North Cascades (where federal lands comprised 94% of the landscape) to 7% in southwest Washington (where there was no federal lands within the study area).

We estimated that 33% (19,000 acres) of the total harvest inside owl management circles on non-HCP lands outside of SOSEAs was in Spotted Owl habitat. Most of this harvest (85%) occurred on private lands. Overall, RCI values averaged 5% (CI = 4% - 6%) and ranged from 1% in the North Cascades to 44% in the Southwest zone.

Analysis Considerations

Certain cautions should be considered, relative to our analyses, which may have influenced the results presented in this report. One underlying assumption inherent in this analysis was that our ability to accurately classify habitat was independent of land ownership. Due to access concerns onto private lands some of our data collection was restricted to public lands. We examined this concern in the report and concluded any potential bias was not significant and did not affect our overall conclusions.

Another caution is that our approach may have overestimated the amount of harvest and harvested habitat on federal lands. Approximately 72% of the total stand replacement harvest (~5,500 acres) estimated on federal lands was derived from applying a non-harvest correction factor (C_{nharv}, see page 33), even though the estimate of C_{nharv} was small (0.45 %). Conversely, stand replacement harvest attributed to C_{nharv} made up only 11% of the estimated harvest for state and private lands.

Estimates of habitat loss due to partial harvest in the East Cascades had a greater level of uncertainty than losses related to stand replacement harvest. We assumed that all partial harvest activity in the East Cascade zone was captured in the DNR

FPA database and that partial change outside of the FPA database (representing ~5,000 acres) was not a result of forest practices. We also assumed that Spotted Owl habitat loss associated with approximately 40,000 acres of uneven-aged forest practices permits in western Washington was not significant. We assumed that most harvest of forests with Spotted Owl habitat attributes in western Washington would be clearcuts. Further analysis would be necessary to determine whether this assumption was valid.

Finally, 21 Status 1-3 Spotted Owl management circles were changed to Status 5 (unoccupied) during the 1996-2004 period. Twelve re-classed sites were in Spotted Owl Special Emphasis Areas, and 9 were outside Spotted Owl Special Emphasis Areas. In addition, 16 Status 1-3 spotted owl sites were new and added to the database during the 1996-2004 period. Most of these (n=12) were located in the East Cascade zone. Ten post 1996 Status 1-3 sites were overlapped SOSEA boundaries. Our study area and summary statistics for landscapes inside and outside of circles were based on the landscapes that were associated with Status 1-3 owls as of 2004. As a result, the status of the landscape at the time of timber harvest in these areas may have been different then the status in 2004.

Conclusions and Recommendations

Quantifying the effects of the habitat loss we documented on regional Spotted Owl subpopulations in Washington was beyond the scope of this project. However, a number of conclusions can be derived regarding the potential effects of habitat loss. Recent Spotted Owl demographic studies have documented significant population declines in each of the study areas that overlap with our study area. Spotted Owls have large home ranges and use large amounts of structurally complex forest within those areas. State Forest Practices Rules identified 40% of the landscape as necessary to maintain the viability of an owl territory. With the possible exception of the East Cascade zone, our results indicate that the average landscape inside of owl management circles within most SOSEA landscapes were likely significantly below this threshold (Table 16, page 53). The percent of non-HCP landscapes (including all ownerships) in 2004, inside of owl management circles, that met Spotted Owl habitat criteria ranged from a low of 18% (95% confidence interval (CI) = 16% to 20%) in the South Cascades to a high of 34% (CI = 30% to 38%) in the East Cascades.

Our estimates of a 4% to 7% loss of habitat inside owl circles within SOSEAs between 1996 and 2004 (Table 32, page 81) magnifies the potential effect on those Spotted Owl sites that use habitat on non-federal lands. Loss of habitat in these landscapes is important because the Spotted Owl Special Emphasis Areas were identified in the state rules as strategic areas within the state where owls and habitat on non-federal lands contributes to the overall health of Washington's population of owls. In addition, RCI values of SOSEA habitat loss outside of management circles were more than twice as high as the RCI values for lands inside of management circles. As a result, if this pattern continues over time, owl habitat inside of SOSEAs will become more and more restricted to only those landscapes inside of Status 1-3 owl circles.

This is not to say the habitat loss we documented is conclusively responsible for the observed Spotted Owl population declines. There is concern that Barred Owls and Spotted Owls may compete for resources, and that the former has a distinct advantage in this relationship that is now influencing the Spotted Owl population decline. The nature of the relationship between these two species is not clear, but the negative effects of a strong competitor like the Barred Owl would likely interact with the effects of habitat loss for Spotted Owls.

Given the results of our study and considering the ongoing decline of Spotted Owl populations we make the following recommendations:

1. *Long-term landscape planning should be encouraged*. Spotted Owl management on non-HCP lands appears to be largely driven by individual owl circle management. Within SOSEAs, we not only documented habitat loss within circles, but also estimated rates of habitat loss outside of circles that were approximately twice the rates inside circles. This pattern of habitat loss isolates habitat near the cores of Spotted Owls' home ranges and compromises the ability of the entire landscape to contribute to Spotted Owl conservation over time. While some habitat lands within SOSEAs are currently managed under habitat conservation plans, stronger regulatory approaches to conserving habitat at the landscape level may be needed if SOSEAs are to function as more than groups of occupied circles. As Spotted Owl populations decline and fewer circles are consistently occupied, the current structure of the Forest Practices Rules coupled with "decertification" of circles that are inconsistently occupied may result in further habitat loss within SOSEAs.

2. *High quality, spatially accurate habitat maps should be developed* - It is important to accurately identify the location and amount of Spotted Owl habitat in areas that are identified to contribute to the long-term conservation of Spotted Owls (e.g. SOSEAs). The sampling approach that we adopted to assess habitat abundance and change was necessitated by the lack of such maps. While these data may be available for some management circles, areas, or ownerships, they are neither common nor consistent. High-quality habitat maps based on the habitat definitions in the Forest Practices Rules are essential both for day-to-day rule implementation (i.e. review of Forest Practices Applications) and for policy evaluation. Additionally, habitat criteria and definitions should be periodically reviewed and updated to ensure maps are consistent with owl habitat requirements in the specific areas identified to support conservation.

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INTRODUCTION

The Washington Forest Practices Board adopted Forest Practices Rules for the Northern Spotted Owl (*Strix occidentalis caurina*) in May 1996 (WAC 222-10-041). One of the key components of the rules is the identification of 10 important landscapes, known as Spotted Owl Special Emphasis Areas (SOSEAs). Within SOSEAs, the rules generally subject a larger category of timber harvest activities to environmental analysis and provide for a higher level of habitat protection than landscapes outside SOSEAs. Prior to rule adoption, proposed timber management activities in owl management circles were the bases for the majority of regulatory review. SOSEAs were established to provide voluntary options to shift away from the regulatory focus on landscapes within owl management circles and to provide for long-term landscape-level management planning (Washington State Forest Practices Board 1996).

In addition to the establishment of SOSEAs, the rules focus environmental review and protective measures on habitat within the areas surrounding site centers of Status 1-3 owls. Status 1-3 owl management circles are those locations occupied by territorial Spotted Owls (see Table 1) that include buffered distances around known owl site centers. Certain amounts (i.e. 40%) of suitable owl habitat within these "circles" were "generally assumed to be necessary to maintain the viability of the owl(s) associated with each . . . owl site center" (WAC 222-10-041(4)). For the Hoh-Clearwater / Coastal Link SOSEA, this amount totals 5,863 acres within a 2.7-mile radius around each owl site center. For all other SOSEAs, the minimum area assumed to be necessary for viability equals 2,605 acres of habitat within a 1.8-mile radius around owl site centers. Outside of SOSEAs, the rules indicate the 70 acres of highest quality habitat surrounding a site center should be maintained during the nesting season. Definitions of suitable Spotted Owl habitat are contained in the Forest Practices Rules (see Appendix A). Habitat suitability and suitable Spotted Owl habitat are terms used throughout this report and refer to forest stand conditions that meet the definitions of suitable Spotted Owl habitat contained in the Forest Practices Rules.

Table 1. Categories and definitions of Spotted Owl site status (taken from U.S. Fish and Wildlife Service 1991, 1992).

Status	Definition and explanation
1	Pair location. This determination is based on the detection of a pair of owls, a single adult with young, or young owls identifiable as Spotted Owls.
2	Two birds, pair status unknown. This determination is made when two birds of the opposite sex are detected, but it is unknown whether the birds are paired.
3	Resident single. This determination reflects sites with three or more detections (without detections of the opposite sex) in the same general area, an indication of territorial behavior.
4	Status unknown. This determination reflects sites with less than three detections, such that territorial status can't be assigned.
5	Unoccupied.

Last year the Forest Practices Board initiated a process to evaluate the existing forest practices rules for Spotted Owls. Recent analysis and reports on the status and trends of Spotted Owls and their habitat have focused mostly on federal lands (Lint in press; Moeur et al. in press; Anthony et al. 2005). Information on status and recent changes related to Spotted Owl habitat on state and private lands would be valuable to their review. In the summer of 2004 the Department of Natural Resources contracted with the Washington Department of Fish and Wildlife to gather information needed to help in this review.

In this paper we present the results of our analyses in addressing the following three primary objectives:

1. Estimate the amount of suitable Spotted Owl habitat in 2004 on landscapes affected by state and private forest practices,
2. Estimate the amount of Spotted Owl habitat harvested under the regulatory authority of the Forest Practices Rules between 1996 and 2004, and

3. Determine the current status and net change, accounting for both gains and losses, of Spotted Owl habitat on landscapes influenced by State Forest Practices Rules adopted in 1996.

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We were fortunate to have hard working and dedicated field crews. Greg Falxa was an important member of our team; he served as navigator and on-board coordinator for most of the helicopter flights, recorded voucher images of the plots we visited from the air, and developed databases for photo images and vegetation information. We appreciate the efforts of Gina Blankenship, Scott Downes, Melissa Hill, Rob Hollingshead, Paul Moorehead and Clay Small. We also contracted with ABR Inc.- Environmental Research and Services; we thank Brian Cooper for project coordination and the field crew of Jon

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Ray Davis, Joe Lint, Marty Raphael, Beth Galleher and Jon Martin (Pacific Northwest Interagency Regional Monitoring Program Team) provided valuable insight into their modeling work for the Northwest Forest Plan monitoring report. We are grateful to Warren Cohen and Sean Healey (U.S. Forest Service, Pacific Northwest Research Station, Forestry Sciences Laboratory, Corvallis, Oregon) for their interest in the study, for the time they spent in discussions with us (particularly with respect to their change detection model), and for their efforts to develop the change detection model for partial overstory removal. Norm Roller, John Colwell, Brian Scott from Marshall and Associates, and Emily Silverman from the University of Michigan, provided valuable assistance in key components of GIS and logistic regression analysis, and influencing our final decision to use a statistical based approach.

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STUDY AREA

The focus of this project was to determine the status of Spotted Owl habitat on landscapes influenced by state, local and private lands subject to state Forest Practices Rules. For this reason, our study area was limited to areas outside of SOSEAs defined by 2004 Status 1-3 Spotted Owl management circles, where at least 10% of the acres in the circle were under state or private ownership, and by the area within the boundaries of the SOSEAs defined by state rules. Both federal Endangered Species Act (ESA) guidelines and Forest Practices rules recognize that all habitat within owl landscapes may be important and should be examined together when assessing Spotted Owl habitat status and conditions. Therefore we included all lands, regardless of ownership, within the boundaries of the SOSEAs. All parts of owl management circles that fell within SOSEA boundaries regardless of the percent of state or private ownership were included for analysis (Figure 1).

The study area boundary encompassed 3,624,557 acres. Missing or incomplete data reduced our analysis area to 3,233,942 acres and included 450 Spotted Owl management circles and all 10 Spotted Owl Special Emphasis Areas. This included 58 owl circles with federal ownership exceeding 90% that overlapped with SOSEA boundaries. We divided the study area into zones for the purposes of allocating sample sizes and developing sampling procedures: East Cascades, North Cascades, South Cascades, Olympic Peninsula, and Southwest Washington. These zones were designated based on differences in forest association (e.g. western Washington vs. East Cascades zone; (Franklin & Dyrness 1973) that often are reflected in differing Spotted Owl life history attributes (e.g. Olympics vs. Cascades), or on forest management regime (Southwest Washington vs. other regions). Finally, the western Cascades were stratified into Northern and Southern zones to facilitate the sampling logistics and to accommodate possible differences in forest stand communities over any north-south environmental gradient.

For purposes of data summarization and relevance to the existing state Forest Practices Rules, the study area was further subdivided into areas located inside and outside Spotted Owl Special Emphasis Areas, inside and outside Spotted Owl management circles, and inside and outside federally approved Habitat Conservation Plans (Figure 2).

We obtained GIS layers of Spotted Owl Special Emphasis Areas from the DNR (http://www.dnr.wa.gov/forestpractices/data/) and Habitat Conservation Plan areas from U.S. Fish and Wildlife Service (updated April 2004). A small number of acres of federal and tribal lands were included within the HCP boundaries. We removed all federal and tribal lands from our HCP statistics. Private lands (39%) and federal lands (37%) made up the largest proportion of the study area overall (Table 2). Ownership in the Southwest Washington study area zone was restricted to private and state-local lands. A detailed breakdown of ownership by acres in SOSEAs, Spotted Owl management circles and Habitat Conservation Plan categories is provided in Appendix B.

Table 2. Size (in acres) of study area according to major ownership groups and number of Status 1-3 Spotted Owl sites in each of five zones within the overall study area.

Zone	State-Local	Private	Federal	Tribe	Grand Total	Number of owl sites [1]
East Cascades	125,076	362,072	397,520	13,864	898,531	158
North Cascades	136,871	235,170	270,082	0	642,123	94
Olympic	297,913	237,311	402,450	11,589	949,262	102
South Cascades	116,560	310,432	141,441	0	568,433	82
Southwest	53,202	122,203	188	0	175,592	14
Grand Total	729,622	1,267,188	1,211,680	25,453	3,233,942	450

1 The values reported represent the number of 2004 Status 1-3 activity centers in each study zone to eliminate double-counting where owl circles extended from one region to another.

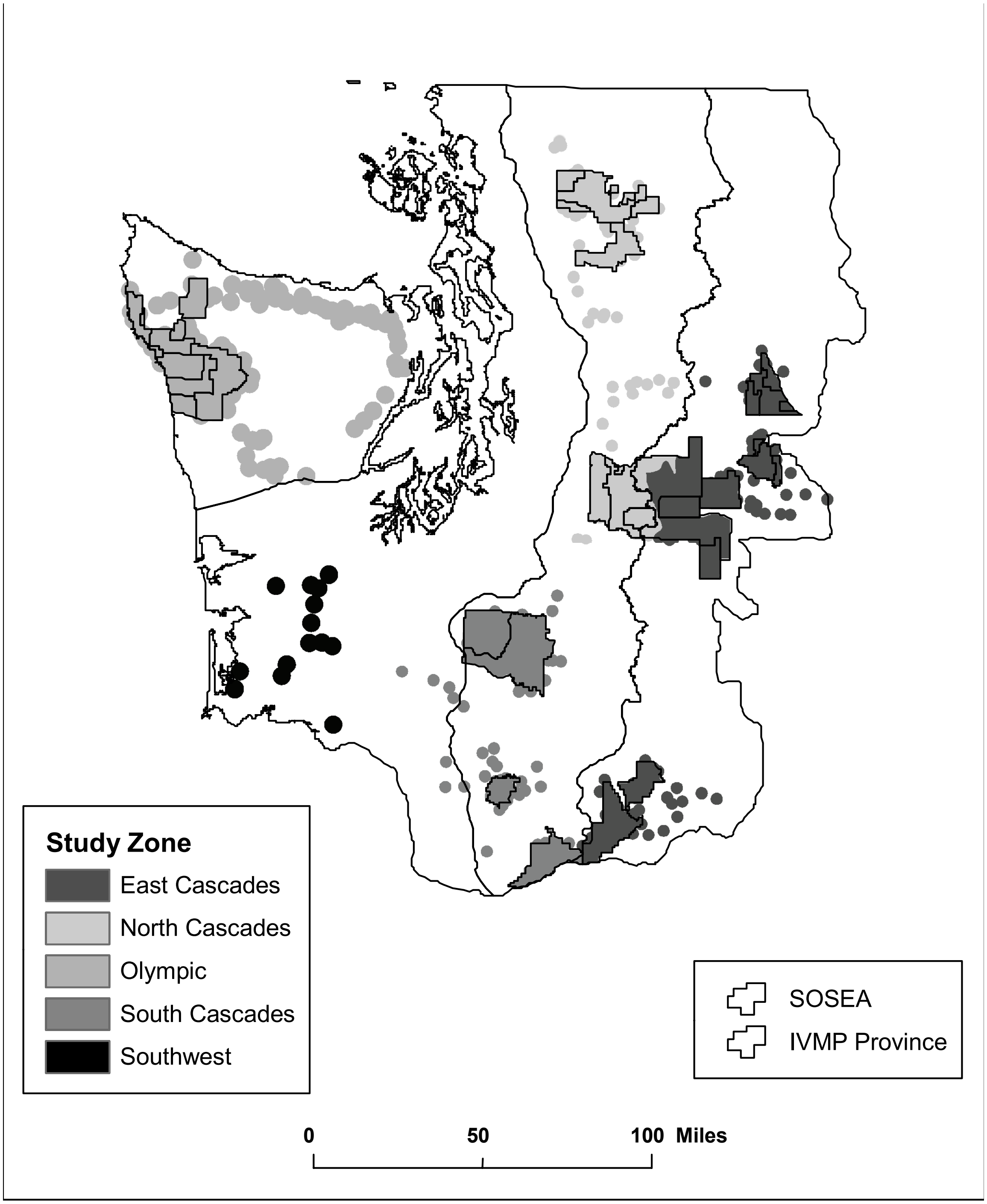

Figure 1. Study area shown as shaded zones, illustrating five geographic zones, SOSEA boundaries within study area zones, and location within Interagency Vegetation Mapping Project (IVMP) Province boundaries.

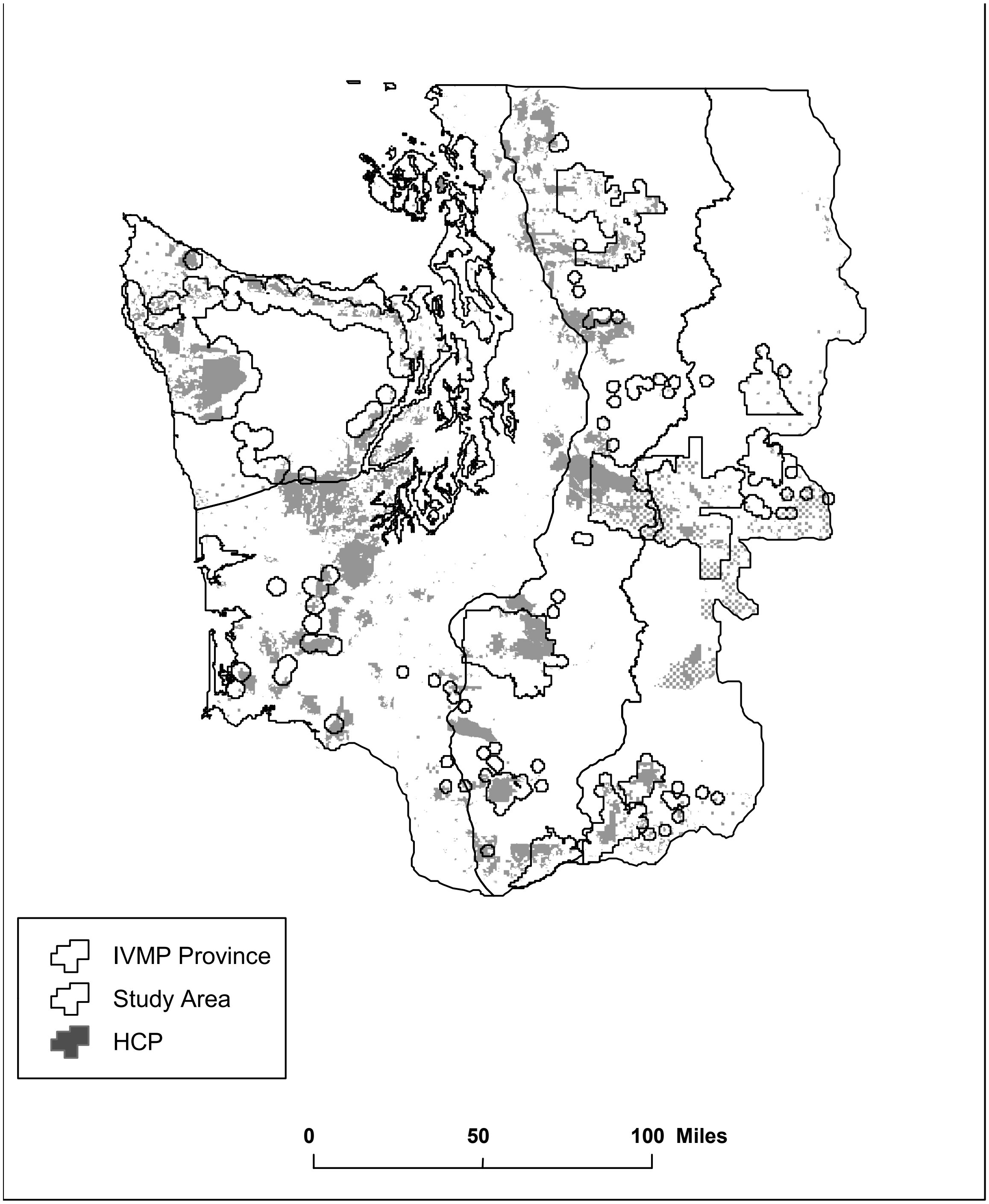

Figure 2. Federally approved Habitat Conservation Plan (HCP) boundaries in Washington State and relationship to IVMP province and study area boundaries, HCP data updated April 2004.

METHODS

Estimating the amount of suitable habitat and recent harvest over an area exceeding 3 million acres was a significant task. One approach we considered was to create a wall-to-wall map of habitat using traditional classification methods for analyzing Landsat imagery. Once a habitat map was produced we could overlay a map of 1996-2004 harvest (generated from Landsat imagery temporal analysis; see below) to estimate the amount of habitat that was harvested and the amount of habitat that existed in 2004. We identified early in the project that one required component of the study was to incorporate estimates of uncertainty and confidence intervals associated with our point estimates of habitat and harvested habitat at different levels across the landscape. In addition, given the nature of Spotted Owl habitat criteria adopted by the Forest Practices Board (e.g. inclusion of stem densities, down and woody debris, snags and mistletoe infection) it would have been extremely difficult to complete such a project with any significant spatial accuracy in the final product. The federal government recognized this feasibility issue in their recent assessment of Spotted Owl habitat status and trends under the Northwest Forest Plan (Davis & Lint in press). Given the daunting prospect of conducting a map-based assessment of Spotted Owl habitat, we instead developed a sampling-based, probabilistic approach that produced the desired information on Spotted Owl habitat and timber harvests at relevant regional scales. A complete listing of data used in the analysis and associated metadata information are provided in Appendix C.

Estimating the Amount of Spotted Owl Suitable Habitat in 2004 on Selected Forested Landscapes of Washington

The first major objective was to estimate the amount of forested landscape existing in 2004 that met the legal definitions of the Forest Practices Rules (WAC 222-16-085, Appendix B). Although Spotted Owls are most strongly associated with old forest (Gutiérrez et al. 1995), they also use comparatively younger forests throughout their range in Washington (Buchanan et al. 1999; Hanson et al. 1993). Two classes of non-old forest are recognized in Washington's Forest Practices Rules: sub-mature forest and young forest marginal.

The two categories of comparatively younger forests typically lack some of the structural complexity exhibited in old forests. As in older forests, important habitat attributes of the younger forests include a high degree of canopy closure, tall coniferous trees (predominantly Douglas-fir, *Pseudotsuga menziesii*, but also including species such as grand fir, *Abies grandis*, western hemlock, *Tsuga heterophylla,* and western redcedar, *Thuja plicata*), multiple canopy layers, and, in different parts of the state, snags, downed wood, moderate shrub cover, or conifers infected with mistletoe. Canopy complexity is readily observed from the air or from newer, high-resolution aerial photographs, and is an obvious component of older forests. Unfortunately, some younger aged forest stands that are used by Spotted Owls lack canopy gaps, super-dominant trees, or broken-topped trees characteristic of older forests, and many of the key habitat attributes (snags, logs, shrubs, mistletoe) may not always be detected below the canopy when viewed from above, and would require additional verification methods. The state rules apply equally to all three classes of habitat and we did not attempt to distinguish among these classes in our analysis.

Our overall approach was to couple a simple stratified random sampling design with a double sampling scheme to account for misclassification errors during the random sampling (Smiatek 1995; Tenenbein 1970). The study area was divided into two strata categories: the five geographic zones (Figure 1), and a GIS layer that mapped seral strata (early, mid, late, and other lands in forested areas, hereafter, "other", Table 3) within each geographic zone. We chose seral class as a sample strata because we expected that Spotted Owl habitat would occur most frequently on late seral landscapes, less frequently on mid seral landscapes and least frequently on early and other seral landscapes. For example, if the seral conditions were mapped perfectly (i.e. without error) most if not all of the late seral stands would meet state definitions of suitable owl habitat, and most if not all of the early and other seral stands would **not** meet state definitions of suitable owl habitat. We expected the frequency of suitable owl habitat in mid seral stands to fall somewhere in between.

We used a stage GIS layer obtained from the Washington Department of Natural Resources. In this dataset, Landsat Thematic Mapper imagery from 1988 was used to classify crown cover, cover type and forest age (Green et al. 1993). Landcover mapping was performed for every forested Water Resource Inventory Area in Washington. Vegetation data for federal lands in this dataset were generalized from size/structure, crown cover, and cover type data previously developed by the USFS. WDNR subsequently updated the 1988 map to 1991/1993. In this process, harvest activity detected over the time interval was mapped into the strata category other (Table 3). Accuracy rates for this layer prior to the 1991/1993 update ranged from 86.7% to 97.4% (Green et al. 1993).

We further refined and updated the seral strata map by overlaying a stand replacement disturbance map produced by the U.S. Forest Service Pacific Northwest Forestry Sciences Laboratory in Corvallis, Oregon. The disturbance layer, described in greater detail in subsequent sections of this report, indicated stand replacement disturbance (harvest, wildfire, volcanic) that occurred between 1972 and 1996. These areas of landscape change were merged with the DNR seral class map to better define early seral stands and update the DNR layer to 1996 conditions. We used this layer to stratify the study area to guide the allocation of randomly selected points. In general, the amount of landscape in each stratum was similar across geographic zones we sampled, with the exception that amount of late seral strata was particularly low in the Southwest and South Cascades zone (Table 4).

We determined presence and absence of suitable Spotted Owl habitat at randomly selected locations within each stratum using orthophoto interpretation (for early and other strata) or using a combination of helicopter and ground plots (for mid and late seral strata) at selected GPS coordinates (Figure 3, see detailed description below). Helicopter classification accuracy rates (probability of classifying forest as habitat when forest is actually habitat and the probability of classifying forest as non-habitat when forest is actually habitat) were determined by visiting a subset of these same plots on the ground where quantitative stand plot data were collected to determine whether or not the stand met the suitable habitat definitions of the Forest Practices Rules. These accuracy rates were used to adjust the helicopter data to more accurately estimate the percentage of randomly selected plots that met habitat criteria within each stratum.

Table 3. Seral stage remote sensing land cover classes maintained by the Washington Department of Natural Resources. Original compilation occurred in 1988; updated in 1991 and 1993.

Seral Strata	Conifer cover	Proportion of trees ≥21 inches	Crown cover in hardwood or shrubs
Late	> 70%	≥10%	<75%
Mid	> 70%	<10%	<75%
Early	10-70%	Not applicable	<75%
Other [1]	< 10%	Not applicable	>75%

1 Only one of the conditions (canopy cover or crown cover of hardwoods or shrubs) must be met for this condition. Other refers to other lands in forested areas such as clearcuts, hardwood stands, meadows, etc.

Table 4. The number of acres in study area, according to geographic zone and seral class strata.

	Seral Strata				
Zone	Other	Early	Mid	Late	Grand Total
East Cascades	240,176	246,389	165,414	246,553	898,531
North Cascades	131,456	160,918	149,598	200,152	642,123
Olympic	112,583	296,010	236,658	304,011	949,262
South Cascades	106,137	216,321	188,998	56,977	568,433
Southwest	28,923	69,398	69,899	7,372	175,592
Grand Total	619,275	989,036	810,568	815,064	3,233,942

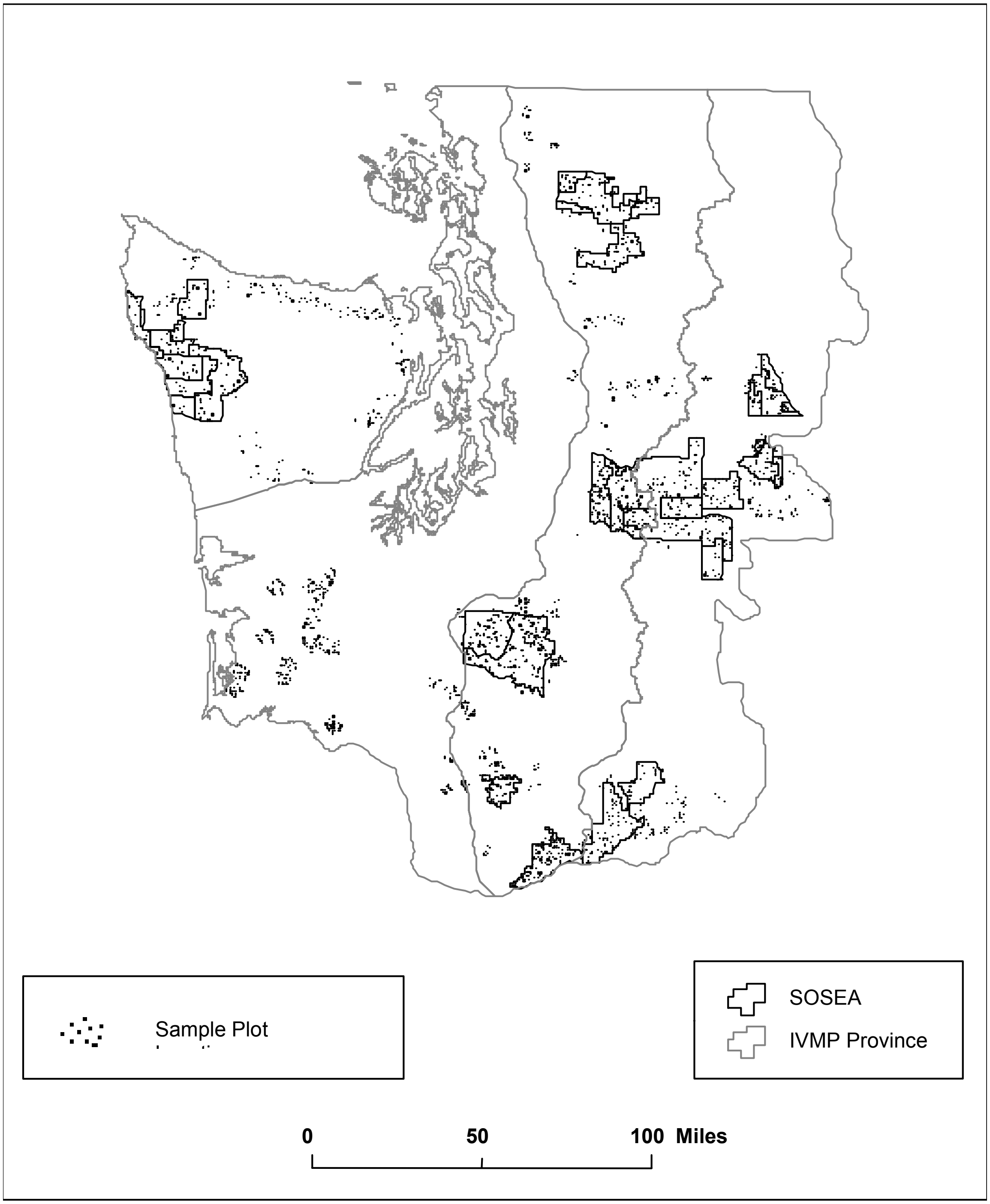

Figure 3. Study area, illustrating 1,061 helicopter plots in relation to SOSEAs and location within Interagency Vegetation Mapping Project Province boundaries used to estimate presence or absence of Spotted Owl habitat.

Preliminary data from visits to 207 plots and best guess estimates of the proportion of each strata that was owl habitat were used to allocate the number of random plots to each stratum (Table 5). Since preliminary sample sizes for other and early strata were too small we used best guess estimates of the proportion that these strata would meet Spotted Owl habitat conditions. Sample size allocations to improve precision for a fixed sample size were made according to optimal proportions (equation 1.1) following (Cochran 1977, p 108):

$$p_{ni} \doteq \left[\frac{Acres_i \sqrt{p_i\left(1-p_i\right)}}{\sum_{i=1}^{nstrata} Acres_i \sqrt{p_i\left(1-p_i\right)}} \right], \qquad (1.1)$$

where p_{ni} is the proportion of the total plots to sample within strata *i,* and p_i is the expected probability of occurrence of suitable Spotted Owl habitat in stratum *i.* Total sample size (*n*) was constrained by cost and time. Given our approved budget and time constraint to complete sampling over a 5-month period, our targeted sample size to allocate was 1,200 helicopter plots.

Plot Selection

Each random point was the center of a 10-acre (western Washington) or 4-acre (eastern Washington) site. We began the project in western Washington and found that a 10-acre plot could be viewed relatively thoroughly from the air, afforded effective sub-sampling from the ground, and could be easily mapped. In the East Cascades zone, however, we found that a 10-acre plot captured a great deal of variation in forest condition and would compromise our ability to make determinations of suitability. For this reason, we used a 4-acre plot. As we found in western Washington, a plot of this size was a good scale for sampling. All plots compiled were aligned to cardinal directions in the Washington State Plane Coordinate System. We randomly selected plot locations distributed in the sample allocation pattern based on proportion of the landscape in a seral strata and expected probability of encountering suitable habitat across the study area (Table 6). Helicopter and associated ground sampling were used mostly to sample plots within the mid and late seral strata category (see data collection description below). Plots in early and other seral strata were mostly sampled by orthophoto and aerial photo interpretation.

Table 5. Expected *a priori* probability of occurrence of suitable Spotted Owl habitat according to strata. Source data from 207 ground plots.

	Seral Strata			
Zone	Other [1]	Early [1]	Mid	Late
East Cascades	0.01	0.14	0.81	0.83
North Cascades	0.01	0.14	0.20	0.53
Olympic	0.01	0.14	0.31	0.79
South Cascades	0.01	0.14	0.59	0.46
Southwest	0.01	0.14	0.10	0.50

1. Preliminary sample sizes were too small for other and early seral classes to generate estimates. Probabilities used for allocations of other and early seral classes were based on best guess estimates that owl habitat was much less likely to occur on other and early strata landscapes relative to mid and late seral landscapes.

After a preliminary test flight used to evaluate in-flight navigation and sampling procedures, we estimated that between 50 and 70 plots could be visited in a single day by helicopter depending on the distribution of plots. We divided the study area into 12 flight areas coinciding with the five geographic zones we used for stratification: Western Olympic Peninsula, Northern Olympic Peninsula and Hood Canal, Southwest Washington, Finney Block and vicinity, I-90 West and vicinity, Mineral Block and Mineral Link, Siouxon, Columbia Gorge, White Salmon, I-90 East, North Blewett and vicinity, and Entiat Ridge.

Table 6. Desired percent distribution of sample plots assigned to two strata; geographic zone and seral class, based on proportion of landscape in the study area and preliminary estimates of the probability of occurrence of Spotted Owl habitat within each strata category.

	Seral Strata				
Zone	Other	Early	Mid	Late	Total
East Cascades	3%	4%	6%	9%	22%
North Cascades	3%	1%	8%	12%	23%
Olympics	2%	3%	9%	10%	24%
South Cascades	4%	2%	15%	4%	25%
Southwest	2%	1%	4%	1%	7%
Total	14%	10%	41%	35%	100%

We then took a subset of the total plots selected to include as ground plot sampling locations. Plots that were eligible for ground sampling were restricted to plots meeting certain logistic conditions. Because it was important that the field crews effectively locate the actual sample location (using Global Positioning System devices, compasses, distance tapes, and laser range finders) we limited the distance from a road or other access point (e.g. the edge of a clear-cut) to the nearest corner of a plot to ≤1000 feet. In addition, we used digital topographic data to avoid sampling in areas with cliffs. During the early phases of project design and development, concerns were raised by some landowner's representatives regarding access and related issues. Because of the limited time and seasonal window available for field sampling we decided to conduct most of the mid and late seral strata ground sampling on public lands where access was not restricted. Although this had the potential to bias results, we felt that the bias would be small and that the overall results of the study would not be significantly affected (see Additional Considerations section at the end of this report for a discussion on the potential bias associated with this assumption).

Some of the 10-acre cells surrounding the random point extended across seral strata boundaries (e.g. from a forest area to a recent harvest unit). For this reason, it was necessary to move some 10-acre cells slightly to fit within the target forest type, defined by the random point, and minimize heterogeneity. We moved cells only as far as would be possible to retain the original center point within the bounds of the new mapped location. If such a move was not possible the site location was discarded. We used a similar approach in the East Cascades. However, due to the great heterogeneity of forest conditions (Cobb 1988), and the difficulty this caused in situating random plots, we also used IVMP canopy cover data (Browning et al. 2002a; Browning et al. 2002b; Browning et al. 2003a) as a guide for identifying open (50-70% canopy cover) and closed (>70% canopy cover) stands, so as to minimize within-plot heterogeneity. We did not attempt to correct for potential differences between canopy closure measures from the ground and canopy cover measures taken from the air.

Data Collection

Photo Interpretation Protocols

A basic assumption of our sampling approach was that plots in mid and late seral strata would best be sampled from either a ground visit and/or helicopter, and that the vast majority of sites in the early and other seral categories could be correctly classified without error using digital orthophotographs and aerial photo prints. All 890 mid and late seral sites were sampled from the ground and/or the air. Plots selected that did not have adequate aerial photo coverage were removed from the sample. The vast majority (88% of n = 572) of orthophoto images examined were easily scored and identified as non-habitat (Table 7). However, a significant number of plots in early seral stratum, especially in the East Cascades, were not readily scored by photo interpretation. Interpretation difficulties arose primarily when image quality was poor (e.g. shadowing) or tree species/stand-composition could not be determined. In these cases the habitat condition for the plots were classed as unknown, and the plots were added to the pool of sites that we observed from the air. Habitat classification for these unknown sites was determined using the methods for aerial sampling described below.

Table 7. The number of photo interpretative samples classified according to whether aerial photo evidence was clear enough to determine Spotted Owl habitat suitability or if helicopter visit was required.

Seral Strata	Region	Helicopter Visit Needed	Photo Interpretation Clear	Total Plots Sampled
Early	East	21	29	50
	West	9	201	210
Other		40	272	312
Grand Total		70	502	572

Aerial Plot Sampling Protocols.

All aerial work was done from a helicopter with an on-board GPS device with a display unit (i.e. Trimble AgGPS 170 field computer) developed for guiding and documenting precise real-time flight paths. After receiving a unique identification code, the coordinates and associated ESRI shape file polygons of each plot selected for sampling were loaded onto the GPS unit on the helicopter. A navigator was aboard for all flights and directed the pilot from plot to plot, relayed plot identification codes to the observer, and announced plot begin and end points. The observer sat in the back seat of the helicopter and gathered information at each site (see below).

The pilot flew above the perimeter of each plot at altitudes ranging between 10 and 50 meters above tree height, depending on the terrain and wind conditions. The plot outline was displayed on the AgGPS and the real-time position of the helicopter was shown on the screen (Figure 4). In this manner the pilot was able to stay on track and carefully turn at plot corners. The route of each plot flight was recorded in the AgGPS and later imported to a GIS. Twenty-three of the 25 flights were flown in a Bell Jet Ranger 206 and two flights were flown in a turbine-powered Enstrom 480.

At each plot the observer carefully evaluated the forest within the plot boundary and recorded information on a data sheet. The observer had no knowledge of the condition or category of the forest in the plots. Because of differences contained in the Forest

Practices Rules in definitions of suitable Spotted Owl habitat between the East Cascades zone and all western Washington areas (Appendix A), there were slight differences in the type of information collected in flights in the two parts of the state. In western Washington, plot information recorded by the observer included categorical ocular estimates of canopy cover (<70%, 70-90%, or >90%), canopy structure (i.e. uniform, characterized by trees of similar height and canopy position; complex, characterized by canopy gaps or trees of substantially differing size; and mixed, characterized by both uniform and complex conditions), and percent conifer composition (<30%, 30-70%, or >70%). All snags or dead-topped trees judged to be at least 20 inches diameter at breast height and at least 16 feet tall were tallied in one of three categories: snags below the canopy, snags extending into or above the canopy, and dead-topped live trees. In addition, the observer recorded an opinion as to whether the plot represented suitable or unsuitable habitat for Spotted Owls.

In the East Cascades zone, categorical information was recorded on canopy cover (<50%, 50-70%, or >70%), canopy structure (as described above), and the percent crown cover of fir (i.e. Douglas-fir and grand fir, but also including western hemlock and western redcedar) trees present (<40% or ≥40%). A list of dominant tree species present was recorded if fir composition was <40%. A snag tally was recorded as described above for western Washington. The number of trees with visible mistletoe infection, primarily due to dwarf mistletoe, *Arceuthobium douglasii,* was also tallied.

The observer also made a qualitative assessment of habitat suitability for Spotted Owls. All helicopter plot data collection and habitat assessments were conducted by one observer with over 15 years Spotted Owl experience in Washington. The observer's judgment of site suitability was based on the combination of snags counted and the ocular estimation of key habitat condition criteria at each site. Sites with the appropriate tree species composition, tree height and canopy closure were considered suitable for Spotted Owls if multiple large snags (western Washington), canopy layering (all areas) or mistletoe infection (East Cascades only) was observed within plot boundaries. Presence of downed wood was rarely used (i.e. <10 times) to classify habitat, as this feature was difficult to assess from the air. Stands with a uniform canopy were not considered suitable unless other features (typically snags) were present. Attributes such as stem density and shrub cover could not be estimated from the air.

Figure 4. AgGPS unit used during helicopter data collection, showing flight path overlaid with target plot.

We used Global Positioning Systems to navigate to field plots and delineate plot boundaries from the air. In some cases, the helicopter pilot had difficulty maintaining the track line in strong winds. We visually compared the flown track lines with target plot locations to determine whether any plots had mismatched plot boundaries. Although the flight routes occasionally deviated from the sample square, the coverage from the air was largely concordant with the target plot. In one instance we found that an aerial plot deviated substantially from the target plot such that the ground vegetation plots were not contained within the perimeter of the flight route. As a result, we discarded the data from this site.

Ground Plot Sampling Protocols

Navigation to the plots was an important consideration. Prior to deploying field crews we generated maps and reproduced recent orthophotos that were used to facilitate accurate and efficient access to the sites. All plots had waypoints associated with each plot corner and the plot center. Waypoints were listed on a printout and loaded onto GPS units. Field crews navigated to the sites using compasses, measuring tapes, laser range finders and GPS units. Differences contained in the Forest Practices Rules definitions of suitable Spotted Owl habitat between the East Cascades zone and all western Washington areas (Appendix A) necessitated slight differences in the type of information collected by field crews in the two parts of the state. Because field crews collected vegetation data at plots in all zones within the study area, these details are outlined below.

In western Washington, we collected data at two scales within a plot. The largest scale was the snag transect. We began the ground sampling by using a single randomly selected 0.25-acre vegetation subplot along a randomly selected 2-acre snag transect at each site. A preliminary comparison of ground and aerial data indicated an overall concordance of snag values. However, we identified a few plots that suggested that one snag transect may not be enough to capture a representative view of the snag component of a stand. Consequently, we changed our approach and added a second snag transect and associated 0.25-acre subplot for each plot.

Transects were 660 feet in length and 132 feet wide, 66 feet on either side of the transect line. The length of snag transects was calculated across the ground using measuring tapes. Transect dimensions were such that five potential transects could be placed side-by-side (e.g. non-overlapping) and fill the entire square 10-acre cell. Transect direction (north-south or east-west) was random, but once selected, both transects were situated in the same direction so they would not overlap. Five transect positions were possible, and two of these positions were randomly selected once transect direction had been established. Within the snag transect, field crews recorded the number of snags and dead-topped live trees at least 20 inches diameter at breast height and at least 16 feet tall.

Separate tallies were made for snags below the canopy, snags extending into or above the canopy, and dead-topped live trees. In addition, while on transect the field crews estimated tree species composition.

The 0.25-acre plot was situated at a random point along the length of each 2-acre snag transect. The entire 0.25-acre plot was constrained to fall within the snag transect. In this 0.25-acre circular plot the field crews recorded canopy closure. Values were recorded while facing the cardinal directions at the center of the plot; (Lemmon 1956). Field crews tallied the number of live trees (according to whether intermediate, suppressed, or hardwood), recorded the number of vertical layers, measured the height of three randomly-selected dominant or co-dominant trees (using a hand-held range finder) and estimated the percent of ground covered by both downed wood and shrubs.

We used a 4-acre plot size in the East Cascades zone to ensure generally homogeneous stand conditions in the sample units. Because the habitat definitions for East Cascades did not necessarily require that snags be present we changed the 0.25-acre subplot approach. We divided each four-acre site into 16 square 0.25-acre blocks and randomly selected two blocks for sampling at each site. Because snags and/or mistletoe are only required when canopy closure is less than 70% we only collected snag and mistletoe data at plots with canopy closure below 70%. This was intended to save time and allow more plots to be visited during the field season. Because of the smaller plot size (4 ac) we conducted four snag/mistletoe transects that were designed to cover the entire four-acre site. All snags at least 20 inches diameter at breast height and 16 feet tall were tallied within the transect bounds. In addition, the number of trees with mistletoe infection was tallied in categories of 10 percent (none, 1-10%, 11-20%, and so forth).

Vegetation sampling within the 0.25-acre plot in the East Cascade zone was similar to sampling in western Washington, with two exceptions. In stands that had a substantial component of non-fir tree species, the crews calculated the proportion of non-fir trees and listed the proportion and identity of these species. In contrast to western Washington, hardwoods are very rarely encountered in east-side forests. For this reason, there was no tally of hardwoods.

Estimating the Amount of Forest Harvested Using Temporal Landsat Change Detection Methods

The substantial size of the Spotted Owl study area and multi-temporal analysis needs left few cost-effective choices for mapping landscape change. Landsat satellite imagery provided the base data for mapping forest stand replacement and partial canopy change. We describe two methodologies that we used in mapping landscape change and describe how the change data were integrated into the final project map.

Stand Replacement Harvest

The largest source of landscape change data in the project area was mapped using stand replacement remote sensing techniques. A stand replacement event occurred when stand crown cover was completely removed or substantially reduced (Healey et al. in press). We contracted with the USDA Pacific Northwest Forestry Sciences Laboratory (FSL) in Corvallis, Oregon, to quantify stand replacement harvest in forested cover using techniques they developed while working on the 10-year review of the Northwest Forest Plan (Cohen et al. 1998; Cohen et al. 2002; Healey et al. in press).

The data derived from these processes were used to create a map of forest change, from all sources (e.g. harvest, fire, volcanic eruption), from 1972 to 2004. The 1972-2004 change data spanned 22 time intervals and covered all land ownerships within our study area. The change intervals from 1972 to 1984 were developed from Landsat Multispectral Scanner (MSS) imagery. Post-1984 intervals were processed with the higher resolution (spatial, spectral, and radiometric) Landsat Thematic Mapper (TM) or Enhanced Thematic Mapper Plus (ETM+) sensors.

Non-forest areas were masked from the FSL processing area using raster land cover data from the Interagency Vegetation Mapping Project (IVMP) (Moeur et al. in press;

Fassnacht et al. In prep.). To minimize spatial mis-registration between the many image dates an automated "tie-point" procedure was applied (Healey et al. in press). Radiometric normalization was not applied in the stand replacement procedures. As noted by (Cohen et al. 1998), stand replacement events typically produce a strong spectral response, and thus the "effort/cost" to normalize imagery may outweigh potential benefits of normalization.

An essential image processing procedure used in developing the stand replacement map applied the Tasseled Cap transformation. This procedure transforms Landsat imagery to a feature space dimensioned by brightness, greenness, and wetness. An additional transformation combined the feature space dimensions into a single disturbance index for each Landsat acquisition year (Figure 5). Brightness is related to soil reflectance, greenness is related to vegetation cover, and wetness is related to maturity and structure of closed canopy forests (Cohen et al. 1995). Interpretation of Tasseled Cap data, therefore, reveals a range of feature contrasts depending on a feature's spectral "trajectory" over a time period (e.g. full conifer cover to clearcut). The transformation also improves processing efficiency by reducing data volume while simultaneously preserving landscape change information and providing index values transferable across image years. The lower spectral resolution MSS data were transformed into MSS Tasseled Cap brightness and greenness. The higher spectral resolution TM/ETM+ data were transformed into TM Tasseled Cap brightness, greenness, and wetness. A post-process smoothing filter procedure was applied to the change data resulting in removal of clearcuts or forest features smaller than two hectares (Healey et al. in press). A more thorough description of the digital image interpretation techniques and a case history example are provided in Appendix D.

Partial Canopy Change: East Cascades

Partial-stand harvesting is a common forest practice in the East Cascades. The techniques for determining stand replacement harvest introduced above were not designed to identify light to moderate reduction in canopy cover. Characterization of the subtle Landsat spectral response in partial change areas requires more rigorous image processing techniques to prepare the imagery for analysis. Likewise, stand-level field and aerial photo data are required to model and validate the partial canopy change maps. To address this mapping refinement need, we also contracted with the FSL to develop a model that would predict levels of forest stand change along a continuum and to quantify the amount of landscape that was impacted by partial overstory removal between 1996 and 2004.

There were many steps in the procedure used by the FSL to estimate change resulting from partial harvest. Details of the approach used for modeling partial harvest are provided in Appendix E. For this analysis, the FSL added a 1998 Landsat acquisition year, thus improving the temporal resolution to four two-year intervals: 1996-1998,1998-2000, 2000-2002, and 2002-2004. Image co-registration procedures were applied to the terrain-corrected imagery similar to the stand replacement image preparation procedures. Radiometric normalization was performed on the imagery, converting digital counts to reflectance. As in the stand-replacement change detection procedure described previously, the Tasseled Cap transformation was applied to image data, producing indices of brightness, greenness, and wetness. These indices were used in subsequent analyses.

Subsequent procedures used by the FSL involved collection of field data and model development. Vegetation data were collected at 81 1-hectare sites situated in Forest Practice Application (FPA) polygons taken from the database maintained by DNR (January 2004 publication date). A variety of field measurements were recorded, including diameter at breast height of live trees, canopy class (of individual trees), basal area, and for sites thinned after 1996, the diameter of stumps. These data were used to develop a regression model that estimated the amount of basal area removed by thinning (Appendix E). Photo interpretation was used to estimate canopy cover at each field plot visited in years representing both pre- and post-disturbance. Aerial photos used for the pre-disturbance time period were from 1998/1999. Aerial photos used for post-disturbance were from 2002/2003. Canopy cover was estimated in increments of 10%

from 5% to 95% by the average of three different photo-interpreters rating a photo for each site using a canopy cover key that captured the range of cover classes.

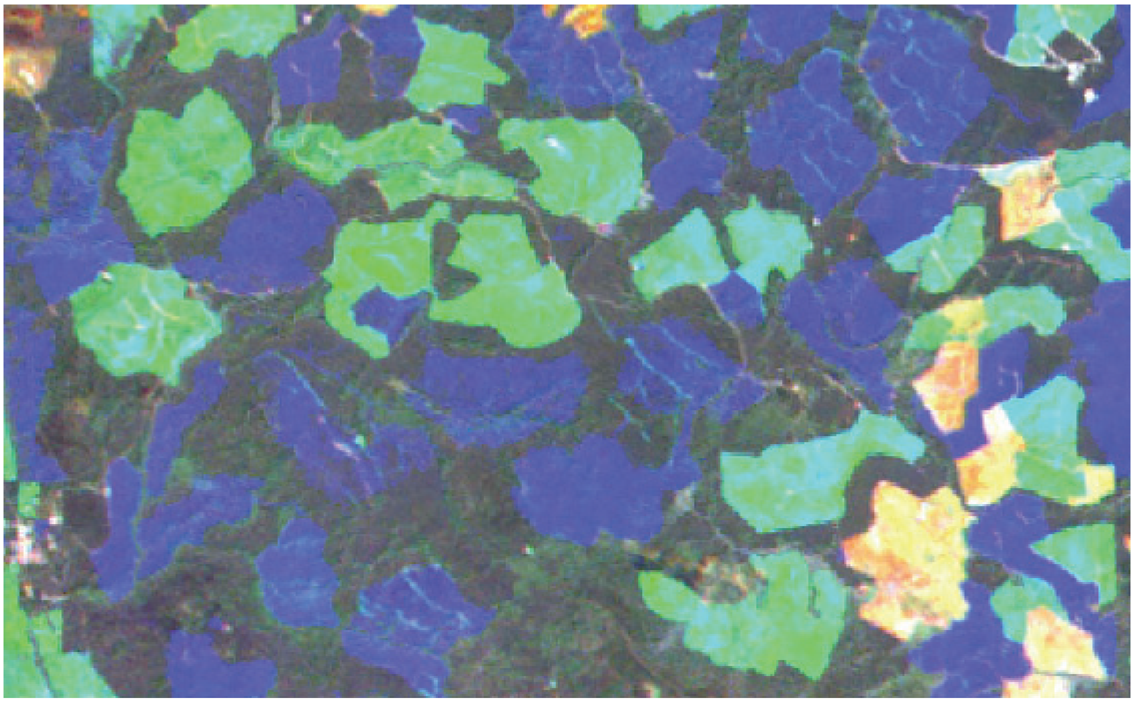

Figure 5. Color composite of three disturbance index years indicating stand replacement change. Figure from Healy et al. (in press, Appendix D). Cyan colored areas indicate change between time period 1 and 2, blue areas indicate disturbance between time periods 2 and 3, and yellowish areas represent areas that were disturbed prior to time period 1 becoming re-vegetated during the three time periods examined.

The observation data provided input to dynamic and static regression model development (Appendix E). The dynamic model incorporates variation across multiple image dates for estimating change, whereas the static model predicts, using single-date imagery, forest attributes for a single year. Prior to implementation of the regression models, the input imagery was broadly classified into disturbed and undisturbed classes. The classified data were refined using manual editing and application of a 1-hectare filter. The filter removed disturbed patches smaller than one hectare from the analysis. The FSL delivered 36 basal area and crown cover model outputs: 16 images depicting percent relative change in two-year date pairs for basal area and crown cover, and 20 images depicting single-date absolute basal area (square meters) and crown cover (percent). We mapped the continuous partial canopy cover change data provided by the FSL into discrete categories using GIS raster modeling procedures. The static model crown cover maps for 1996 and 2004 were the source of the cover data. The modeling cell size was 25 meters (82.02 feet). The map category ranges were designed to capture Spotted Owl regulatory forest cover specifications (Table 8).

Partial Canopy Change: Western Washington

Although most partial harvest practices occur in the East Cascades zone, there were many FPAs in western Washington forests that were classified as uneven-age harvests. Because of time and funding constraints the partial harvest model development by the FSL was limited to eastside forests. The FSL conducted manual interpretation of temporal changes in sequenced Landsat scenes to identify significant forest cover decrease inside westside uneven-aged FPA polygons (using the DNR database published on the DNR Forest Practices website, January 2004). Our harvest statistics for the westside partial change areas are based only on those areas where the stand replacement model detected change. We assumed the level of timber removal on the remaining landscape associated with uneven-aged FPAs did not result in significant loss of Spotted Owl habitat.

Table 8. Change detection crown cover thresholds between 1996 and 2004 for East Cascades geographic zone.

Class Code	Category of Change	1996 canopy cover	2004 canopy cover
100/108	Stand replacement [1]	≥70%	<15%
101/109	Moderate	≥70%	15-49%
102/110	Low	≥70%	50-69%
103/111	Stand replacement [1]	50-69%	<15%
104/112	Moderate	50-69%	15-49%
105/113	Change not in owl forest cover	Variable	Variable
106/114	Stable	Stable	Stable

1. Stand Replacement = 2004 canopy cover was < 15%.

We extended the westside partial canopy change review by applying automated GIS procedures on a larger set of FPA polygons. For this procedure, FPARS database (Appendix C) entries up to March 30, 2005 were obtained as well as additional locations not selected in the manual procedures. Cross tabulation summary statistics were computed using the stand replacement model and the uneven age FPA polygon "footprint".

Combining Stand Replacement Disturbance and Partial Change in a Single Map

Within the East Cascades zone, partial canopy change and stand replacement disturbance data were combined to create one change layer. Partial change model data were used to map all areas inside the FPA polygons. Outside of FPA polygons partial change data were overlaid on areas where stand replacement indicated no-change. The partial change data exterior to FPA polygons were encoded separately from interior FPA data. We adopted this procedure to minimize the effects of partial canopy cover changes that were caused by non-harvest activities (e.g. disease, drought, wind-throw). Because of processing limitations, the partial change model data did not completely cover some peripheral areas in the East Cascades zone, and in these areas we defaulted to the stand replacement disturbance model. For the westside zones, stand replacement modeled data were applied throughout the zone.

Both eastside and westside change data were then merged into one change map for the entire study area. We considered seven of the 41 total categories that were mapped as representing potential reductions in Spotted Owl habitat due to harvest activities since the adoption of the Spotted Owl regulations in 1996 (Table 9). The partial change detection categories used to indicate possible owl habitat loss due to harvest from 1996 to 2004 were categories 100, 101, 103 and 104. Change codes 4, 5 and 6 represented habitat loss due to stand replacement harvest and codes 12-14 indicate replacement from fire during the 1996-2004 period.

Table 9. Forest change map categories after combining change data from stand replacement models (Codes 3-25) and East Cascades zone partial change polygons (Codes 100-114).

Code	Change	Forest Change 1996-2004	Harvest 1996-2004	Potential Habitat Loss 1996-2004
0	Background	99	99	99
1	Water	99	99	99
2	Non-Forest	99	99	99
3	Forest, No Change	0	0	0
4	Cut 02-04	1	1	1
5	Cut 00-02	1	1	1
6	Cut 96-00	1	1	1
7	Cut 92-96	0	0	0
8	Cut 88-92	0	0	0
9	Cut 84-88	0	0	0
10	Cut 77-84	0	0	0
11	Cut 72-77	0	0	0
12	Fire 02-04	1	0	1
13	Fire 00-02	1	0	1
14	Fire 96-00	1	0	1
15	Fire 92-96	0	0	0
16	Fire 88-92	0	0	0
17	Fire 84-88	0	0	0
18	Fire 77-84	0	0	0
19	Fire 72-77	0	0	0
20	Volcano 1980	0	0	0
21	Cut 72-77, Fire 92-96	0	0	0
22	Cut 77-84, Fire 92-96	0	0	0
23	Cut 84-88, Fire 00-02	1	0	0
24	Cut 77-84, Fire 00-02	1	0	0
25	Cut 77-84, Fire 02-04	1	0	0
100	High Decrease: Closed Canopy	1	1	1
101	Moderate Decrease: Closed Canopy	1	1	1
102	Low Decrease: Closed Canopy	1	1	0
103	High Decrease: Open Canopy	1	1	1
104	Moderate Decrease: Open Canopy	1	1	1
105	Other Veg. Change Non-impact	0	0	0
106	Stable Cover 1996-04 Not Modeled	0	0	0
107	Nonforest/Background	99	99	99
108	OutFPA High Decrease: Closed Canopy	1	0	1
109	OutFPA Moderate Decrease: Closed Canopy	1	0	1
110	OutFPA Low Decrease: Closed Canopy	1	0	0
111	OutFPA High Decrease: Open Canopy	1	0	1
112	OutFPA Moderate Decrease: Open Canopy	1	0	1
113	OutFPA Other Veg. Change Non-impact	1	0	0
114	OutFPA Stable Cover 96-04 Not Modeled	0	0	0

Statistical Analysis

Estimating the Amount of Suitable Habitat on the Landscape in 2004

Because our field sampling excluded plots that fell in recently (1996-2004) harvested stands we defined the total acres as only those acres that had not been harvested between 1996 and 2004, using the modeled information described above. Harvest activities that reduced canopy closure below 70% on westside and below 50% in eastern Washington were assumed to represent potential losses of Spotted Owl habitat suitability (see Tables 8 & 9). The amount of suitable owl habitat in 2004 was estimated by the following formula:

$$Tot\_habitat = \sum_{i=1}^{n\_strata} Tot\_acres_i \cdot \hat{p}_i \qquad (1.2)$$

Where $\hat{p}_i$ = the percentage of strata *i* landscape that met Forest Practices Rule definitions of suitable Spotted Owl habitat.

Let

$$\hat{p}_{i\,helicopter} = \frac{\text{number of helicopter plots classified as habitat}}{\text{total number of helicopter plots}}$$

where $$\hat{p}_i = \hat{p}_{i\,helicopter}\left(HCF\right) + \left(1 - \hat{p}_{i\,helicopter}\right)\left(NCF\right)$$

Where the habitat correction factor (HCF) and non-habitat correction factor (NCF) were calculated by a 2x2 contingency table comparing known habitat conditions from ground sampling methods with fallible habitat estimates using helicopter sampling methods. We adapted the notation of (Tenenbein 1970) (Table 10) as follows:

$$HCF = \frac{n_{11}}{n_{.1}}; \;\; NCF = \frac{n_{10}}{n_{.0}} \qquad (1.3)$$

Table 10. Classification accuracy table notation used in formulas to estimate the total amount (and associated confidence interval) of Spotted Owl habitat and forest harvested from 1996-2004.

	Fallible Prediction		
Verified Event	Not habitat	Habitat	Total
No Habitat	n_{00}	n_{01}	$n_{0.}$
Habitat	n_{10}	n_{11}	$n_{1.}$
Total	$n_{.0}$	$n_{.1}$	n

The variance of $\hat{p}_i$, using the delta *method* (Rao 1965) and derived by Tenenbein (1970), is approximated by :

$$V\left(\hat{p}_i\right) \approx \frac{\hat{p}_i(1-\hat{p}_i)}{n_i}\left(1-K_i\right)+\frac{\hat{p}_i(1-\hat{p}_i)}{N_i}\left(K_i\right) \qquad (1.4)$$

where:

$$K_i = \frac{\hat{p}_i\left(1-\hat{p}_i\right)\left(1-\theta-\phi\right)^2}{p_{i\,helicopter}\left(1-p_{i\,helicopter}\right)},$$

$$\theta_i = \frac{\frac{n_{10}}{n_{.0}}\left(1-p_{i\,helicopter}\right)}{\hat{p}_i}, \quad and$$

$$\phi_i = \frac{\frac{n_{01}}{n_{.1}}\,p_{i\,helicopter}}{1-\hat{p}_i}$$

We tested differences in the 2 X 2 accuracy tables (Table 10; Chi-square or Fisher Exact probability test, alpha = 0.05) among geographic zones within seral strata to determine if the frequency rate of habitat plots from helicopter data could be pooled. Fisher Exact test was used when 50% or more of the expected cell frequencies were less than 5. If differences among geographic zones were not significant, helicopter data were pooled into eastside and westside categories. Differences between eastside and westside data were then tested. Next we tested for differences (alpha = 0.05) among seral strata within pooled geographic strata to determine if data could be pooled across seral strata. We also tested in the same way as described above to determine if the accuracy rates from helicopter data compared to ground plot data varied significantly (alpha = 0.05) among geographic zones within seral strata to determine pooling levels for calculating HCF and NCF estimates.

The probability of habitat $\left(\hat{p}_i\right)$ in early and other seral strata was determined combining data from photo interpretation methods (n_{photo}), where we assumed habitat conditions were determined without error (see methods above) with helicopter results for those confused sites that were classified as unknown by photo interpretation ($n_{nonphoto}$).

$$\hat{p}_{early/other} = \hat{p}_{i\,photo}\frac{n_{photo}}{n_{early/other}} + \hat{p}_{i\,helicopter}\frac{n_{nonphoto}}{n_{early/other}}$$

and the variance, using the delta method (Rao 1965) was approximated by:

$$Var\left(\hat{p}_{early/other}\right) \approx \left[\left(\frac{n_{photo}}{n_{early/other}}\right)\left(\frac{n_{nonphoto}}{n_{early/other}}\right)\left(\hat{p}_{i\ photo} - \hat{p}_{i\ helicopter}\right)^2\right] + \left(\frac{n_{nonphoto}}{n_{early/other}}\right)^2 Var\left(\hat{p}_{i\ helicopter}\right)$$

Estimating the Amount of Spotted Owl Suitable Habitat Harvested from 1996-2004

Micro-habitat data (e.g. snag densities, down wood material, stem densities, etc.) were not readily available to determine actual condition of harvested stands at the time of harvest. We used a two-step process to estimate the amount of Spotted Owl habitat that was harvested between 1996 and 2004. The first step estimated whether or not any given forested stand (i.e. regardless of whether or not it met Spotted Owl habitat definitions) within the study area was harvested during 1996-2004. The second step estimated the amount of landscape that was identified as harvested from 1996-2004 that likely met Spotted Owl habitat conditions at the time it was harvested.

Estimating the Total Amount of Forest Land Harvested

The process used to model the areas that were harvested (both stand replacement and partial harvest) is described above. However as described above, there is error in the models and not all lands estimated to be harvested were harvested and some lands that were estimated to not be harvested were in fact harvested (see Table 10 for notation).

Let

$N_{harv} =$ total acres of harvested area in study area estimated from change detection model

$N_{Total} =$ total number of acres in study area

Then the change detection model harvest level $\left(p_{change}\right) = \dfrac{N_{harv}}{N_{Total}}$;

And using the notation from Table 10 :

n_{11} = the number of random samples actually verified as harvested
$n_{.1}$ = the number of random samples that were predicted from model as harvested

n_{01} = the number of change detection model non-harvest acres that were actually verified as harvested (from random sample)

$n_{.0}$ = the number of total random samples that were predicted from model as not harvested

Using the same approach as described for Equation (1.3):

Harvest correction factor $\left(\hat{C}_{harv}\right) = \dfrac{n_{11}}{n_{.1}}$

and

Non-harvest correction factor $\left(\hat{C}_{nharv}\right) = \dfrac{n_{01}}{n_{.0}}$

In order to estimate the total amount of landscape harvested we combined results from the change detection model with the harvest and non-harvest correction factors so that:

$$\hat{p}_{harv} = \left(p_{change}\, \hat{C}_{harv} \right) + \left(\left(1 - p_{change} \right) \hat{C}_{nharv} \right)$$

and

$$\begin{aligned} Var(\hat{p}_{harv}) = {} & Var\left(p_{change} \cdot \hat{C}_{harv} \right) + Var\left(\hat{C}_{nharv} \right) + Var\left(-p_{change} \cdot \hat{C}_{nharv} \right) + \\ & 2\left[\begin{array}{l} Cov\left(p_{change} \cdot \hat{C}_{harv}, \hat{C}_{nharv} \right) + Cov\left(-p_{change} \cdot \hat{C}_{nharv}, \hat{C}_{nharv} \right) + \\ Cov\left(p_{change} \cdot \hat{C}_{harv}, -p_{change} \cdot \hat{C}_{nharv} \right) \end{array} \right] \end{aligned}$$

Assume $\hat{C}_{harv}, \hat{C}_{nharv}, p_{change}$ are independent, then

$$\begin{aligned} Var(\hat{p}_{harv}) = {} & \left[Var\left(p_{change} \right) Var\left(\hat{C}_{harv} \right) + \left(p_{change}{}^{2} \cdot Var\left(\hat{C}_{harv} \right) \right) + \left(\hat{C}_{harv}{}^{2} \cdot Var\left(p_{change} \right) \right) \right] \\ & + Var\left(\hat{C}_{nharv} \right) + \left[Var\left(p_{change} \right) Var\left(\hat{C}_{harv} \right) + \left(p_{change}{}^{2} \cdot Var\left(\hat{C}_{nharv} \right) \right) + \left(\hat{C}_{nharv}{}^{2} \cdot Var\left(p_{change} \right) \right) \right] \quad (1.5) \\ & + 2\left[p_{change} Var\left(\hat{C}_{nharv} \right) + \hat{C}_{harv} \hat{C}_{nharv} Var\left(p_{change} \right) \right] \end{aligned}$$

Note $Var\left(p_{change} \right) = 0$, and not a sample therefore equation (1.5) simplifies to :

$$Var(\hat{p}_{harv}) = \left[p_{change}{}^{2} Var\left(\hat{C}_{harv} \right) \right] + \left[\left(1 - p_{change} \right)^{2} Var\left(\hat{C}_{nharv} \right) \right] \qquad (1.6)$$

Since sample sizes in estimating the correction factors are significantly smaller (n < 1000) than the total population (N > 20,000,000) we ignored the Finite Population Correction factor and estimated the variance of the correction factors as:

$$Var(\hat{C}_{harv}) \approx \frac{\hat{C}_{harv}\left(1 - \hat{C}_{harv} \right)}{\left(n_{.1} - 1 \right)}$$

$$Var(\hat{C}_{nharv}) \approx \frac{\hat{C}_{nharv}\left(1-\hat{C}_{nharv}\right)}{\left(n_{.0}-1\right)}$$

We estimated the total number of acres harvested from 1996-2004 as:

$$Total\ acres\ harvested\left(\hat{H}\right) = N_{total}\ \hat{p}_{harv}$$

and

$$Var\left(\hat{H}\right) = N_{Total}^{2}\ Var\left(\hat{p}_{harv}\right)$$

Estimating the amount of Spotted Owl habitat harvested from 1996-2004.

Our next task was to estimate the amount of Spotted Owl habitat loss associated with the harvested lands identified in the previous step. We approached this task two different ways. First, we used an Ecological Niche Factor Analysis (ENFA) (Hirzel et al. 2002) using Biomapper software version 3.1.2.235, (http://www2.unil.ch/biomapper, Hirzel et al. 2004). The technique has been used successfully on a variety of species (Hirzel et al. 2002; Hirzel et al. 2004; Brotons et al. 2004; Zaniewski et al. 2002) and requires only presence data, which may be more robust for data that do not fit the assumptions of presence and absence models (Hirzel et al. 2001; Reese et al. 2005).

Recently Biomapper was used for defining Spotted Owl habitat suitability on federally-owned lands in Washington state as part of the 10-year review of the Northwest Forest Monitoring Plan (Davis & Lint in press). We wanted to use similar methodology as Davis and Lint (in press), since it had recently undergone a peer review process and was successful in mapping suitable habitat that was independently validated.

Our second approach was to use logistic regression analysis to corroborate the results of the ENFA modeling approach. The data we had available to use lent itself appropriately to the use of logistic regression since it comprised both presence and absence data and was representative of the relative proportions of habitat and non-habitat stands on the landscape (Keating & Cherry 2004). Habitat suitability models that use well defined presence and absence data may perform better than models that use only presence data (Reese et al. 2005). In our problem, we were interested in estimating the amount of land that met legal habitat definition criteria (i.e. habitat conditions were present) vs. land that did not meet legal definition criteria (i.e. habitat conditions were absent). Department of Natural Resources stand inventory data (Forest Resource Inventory System, or FRIS; Appendix F) were used to identify locations on the landscape where habitat conditions were present and locations on the landscape where habitat conditions were absent.

Typically in modeling habitat, researchers use known animal locations (often times telemetry data) to identify habitat. As we expect to be the case, animal location data should be biased toward the higher quality habitat conditions. Our problem was somewhat unique in that we were interested in mapping marginal quality habitat equally as well as high quality habitat. By using the DNR FRIS stand inventory data we were better able to capture the range of habitat conditions (in relative proportion to their occurrence on the landscape) than using animal location data. The objective of our models was to predict which forested stands in 1996 had conditions that met the legal criteria used to define Spotted Owl habitat. In particular we wanted the models to identify all habitat types including old forest, mature and sub-marginal as suitable or non-suitable habitat.

All known stands within our study area were initially eligible for logistic regression analysis. However, we were not able to classify all stands into habitat or not habitat stands. Some stands had not yet been field surveyed, other stands were surveyed using older and less comprehensive techniques, and other stands lacked field data necessary to determine habitat condition. Habitat condition in these stands was classified as unknown. The remaining stands that we could classify served as the response data in our models. For the Biomapper model all pixels within stands where average conditions clearly met habitat criteria were treated as presence data. For the logistic regression model the analysis unit was each stand.

The Interagency Vegetation Mapping Project (IVMP) GIS layers were used as covariates (i.e. predictor variables) in both modeling approaches (Table 11) and are available for downloading from the Internet at http://www.or.blm.gov/gis/projects/ivmp.asp (see Moeur et al. in press, for discussion of IVMP data). This is the same source of data used in modeling Spotted Owl and Marbled Murrelet habitat suitability in the Northwest Forest Monitoring Plan 10 year review (Davis & Lint in press; Raphael et al. in press).

The Interagency Vegetation Mapping Project used Landsat scenes from 1996 to predict vegetation conditions in Washington. Raster-based maps at 25 m resolution were created for conifer cover, broadleaf cover, quadratic mean diameter (QMD), and tree size using regression techniques (Cohen et al. 2001; Fassnacht et al. in prep.). IVMP layers were masked to exclude federal lands outside of the project study area (Figure 6).

We created three new layers generated from IVMP layers of conifer cover and QMD. The first layer was created by multiplying the conifer cover value with the QMD value for each pixel, following Raphael et al. (in press). Two additional layers were generated using ESRI ArcGis 9.0 neighborhood analysis at each focal cell to describe the average conifer cover-QMD conditions in the surrounding 70 acres of each focal cell. We used a 70-acre analysis circle because it is the size of the core area deemed by the U.S. Fish and Wildlife Service to be essential around Spotted Owl activity centers and is used by the state Forest Practices Rules to be considered around Spotted Owl site centers outside of SOSEAs. In the first layer (Con _QMD 13-19), each pixel was attributed with the percentage of the surrounding 70 acres where conifer cover $\geq 70\%$ and QMD values were ≥ 13 and <20. In the second layer (Con _QMD 20), each pixel was attributed with the percentage of the surrounding 70 acres where conifer cover was $\geq 70\%$ and QMD values were ≥ 20. Plot data of known habitat condition collected as part of this study were used to validate the accuracy and performance of both the logistic regression and ENFA models.

Ecological Niche Factor Analysis

Spotted Owl habitat suitability maps were generated for each IVMP province within the study area (Figure 6) using Biomapper software (Hirzel et al. 2002). All ecogeographical variables (EGV) (IVMP layers; Table 11) were transformed using Box-Cox transformation procedures within Biomapper. All factors with eigenvalues greater than 1.0 were included in the final model. All EGV maps were standardized, as required by the software, so that only pixels with data for all seven GIS layers were included in the analysis. Habitat suitability maps were validated using the area-adjusted cross frequency analysis (Boyce et al. 2002) using the modified and integrated program features in Biomapper.

Habitat suitability scores were grouped into 10 bins, with bin range boundaries adjusted individually so that each bin captured approximately the same proportion of global area on the landscape. Habitat locations (i.e. FRIS habitat stand pixels) were randomly partitioned into 10 mutually exclusive but identically sized sets. Biomapper then computed 10 different HS models, removing one of the partitions each time. The left-out partition was then used to validate each of the habitat suitability models. The Spearman-rank correlations (r_s) between the frequencies of habitat stand pixels within individual bins and the bin rank was calculated by Biomapper. The average r_s across all partition models are presented as an indicator of the performance of the HSI model for each IVMP province. The study area 1996 landscape was summarized by the amount of total area that occurred in each of the 10 HSI bins.

Strong performing models should have a strong positive correlation between the numbers of habitat locations falling within habitat suitability bins as the HSI bin value increases.

Table 11. Seven IVMP-based GIS layers used in modeling suitable Spotted Owl habitat in 1996 on state and private lands in Washington.

Abbreviation	Description	Unit
BDLF	Canopy cover of broadleaved species	1 percent increments from 0 to 100; coded as 0 to 100
Conifer	Canopy cover of coniferous species	10 percent (x 100) increments from 0 to 100; coded as 0 to 9
QMD	Quadratic mean diameter	Inches; in classes 0-1, 1-4.9, 5-11.9, 12-19.9, 20-29.9, 30-39.9, 40-49.9, 50+ Coded using class mid-points (55 for highest class)
Conifer*QMD	Interaction of conifer cover and QMD	Product of CONIF10 and QMD
Variety	The number of different QMD categories across a 3 x 3 pixel square neighborhood around each pixel	Integer from 0 to 9
Con _QMD 13-19	The percentage of a 23 x 23 pixel square (~70 acres) neighborhood around each pixel with conifer cover >=70% and QMD value between 13 and 20.	Percent (x 100); integer from 0 to 100
Con _QMD 20	The percentage of a 23 x 23 pixel square (~70 acres) neighborhood around each pixel with conifer cover >=70% and QMD value >=20.	Percent (x 100); integer from 0 to 100

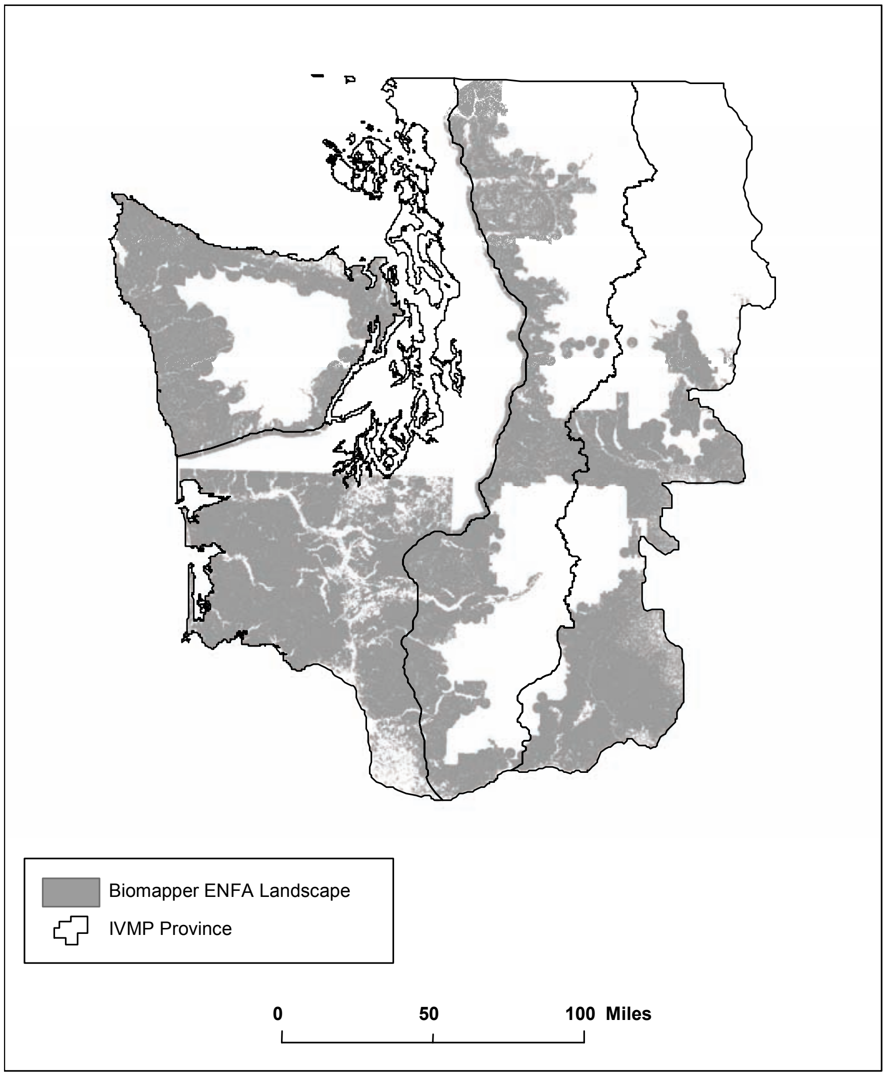

Figure 6. IVMP Province boundaries showing masked landscape areas used in Biomapper ENFA analysis.

The theoretical threshold where habitat suitability conditions of forested stands are more likely to occur than expected by random chance is the HSI value where the area-adjusted frequency score exceeds the value of 1.0 (Boyce et al. 2002). We identified the HSI bin for each model where this threshold occurred and used that bin's lower boundary as a threshold of habitat suitability that defined the habitat / non-habitat condition (Figure 7).

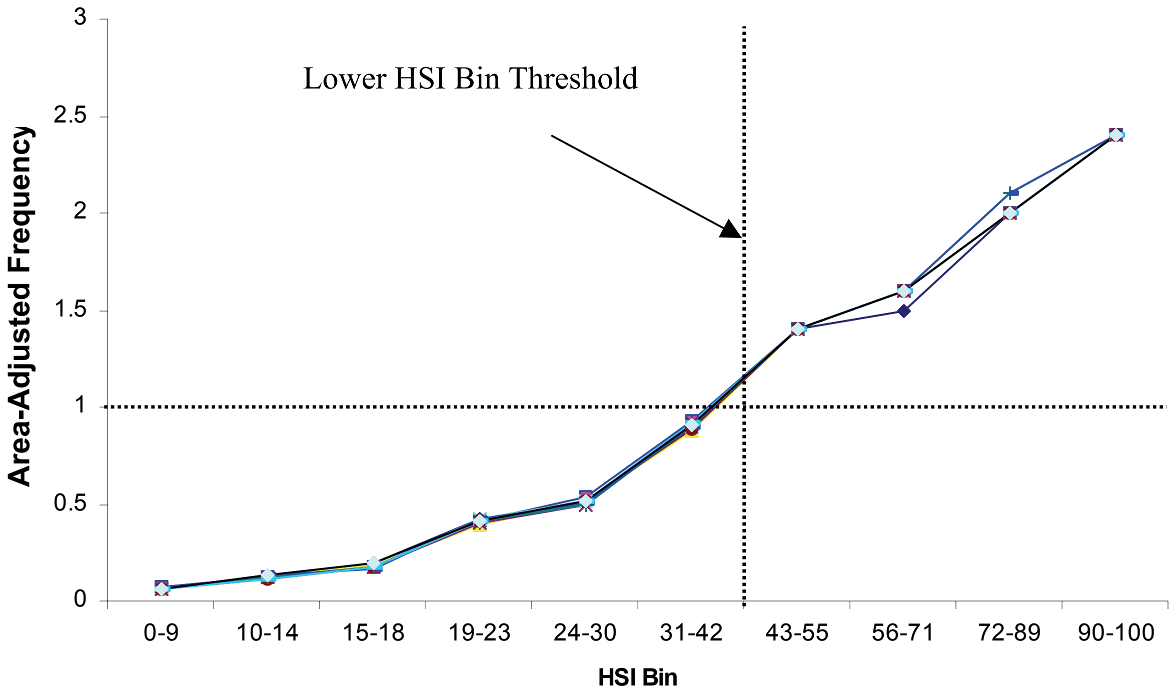

Figure 7. Area-adjusted HSI bin plot showing HSI threshold used to categorize landscape into habitat areas (HSI values above threshold) and non-habitat areas (HSI values below threshold). Figure illustrates western Cascades data from 10 ENFA model replicates using Biomapper. Threshold value selected was the lower boundary of the first bin that had all values greater than 1.

Logistic Regression

Each FRIS stand in the analysis was overlaid on top of each IVMP layer used in the analysis to determine the average and standard error values of the covariates for all grids within each stand. The entire stand database was randomized and approximately 50% of the stands were used in model development and 50% of the stands were used as validation data for each model. This resulted in approximately 1,000 samples available in each dataset for model and validation. SAS Enterprise Guide (Version 2.1.39) was used to run all logistic regression procedures using the logit link option. Stepwise selection procedures (significance for entry = 0.2, significance to stay in model = 0.10) were used on a simple main effects model for all variables in each province. Hosmer-Lemeshow Goodness-of-Fit Chi-Square statistic was used to determine overall significance (alpha = 0.05). A threshold of habitat / non-habitat score was determined for each model by choosing from the classification table the probability level where Sensitivity (percentage known habitat site correctly classified as habitat) were most equal to Specificity (percentage of known non-habitat correctly classified as non-habitat). We then used the validation data scored by the model coefficients derived from the model data for that province and developed a classification table as suggested by Hosmer and Lemeshow (1989). Validation data were classified as habitat or non-habitat according to the habitat / non-habitat threshold for that province, and overall correct classification rates were reported.

Creating Habitat Maps from ENFA and Logistic Regression Models

We applied the ENFA and logistic regression models to the IVMP data throughout the landscape to create a wall-to-wall map of Spotted Owl habitat suitability. Moving window analyses of 10 acres on the westside provinces and 4 acres on the eastside province were used to generate means and standard deviation values used by the logistic regression model. We then overlaid the 1996-2004 harvest layer with the HSI maps to calculate the amount of harvested landscape associated with the Spotted Owl habitat suitability scores. We also overlaid the plots of known habitat condition information, from photo interpretation and ground plots, onto the HSI value habitat maps and calculated the average HSI score within each plot.

To estimate the amount of harvested area that met Forest Practices Rule Spotted Owl habitat condition definitions, we converted the ENFA and logistic regression HSI maps, using the model determined thresholds, into a Boolean map of habitat / non-habitat predictions across the entire landscape within the study area. We applied these same thresholds to the average HSI values for each of our plots and calculated habitat and non-habitat correction factors from a classification accuracy table (following notation in Table 10 and Equations (1.3) to estimate the probability that a site met habitat criteria):

$$\hat{p}_{habitat} = \left(p_{hsi}\,\hat{C}_{habitat} \right) + \left((1 - p_{hsi})\,\hat{C}_{nhabitat} \right)$$

where

$$p_{hsi} = \frac{Acres_{habitat}}{Acres_{total}},$$

$$\left(\hat{C}_{habitat} \right) = \frac{n_{11}}{n_{1.}} \; and \; \left(\hat{C}_{nhabitat} \right) = \frac{n_{01}}{n_{0.}}$$

Since the correction factors for the predictions from harvest and habitat models were based on independent sample observations we assumed independence between the correction factors. Given this assumption the probability that a given site was harvested and also met habitat criteria was estimated by:

$$\hat{p}_{harv\,hab} = P_{rcbc}\left(\hat{C}_{nharv}\hat{C}_{nhabitat} \right) + P_{rcb}\left(\hat{C}_{nharv}\hat{C}_{habitat} \right) + P_{rbc}\left(\hat{C}_{harv}\hat{C}_{nhabitat} \right) + P_{rb}\left(\hat{C}_{harv}\hat{C}_{habitat} \right)$$

Where:

p_{rb} = proportion of landscape mapped as harvested and also as habitat
p_{rbc} = proportion of landscape mapped as harvested and also mapped as non-habitat
p_{rcb} = proportion of landscape mapped as not harvested and also mapped as habitat
p_{rcbc} = proportion of landscape mapped as not harvested and also mapped as non-habitat

The total number of Spotted Owl habitat acres harvested from 1996-2004 was estimated as:

$$\hat{H}arvHab_{1996-2004} = N_{total}\ \hat{p}_{harv\,hab}\text{; with } Var\left(\hat{H}arvhab_{1996-2004}\right) = N_{Total}^2\ Var\left(\hat{p}_{harv\,hab}\right),$$

Assuming independence between $\left(\hat{C}_{harv}, \hat{C}_{habitat}, \hat{C}_{nharv}, \hat{C}_{nhabitat}\right)$ then:

$$\begin{aligned} Var\left(\hat{p}_{harvhab}\right) = \ & p_{rb}{}^2 Var\left(\hat{C}_{harv}\hat{C}_{habitat}\right) + p_{rbc}{}^2 Var\left(\hat{C}_{harv}\hat{C}_{nhabitat}\right) \\ & + p_{rcb}{}^2 Var\left(\hat{C}_{nharv}\hat{C}_{habitat}\right) + p_{rcbc}{}^2 Var\left(\hat{C}_{nharv}\hat{C}_{nhabitat}\right) \\ & + 2\begin{bmatrix} p_{rb}p_{rbc}Cov\left(\hat{C}_{harv}\hat{C}_{habitat}, \hat{C}_{harv}\hat{C}_{nhabitat}\right) \\ + p_{rb}p_{rcb}Cov\left(\hat{C}_{harv}\hat{C}_{habitat}, \hat{C}_{nharv}\hat{C}_{habitat}\right) \\ + p_{rbc}p_{rcbc}Cov\left(\hat{C}_{harv}\hat{C}_{nhabitat}, \hat{C}_{nharv}\hat{C}_{nhabitat}\right) \\ + p_{rcb}p_{rcbc}Cov\left(\hat{C}_{nharv}\hat{C}_{habitat}, \hat{C}_{nharv}\hat{C}_{nhabitat}\right) \end{bmatrix} \end{aligned}$$

Variance terms follow the rule for the product of two independent random variables:

$$Var(XY) = Var(X)Var(Y) + E(X)^2\ Var(Y) + E(Y)^2\ Var(X)$$

Covariance terms follow the following rule :

$$Cov(XY, XZ) = \left[Var(X) + E(X)^2\right]\left[Cov(Y,Z) + E(Y)E(Z)\right] - E(X)^2\ E(Y)E(Z)$$

Which, assuming X, Y and Z are independent, simplifies to :

$$Cov(XY, XZ) = Var(X)E(Y)E(Z)$$

Harvest estimates were summarized according to areas within known owl circles, both inside and outside of SOSEAs, and lands outside of owl circles within SOSEAs. Statistics for HCP lands were separated from statistics for non-HCP lands.

Estimating Relative Change in the Amount of Spotted Owl Habitat from 1996-2004

Conceptually, the amount of Spotted Owl habitat that exists on the landscape in 2004 is a result of the combination of three elements: 1) the amount of habitat that existed on the landscape in 1996, 2) the amount of habitat harvested from 1996-2004, and 3) the net gain (or loss) of new habitat that was created as stand conditions grew into conditions or were lost due to natural disturbance:

$$Habitat_{\ 2004} = Habitat_{\ 1996} - Habitat_{\ \text{1996-2004 harvest}} + Habitat_{\text{1996-2004 net growth}} \qquad (1.7)$$

Where *Habitat* $_{\textit{1996-2004 netgrowth}}$ represents net increase or decrease in the amount of habitat attributed to changes in stand conditions due to tree growth and natural disturbance. Note that if no Spotted Owl habitat was harvested from 1996-2004 (i.e. Habitat $_{\text{1996-2004 harvest}}$ = 0) the right-hand side of equation (1.7) represents the maximum potential amount of Spotted Owl habitat in the study area in 2004. We defined the ratio of the amount of harvested habitat from 1996-2004 to the maximum potential habitat in 2004 as the relative change index (RCI) of the status of Spotted Owl habitat from 1996-2004:

$$RCI_{\ 1996-2004} = \frac{Habitat_{\ \text{1996-2004 harvest}}}{Habitat_{\ 1996} + Habitat_{\ \text{1996-2004 net growth}}}$$

or by rearranging Equation (1.7)**,**

$$RCI_{1996-2004} = \frac{Habitat_{1996\text{-}2004\ \text{harvest}}}{Habitat_{2004} + Habitat_{1996\text{-}2004\ \text{harvest}}}$$

We reported the Relative Change Index (RCI) according to areas within known owl circles, both inside and outside of SOSEAs, and lands outside of owl circles within SOSEAs, separating statistics for HCP lands from non-HCP lands.

RESULTS

Estimating the Amount of Spotted Owl Habitat in 2004

A total of 1,588 individual plots were sampled by photo interpretation or helicopter sampling methods (Table 12). A subset of 250 helicopter plots was also visited where field crews collected additional data using ground sample methods describe above. Stand conditions, as viewed from the helicopter, were unclear at a few sites and Spotted Owl habitat was classified as unknown, resulting in a total of 1,514 plots with data that were useable (Table 13). We performed a series of tests to determine which strata differences were not statistically significant and could be pooled to calculate the probability of habitat.

We first tested for differences in habitat correction factors (HCF) and non-habitat correction factors (NCF). The total number of plots visited by both helicopter and ground crews in the "other" strata was small (n=3) so data were pooled with "early" seral plots. Helicopter classification errors from data collected in westside zones did not differ from each other for NCF (two-tailed probability (pr) <= Fisher's exact test statistic (p) = 0.676, n = 79) or HCF (pr = 0.503, n = 72) and data were combined to create two geographic strata: westside and eastside. Non-habitat correction factors (NCF) did not differ significantly between eastside vs. westside for early- (pr = 1.0, n = 25), mid- (pr = 0.251, n = 68), or late- (pr = 0.191, n = 17) seral classes and seral data were pooled across all geographic strata. The ability to correctly identify non-habitat (NCF) from the helicopter was significantly associated with seral strata (pr = 0.08, n = 110). Helicopter data were most likely to correctly identify non-habitat in early seral strata plots compared to mid or late seral strata plots. NCF values were therefore calculated separately for early/other, mid, and late seral strata (Table 14). The ability to correctly identify habitat in a plot from the air (HCF) was not associated with seral strata (pr = 0.926, n = 120). Therefore all data were pooled to calculate one HCF across the entire study area (Table 14).

Next we tested for differences in the proportion of helicopter data that was classified as suitable habitat ($\hat{p}_{i\ helicopter}$) according to geographic and/or seral strata in the same way we described above for HCF and NCF data. The proportion of a landscape that was classified as Spotted Owl habitat from photo interpretation and helicopter surveys was highly associated with seral strata as expected (χ^2 = 431, pr $\leq$0.001, 3 df). Late seral plots contained the highest overall proportion of estimated habitat (p = 0.72). The lowest proportion of landscapes in habitat occurred overall in early seral (p = 0.07) and other seral strata (p = 0.03).

Habitat presence within strata varied differently among geographic zones as well. Westside zones did not differ from each other for early (pr = 0.352, n = 233), or late seral strata (pr = 0.316, n = 211). Differences among zones were not significant (pr = 0.271, n = 249). Therefore, data were combined within early, other and late strata to create two geographic strata: westside and eastside.

Highly significant differences among westside zones occurred within the mid seral strata (pr <0.0001, n = 505) therefore $\hat{p}_{i\ helicopter}$ was estimated separately for each zone within the mid seral strata. Significant differences were found between eastside and westside zones for early (pr <0.0001, n = 310), and late seral strata (pr $\leq$0.035, n = 343). No significant difference was found between eastside and westside zones for other seral strata (pr $\leq$1.00, n = 231).

Table 12. Distribution of the 1,588 randomly sampled plots, according to geographic, seral strata, land ownership category and sampling method.

		Seral Strata Category												
		Other			Early			Mid			Late			
Zone	Land Owner	Photo Interp.	Air	Air & Ground	Photo Interp.	Air	Air & Ground	Photo Interp.	Air	Air & Ground	Photo Interp.	Air	Air & Ground	Grand Total
East Cascades	Gov	40	10	3	13	17	17	0	34	25	0	61	37	257
	Pvt	56	6	0	21	13	1	0	43	0	0	29	7	176
Total		96	16	3	34	30	18	0	77	25	0	90	44	433
North Cascades	Gov	19	3	0	15	4	2	0	47	15	0	52	15	172
	Pvt	24	2	0	25	2	0	0	68	0	0	14	0	135
Total		43	43	5	0	40	6	2	0	115	15	0	66	15
Olympics	Gov	18	4	0	20	12	0	0	32	16	0	55	14	171
	Pvt	21	3	0	18	1	1	0	13	0	0	7	0	64
Total		39	39	7	0	38	13	1	0	45	16	0	62	14
South Cascades	Gov	14	2	0	30	15	6	0	56	59	0	27	14	223
	Pvt	42	11	0	38	5	2	0	59	3	0	6	0	166
Total		56	56	13	0	68	20	8	0	115	62	0	33	14
Southwest	Gov	11	6	0	12	2	2	0	29	8	0	5	2	77
	Pvt	41	2	0	49	0	0	0	47	0	0	7	1	147
Total		52	8	0	61	2	2	0	76	8	0	12	3	224
Grand Total		286	49	3	241	71	31	0	428	126	0	263	90	1,588

Table 13. The percentage of total (n=1514) randomly sampled plots that were classified as Spotted Owl habitat, according to geographic and seral strata. and sampling method.

	Seral Category											
	Other				Early				Mid		Late	
	Photo Interpretation		Air**		Photo Interpretation		Air**		Air		Air	
Zone	% Habitat	(n)	% Hab	(n)	% Hab	(n)	% Hab	(n)	% Hab	(n)	% Hab	(n)
East Cascades	0%	92	16%	19	0%	28	35%	49	71%	99	78%	133
North Cascades	0%	40	0%	4	0%	39	0%	8	19%	129	64%	77
Olympics	0%	34	43%	7	0%	37	14%	14	23%	56	69%	74
South Cascades	0%	54	8%	12	0%	64	8%	24	47%	170	78%	45
Southwest	0%	45	13%	8	0%	60	0%	4	7%	71	56%	18
Total	0%	265	16%	50	0%	228	21%	99	37%	525	72%	347

** Air visits to plots in other and early seral strata were used to determine habitat conditions for plots that we were not able to classify by photo interpretation alone.

Highly significant differences were found among seral strata within geographic zones (eastside pr < 0.0001, χ^2 = 151.3, df=3; westside pr < 0.0001, χ^2 = 305.6, df=3). Separate $\hat{p}_{i\ helicopter}$ were estimated for eastside and westside zones for early and late seral strata., one $\hat{p}_{i\ helicopter}$ was estimated for the entire study area for other strata, and one $\hat{p}_{i\ helicopter}$ was estimated for each of the 5 geographic zones for the mid strata. Final corrected habitat probability estimates $(\hat{p}_i)$ were most different within mid seral strata across all geographic zones; different between eastside and westside zones for early and late strata; and were the same across all geographic areas within the other seral strata (Table 15).

Table 14. Sampling strata classification accuracy tables for estimating the probability of Spotted Owl habitat for given strata, using helicopter habitat predictions corrected by habitat classification from ground visit plots.

Ground Habitat Condition	Helicopter Prediction			
	Not Habitat			Habitat
	Early-Other	Mid	Late	All Seral Strata
Not Habitat	24	56	12	29
Habitat	1	12	5	91
Total	25	68	17	120
Classification Factors	Nonhabitat Correction Factors (NCF)			Habitat Correction Factor (HCF)
	4.0%	17.7%	29.4%	75.8%

Distribution of Suitable Habitat in 2004 on Non-HCP Landscapes

We estimated there were approximately 615,800 (548,800-682,900) acres of forested landscapes outside of HCP agreements that met Forest Practices Rule definitions of habitat representing 26% of the 2.3 million acre non-HCP study area in 2004 (Table 16). An estimated 277,200 acres (45%) of the non-HCP suitable habitat occurred inside

Spotted Owl Special Emphasis Areas. Approximately 58% of the habitat inside of SOSEAs occurred inside of owl management circles. The overall percentage of the non-HCP landscape in suitable habitat was lowest in Southwest Washington (7%) and highest in the Olympic and East Cascade zones (30-31%) (Table 16). The majority of Spotted Owl habitat in the non-HCP landscape was on either federal (74%) or private (23%) lands.

Table 15. Estimated corrected proportion $(\hat{p}_i)$ and s.e. of Spotted Owl suitable habitat in 2004, within geographic and forest seral stand condition on lands within study area.

	Other [1]		Early [2]		Mid [3]		Late [4]	
Zone	$\hat{p}_i$	s.e.	$\hat{p}_i$	s.e.	$\hat{p}_i$	s.e.	$\hat{p}_i$	s.e.
East Cascades	0.021	4.73E-05	0.125	4.29E-03	0.588	2.21E-03	0.657	2.47E-03
North Cascades	0.021	4.73E-05	0.004	9.81E-07	0.289	1.74E-03	0.609	2.44E-03
Olympics	0.021	4.73E-05	0.004	9.81E-07	0.312	2.42E-03	0.609	2.44E-03
South Cascades	0.021	4.73E-05	0.004	9.81E-07	0.450	1.92E-03	0.609	2.44E-03
Southwest	0.021	4.73E-05	0.004	9.81E-07	0.217	1.60E-03	0.609	2.44E-03

1. $\hat{p}_i$ did not differ significantly among geographic zones.
2. $\hat{p}_i$ differed significantly between eastside westside.
3. $\hat{p}_i$ differed significantly among 5 geographic zones.
4. $\hat{p}_i$ differed significantly between eastside westside.

We found significant variation in the estimated 2004 proportion of the landscape area comprised of suitable Spotted Owl habitat in non-HCP areas among and within zones. Combining all zones and looking just within SOSEAs, non-HCP landscapes within owl circles had proportionately more habitat (28%) than lands outside of circles (18%) (Table 16). Within SOSEAs, there was significantly more habitat inside of circles than outside of circles in all geographic zones.

Inside of SOSEAs, the proportion of non-HCP lands inside owl management circles that met Spotted Owl habitat conditions was highest in East Cascades (34%) and lowest in the Olympic and South Cascade zones (18%). In all of the western Washington zones with

SOSEAs, the percentage of non-HCP lands within owl circles that met habitat conditions was significantly greater outside of SOSEAs (34%) than inside of SOSEAs (21%). The amount of habitat relative to the total area within owl circles in the East Cascades zone did not significantly differ inside (34%) vs. outside (31%) of SOSEAs.

Distribution of Suitable Habitat in 2004 on HCP Landscapes

We estimated there were a total of 200,500 (177,700-223,300) acres of forested landscapes within areas managed by HCP agreements that met Forest Practices Rule definitions of habitat representing 22% of the 899,000 acre HCP study area in 2004 (Table 17). An estimated 149,000 acres (74%) of the HCP suitable habitat occurred inside Spotted Owl Special Emphasis Areas. Approximately 59% of the habitat inside of SOSEAs occurred inside of owl management circles. The overall percentage of the HCP landscape meeting suitable habitat conditions was lowest in Southwest Washington (14%) and highest in the East Cascades (28%) (Table 17). The majority of Spotted Owl habitat in the HCP landscape was on state (83%) lands.

The estimated relative amount of suitable Spotted Owl habitat in 2004 on HCP landscapes varied among and within zones. Over the entire HCP landscape within SOSEAs, the relative amount of habitat inside of owl circles (24%) was not significantly different from the relative amount of habitat outside of circles (20%) (Table 17). However, this difference was significant in both the Olympics (20% vs 14%) and South Cascades (29% vs 19%). Inside of SOSEAs, the proportion of HCP lands inside owl management circles that met Spotted Owl habitat conditions was highest in the East Cascades (31%) and lowest in the Olympics (20%). The percentage of HCP lands within owl circles that met habitat conditions was not significantly different outside of SOSEAs (23%) compared to inside of SOSEAs (24%).

Table 16. 2004 Spotted Owl habitat estimate (x 1,000 acres), 95% confidence interval (CI) and percentage of landscape in Spotted Owl habitat on lands **outside** of USFWS approved HCPs. Data are summarized for landscapes within SOSEAs: inside and outside of known owl management circles and outside of SOSEAs within owl management circles.

		Inside SOSEA			Outside SOSEA	
Zone	Data	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	Landscape Acres	290	227	518	205	723
	Habitat (CI) in 2004	98.2 (87-109.4)	59.9 (52.2-67.6)	158.1 (139.2-177)	64.5 (56.5-72.4)	222.5 (195.7-249.4)
	Habitat Proportion (CI)	0.34 (0.30-0.38)	0.26 (0.23-0.30)	0.31 (0.27-0.34)	0.31 (0.28-0.35)	0.31 (0.27-0.34)
North Cascades	Landscape Acres	109	179	288	162	450
	Habitat (CI) in 2004	30.8 (27.7-33.9)	28 (24.8-31.2)	58.8 (52.5-65.1)	60 (54.3-65.8)	118.9 (106.8-130.9)
	Habitat Proportion (CI)	0.28 (0.25-0.31)	0.16 (0.14-0.17)	0.20 (0.18-0.23)	0.37 (0.33-0.41)	0.26 (0.24-0.29)
Olympics	Landscape Acres	104	72	176	465	641
	Habitat (CI) in 2004	18.3 (16.3-20.3)	10.1 (8.9-11.2)	28.4 (25.2-31.6)	163.2 (147.6-178.9)	191.6 (172.8-210.4)
	Habitat Proportion (CI)	0.18 (0.16-0.19)	0.14 (0.12-0.16)	0.16 (0.14-0.18)	0.35 (0.32-0.38)	0.30 (0.27-0.33)
South Cascades	Landscape Acres	84	161	245	159	404
	Habitat (CI) in 2004	14.8 (13.3-16.4)	17.1 (15-19.2)	31.9 (28.2-35.6)	43 (38.7-47.2)	74.9 (66.9-82.8)
	Habitat Proportion (CI)	0.18 (0.16-0.20)	0.11 (0.09-0.12)	0.13 (0.12-0.15)	0.27 (0.24-0.30)	0.19 (0.17-0.21)
Southwest	Landscape Acres				116	116
	Habitat (CI) in 2004				7.9 (6.6-9.3)	7.9 (6.6-9.3)
	Habitat Proportion (CI)				0.07 (0.06-0.08)	0.07 (0.06-0.08)
	Total Landscape Acres	588	639	1,227	1,108	2,335
	Total Habitat (CI) in 2004	162.2 (144.3-180.1)	115 (100.8-129.3)	277.2 (245.1-309.4)	338.6 (303.7-373.5)	615.8 (548.8-682.9)
	Habitat Proportion (CI)	0.28 (0.25-0.31)	0.18 (0.16-0.20)	0.23 (0.20-0.25)	0.31 (0.27-0.34)	0.26 (0.24-0.29)

Table 17. 2004 Spotted Owl habitat estimate (x 1,000 acres), 95% confidence interval (CI) and percentage of landscape in Spotted Owl habitat on lands **inside** of USFWS approved HCPs. Data are summarized for landscapes within SOSEAs: inside and outside of owl management circles and outside of SOSEAs within owl management circles.

		Inside SOSEA			Outside SOSEA	
Zone	Data	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	Landscape Acres	84	69	153	23	176
	Habitat (CI) in 2004	26.3 (22.9-29.7)	17 (14.6-19.5)	43.3 (37.4-49.2)	6.5 (5.6-7.3)	49.8 (43.1-56.6)
	Habitat Proportion (CI)	0.31 (0.27-0.35)	0.25 (0.21-0.28)	0.28 (0.25-0.32)	0.28 (0.25-0.32)	0.28 (0.25-0.32)
North Cascades	Landscape Acres	69	104	173	19	192
	Habitat (CI) in 2004	14.4 (12.9-16)	20.7 (18.5-23)	35.2 (31.4-39)	6.2 (5.6-6.8)	41.4 (36.9-45.8)
	Habitat Proportion (CI)	0.21 (0.19-0.23)	0.20 (0.18-0.22)	0.20 (0.18-0.23)	0.33 (0.3-0.36)	0.22 (0.19-0.24)
Olympics	Landscape Acres	145	57	202	106	308
	Habitat (CI) in 2004	28.5 (25.5-31.6)	7.9 (7-8.9)	36.5 (32.5-40.5)	25.1 (22.6-27.7)	61.6 (55.1-68.2)
	Habitat Proportion (CI)	0.20 (0.18-0.22)	0.14 (0.12-0.16)	0.18 (0.16-0.2)	0.24 (0.21-0.26)	0.20 (0.18-0.22)
South Cascades	Landscape Acres	62	84	146	19	165
	Habitat (CI) in 2004	18.1 (16.4-19.9)	15.9 (14.3-17.6)	34.1 (30.7-37.5)	5.3 (4.8-5.8)	39.4 (35.5-43.3)
	Habitat Proportion (CI)	0.29 (0.26-0.32)	0.19 (0.17-0.21)	0.23 (0.21-0.26)	0.28 (0.26-0.31)	0.24 (0.22-0.26)
Southwest	Landscape Acres				60	60
	Habitat (CI) in 2004				8.4 (7.2-9.6)	8.4 (7.2-9.6)
	Habitat Proportion (CI)				0.14 (0.12-0.16)	0.14 (0.12-0.16)
	Total Landscape Acres	360	314	674	226	899
	Total Habitat (CI) in 2004	87.4 (77.6-97.2)	61.6 (54.3-68.9)	149 (132-166.1)	51.5 (45.7-57.2)	200.5 (177.7-223.3)
	Habitat Proportion (CI)	0.24 (0.22-0.27)	0.20 (0.17-0.22)	0.22 (0.2-0.25)	0.23 (0.2-0.25)	0.22 (0.2-0.25)

Estimating the Amount of Total Landscape Harvested During 1996-2004

A total of 490 randomly selected points was used to determine accuracy of the stand replacement change model that was subsequently used to identify areas that were harvested from 1996-2004. We found that error rates associated with the stand replacement model were greater within the boundary edge (± 2 pixels) around the predicted change areas compared to non-edge areas. In areas outside of the edge boundary, the model predictions were correct at 98% of 345 random points we examined, compared to an overall accuracy rate of 92% inside edge areas (Table 18a). The harvest correction factor (i.e. the percentage of stand replacement change predictions that were in confirmed areas of stand replacement change) for non-edge areas was 95%. The stand replacement model was correct at over 99% of the 272 points predicted as non-change in non-edge areas. In areas inside the edge boundary, the model predictions were correct at 91% of 145 random points we examined (Table 18a). The harvest correction factor for edge areas was 90%. The stand replacement model was correct at 93% of the 30 points predicted as non-change in edge boundary areas. Overall HCF and NCF estimates for stand replacement predictions were calculated as the weighted average based on the proportion of the area that fell inside and outside of an edge area.

The accuracy correction data for the partial harvest model were collected at the stand level and errors associated with edge boundaries were not distinguished from errors outside of edge areas, therefore one accuracy correction table was generated for the model and applied across the partial harvest model area. Partial harvest model performance for predicting areas of significant partial harvest was less than that of the stand replacement model. The partial harvest model correctly predicted 76% of all field plots visited in the model area (Table 18b). The non-partial harvest correction factor (NCF) was 23% and the partial harvest correction factor (HCF) was 74%.

Table 18a. Classification accuracy table for stand replacement model, data derived from visual inspection of Landsat imagery at 490 random locations within study area.

Verified Condition	No-Harvest Predicted		Harvest Predicted	
	Edge Areas [1]	Non-edge Areas	Edge Areas	Non-edge Areas
No Harvest	28	271	10	3
Harvest	2	1	105	70
Total	30	272	115	73
Classification Factors	Non-harvest Correction Factors NCF (s.e.)		Harvest Correction Factor HCF (s.e.)	
	0.067 (0.002)	0.004 (0.00001)	0.913 (0.0007)	0.959 (0.001)

1. Edge areas were defined as lands within 50 meters of an edge between change and nochange areas predicted by the stand replacement model.

Table 18b. Classification accuracy table for partial harvest model, comparing model predictions with verified significant harvest [1] from data derived from 74 field plots collected in East Cascade zone.

Verified Condition	Modeled Prediction		
	No harvest	Harvest	Total
No significant harvest detected	36	7	43
Significant harvest detected	11	20	31
Total	47	27	74
Classification Factors	Non-harvest Correction Factors, NCF (s.e.)	Harvest Correction Factor, HCF (s.e.)	
	0.23 (0.062)	0.74 (0.086)	

1. Significant harvest was defined as overstory removal categories representing canopy reductions resulting in 2004 conditions below Forest Practices Rule definitions of cover criteria for Spotted Owl habitat.

Table 19. Proportion of the landscape harvested for five geographic zones within the study area determined from temporal analysis of Landsat data from 1996-2004. Modeled results adjusted by stand replacement and partial harvest model NCF and HCF values from Table 18a and 18b.

Zone	Uncorrected Harvest Proportion	Corrected Harvest Proportion (s.d.)		Corrected Predictions	
				Harvested	Not Harvested
East Cascades					
Partial Harvest	0.213	0.342	(0.0583)	42,420	81,574
Stand Replacement	0.016	0.022	(0.0045)	17,339	757,198
North Cascades	0.039	0.041	(0.0038)	26,426	615,697
Olympics	0.031	0.034	(0.0037)	32,018	917,244
South Cascades	0.054	0.056	(0.0040)	31,752	536,681
Southwest	0.126	0.126	(0.0055)	22,054	153,539
Study Area Total	0.045	0.053	(0.0121)	172,010	3,061,933

1. Harvested condition for partial harvest landscapes represent only those harvested areas where overstory removal was significant enough to reduce stand conditions to cover values below Spotted Owl habitat criteria definitions in Forest Practices Rules.

Using both the stand replacement and partial harvest model predictions and associated correction factors, we estimated that approximately 5.3% of the entire study area was harvested since the adoption of the Spotted Owl Forest Practices Rules in 1996 (Corrected Study Area Total, Table 19). The adjusted harvest level was slightly higher (0.8%) than the uncorrected model predictions.

Overall the Southwest zone landscape received the highest level of harvest (12.6%), and the Olympic zone received the lowest harvest level (3.4%) during the 9-year period. The harvest rates varied significantly among landowner categories. We estimated that less than 1% of the federal lands, 13% of the tribal lands, 11% of the private lands and 3% of the state-local lands within the entire study area were harvested from 1996-2004.

Westside Partial Harvest Estimates.

We examined a total of 765 westside uneven-aged FPA polygons (with applications dated 1996-2003) encompassing approximately 35,000 acres of the study area (Table 20). We were unable to determine whether or not any harvest occurred at 105 polygons, due to either cloud cover or unclear interpretation of the Landsat imagery. A total of 206 polygons did not show any evidence of overstory change. We did however, detect some level of harvest activity in the remaining 454 polygons representing ~ 22,000 acres in the study area. We found that the activity detected inside the polygons did not usually cover the entire area, but was restricted to a smaller area within the overall extent of the compiled FPA boundary. We were not able to manually quantify the intensity and extent of overstory removal in these areas due to time and logistical constraints.

Automated GIS procedures applied on an updated set of FPAs (FPARS database entries up to March 30, 2005) indicated that 1996-2004 stand replacement applications covered approximately 6,000 acres of the 54,000-acre uneven age FPA area we examined. In addition, of the remaining 48,000 total acres covered by 1996-2004 approved applications there were 6,000 acres that occurred on lands identified by the stand replacement model as being clearcut harvested from 1972-1996. We assumed these areas were not habitat after 1996. This left a total of 42,000 acres of uneven-aged FPAs that we assumed for the purposes of our harvest statistic calculations were not significant enough to represent lost Spotted Owl habitat, and were treated as no-change areas (see Additional Considerations discussion later in this report for further comments on this assumption).

Table 20. The number of westside uneven-aged forest practice applications and status of harvest activity determined by inspection of Landsat temporal sequenced scenes.

Evidence of Harvest Activity	No. Polygons	Acres	Percent of total
Undetermined [1]	105	4,619	0.13
No	206	7,973	0.23
Yes	454	22,423	0.64
Total	765	35,015	

1. Cloud cover obscured area or indicators of change were unclear.

Distribution of Harvested Landscapes 1996-2004 on non-HCP Lands

We estimated approximately 130,000 (101,600-158,500) acres of forested landscapes (of any suitability condition) outside of HCP agreements were harvested during the time period 1996-2004, representing approximately 6% of the non-HCP study area (Table 21). An estimated 71,800 acres (55%) of the harvested non-HCP lands occurred inside Spotted Owl Special Emphasis Areas. Approximately 31% of the harvest inside of SOSEAs occurred inside of owl management circles. The overall percentage of the non-HCP landscape harvested was highest in Southwest Washington (16%) and lowest in the Olympic and North Cascade zones (4%) (Table 21). The majority of harvested lands in the non-HCP landscape were private (90%).

In the 2.3 million acre non-HCP portion of our study area, 45% of the total harvest occurred inside owl circles located outside Spotted Owl Special Emphasis Areas. There was significant variation in the relative amount of landscape harvested in non-HCP areas among and within zones. Outside of Spotted Owl Special Emphasis Areas, the percentage of the landscape harvested inside all owl management circles ranged between 1% and 16% among the five geographic zones. Relative harvest levels inside circles that were outside of SOSEAs were lowest in the North Cascades and greatest in Southwest Washington (Table 21).

Over all zones combined, and looking just within landscapes with Spotted Owl Special Emphasis Areas, relative harvest outside of circles (8%) was significantly greater compared to relative harvest inside circles (4%) (Table 21). Relative harvest outside of circles in all zones except the East Cascades was significantly greater compared to harvest levels inside circles. Over the entire non-HCP study area harvest levels in circles outside of Spotted Owl Special Emphasis Areas were not significantly different than harvest levels inside circles inside of Spotted Owl Special Emphasis Areas.

Distribution of Harvested Landscapes 1996-2004 on HCP Lands

We estimated approximately 42,000 (31,800-52,100) acres of the HCP forested landscape were harvested during the time period 1996-2004, representing 5% of the HCP study area (Table 22). On the 899,000-acre HCP portion of our study area, 25% of the total area and 30% of the total harvest occurred inside owl circles located outside Spotted Owl Special Emphasis Areas. The majority of the harvest on HCP lands occurred on State-local (55%) lands.

Table 21. Estimated amount (x 1,000 acres), 95% confidence interval (CI) and percentage of total landscape harvested from 1996-2004 on lands **outside** of USFWS approved HCPs. Data are summarized for landscapes within SOSEAs: inside and outside of owl management circles and outside of SOSEAs within owl management circles.

		Inside SOSEA			Outside SOSEA	
Zone	Data	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	Landscape Acres	290	227	518	205	723
	1996-2004 Total Harvest (CI)	12.1 (7.2-17)	16.8 (11.1-22.5)	28.9 (18.3-39.5)	15.9 (11.6-20.2)	44.7 (29.9-59.6)
	Harvest Proportion (CI)	0.04 (0.02-0.06)	0.07 (0.05-0.1)	0.06 (0.04-0.08)	0.08 (0.06-0.10)	0.06 (0.04-0.08)
North Cascades	Landscape Acres	109	179	288	162	450
	1996-2004 Total Harvest (CI)	4.0 (3.2-4.9)	13 (11.4-14.6)	17.1 (14.6-19.5)	1.0 (-0.1-2.2)	18.1 (14.5-21.7)
	Harvest Proportion (CI)	0.04 (0.03-0.04)	0.07 (0.06-0.08)	0.06 (0.05-0.07)	0.01 (0.00-0.01)	0.04 (0.03-0.05)
Olympics	Landscape Acres	104	72	176	465	641
	1996-2004 Total Harvest (CI)	4.2 (3.4-5)	5.2 (4.6-5.9)	9.5 (8.1-10.9)	14.4 (10.7-18)	23.8 (18.8-28.9)
	Harvest Proportion (CI)	0.04 (0.03-0.05)	0.07 (0.06-0.08)	0.05 (0.05-0.06)	0.03 (0.02-0.04)	0.04 (0.03-0.05)
South Cascades	Landscape Acres	84	161	245	159	404
	1996-2004 Total Harvest (CI)	1.9 (1.2-2.5)	14.6 (13.1-16)	16.4 (14.3-18.5)	8.7 (7.4-10.1)	25.2 (21.7-28.6)
	Harvest Proportion (CI)	0.02 (0.01-0.03)	0.09 (0.08-0.1)	0.07 (0.06-0.08)	0.05 (0.05-0.06)	0.06 (0.05-0.07)
Southwest	Landscape Acres				116	116
	1996-2004 Total Harvest (CI)				18.2 (16.8-19.6)	18.2 (16.8-19.6)
	Harvest Proportion (CI)				0.16 (0.14-0.17)	0.16 (0.14-0.17)
	Total Landscape Acres	588	639	1,227	1,108	2,335
	Total 1996-2004 Harvest (CI)	22.2 (15-29.4)	49.6 (40.3-59)	71.8 (55.3-88.4)	58.2 (46.3-70.1)	130.0 (101.6-158.5)
	Harvest Proportion (CI)	0.04 (0.03-0.05)	0.08 (0.06-0.09)	0.06 (0.05-0.07)	0.05 (0.04-0.06)	0.06 (0.04-0.07)

Table 22. Estimated amount (x 1,000 acres), 95% confidence interval (CI) and proportion of total landscape harvested from 1996-2004 on lands **inside** of USFWS approved HCPs. Data are summarized for landscapes within SOSEAs: inside and outside of owl management circles and outside of SOSEAs within owl management circles.

		Inside SOSEA			Outside SOSEA	
Zone	Data	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	Landscape Acres	84	69	153	23	176
	1996-2004 Total Harvest (CI)	7.6 (5.4-9.8)	6.3 (4.2-8.3)	13.9 (9.7-18.1)	1.1 (0.8-1.5)	15.0 (10.4-19.6)
	Harvest Proportion (CI)	0.09 (0.06-0.12)	0.09 (0.06-0.12)	0.09 (0.06-0.12)	0.05 (0.03-0.06)	0.09 (0.06-0.11)
North Cascades	Landscape Acres	69	104	173	19	192
	1996-2004 Total Harvest (CI)	4.0 (3.4-4.6)	4.2 (3.4-5)	8.2 (6.9-9.6)	0.1 (0-0.2)	8.3 (6.8-9.8)
	Harvest Proportion (CI)	0.06 (0.05-0.07)	0.04 (0.03-0.05)	0.05 (0.04-0.06)	0.01 (0.00-0.01)	0.04 (0.04-0.05)
Olympics	Landscape Acres	145	57	202	106	308
	1996-2004 Total Harvest (CI)	1.4 (0.4-2.5)	0.6 (0.2-1)	2.1 (0.6-3.5)	6.1 (5.3-7)	8.2 (5.9-10.5)
	Harvest Proportion (CI)	0.01 (0.00-0.02)	0.01 (0.00-0.02)	0.01 (0.00-0.02)	0.06 (0.05-0.07)	0.03 (0.02-0.03)
South Cascades	Landscape Acres	62	84	146	19	165
	1996-2004 Total Harvest (CI)	1.9 (1.4-2.3)	3.5 (2.9-4.1)	5.4 (4.3-6.5)	1.2 (1.1-1.4)	6.6 (5.3-7.9)
	Harvest Proportion (CI)	0.03 (0.02-0.04)	0.04 (0.03-0.05)	0.04 (0.03-0.04)	0.07 (0.06-0.08)	0.04 (0.03-0.05)
Southwest	Landscape Acres				60	60
	1996-2004 Total Harvest (CI)				3.9 (3.4-4.4)	3.9 (3.4-4.4)
	Harvest Proportion (CI)				0.07 (0.06-0.07)	0.07 (0.06-0.07)
	Total Landscape Acres	360	314	674	226	899
	Total 1996-2004 Harvest (CI)	15.0 (10.7-19.3)	14.6 (10.7-18.4)	29.5 (21.4-37.7)	12.4 (10.4-14.4)	42.0 (31.8-52.1)
	Harvest Proportion (CI)	0.04 (0.03-0.05)	0.05 (0.03-0.06)	0.04 (0.03-0.06)	0.06 (0.05-0.06)	0.05 (0.04-0.06)

Outside of Spotted Owl Special Emphasis Areas, the percentage of the landscape harvested ranged between 1% (North Cascades) and 7% (South Cascades) (Table 22). Harvest levels within Spotted Owl Special Emphasis Area boundaries on HCP lands were not different inside of circles (4%) compared to lands outside of circles (5%). Harvest levels on HCP lands inside the Olympic SOSEA (1%) were significantly less than harvest levels on HCP lands inside of all other SOSEAs.

Estimating the Amount of Spotted Owl Habitat Harvested During 1996-2004

ENFA Habitat Suitability Model

Ecogeographical variables (EGV) differed between global landscapes and FRIS forest stands that met criteria of Spotted Owl habitat definitions. Spotted Owl habitat was most strongly associated with landscapes composed of larger QMD values compared with the global landscape (Table 23). Marginality coefficients indicated that Spotted Owl habitat was linked to sites with high conifer cover and larger trees (i.e. QMD scores; Table 23) less fragmented stands that were composed of conifer cover >70% with QMD values greater than 20 inches (Table 23) or QMD values between 13 and 20 (Table 23), and on the westside, stands with less broadleaf cover (Table 23). It is important to note that the marginality factors are relative within a modeled area (e.g. IVMP province) and not necessarily comparable from one zone to the next. For example, the importance of the amount of the neighboring landscape with greater than 70% conifer and QMD values >20 was less important in the western Washington lowland province than in other provinces, presumably because it was less available on the landscape.

All four province models were highly significant indicating strong differentiation in EGV maps between known stands that met Spotted Owl habitat criteria compared to the average available condition in all stands across the landscape (Table 24). Differences between owl habitat stands from the surrounding landscape (i.e. marginality separation) was strongest in

Southwest Washington and weakest on landscapes in the East Cascades zone. The amount of the landscape above ENFA Spotted Owl habitat suitability thresholds scores varied significantly among the seral strata within each geographic zone (Table 25). Low HSI values were predominately associated with early and other seral strata, while higher HSI values were mostly associated with mid and late seral strata (Figure 8).

The ability of the ENFA model to correctly predict habitat conditions at known plots varied according to seral condition. Non-habitat correction data did not differ between early and other strata (Fisher's exact test two-tailed prob (pr) = 1.0, n=388) or between mid and late strata (pr = 0.6534, n=37) therefore data were pooled to estimate NCFs for combined strata (Table 26). Habitat correction data did not differ between early and other strata (pr = 0.07, n=55) but were different between mid and late strata (pr = 0.001, n=160) therefore data were pooled to estimate three HCFs (Table 26). Biomapper ENFA models had the highest level of accuracy classifying non-habitat (low NCF values) in early and other seral strata (NCF = 0.3%). ENFA models had the highest level of accuracy classifying habitat (high HCF values) in late seral strata (HCF = 69.6%).

Logistic Regression Habitat Suitability Model

Logistic regression models were developed for each IVMP province (Table 27). East Cascades and Olympic models performed best and classified approximately 80% of the independent validation data correctly. Southwest and West Cascade models did not perform as well, classifying ~ 65% of the validation data correctly. Percent cover (vegetation layer) was a significant factor in all four provinces, followed by the variety factor, which was present in three of the models (Table 28). Two factors, conifer cover and Con QMD 20, were not significant enough to remain in any of the final models.

Logistic regression HSI scores varied among seral strata in the same way found for ENFA HSI scores (Table 29). Highest scores were found in late and mid seral strata and lowest scores were found in early and other strata. Logistic regression models performed slightly

Table 23. Landscape variable (LV) landscape means (s.d.), FRIS habitat means(s.d.) and marginality factor scores from Ecological Niche Factor Analysis using Biomapper, according to four Washington State IVMP provinces.

LV	Landscape Means				FRIS Habitat Stand Means			
	Oly	WLO	WCW	ECW	Oly	WLO	WCW	ECW
% Broadleaf	23.1(25.2)	31.3(30.9)	24.3(20.1)	11.2(13.1)	12.7(18.3)	19.1(27.5)	16.1(17.2)	15.4(13.6)
% Conifer	61.5(35.8)	52.3(38.8)	60.7(31.8)	58.1(31.0)	84.0(21.0)	77.8(29.8)	79.3(20.5)	78.4(17.8)
% QMD 13-19; CC > 70	10.7(9.9)	10.0(12.4)	10.4(11.7)	25.9(20.7)	17.0(10.3)	25.9(17.5)	19.2(12.7)	41.8(18.6)
% QMD > 20; CC > 70	15.1(21.0)	3.6(8.9)	13.9(20)	4.6(4.8)	34.3(21.4)	11.5(17.0)	29.1(23.1)	7.91(4.2)
QMD	11.4(11.1)	7.7(5.9)	10.6(10.6)	9.6(7.2)	20.8(12.0)	13.0(7.1)	16.9(11)	12.1(8.3)
QMD x% Conifer	86.3(107.9)	48.2(62.0)	76.8(98.9)	69.1(69.0)	184.0(115.7)	110.5(77.6)	144.3(106.5)	102.5(74.2)
Variety Index	3.1(1.3)	2.4(1.0)	2.9(1.2)	2.9(0.8)	3.9(1.0)	2.9(0.9)	3.5(1)	3.2(0.8)

EGV	IVMP Province Marginality Factor Score			
	Oly	WLO	WCW	ECW
% Broadleaf	-0.21	-0.23	-0.24	0.25
% Conifer	0.32	0.32	0.35	0.44
% QMD 13-19; CC > 70	0.35	0.53	0.47	0.51
% QMD > 20 ; CC > 70	0.51	0.38	0.47	0.53
QMD	0.43	0.42	0.36	0.19
QMD x% Conifer	0.45	0.43	0.43	0.33
Variety Index	0.29	0.23	0.27	0.26

Marginality factor scores represent the mean parameter values that maximize the separation between the FRIS habitat attributes from the surrounding global landscape attributes.

Table 24. Habitat Suitability Model results from Ecological Niche Factor Analysis using Biomapper, according to four Washington State IVMP provinces.

IVMP Province	Factors in Model	Percent of Explained Information	Marginality	Tolerance	H.S. Threshold [1]	Spearman Correlation
OLY	5	0.96	0.98	0.55	37	1.00 p <= 0.001
WLO	5	0.95	1.01	0.68	38	1.00 p <= 0.001
WCW	5	0.96	0.86	0.56	43	1.00 p <= 0.001
ECW	4	0.98	0.75	0.34	28	0.89 p<=0.001

1. H.S. threshold defined as lower bin range of Habitat Suitability Index value where area-adjusted frequency curve cross value of 1.0 (see Figure 3). This threshold was used as minimum value in HS map.

Table 25. Percentage of the 1996 landscape scored above Spotted Owl habitat ENFA HSI threshold, according to geographic zone and seral sampling strata.

		Seral Strata			
Zone	HSI Threshold [1]	Other	Early	Mid	Late
East Cascades	28	28%	35%	62%	86%
North Cascades	43	18%	11%	45%	61%
Olympics	37	11%	9%	47%	56%
South Cascades	43	16%	9%	39%	54%
Southwest	38	18%	15%	65%	77%
Grand Total		20%	16%	49%	66%

1. HSI threshold determined at HSI bin where adjusted-area frequency scores of suitable habitat exceed value expected for random distribution (i.e. > 1.0).

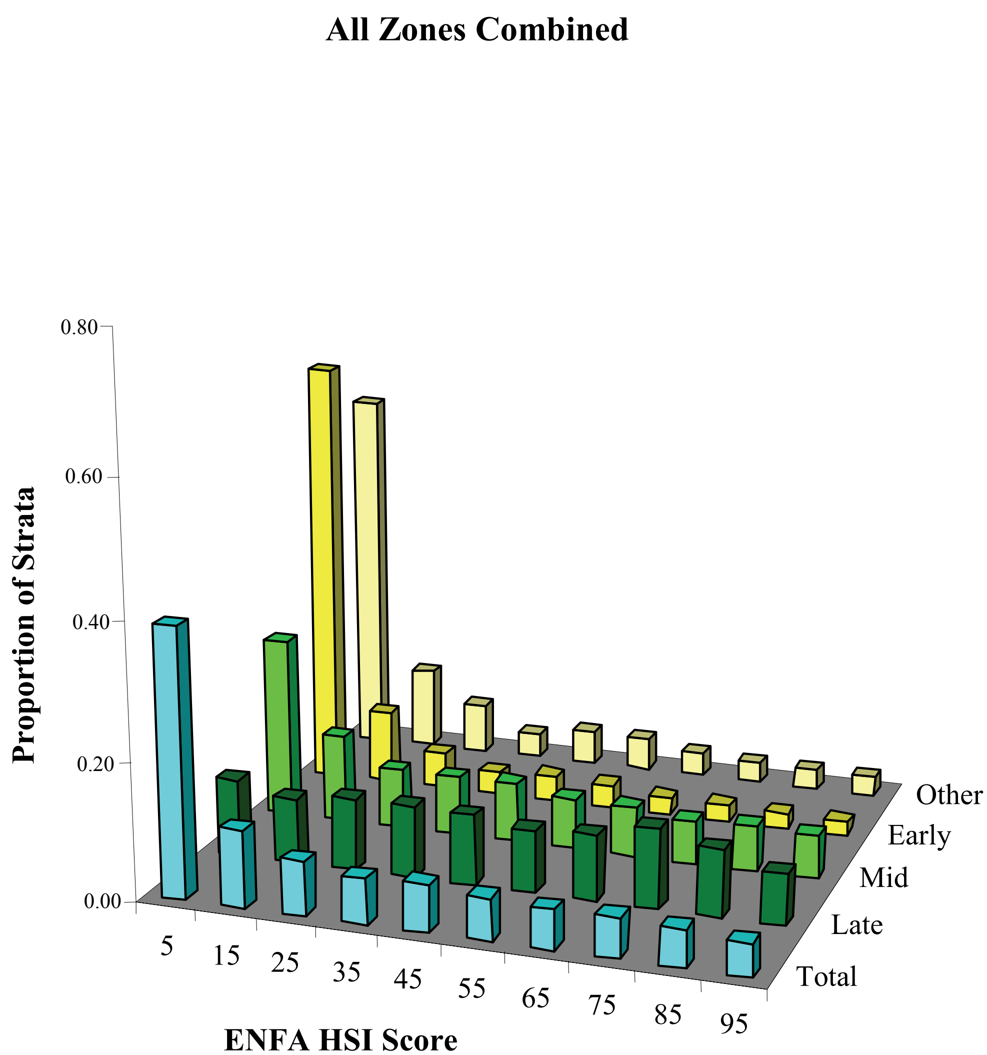

Figure 8a. Distribution of ENFA HSI scores across geographic zone according to seral strata class.

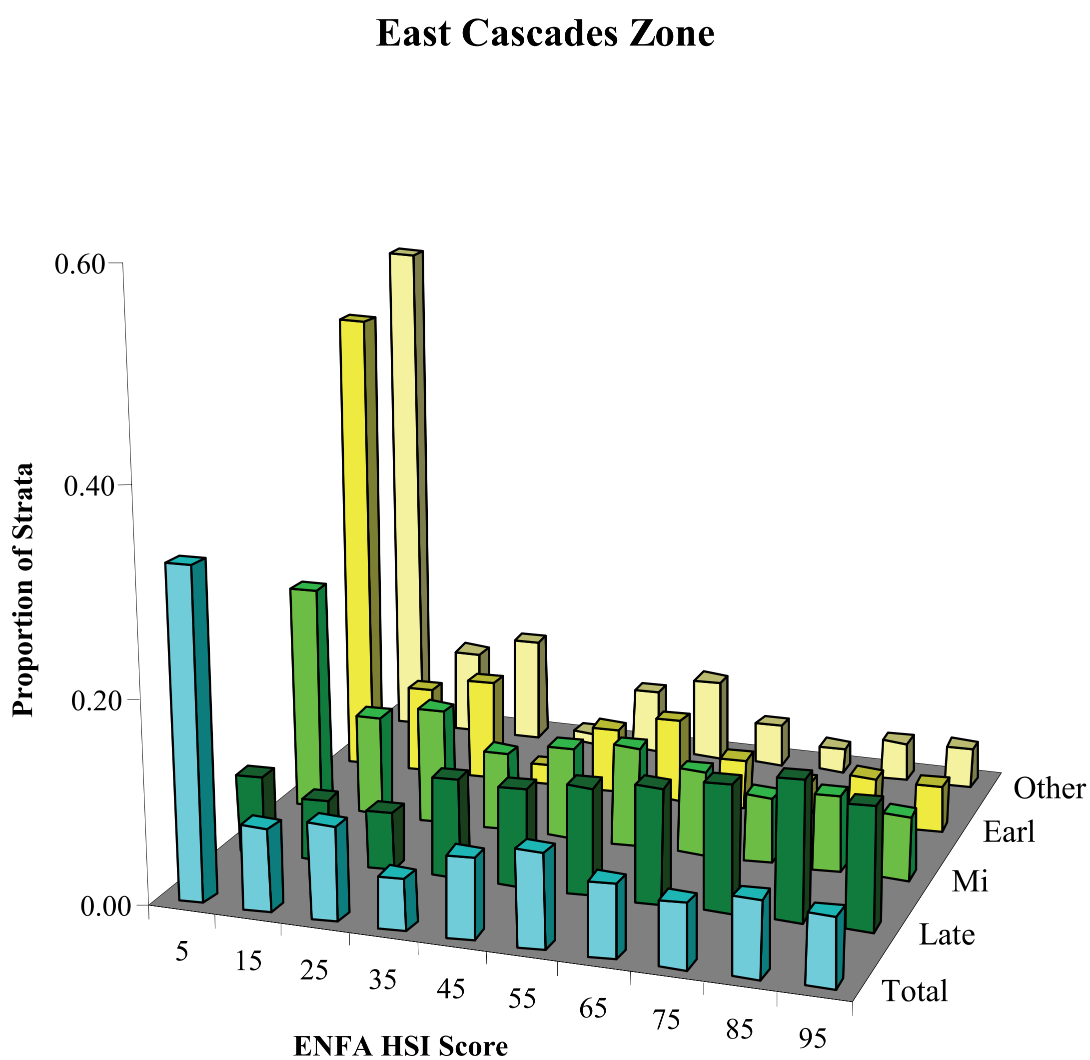

Figure 8b. Distribution of ENFA HSI scores across geographic zone according to seral strata class.

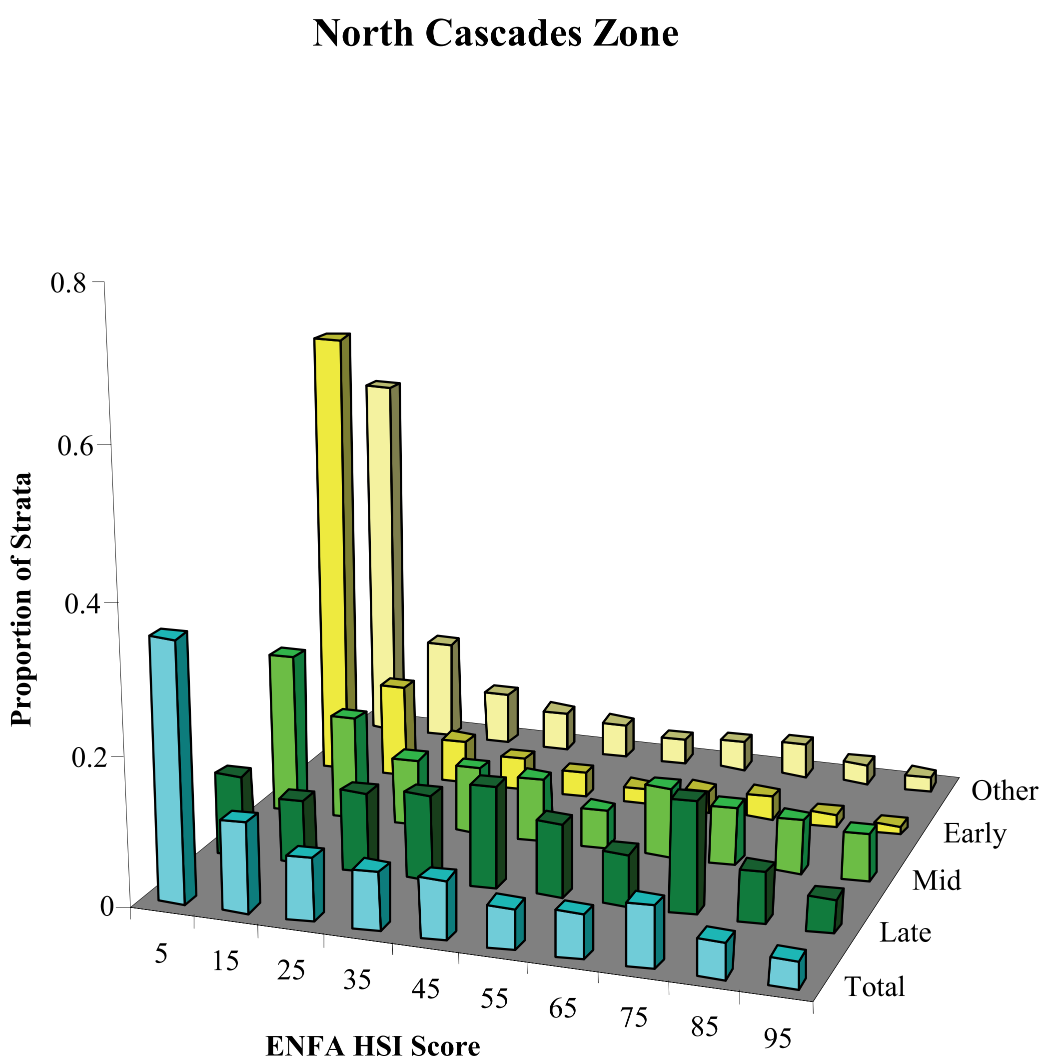

Figure 8c. Distribution of ENFA HSI scores across geographic zone according to seral strata class.

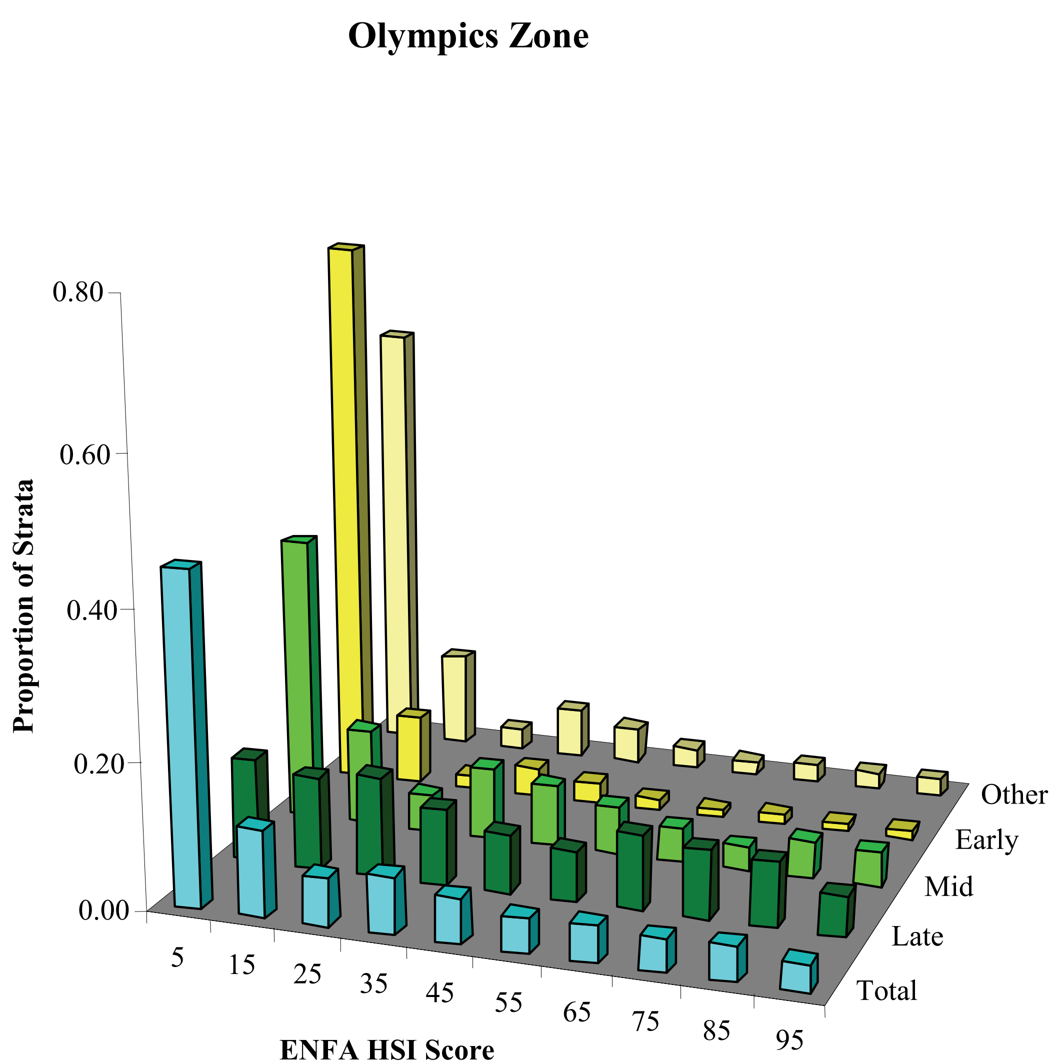

Figure 8d. Distribution of ENFA HSI scores across geographic zone according to seral strata class.

South Cascades Zone

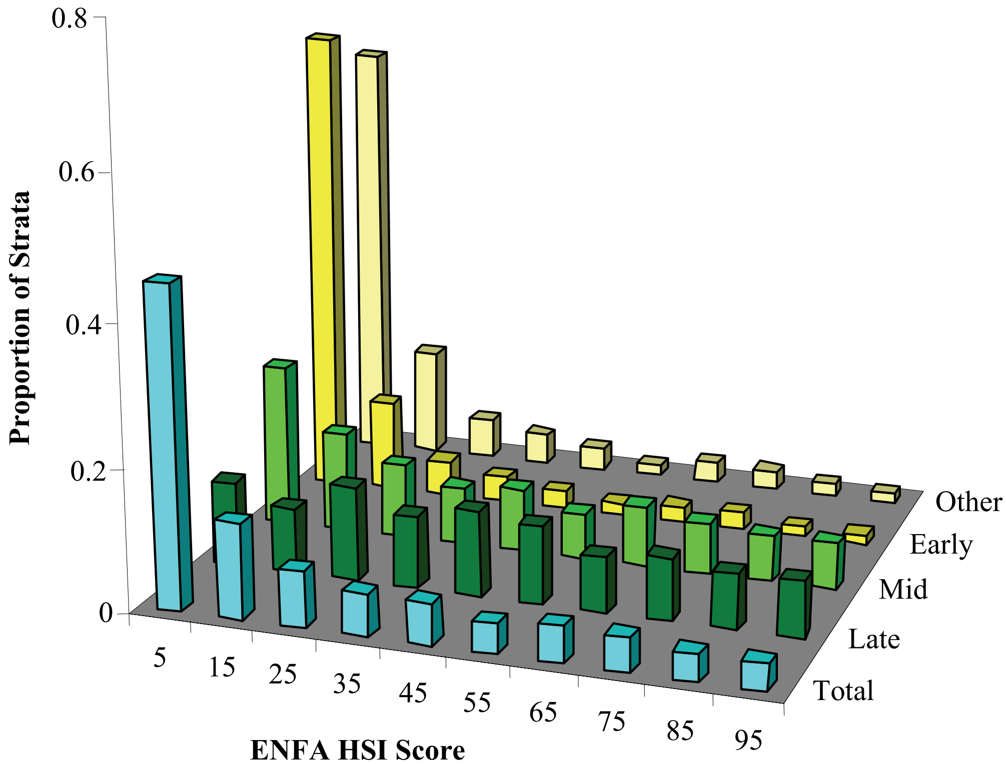

Figure 8e. Distribution of ENFA HSI scores across geographic zone according to seral strata class.

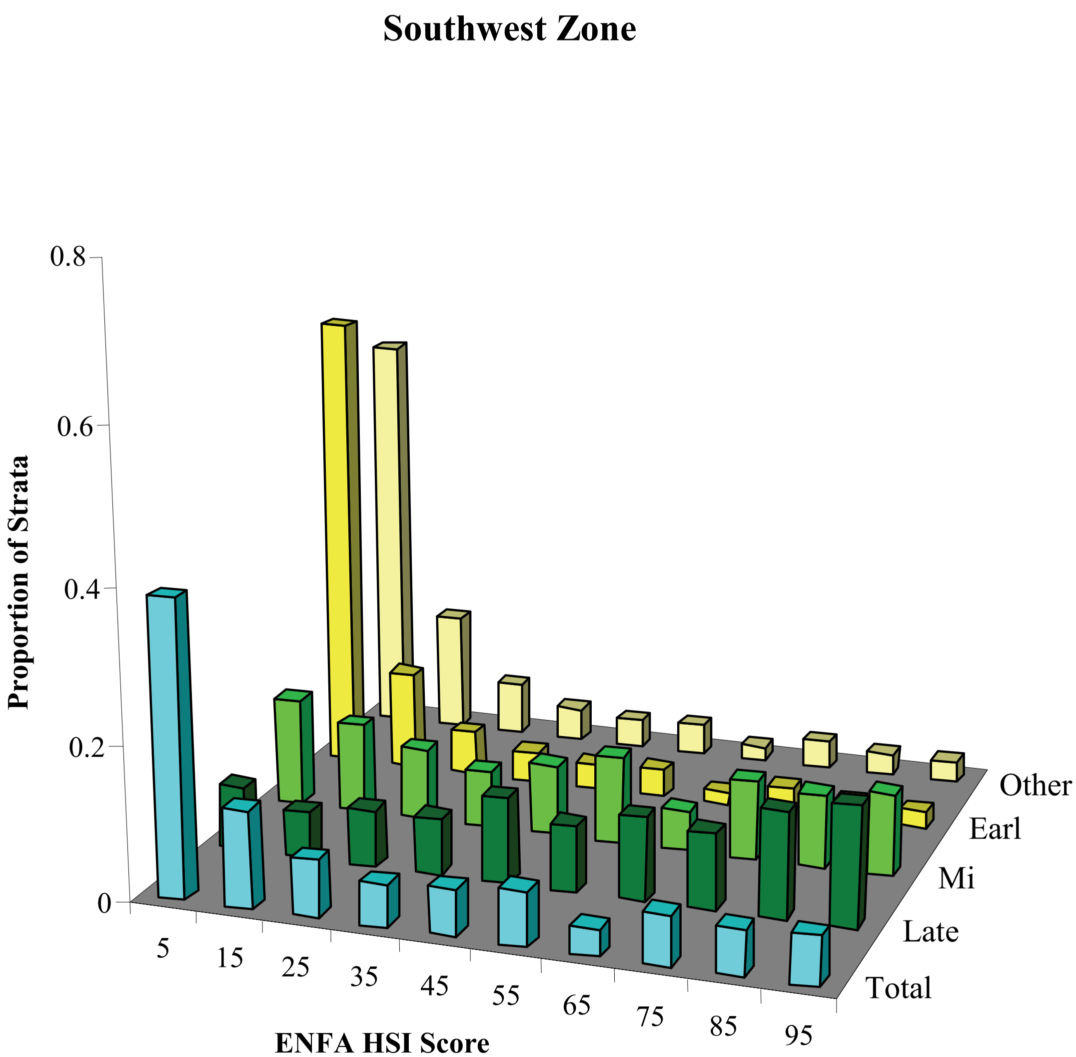

Figure 8f. Distribution of ENFA HSI scores across geographic zone according to seral strata class.

Table 26. Sampling strata classification accuracy tables for estimating the probability of Spotted Owl habitat for given strata, using ENFA-Biomapper model predictions and associated habitat threshold determinations corrected by habitat classification from known conditions determined from ground visit and photo interpretation plots.

Known Habitat Condition	Biomapper ENFA Prediction				
	Not Habitat		Habitat		
	Early-Other	Mid-Late	Early-Other	Mid	Late
Not Habitat	387	20	50	47	24
Habitat	1	16	5	35	55
Total	388	36	55	82	79
Classification Factors	Non-habitat Correction Factors (NCF)		Habitat Correction Factor (HCF)		
	0.3%	44.4%	9.1%	42.7%	69.6%

Table 27. Summary of performance measures of the logistic regression models according to IVMP province.

IVMP Province	Hosmer-Lemeshow Goodness of Fit Test Chi-Sq (Pr)	Habitat Threshold [1]	Correct Classification [2] % (n)	Specificity	Sensitivity
East Cascades	2.77 (0.95)	0.13	79% (917)	79%	83%
West Cascades	8.72 (0.37)	0.21	65% (2,375)	65%	66%
Olympics	8.14 (0.42)	0.21	82% (1,229)	82%	76%
Southwest	7.38 (0.50)	0.37	63% (1,395)	63%	63%

1. Habitat threshold defined as probability level where model sensitivity (% habitat correctly classified) was equal to model specificity (% non habitat correctly classified).

2. Percentage of independent validation test data that were correctly classified as habitat or not habitat using habitat threshold determined from modeled data.

Table 28. The coefficients (pr > ChiSq) from logistic regression model used to predict presence or absence of Spotted Owl habitat given selected covariates for each modeled IVMP province.

	IVMP Province			
Covariate	East Cascades	West Cascades	Olympics	Southwest
Intercept	-34.10 (< 0.0001)	-8.91 (< 0.0001)	-43.89 (< 0.0001)	-16.64 (<0.0001)
Variety mean	n.s.	0.24 (< 0.0823)	-1.25 (< 0.0001)	n.s.
Variety sdev	3.42 (< 0.0330)	1.16 (< 0.0043)	2.69 (< 0.0008)	n.s.
% Vegetation mean	0.27 (< 0.0001)	0.05 (< 0.0001)	0.39 (< 0.0001)	0.11 (<0.0001)
% Vegetation sdev	0.17 (< 0.0120)	n.s.	n.s.	0.04 (0.021)
% Conifer mean	n.s.	n.s.	n.s.	0.010 (0.029)
% Conifer sdev	n.s.	n.s.	0.08 (< 0.0001)	0.11 (<0.0001)
QMD mean	n.s.	0.09 (< 0.0001)	0.28 (< 0.0001)	0.25 (<0.0001)
QMD sdev	3.06 (< 0.0004)	n.s.	n.s.	-0.27 (<0.0001)
Con _QMD 13-19 mean	0.01 (< 0.0620)	n.s.	0.02 (< 0.083)	0.01 (<0.013)
Con _QMD 20.mean	n.s.	n.s.	n.s.	-0.02 (<0.012)

n.s. = variable not selected in step-wise procedure.

better, correctly classifying 85% of the known plot conditions, compared to the ENFA models, which correctly classified 78% of the known plot conditions (Table 30 and Table 26). However, Biomapper and logistic regression results did not differ significantly in estimating the relative amounts of harvested habitat (see below). We elected to present summary tables using the Biomapper estimates since there were more cells (i.e. acres) on the landscape populated with data used for the Biomapper model than for the logistic regression model within our study area.

Distribution of 1996-2004 Harvested Spotted Owl Habitat on Non-HCP Lands

We estimated approximately 40,300 (26,400-54,200) acres of Spotted Owl habitat were harvested on lands outside of HCP agreements from 1996-2004, representing 2% of the total landscape (Table 31). In the 2.3 million acre non-HCP portion of our study area, 47% of the total non-HCP study area and 47% of the total habitat harvested occurred inside owl circles located outside Spotted Owl Special Emphasis Areas. Most of the harvested habitat on non-HCP lands (87%) was on private lands.

Since Spotted Owl habitat made up a small percentage of the overall landscape, harvest levels relative to the total landscape did not vary greatly in non-HCP areas among and within zones. The only significant difference was in Southwest Washington where harvested Spotted Owl habitat made up 5% of the landscape compared to 1-2% of the landscape in all other zones (Table 31).

More significant differences were found in the amount of habitat harvested from 1996-2004 relative to the potential maximum amount of habitat among and within zones (RCI values, Table 32). Outside of HCP lands, approximately 6% (5-7%) of the estimated maximum amount of Spotted Owl habitat possible in 2004 was harvested during 1996-2004. The Relative Change Index (RCI) varied from a low of 4% in the Olympics to a high of 44% in Southwest Washington. Inside of SOSEA landscapes, RCI values were significantly greater outside of circles (11%) compared to inside of circles (4%).

This pattern was true for all SOSEAs. RCI values inside of circles were significantly lower outside compared to inside of SOSEAs in both the North Cascades (1% vs. 5%) and Olympics (3% vs 6%).

These relationships changed when federal lands were removed from the statistics (Table 33). Overall RCI values increased significantly when calculated for state and private lands only (19%) compared to RCI values when federal lands were included (6%). RCI values for state lands only were highest in the Southwest zone (44%) and smallest in the East Cascades (12%). RCI values for state and private lands within owl circles were significantly greater inside (22%) compared to outside of SOSEAs (6%) in the North Cascade zone. However, this pattern was opposite to most other zones. RCI values on state and private lands inside of circles were significantly greater outside of SOSEAs compared to inside of SOSEAs in the South Cascades (27% vs 9%) and Olympics (29% vs 16%).

The total footprint of the landscape attributed with HSI values was ~ 120,000 acres less than that for Biomapper HSI values resulting from a greater number of cells with no data. Therefore we did not report logistic regression estimates of the acres of Spotted Owl habitat harvested with ENFA estimates. Instead of comparing total acres between the two models, we compared model results by examining the relative percentages of the amount of habitat and change from 1996-2004 (i.e. RCI values). There were no significant differences among any of the spatial areas in the RCI values generated from the two models (Table 34).

Table 29. Percentage of the 1996 landscape scored above Spotted Owl Habitat logistic regression HSI threshold, according to geographic zone and seral sampling strata.

		Seral Strata			
Zone	HSI Threshold [1]	Other	Early	Mid	Late
East	13	8%	11%	40%	37%
N Cascades	21	19%	12%	40%	73%
Olympics	21	5%	3%	15%	49%
S Cascades	21	14%	11%	48%	81%
Southwest	37	9%	4%	24%	40%
Grand Total		11%	8%	33%	53%

1. HSI threshold determined by choosing the predicted probability that equalizes sensitivity and specificity values.

Table 30. Sampling strata classification accuracy tables for estimating the probability of Spotted Owl habitat for given strata, using logistic regression model predictions and associated habitat threshold determinations corrected by habitat classification from known conditions determined from ground visit and photo interpretation plots.

	Logistic Regression Prediction				
	Not Habitat		Habitat		
Known Habitat Condition	Early-Other	Mid-Late	Early-Other	Mid	Late
Not Habitat	419	56	18	24	11
Habitat	4	38	2	33	35
Total	423	94	20	57	46
	Nonhabitat Correction Factors (NCF)		Habitat Correction Factor (HCF)		
Classification Factors	0.9%	40.4%	10.0%	57.9%	76.1%

Table 31. Estimated amount (x 1,000 acres) of Spotted Owl habitat harvested (partial and clearcut) based on Biomapper ENFA models, 95% confidence intervals and harvested habitat proportion of the total landscape during 1996-2004, on lands **outside** of USFWS approved HCPs. Data are summarized for landscapes within SOSEAs: inside and outside of owl management circles and outside of SOSEAs within owl management circles

		Inside SOSEA			Outside SOSEA	
Zone	Data	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	Landscape Acres	290	227	518	205	723
	Habitat Harvested (CI)	3.6 (1.9-5.2)	5.0 (3.2-6.9)	8.6 (5.1-12.1)	4.5 (2.8-6.2)	13.1 (7.9-18.3)
	Harvest Proportion (CI)	0.01 (0.01-0.02)	0.02 (0.01-0.03)	0.02 (0.01-0.02)	0.02 (0.01-0.03)	0.02 (0.01-0.03)
North Cascades	Landscape Acres	109	179	288	162	450
	Habitat Harvested (CI)	1.7 (1.2-2.3)	4.5 (3.2-5.8)	6.2 (4.4-8.1)	0.5 (0-0.9)	6.7 (4.4-9)
	Harvest Proportion (CI)	0.02 (0.01-0.02)	0.03 (0.02-0.03)	0.02 (0.02-0.03)	0.00 (0-0.01)	0.01 (0.01-0.02)
Olympics	Landscape Acres	104	72	176	465	641
	Habitat Harvested (CI)	1.2 (0.8-1.6)	1.8 (1.2-2.4)	3.0 (2-4)	5.1 (3-7.2)	8.1 (5-11.3)
	Harvest Proportion (CI)	0.01 (0.01-0.02)	0.02 (0.02-0.03)	0.02 (0.01-0.02)	0.01 (0.01-0.02)	0.01 (0.01-0.02)
South Cascades	Landscape Acres	84	161	245	159	404
	Habitat Harvested (CI)	0.6 (0.4-0.8)	2.9 (2.1-3.8)	3.5 (2.5-4.5)	2.7 (1.9-3.5)	6.2 (4.3-8)
	Harvest Proportion (CI)	0.01 (0-0.01)	0.02 (0.01-0.02)	0.01 (0.01-0.02)	0.02 (0.01-0.02)	0.02 (0.01-0.02)
Southwest	Landscape Acres				116	116
	Habitat Harvested (CI)				6.3 (4.9-7.6)	6.3 (4.9-7.6)
	Harvest Proportion (CI)				0.05 (0.04-0.07)	0.05 (0.04-0.07)
	Total Landscape Acres	588	639	1,227	1,108	2,335
	Total Habitat Harvested (CI)	7.1 (4.3-9.9)	14.3 (9.6-18.9)	21.3 (13.9-28.8)	19.0 (12.5-25.5)	40.3 (26.4-54.2)
	Harvest Proportion (CI)	0.01 (0.01-0.02)	0.02 (0.02-0.03)	0.02 (0.01-0.02)	0.02 (0.01-0.02)	0.02 (0.01-0.02)

Table 32. Estimated amount (x 1,000 acres) of Spotted Owl habitat in 2004, the amount of habitat harvested (partial and clearcut) during 1996-2004, based on Biomapper ENFA models, and the relative change (RCI) [1] on lands **outside** of USFWS approved HCPs, 95% confidence intervals in parentheses. Data are summarized for landscapes within SOSEAs: inside and outside of owl management circles and outside of SOSEAs within owl management circles.

		Inside SOSEA			Outside SOSEA	
Zone	Data	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	2004 Habitat	98 (87-109)	60 (52-68)	158 (139-177)	64 (57-72)	223 (196-249)
	1996-2004 Harvested Habitat	3.6 (1.9-5.2)	5 (3.2-6.9)	8.6 (5.1-12.1)	4.5 (2.8-6.2)	13.1 (7.9-18.3)
	RCI	0.04 (0.02-0.05)	0.08 (0.06-0.09)	0.05 (0.04-0.06)	0.06 (0.05-0.08)	0.06 (0.04-0.07)
North Cascades	2004 Habitat	31 (28-34)	28 (25-31)	59 (52-65)	60 (54-66)	119 (107-131)
	1996-2004 Harvested Habitat	1.7 (1.2-2.3)	4.5 (3.2-5.8)	6.2 (4.4-8.1)	0.5 (0-0.9)	6.7 (4.4-9)
	RCI	0.05 (0.04-0.06)	0.14 (0.11-0.16)	0.1 (0.08-0.11)	0.01 (0-0.01)	0.05 (0.04-0.06)
Olympics	2004 Habitat	18 (16-20)	10 (9-11)	28 (25-32)	163 (148-179)	192 (173-210)
	1996-2004 Harvested Habitat	1.2 (0.8-1.6)	1.8 (1.2-2.4)	3 (2-4)	5.1 (3-7.2)	8.1 (5-11.3)
	RCI	0.06 (0.05-0.07)	0.15 (0.12-0.18)	0.1 (0.07-0.11)	0.03 (0.02-0.04)	0.04 (0.03-0.05)
South Cascades	2004 Habitat	15 (13-16)	17 (15-19)	32 (28-36)	43 (39-47)	75 (67-83)
	1996-2004 Harvested Habitat	0.6 (0.4-0.8)	2.9 (2.1-3.8)	3.5 (2.5-4.5)	2.7 (1.9-3.5)	6.2 (4.3-8)
	RCI	0.04 (0.03-0.04)	0.15 (0.12-0.16)	0.1 (0.08-0.11)	0.06 (0.05-0.07)	0.08 (0.06-0.09)
Southwest	2004 Habitat				8 (7-9)	8 (7-9)
	1996-2004 Harvested Habitat				6.3 (4.9-7.6)	6.3 (4.9-7.6)
	RCI				0.44 (0.43-0.45)	0.44 (0.43-0.45)
	Total Habitat Estimate	162 (144-180)	115 (101-129)	277 (245-309)	339 (304-373)	616 (549-683)
	Total Harvested Habitat	7.1 (4.3-9.9)	14.3 (9.6-18.9)	21.3 (13.9-28.8)	19 (12.5-25.5)	40.3 (26.4-54.2)
	RCI	0.04 (0.03-0.05)	0.11 (0.09-0.13)	0.07 (0.05-0.09)	0.05 (0.04-0.06)	0.06 (0.05-0.07)

RCI is defined as the ratio of 1996-2004 harvest / (2004 Habitat + 1996-2004 harvest), see methods for further explanation

Table 33. Comparison between Relative Change Index (RCI [1]) (and 95% CI) on landscapes including all ownerships combined compared to landscapes including only state and private lands in the study area **outside** of federally approved Habitat Conservation Plans.

		Inside SOSEA			Outside SOSEA	
Zone	Ownership	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	All Lands	0.04 (0.02-0.05)	0.08 (0.06-0.09)	0.05 (0.04-0.06)	0.06 (0.05-0.08)	0.06 (0.04-0.07)
	State & Private	0.10 (0.07-0.11)	0.14 (0.11-0.16)	0.12 (0.09-0.14)	0.14 (0.11-0.16)	0.12 (0.10-0.14)
North Cascades	All Lands	0.05 (0.04-0.06)	0.14 (0.11-0.16)	0.10 (0.08-0.11)	0.01 (0.00-0.01)	0.05 (0.04-0.06)
	State & Private	0.22 (0.20-0.24)	0.25 (0.22-0.27)	0.24 (0.21-0.26)	0.06 (0.05-0.06)	0.22 (0.19-0.23)
Olympics	All Lands	0.06 (0.05-0.07)	0.15 (0.12-0.18)	0.10 (0.07-0.11)	0.03 (0.02-0.04)	0.04 (0.03-0.05)
	State & Private	0.16 (0.14-0.18)	0.22 (0.17-0.25)	0.19 (0.16-0.21)	0.29 (0.27-0.30)	0.24 (0.21-0.26)
South Cascades	All Lands	0.04 (0.03-0.04)	0.15 (0.12-0.16)	0.10 (0.08-0.11)	0.06 (0.05-0.07)	0.08 (0.06-0.09)
	State & Private	0.09 (0.08-0.10)	0.19 (0.16-0.20)	0.16 (0.14-0.18)	0.27 (0.24-0.28)	0.19 (0.17-0.21)
Southwest	All Lands				0.44 (0.43-0.45)	0.44 (0.43-0.45)
	State & Private				0.44 (0.43-0.45)	0.44 (0.43-0.45)
Study Area Totals	All Lands	0.04 (0.03-0.05)	0.11 (0.09-0.13)	0.07 (0.05-0.09)	0.05 (0.04-0.06)	0.06 (0.05-0.07)
	State & Private	0.12 (0.10-0.14)	0.18 (0.15-0.20)	0.16 (0.13-0.18)	0.25 (0.22-0.26)	0.19 (0.17-0.21)

1. RCI is defined as the ratio of 1996-2004 harvest / (2004 Habitat + 1996-2004 harvest), see methods section for further explanation.

Table 34. Comparison between Biomapper ENFA and logistic regression (LR) modeled estimates of the Relative Change Index (RCI [1]) (and 95% CI) in the study area **outside** of federally approved Habitat Conservation Plans that met Spotted Owl suitable habitat definitions in 2004.

		Inside SOSEA			Outside SOSEA	
Zone	Model	Inside Circle	Outside Circle	Total	Inside Circle	Grand Total
East Cascades	ENFA	0.04 (0.02-0.05)	0.08 (0.06-0.09)	0.05 (0.04-0.06)	0.06 (0.05-0.08)	0.06 (0.04-0.07)
	LR	0.03 (0.02-0.04)	0.07 (0.05-0.08)	0.04 (0.03-0.05)	0.06 (0.04-0.07)	0.05 (0.03-0.06)
North Cascades	ENFA	0.05 (0.04-0.06)	0.14 (0.11-0.16)	0.10 (0.08-0.11)	0.01 (0.00-0.01)	0.05 (0.04-0.06)
	LR	0.05 (0.04-0.06)	0.14 (0.12-0.16)	0.10 (0.08-0.11)	0.01 (0.00-0.02)	0.05 (0.04-0.07)
Olympics	ENFA	0.06 (0.05-0.07)	0.15 (0.12-0.18)	0.10 (0.07-0.11)	0.03 (0.02-0.04)	0.04 (0.03-0.05)
	LR	0.06 (0.04-0.08)	0.16 (0.11-0.19)	0.10 (0.07-0.12)	0.03 (0.01-0.04)	0.04 (0.02-0.05)
South Cascades	ENFA	0.04 (0.03-0.04)	0.15 (0.12-0.16)	0.10 (0.08-0.11)	0.06 (0.05-0.07)	0.08 (0.06-0.09)
	LR	0.04 (0.03-0.05)	0.15 (0.12-0.17)	0.10 (0.08-0.12)	0.06 (0.04-0.07)	0.08 (0.06-0.09)
Southwest	ENFA				0.44 (0.43-0.45)	0.44 (0.43-0.45)
	LR				0.44 (0.39-0.46)	0.44 (0.39-0.46)
Study Area Totals	ENFA	0.04 (0.03-0.05)	0.11 (0.09-0.13)	0.07 (0.05-0.09)	0.05 (0.04-0.06)	0.06 (0.05-0.07)
	LR	0.04 (0.03-0.05)	0.11 (0.08-0.12)	0.07 (0.05-0.08)	0.05 (0.03-0.07)	0.06 (0.04-0.07)

1. RCI is defined as the ratio of 1996-2004 harvest / (2004 Habitat + 1996-2004 harvest), see methods section for further explanation

Distribution of 1996-2004 Harvested Spotted Owl Habitat on HCP Lands

We estimated approximately 16,100 (11,500-20,700) acres of Spotted Owl habitat were harvested on lands with approved HCP agreements from 1996-2004, representing 2% of the total HCP landscape (Table 35). In the 899,000 acre HCP portion of our study area, 25% of the total HCP study area and 29% of the total habitat harvested on HCP lands occurred inside owl circles located outside Spotted Owl Special Emphasis Areas. Approximately 50% of the harvested habitat on HCP areas occurred on private lands.

As was found on non-HCP lands, Spotted Owl habitat on HCP lands made up a small percentage of the landscape and relative amounts of harvested did not vary greatly among and within zones (Table 35). We estimated that approximately 7% (6-8%) of the maximum amount of Spotted Owl habitat possible in 2004 on HCP lands was harvested from 1996-2004 (Table 36). The Relative Change Index (RCI) varied from a low of 5% in the Olympics and South Cascades to a high of 14% in Southwest Washington. RCI levels inside of owl management circles were significantly higher inside SOSEAs compared to outside SOSEAs in the East Cascades (11% vs. 4%) and North Cascades (12% vs. 1%), but were lower inside SOSEAs compared to outside SOSEAs in the Olympics (2% vs. 9%) and South Cascades (4% vs. 7%). Within SOSEA landscapes, RCI values inside of circles were not significantly different on lands outside of circles. RCI values did not differ significantly between logistic regression estimates and ENFA estimates (Table 37).

DISCUSSION

Our study represents a comprehensive look at the amount of current habitat and changes in the amount of habitat, in the 9 years after adoption of the rules, inside and outside Spotted Owl Special Emphasis Areas. The purpose of this study was to estimate the recent changes and amount of suitable Spotted Owl habitat on lands affected by the Washington State Forest Practices Rules. The Forest Practices Rules address two general

Table 35. Estimated amount (x 1,000 acres) of Spotted Owl habitat harvested (partial and clearcut) based on Biomapper ENFA models, 95% confidence intervals and harvested habitat proportion of the total landscape during 1996-2004, on lands **inside** of USFWS approved HCPs. Data are summarized for landscapes within SOSEAs: inside and outside of owl management circles and outside of SOSEAs within owl management circles

		Inside SOSEA			Outside SOSEA	
Zone	Data	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	Landscape Acres	84	69	153	23	176
	Habitat Harvested (CI)	3.4 (2.3-4.4)	2 (1.3-2.7)	5.4 (3.7-7.1)	0.3 (0.1-0.4)	5.7 (3.8-7.5)
	Harvest Proportion (CI)	0.04 (0.03-0.05)	0.03 (0.02-0.04)	0.04 (0.02-0.05)	0.01 (0.01-0.02)	0.03 (0.02-0.04)
North Cascades	Landscape Acres	69	104	173	19	192
	Habitat Harvested (CI)	1.9 (1.5-2.3)	1.7 (1.3-2.1)	3.6 (2.8-4.4)	0.00 (0-0.1)	3.7 (2.8-4.5)
	Harvest Proportion (CI)	0.03 (0.02-0.03)	0.02 (0.01-0.02)	0.02 (0.02-0.03)	0.00 (0-0)	0.02 (0.01-0.02)
Olympics	Landscape Acres	145	57	202	106	308
	Habitat Harvested (CI)	0.5 (0.2-0.8)	0.2 (0.1-0.3)	0.7 (0.3-1)	2.5 (1.9-3.2)	3.2 (2.3-4.2)
	Harvest Proportion (CI)	0.00 (0.00-0.01)	0.00 (0.00-0.00)	0.00 (0.00-0.01)	0.02 (0.02-0.03)	0.01 (0.01-0.01)
South Cascades	Landscape Acres	62	84	146	19	165
	Habitat Harvested (CI)	0.7 (0.5-0.9)	1.1 (0.8-1.4)	1.8 (1.3-2.3)	0.4 (0.3-0.5)	2.2 (1.6-2.8)
	Harvest Proportion (CI)	0.01 (0.01-0.01)	0.01 (0.01-0.02)	0.01 (0.01-0.02)	0.02 (0.02-0.03)	0.01 (0.01-0.02)
Southwest	Landscape Acres				60	60
	Habitat Harvested (CI)				1.3 (1-1.7)	1.3 (1-1.7)
	Harvest Proportion (CI)				0.02 (0.02-0.03)	0.02 (0.02-0.03)
	Total Landscape Acres	360	314	674	226	899
	Total Habitat Harvested (CI)	6.5 (4.6-8.4)	5 (3.5-6.5)	11.5 (8.1-14.9)	4.6 (3.4-5.8)	16.1 (11.5-20.7)
	Harvest Proportion (CI)	0.02 (0.01-0.02)	0.02 (0.01-0.02)	0.02 (0.01-0.02)	0.02 (0.01-0.03)	0.02 (0.01-0.02)

Table 36. Estimated amount (x 1,000 acres) of Spotted Owl habitat in 2004, the amount of habitat harvested (partial and clearcut) during 1996-2004, based on Biomapper ENFA models, and the relative change (RCI) [1] on lands **inside** of USFWS approved HCPs, 95% confidence intervals in parentheses.

Zone	Data	Inside SOSEA			Outside SOSEA	
		Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	2004 Habitat	26 (23-30)	17 (15-19)	43 (37-49)	6 (6-7)	50 (43-57)
	1996-2004 Harvested Habitat	3.4 (2.3-4.4)	2.0 (1.3-2.7)	5.4 (3.7-7.1)	0.3 (0.1-0.4)	5.7 (3.8-7.5)
	RCI	0.11 (0.09-0.13)	0.11 (0.08-0.12)	0.11 (0.09-0.13)	0.04 (0.02-0.05)	0.10 (0.08-0.12)
North Cascades	2004 Habitat	14 (13-16)	21 (18-23)	35 (31-39)	6 (6-7)	41 (37-46)
	1996-2004 Harvested Habitat	1.9 (1.5-2.3)	1.7 (1.3-2.1)	3.6 (2.8-4.4)	0.0 (0-0.1)	3.7 (2.8-4.5)
	RCI	0.12 (0.11-0.13)	0.08 (0.07-0.08)	0.09 (0.08-0.10)	0.01 (0.00-0.01)	0.08 (0.07-0.09)
Olympics	2004 Habitat	29 (25-32)	8 (7-9)	36 (32-40)	25 (23-28)	62 (55-68)
	1996-2004 Harvested Habitat	0.5 (0.2-0.8)	0.2 (0.1-0.3)	0.7 (0.3-1)	2.5 (1.9-3.2)	3.2 (2.3-4.2)
	RCI	0.02 (0.01-0.02)	0.02 (0.01-0.03)	0.02 (0.01-0.02)	0.09 (0.08-0.1)	0.05 (0.04-0.06)
South Cascades	2004 Habitat	18 (16-20)	16 (14-18)	34 (31-37)	5 (5-6)	39 (35-43)
	1996-2004 Harvested Habitat	0.7 (0.5-0.9)	1.1 (0.8-1.4)	1.8 (1.3-2.3)	0.4 (0.3-0.5)	2.2 (1.6-2.8)
	RCI	0.04 (0.03-0.04)	0.06 (0.05-0.07)	0.05 (0.04-0.06)	0.07 (0.06-0.08)	0.05 (0.04-0.06)
Southwest	2004 Habitat				8 (7-10)	8 (7-10)
	1996-2004 Harvested Habitat				1.3 (1-1.7)	1.3 (1-1.7)
	RCI				0.14 (0.12-0.15)	0.14 (0.12-0.15)
	Total Habitat Estimate	87 (78-97)	62 (54-69)	149 (132-166)	51 (46-57)	201 (178-223)
	Total Harvested Habitat	6.5 (4.6-8.4)	5.0 (3.5-6.5)	11.5 (8.1-14.9)	4.6 (3.4-5.8)	16.1 (11.5-20.7)
	RCI	0.07 (0.06-0.08)	0.08 (0.06-0.09)	0.07 (0.06-0.08)	0.08 (0.07-0.09)	0.07 (0.06-0.08)

1 RCI is defined as the ratio of 1996-2004 harvest / (2004 Habitat + 1996-2004 harvest), see methods section for further explanation

Table 37. Comparison between Biomapper ENFA and logistic regression (LR) modeled estimates of the Relative Change Index (RCI [1]) (and 95% CI) in the study area **inside** of federally approved Habitat Conservation Plans that met Spotted Owl suitable habitat definitions in 2004.

		Inside SOSEA			Outside SOSEA	
Zone	Model	Inside Circle	Outside Circle	Total	Inside Circle	Grand Total
East Cascades	ENFA	0.11 (0.09-0.13)	0.11 (0.08-0.12)	0.11 (0.09-0.13)	0.04 (0.02-0.05)	0.10 (0.08-0.12)
	LR	0.10 (0.07-0.11)	0.09 (0.07-0.11)	0.09 (0.07-0.11)	0.04 (0.02-0.05)	0.09 (0.06-0.10)
North Cascades	ENFA	0.12 (0.11-0.13)	0.08 (0.07-0.08)	0.09 (0.08-0.10)	0.01 (0.00-0.01)	0.08 (0.07-0.09)
	LR	0.11 (0.10-0.12)	0.08 (0.07-0.09)	0.09 (0.08-0.10)	0.01 (0.00-0.01)	0.08 (0.07-0.09)
Olympics	ENFA	0.02 (0.01-0.02)	0.02 (0.01-0.03)	0.02 (0.01-0.02)	0.09 (0.08-0.10)	0.05 (0.04-0.06)
	LR	0.02 (0.01-0.02)	0.02 (0.01-0.03)	0.02 (0.01-0.02)	0.08 (0.06-0.10)	0.04 (0.03-0.06)
South Cascades	ENFA	0.04 (0.03-0.04)	0.06 (0.05-0.07)	0.05 (0.04-0.06)	0.07 (0.06-0.08)	0.05 (0.04-0.06)
	LR	0.04 (0.03-0.04)	0.06 (0.05-0.07)	0.05 (0.04-0.06)	0.07 (0.06-0.08)	0.05 (0.04-0.06)
Southwest	ENFA				0.14 (0.12-0.15)	0.14 (0.12-0.15)
	LR				0.14 (0.12-0.15)	0.14 (0.12-0.15)
Study Area Totals	ENFA	0.07 (0.06-0.08)	0.08 (0.06-0.09)	0.07 (0.06-0.08)	0.08 (0.07-0.09)	0.07 (0.06-0.08)
	LR	0.06 (0.05-0.07)	0.07 (0.06-0.08)	0.07 (0.05-0.08)	0.08 (0.06-0.09)	0.07 (0.05-0.08)

1. RCI is defined as the ratio of 1996-2004 harvest / (2004 Habitat + 1996-2004 harvest), see methods section for further explanation

categories of Spotted Owl sites (not including those covered by Habitat Conservation Plans): those inside Spotted Owl Special Emphasis Areas and those outside such landscapes.

Habitat goals and objectives on HCP landscapes are specific to each HCP and may be unrelated to the management circles referred to in the state rules. The Forest Practices Rules require that proposed harvests in HCP landscapes must be consistent with conditions specified in the federally approved plan. We presented data from HCP landscapes to make relative comparisons of the amount of habitat and harvest between HCP and non-HCP landscapes. Definitions of suitable habitat developed for HCP agreements may differ somewhat from the state rule definitions that could affect the estimates of habitat on HCP landscapes.

Estimates of Spotted Owl Habitat

We estimate that there was about 816,000 (726,000-906,000) total acres of Spotted Owl habitat in our study area in 2004. This amount represents all suitable Spotted Owl habitat on all land ownership categories. Most of the landscape was intermixed with state, federal and private lands. The Southwest zone in the study area was the only area without significant federal ownership. Overall a substantial portion of the estimated habitat (56%) occurred on federal lands (Table 38 and see below). The remaining habitat in our study area was divided between state-local lands (21%), private lands (22%) and tribal (1%). Federal lands comprised 43% of the non-HCP lands within SOSEA boundaries and 62% of non-HCP lands outside of SOSEA boundaries within our study area, and likely account for the greater proportion of habitat on landscapes outside of SOSEAs for non-HCP lands. There were a few noteworthy patterns of the distribution of Spotted Owl habitat across the zones of our study area worth mentioning. Including the federal lands in our study area, 26% of the total amount of Spotted Owl habitat on non-HCP lands occurred within owl management circles that were inside Special Emphasis Areas. A total of 55% of the non-HCP habitat within the study area occurred inside of circles outside of SOSEAs. Values for HCP areas were reversed. A total of 44% of the HCP

Table 38. Total estimated acres of Spotted Owl habitat in 2004 according to major land ownership.

Ownership	Zone	Inside SOSEA		Inside SOSEA Total	Outside SOSEA		Outside SOSEA Total	Grand Total
		Inside HCP	Outside HCP		Inside HCP	Outside HCP		
Federal	East	0	105,916	105,916	0	38,075	38,075	143,991
	N Cascades	0	40,438	40,438	0	56,196	56,196	96,634
	Olympics	0	16,024	16,024	0	151,751	151,751	167,775
	S Cascades	0	13,747	13,747	0	36,094	36,094	49,841
	Southwest	0	0	0	0	13	13	13
Federal Total		0	176,125	176,125	0	282,129	282,129	458,254
Private	East	14,926	50,244	65,170	101	20,033	20,134	85,304
	N Cascades	8,471	17,441	25,912	6	3,719	3,725	29,637
	Olympics	64	12,024	12,088	2,721	8,949	11,670	23,758
	S Cascades	6,778	17,149	23,927	28	6,758	6,786	30,713
	Southwest	0	0	0	1,094	7,879	8,973	8,973
Private Total		30,239	96,858	127,097	3,950	47,338	51,288	178,385
State-Local	East	28,403	1,741	30,144	6,374	1,771	8,145	38,289
	N Cascades	26,679	926	27,605	6,197	133	6,330	33,935
	Olympics	36,412	236	36,648	22,423	842	23,265	59,913
	S Cascades	27,314	1,035	28,349	5,236	111	5,347	33,696
	Southwest	0	0	0	7,285	18	7,303	7,303
State-Local Total		118,808	3,938	122,746	47,515	2,875	50,390	173,136
Tribe	East	0	195	195	0	4,566	4,566	4,761
	N Cascades	0	0	0	0	0	0	0
	Olympics	0	109	109	0	1,688	1,688	1,797
	S Cascades	0	0	0	0	0	0	0
	Southwest	0	0	0	0	0	0	0
Tribe Total		0	304	304	0	6,254	6,254	6,558
Grand Total		149,047	277,225	426,272	51,465	338,596	390,061	816,333

habitat within the study area occurred inside of circles inside of SOSEAs, and only 26% of the habitat on HCP lands occurred outside of SOSEAs.

The amount of habitat on the landscape relative to the total acres available varied according to geographic zone and was directly related to the amount of federal ownership in that area. In many of the landscapes we looked at, the relative amount of habitat on the landscape in 2004 was significantly less than the amount identified in the Forest Practices Rules (40%) as necessary to maintain Spotted Owl populations over time. This was particularly true of landscapes inside SOSEAs where the relative amount of federal ownership was less than the areas we examined outside of SOSEAs. We found there was a lower proportion of habitat on the landscape outside circles within Spotted Owl Special Emphasis Areas (19%) than within circles (26%), regardless of HCP status.

Although there were several other differences in the habitat proportion of landscapes, we noted two additional differences: 1) circles in non-HCP landscapes had more habitat in 2004 (30%) than circles in HCP areas (24%), a function of the amount of federal land in non-HCP areas compared to HCP areas, and 2) circles in Southwest Washington, regardless of HCP status, had less habitat than any other area in the state. It is important to remember that because our estimates were derived statistically they represent averages across the landscape, and we expect the percentage of habitat within some owl circles is likely greater or less than the average values we reported in Tables 16 and 17.

General Forest Harvest

With one exception, we found little among-zone differences in harvest levels and proportions of area harvested between 1996 and 2004. The one difference was the high harvest levels in Southwest zone (13%) compared to the rest of the study area (5%). This was attributed to the lack of any federal lands in the Southwest zone. Outside of HCP lands, harvest levels consistently ranged from 4% to 6% in landscapes within Spotted Owl Special Emphasis Areas. On non-HCP lands, North Cascade and Olympic harvest levels were significantly greater inside of SOSEAs compared to areas outside of

SOSEAs. Again this is likely due to the high federal ownership outside of SOSEAs in these zones. Within SOSEAs on non-HCP lands, overall harvest levels tended to be higher outside of circles compared to lands inside of circles. This was not true on HCP landscapes where harvest levels within SOSEAs were the same for lands both inside and outside owl circles.

Changes in the Amount of Spotted Owl Habitat

Between 4% and 6 % of the maximum potential of habitat in 2004 (RCI values) was harvested from 1996-2004 inside of circles within SOSEAs on non-HCP lands. Relative harvest was significantly greater (11%) in areas outside of circles that were inside SOSEAs than inside circles (4%). These differences were significant in all geographic zones. Outside of SOSEAs in non-HCP areas with significant federal lands (i.e. excluding the Southwest zone), the relative loss of habitat attributed to harvest was lowest in the North Cascades (1%) and highest in the East and South Cascades (6%). Relative habitat harvest on non-HCP lands in owl circles within SOSEAs in Olympic and North Cascade zones (6% and 5% respectively) were significantly higher than relative harvest levels inside circles outside of SOSEAs (3 % and 1%). Relative amounts of habitat change were much more uniform on HCP landscapes averaging 7% - 8 % on lands regardless of the presence or absence of owl circles or SOSEAs.

RCI values on non-HCP landscapes differed in several ways depending on whether federal lands were included in the analysis (Table 33). On non-HCP lands, federal ownership made up 62% of the landscape outside of SOSEAs but were only 43% of the landscape inside of SOSEAs (Appendix B). When federal lands are removed from the analysis, the overall relative habitat harvest levels increased by more than three times as much as the levels when federal lands were included in the calculation. This is a direct result that 92% of the habitat that was harvested between 1996 and 2004 in our study area occurred on state and private lands. Second, in two of the four zones with SOSEAs (Olympics and South Cascades), RCI values were significantly higher inside of circles that were outside of SOSEAs compared to lands within management circles inside

SOSEAs. Third, on lands outside of SOSEAs relative habitat harvest levels were highest in Southwest Washington (44%) and lowest in the North Cascades (6%). Finally, when considering only non-HCP state and private lands inside SOSEAs, there was a significant difference in relative harvest rate on lands inside circles (12%) compared to lands outside circles (18%).

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After removing federal ownership from the analysis we examined the eleven possible paired comparisons of relative habitat harvest rates in owl circles (Table 39). We found that RCI values were significantly greater in non-HCP landscapes than HCP landscapes at 10 of the 11 paired comparisons. There was no significant difference in RCI values between East Cascade SOSEA HCP and non-HCP lands.

Potential Effects of Habitat Loss on Spotted Owls

Quantifying the effects of the habitat loss we documented on regional Spotted Owl subpopulations in Washington was beyond the scope of this project. However, a number of conclusions can be derived regarding the potential effects of habitat loss. Demography research on the Spotted Owl has been conducted in Washington since 1987 (Anthony et al. 2005; Forsman et al. 1996). Four demography study areas in Cle Elum, Olympic Peninsula, Rainier, Wenatchee National Forest and vicinity (including Kittitas county) overlapped extensively with five Spotted Owl Special Emphasis Areas and a small portion of a sixth (Table 40). Recently, these demographic studies have documented significant population declines in each of the areas that overlap with our study area (Table 41).

Spotted Owls have large home ranges and use large amounts of structurally complex forest within those areas (see Hanson et al. 1993). A number of efforts have been undertaken to evaluate or summarize the amount of habitat associated with Spotted Owl sites (Hanson et al. 1993; Washington State Forest Practices Board 1996; Lehmkuhl & Raphael 1993). These studies typically indicated between 30% and 50% of the home range or analysis area (i.e. owl management circles) was suitable Spotted Owl habitat; some of the studies indicated significant relationships between the amount of habitat

Table 39. Comparisons of RCI values for state-local and private lands inside owl management circles on HCP and non-HCP landscapes.

Zone	Landscape	Inside SOSEAs	Outside SOSEAs
East Cascades	HCP	**0.11 (0.09-0.13)**	0.04 (0.02-0.05)
	NonHCP	**0.10 (0.07-0.11)**	0.14 (0.11-0.16)
North Cascades	HCP	0.12 (0.11-0.13)	0.01 (0.00-0.01)
	NonHCP	0.22 (0.20-0.24)	0.06 (0.05-0.06)
Olympic	HCP	0.02 (0.01-0.02)	0.09 (0.08-0.10)
	NonHCP	0.16 (0.14-0.18)	0.29 (0.27-0.30)
South Cascades	HCP	0.04 (0.03-0.04)	0.07 (0.06-0.08)
	NonHCP	0.09 (0.08-0.10)	0.27 (0.24-0.28)
Southwest	HCP		0.14 (0.12-0.15)
	NonHCP		0.44 (0.43-0.45)
Total Study Area	HCP	0.07 (0.06-0.08)	0.08 (0.07-0.09)
	NonHCP	0.12 (0.10-0.14)	0.25 (0.22-0.26)

Bold type indicates non-significant difference between HCP and non-HCP comparisons.

Table 40. Location of demography study areas relative to Spotted Owl Special Emphasis Areas in Washington.

Demographic Study Area (and years of investigation)[a]	Geographic Location	Spotted Owl Special Emphasis Areas (and proportion included in demography study)
Cle Elum (1989-2003)	Central East Cascades	I-90 East (entire)
Olympic (1987-2003)	Olympic Peninsula	Hoh-Clearwater (entire area in early period of research[b]; <5% of the SOSEA was included in most recent analysis)
Rainier (1992-2003)	Central western Cascades	I-90 West (entire)
Wenatchee (1990-2003)	East Cascades	Entiat (entire), North Blewett (entire), White Salmon (entire)

[a] From Anthony et al. (2005).
[b] From Figure 2 in Forsman et al. (1996).

Table 41. Estimates of lambda from four Spotted Owl demography study areas in Washington (from Anthony et al. 2005). Values of lambda <1.0 indicate a declining population.

Study Area	Lambda	95% confidence interval	Percent decline
Cle Elum	0.938	0.901-0.976	6.2
Olympic	0.956	0.893-1.018	4.4
Rainier	0.896	0.788-1.003	10.4
Wenatchee	0.917	0.882-0.952	8.3

within the home range landscape and measures of occupancy or reproductive output (see review by Buchanan and Swedeen 2005). The 40% value recognized by the state Forest Practices Rules as the proportion of habitat on a landscape necessary to maintain the viability of an owl territory is based on results from these studies. With the possible exception of the East Cascade SOSEAs, our results indicate that the landscapes within owl management circles inside of SOSEAs were likely well below this threshold (see Table 16) in 2004. The percent of non-HCP landscapes in 2004, inside of owl management circles, that met Spotted Owl habitat criteria ranged from a low of 18% (95% confidence interval (CI) = 16% to 20%) in the South Cascades to a high of 34% (CI = 30 % to 38%) in the East Cascades.

Our estimate of a 4% to 6% loss of Spotted Owl habitat on non-HCP lands inside owl circles within SOSEAs between 1996 and 2004 (Table 32) magnifies the potential effect on those Spotted Owl sites that use habitat on non-federal lands. Loss of habitat in these landscapes is important because the Spotted Owl Special Emphasis Areas were identified in the state rules as strategic areas within the state where owls and habitat on non-federal lands contribute to the overall health of Washington’s population of owls. Even though many of the owl sites in our study were centered on federal lands, the majority (64%) of the lands in owl management circles within SOSEAs were state or privately owned. The loss of habitat documented in this study may be an important contributor to the documented declines in owl populations using these landscapes.

Another potential effect on owl populations related to the amount and pattern of habitat loss documented by this study is the estimated loss of habitat on landscapes inside of SOSEAs but outside of owl management circles. RCI values in these areas were more than twice as high as the RCI values for lands inside of management circles. As a result, if this pattern continues over time, owl habitat inside of SOSEAs will become more and more restricted to only those landscapes inside of Status 1-3 owl circles. Currently, if any Status 1-3 site is not found to be occupied for 3 consecutive years that site is re-classed as a Status 5 circle and harvest in these circles are no longer subject to State Environmental Policy Act review.

This is not to say the habitat loss we documented is conclusively responsible for the observed Spotted Owl declines. The recent Spotted Owl habitat trend analysis conducted by Davis and Lint (in press) documented minor (<1%) habitat loss since 1996, on federal lands in Washington, notably including landscapes with documented owl population declines, suggesting owl populations have been declining even in areas where the amount of habitat has been stable over the past 10 years.

Barred Owls (*Strix varia*) have recently invaded the Pacific Northwest, and now occur over essentially the entire range of the Spotted Owl in Washington. There is concern that Barred Owls and Spotted Owls may compete for resources, and that the former has a distinct advantage in this relationship that is now influencing the Spotted Owl population decline (Courtney et al. 2004). The nature of the relationship between these two species is not clear, but the negative effects of a strong competitor like the Barred Owl would likely interact with the effects of habitat loss for Spotted Owls.

Comparison to Northwest Forest Plan and Other Sources of Information

Based on the assumptions used to classify habitat in categories of suitability for the Northwest Forest Plan assessment, the estimate of owl habitat on federal lands in Washington ranged from 1,142,875 to 2,497,228 acres (values derived from Davis & Lint in press). The federal assessment did not use predefined criteria (like those provided in the state rules) to identify suitable habitat. Instead they used radio telemetry data to determine areas of use, which may have biased their estimates toward higher quality stand conditions. We believe the most restrictive estimate for federal lands (i.e. Habitat Suitability scores ≥81; Table 28 in Davis and Lint, in press) likely excludes much of the comparatively younger and/or managed forest that meets the “sub-mature” and “young forest marginal” habitat definitions of the Forest Practices Rule, and likely identifies primarily late mature to old forests that many consider to be optimal nesting and foraging habitat (see Gutiérrez et al. 1995). The most inclusive federal habitat suitability category (i.e. Habitat Suitability scores of 41-100 in Table 28, Davis & Lint in press) represents the range of conditions at 90% of territorial Spotted Owl activity centers used to develop the model (Davis & Lint in press).

Davis and Lint (in press) interpreted the HSI index as indicating that values closer to 100 have more attributes that are associated with areas where territorial owls were found. Similarly, sites with low HSI scores (e.g. <41) have few attributes in common with sites of known territorial owls. Consequently, we interpret the range of values as a general gradient in habitat quality, with scores at the upper end (e.g. 81-100) reflecting older and/or more structurally complex forests and sites in to 41-60 range reflecting comparatively younger and/or structurally simpler forests. The more inclusive estimate (i.e. HSI scores > 40) seems most likely to include both optimal and marginal habitat conditions found on non-federal lands. We believe this is the range of forest conditions most like those captured in our analysis.

We estimate that Spotted Owl habitat on state-local and private lands in our study made up from 13%-26% of the Spotted Owl habitat relative to the total amount of habitat on federal lands in the surrounding area, including the federal areas outside of our study area (Table 42). Within SOSEA boundaries on non-HCP lands, state and private lands made up an even higher proportion of the existing habitat (30-54%) and in Southwest Washington, Spotted Owl habitat occurred almost exclusively on state and private lands. Federal habitat estimates in our table included adjustments for their estimated amount of lost habitat due to timber harvest and wildfire, but not for other sources of loss including insects, disease or windstorms that occurred from 1996-2004 that were not included in the federal estimates of suitable habitat (Davis & Lint in press). Generally accounting for these losses, we believe the amount of suitable Spotted Owl habitat on federal lands in Washington combined with the state and private lands included in our study (i.e. our study area plus all federal lands) was likely something less than 2.8 million acres (assuming federal habitat with HSI score > 40).

Our estimates of the amount of suitable Spotted Owl habitat on non-federal lands differ somewhat from estimates derived from other sources of information. The most complete source of information available for comparisons came from Habitat Conservation Plans approved for Spotted Owls in the state of Washington (Table 43). These data were difficult to interpret and normalize to our estimates. For example, the state lands covered by the DNR Habitat Conservation Plan (Table 43) include estimates from substantially different HCP area boundaries that include areas outside our study area (see Figure 2). Another possible difference is that Spotted Owl habitat definitions in HCP agreements may differ from state rule definitions. One other important caution is that estimates reported in HCP documents are estimates of habitat at the point in time the HCP was approved, which range from 1995-1999. Still, we felt it important to compare the reported amounts of suitable Spotted Owl habitat to see if they were similar to our estimates. The total amount of Spotted Owl habitat reported in combined HCPs totaled approximately 246,000 acres; which is somewhat greater than our estimate of 200,500 acres in 2004. Finally, according to our habitat analysis, about 60% of the state and private lands habitat within Spotted Owl Special Emphasis Areas occurs inside HCP areas, compared to 68% reported by Buchanan & Swedeen (2005).

The only other estimate of the amount of habitat loss between 1996 and 2004 was presented in the recent analysis of habitat trends conducted for the Northwest Forest Plan assessment. Within the entire range of the Northern Spotted Owl, the percentage of suitable habitat lost on non-federal lands was estimated at 8.0% (Davis and Lint in press). Their estimated percent reduction of Spotted Owl habitat on non-federal lands in

Washington (12.0%) was higher than in Oregon (10.7%) or California (2.2%) (Davis and Lint in press; Raphael et al. in press). Their estimates were made for the total state and private landscape not just lands within SOSEAs or owl management circles. This is similar to our finding of 13% (range = 11-14%) reduction between 1996 and 2004 for all state and private lands in our study area.

Table 42. Comparison of the relative amount of suitable Spotted Owl habitat in Washington on federal lands in 2003 (Davis and Lint, in press) and state and private lands in 2004 (this study).

	Land ownership				
	State	Private	Federal (according to 3 Habitat Suitability Score categories) [1]		
IVMP Province	Acres (% Total Habitat)	Acres (% Total Habitat)	41-100	61-100	81-100
East Cascades	38,000 (6 – 16%)	85,000 (13 – 30%)	592,710	499,375	199,859
Western Cascades	68,000 (5.– 10%)	60,000 (5 – 9%)	1,250,732	883,983	592,934
Olympics	60,000 (8 – 15%)	24,000 (4 – 6%)	653,786	445,769	350,082
Western Washington Lowlands	7,000 (44%)	9,000 (56%)	0	0	0
Total	173,000 (6% – 13%)	178,000 (7 – 13%)	2,497,228	1,829,127	1,142,875

Estimates from federal lands were calculated by subtracting the amount of estimated change from fire and harvest during 1996-2003 from estimated acres on the federal landscape in 1996.

Table 43. Amount of suitable Spotted Owl habitat on lands managed according to approved Habitat Conservation Plans.

Region	Estimated habitat amount	Year of estimate
DNR		
East Cascades	19,431	1997
West Cascades	84,954	1997
Olympic	81,831	1997
Plum Creek		
East & West Cascades	About 34,000 nesting, roosting and foraging; about 34,000 foraging and dispersal	1996
	About 23,400 nesting, roosting and foraging; about 18,200 foraging and dispersal	1999
West Fork Timber		
West Cascades	2,834 >100 years old	1995
City of Seattle		
West Cascades	13,155 >100 years old [a]	1998
City of Tacoma		
West Cascades	0	1998
Port Blakely		
Southwest	2,772	1996
Total	246,000	

a. Only the acreage in the upper portion of the Cedar River watershed is reported. This landscape coincides with the boundary of the I-90 West Spotted Owl Special Emphasis Area.

Additional Considerations

A number of issues should be mentioned relative to our analyses that may have influenced the results presented in this report. The underlying assumption inherent in this analysis was that our ability to accurately classify habitat was independent of land ownership. One reasonable hypothesis to challenge this assumption is that second growth private industrial forest (i.e. mid seral stands) has been managed more intensively than state and federal lands in the past. More intensive management may have resulted in lower densities of snags and down woody debris on the landscape, both of which are components of the state rule definitions of suitable Spotted Owl habitat in western Washington. Snag presence was a key visual cue during helicopter sampling, particularly in western Washington, which influenced the observer's classification determination. If privately owned mid seral stands were less likely to contain enough snags to meet state rule definitions for Spotted Owl habitat (2 snags/acre) then the accuracy rates we used for mid seral private lands would overestimate the amount of habitat. Alternatively, if the management activities on private land reduced snag densities but not enough to fall below the minimum required density, thereby making it more difficult to correctly recognize habitat from a helicopter, the accuracy rates we used would have underestimated the amount of habitat on privately managed mid seral stands. This effect should be less important in the East Cascades where habitat suitability definitions are substantially less dependent on the presence of snags (e.g. snag requirements were triggered at only 1 out of the 42 ground plots we sampled in the East Cascades that were classified as suitable owl habitat).

Due to access restrictions onto private lands we were unable to collect data to test for possible differences in accuracy rates between state and private lands. Accuracy assessment data for the mid and late seral sampling strata used to adjust helicopter and model predictions of suitable Spotted Owl habitat were restricted almost exclusively to state and federal ownership (see Table 12). The mid seral category ground plots on private land were the least represented in our samples. Privately owned lands made up approximately 38% and 14% of the mid and late seral strata in the study area, respectively; yet comprised only 1% and 9% of the ground plot samples in mid and late seral categories, respectively.

Even though we did not have enough data from private lands in the randomly selected ground plot samples to test our assumption, we explored other sources of data to examine the assumption that our ability to predict habitat conditions on private lands was similar to the accuracy rates we found in this study. We extracted from our historical files, suitable habitat maps that were provided by private landowners during the early- to mid-1990s. We found a total of 49 instances where our helicopter plots sampled forest stands identified by private landowners as either habitat or non-habitat. In these cases 34 of the 43 helicopter plots we classified as non-habitat in mid and late seral strata agreed with the non-habitat classification identified on the private landowner habitat maps. The NCF accuracy rate (21%) for these data was not significantly different than the NCF accuracy rate of 20% generated from the paired comparisons of the ground and helicopter plots from this study. Four of the 6 helicopter plots classified as habitat were correctly identified as habitat. Sample sizes were too small to detect if this accuracy rate (67%) was significantly different than the HCF accuracy rate (76%) from this study.

It is possible that our approach may have overestimated the amount of harvest, and therefore harvested habitat, on federal lands. Approximately 72% of the total stand replacement harvest (5,500 acres) estimated on federal lands was derived from applying a non-harvest correction factor (C_{nharv}, see page 33), even though the estimate of C_{nharv} was small (0.45 %). Conversely stand replacement harvest derived from C_{nharv} accounted for 11% of the estimated harvest for state and private lands.

Another consideration is that our western Washington harvest estimates, including estimates of the amount of owl habitat harvested, did not include estimates of potential loss associated with uneven-aged forest practices. Even though we were unable to quantify impacts resulting from such harvests, our qualitative analysis suggested that some of these practices had the potential to impact Spotted Owl habitat. As of March 2005, there were over 54,000 acres of land in western Washington under some type of uneven-aged permit. Most of the acreage (99%) was associated with DNR Timber Harvest Type Code 2 uneven-age class application. Although the stand replacement model classified ~ 6,000 acres as change, it is likely there were more significant impacts than we were able to detect. We believe that most of these harvests involved pre-commercial and commercial thins in mid-seral stands that were not suitable for Spotted Owls. However, additional work is necessary to better evaluate our modeling assumption that these activities were not significantly impacting owl habitat.

We should mention also that there were an additional ~ 5,000 acres of partial canopy change in the East Cascades zone that met our criteria for habitat loss that we did not include in our estimates of habitat harvest. These change areas fell outside of the FPA boundaries digitized by DNR. We assumed this partial change was due to natural disturbances and not due to harvest activities. Through visual inspection, we found the overall level of agreement between our modeled change areas and the FPA polygons to be very good. However it is possible that some of the harvested areas fell outside of these polygons and were responsible for some of this change.

We did not include estimates of the amount of habitat lost due to fire. We relied on the stand replacement model to detect significant loss due to fire on the study area. For this reason, we treated all fires as stand-replacing events. We suspect that the influence of this uncertainty on our estimates of habitat change is relatively minor because the acreage of burned forest in our study area was low between 1996 and 2004. There were only 705 acres within our study area that were classified as stand replacement change resulting from fire during 1996-2004. Some of the burned areas in Spotted Owl habitat in Washington were likely accounted for in the change detection as this type of stand replacement is very distinct (Gaines et al. 1997), but can be poorly mapped in other areas (Moeur et al. in press; Davis and Lint in press).

Finally, 21 Status 1-3 Spotted Owl management circles were changed to Status 5 (unoccupied) during the 1996-2004 period. Eleven sites were located in the North and South Cascade zones, 9 were located in the East Cascade zone, and 1 was located in Southwest Washington. Twelve sites were re-classed during 1996-1999 and nine sites were re-classed from 2000-2004. Twelve re-classed sites were in Spotted Owl Special Emphasis Areas, and 9 were outside Spotted Owl Special Emphasis Areas. Approximately 70,000 acres associated with post-1996 Status 5 sites outside of SOSEAs were removed from the final study area. An additional 37,000 acres associated with post-1996 Status 5 sites remained as part of the study area because they were within a SOSEA boundary. We assumed that none of these acres and associated habitat and harvest activity were within an owl management circle during the 1996-2004 period. In addition, 16 Status 1-3 spotted owl sites were new and added to the database during the 1996-2004 period. Most of these (n=12) were located in the East Cascade zone. Ten of these sites overlapped with SOSEA boundaries. Approximately 50,500 acres of the final study area were associated with post-1996 Status 1-3 owls that did not overlap with other Status 1-3 sites. Our analysis assumed that all of these acres and overlapping habitat and harvest activity were associated with an owl site during 1996-2004. Our study area and summary statistics for landscapes inside and outside of circles were based on the landscapes that were associated with Status 1-3 owls as of 2004. As a result, the status of the landscape at the time of timber harvest in these areas may have been different than the status in 2004.

CONCLUSIONS AND RECOMMENDATIONS

The state Forest Practices Rules were designed to provide long-term protection and conservation incentives to benefit Spotted Owls inside Spotted Owl Special Emphasis Areas and especially inside circles inside Spotted Owl Special Emphasis Areas. State rules were not designed to afford long-term protection to owls in management circles outside Spotted Owl Special Emphasis Areas. Therefore we expected that harvest levels in Spotted Owl habitat would vary with different levels of conservation protection afforded in different zones of the state. For example, we predicted that harvest levels in habitat would be highest outside of Spotted Owl Special Emphasis Areas. Conversely, we expected that the relative amount of habitat on a landscape would be greatest in the areas designated for conservation (e.g. Spotted Owl Special Emphasis Areas) compared to areas outside of SOSEAs. In addition we did not expect to find significant harvest of Spotted Owl habitat in owl management circles inside SOSEAs where the relative amount of habitat was below the 40% level identified in the Forest Practice Rules.

Results relative to our predictions were mixed and depended on whether federal lands were included in the analysis. In general, after removing federal ownership from the statistics, the proportion of Spotted Owl habitat in 2004 on all state and private landscapes in the study area was highest inside circles inside SOSEAs (21%). However, on non-HCP state and private landscapes there was no significant difference in the proportions of habitat on lands inside or outside of circles within SOSEAs (16% vs 13%) or compared to areas inside circles that were outside SOSEAs (13%).

Harvest of suitable Spotted Owl habitat occurred inside circles in and out of Spotted Owl Special Emphasis Areas and in and out of HCPs in all zones of the state. When all ownerships were included, relative habitat harvest levels (RCI) on non-HCP lands were greater outside of circles inside of Spotted Owl Special Emphasis Areas (11%) than inside circles regardless of association with Spotted Owl Special Emphasis Areas (4% – 5%). However, when federal lands were removed, RCI values in owl circles outside of SOSEAs were significantly greater (25%) than RCI values inside of circles inside SOSEAs (12%) and outside of circles that were inside SOSEAs (18%).

Most of the existing non-HCP lands habitat on state and private lands in our study area (67%) occurred inside Spotted Owl Special Emphasis Areas. We estimated there currently exists a considerable amount of suitable habitat on state and private lands in owl circles outside of the

Spotted Owl Special Emphasis Area boundaries. Significantly more of the habitat on state and private non-HCP lands occurred inside management circles outside SOSEAs (33%) than occurred inside circles outside SOSEAs (27%).

Given the results of our study and concerns for the continuing decline of Spotted Owl populations we make the following recommendations:

1. *Long-term landscape planning should be encouraged*. Spotted Owl management on non-HCP lands appear to be largely driven by individual owl circle management. Within SOSEAs, we estimated rates of habitat loss outside of circles that were approximately twice the rates inside circles. This pattern of habitat loss isolates habitat near the cores of Spotted Owls' home ranges and compromises the ability of the entire landscape to contribute to Spotted Owl conservation over time. While some habitat lands within SOSEAs are currently managed under habitat conservation plans, stronger regulatory approaches to conserving habitat at the landscape level may be needed if SOSEAs are to function as more than groups of occupied circles. As Spotted Owl populations decline and fewer circles are consistently occupied, the current structure of the Forest Practices Rules coupled with "decertification" of circles that are inconsistently occupied may result in further habitat loss within SOSEAs.

2. *High quality, spatially accurate habitat maps should be developed* - It is important to accurately identify the location and amount of Spotted Owl habitat in areas that are identified to contribute to the long term conservation of Spotted Owls (e.g. SOSEAs). The sampling approach that we adopted to assess habitat abundance and change was necessitated by the lack of such maps. While these data may be available for some management circles, areas, or ownerships, they are neither common nor consistent. High-quality habitat maps based on the habitat definitions in the Forest Practices Rules are essential both for day-to-day rule implementation (i.e. review of Forest Practices Applications) and for policy evaluation. Additionally, habitat criteria and

definitions should be periodically reviewed and updated to ensure maps are consistent with owl habitat requirements in the specific areas identified to support conservation.

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Appendix A. Spotted Owl Habitat Definitions

Forest Practices Rule definitions of Spotted Owl nesting, roosting and foraging habitat meeting regulatory requirements of state, local government, and private ownership in Washington State.

WAC 222-16-085 Northern Spotted Owl habitats.(1) Suitable Spotted Owl habitat means forest stands which meet the description of old forest habitat, sub-mature habitat or young forest marginal habitat found in (a) and (b) of this subsection. Old forest habitat is the highest quality, followed in descending order by sub-mature habitat and young forest marginal habitat.

(a) **Old forest habitat** means habitat that provides for all the characteristics needed by Northern Spotted Owls for nesting, roosting, foraging, and dispersal, described as stands with:

(i) A canopy closure of ≥60% and a layered, multispecies canopy where ≥50% of the canopy closure is provided by large overstory trees (typically, there should be ≥75 trees >20 inches dbh per acre, or ≥35 trees ≥30 inches dbh); and

(ii) ≥3 snags or trees ≥20 inches dbh and ≥16 feet in height per acre with various deformities such as large cavities, broken tops, dwarf mistletoe infections, and other indications of decadence; and

(iii) >2 fallen trees ≥20 inches dbh per acre and other woody debris on the ground.

(b) **Sub-mature habitat and young forest marginal habitat** Sub-mature habitat provides all of the characteristics needed by Northern Spotted Owls for roosting, foraging, and dispersal. Young forest marginal habitat provides some of the characteristics needed by Northern Spotted Owls for roosting, foraging, and dispersal. Sub-mature habitat and young forest marginal habitat stands can be characterized based on the forest community, canopy closure, tree density and height, vertical diversity, snags and cavity trees, dead and down wood, and shrubs or mistletoe infection. They are described in the following tables:

(i) Western Washington Spotted Owl sub-mature and young forest marginal habitat characteristics.

Characteristic	Habitat Type	
	Sub-Mature	Young Forest Marginal
Forest Community	conifer-dominated or conifer-hardwood (≥30% conifer)	conifer-dominated or conifer-hardwood (≥30% conifer)
Canopy Closure	≥70% canopy closure	≥70% canopy closure
Tree Density and Height	115-280 trees/acre (≥4 inches dbh) with dominants/codominants ≥85 feet high OR	115-280 trees/acre (≥4 inches dbh) with dominants/codominants ≥85 feet high OR
Vertical Diversity	dominants/codominants ≥85 feet high with 2 or more layers and 25 - 50% intermediate trees	dominants/codominants ≥85 feet high with 2 or more layers and 25 - 50% intermediate trees
Snags/Cavity Trees	≥3/acre (≥20 inches dbh and ≥16 feet in height)	≥2/acre (≥20 inches dbh and ≥16 feet in height) OR ≥10% of the ground covered with 4 inch diameter or larger wood, with 25-60% shrub cover
Dead, Down Wood	N/A	
Shrubs	N/A	

The values indicated for canopy closure and tree density may be replaced with a quadratic mean diameter of >13 inches and a basal area of >100.

(ii) Eastern Washington Spotted Owl sub-mature and young forest marginal habitat characteristics.

	Habitat Type		
Characteristic	Sub-Mature	Young Forest Marginal (closed canopy)	Young Forest Marginal (open canopy)
Forest Community	≥40% fir	≥40% fir	≥40% fir
Tree Density and Height	110-260 trees/acre (≥4 inches dbh) with dominants/codominants ≥90 feet high OR	100 - 300 trees/acre (≥4 inches dbh) dominants/codominants ≥70 feet high	100 - 300 trees/acre (≥4 inches dbh) dominants/codominants ≥70 feet high
Vertical Diversity	dominants/codominants ≥90 feet high with 2 or more layers and 25 - 50% intermediate trees	2 or more layers 25 - 50% intermediate trees	2 or more layers 25 - 50% intermediate trees
Canopy Closure	≥70% canopy closure	≥70% canopy closure	≥50% canopy closure
Snags/Cavity Trees	≥3/acre (≥20 inches dbh and ≥16 feet in height) OR	N/A	≥2/acre (≥20 inches dbh and ≥16 feet in height)
Mistletoe	high or moderate infection	N/A	high or moderate infection
Dead, Down Wood	≥5% of the ground covered with 4 inch diameter or larger wood	N/A	N/A

The values indicated for canopy closure and tree density may be replaced with the following:

(A) For sub-mature a quadratic mean diameter of >13 inches and a relative density of >44;

(B) For young forest marginal a quadratic mean diameter of >13 inches and a relative density of >28.

[Statutory Authority: Chapters 76.09 and 34.05 RCW. 96-12-038, § 222-16-085, filed 5/31/96, effective 7/1/96.]

Appendix B. Total Study Area Acres

Total acres in study area **outside** HCP landscape, divided into geographic zone, relation to SOSEAs, and relation to Spotted Owl management circles.

		Inside SOSEA			Outside SOSEA	
Zone	Own Group	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	State-Local	2,438	9,070	11,508	5,582	17,090
	Private	91,516	119,317	210,833	83,642	294,475
	Federal	195,851	98,892	294,743	102,777	397,520
	Tribe	390	101	491	13,373	13,864
East Cascades Total		290,195	227,379	517,574	205,373	722,948
North Cascades	State-Local	526	3,470	3,996	506	4,502
	Private	31,027	122,939	153,966	21,839	175,806
	Federal	77,838	52,479	130,316	139,766	270,082
	Tribe	0	0	0	0	0
North Cascades Total		109,391	178,888	288,279	162,111	450,390
Olympic	State-Local	653	739	1,392	3,398	4,790
	Private	67,105	57,913	125,019	97,357	222,376
	Federal	35,770	13,007	48,776	353,674	402,450
	Tribe	834	127	961	10,628	11,589
Olympic Total		104,362	71,786	176,148	465,057	641,205
South Cascades	State-Local	208	5,186	5,394	1,470	6,864
	Private	50,251	134,240	184,491	71,042	255,533
	Federal	33,076	21,642	54,718	86,723	141,441
	Tribe	0	0	0	0	0
South Cascades Total		83,535	161,068	244,603	159,235	403,838
Southwest	State-Local	0	0	0	256	256
	Private	0	0	0	115,671	115,671
	Federal	0	0	0	188	188
Southwest Total		0	0	0	116,115	116,115
Grand Total		587,484	639,122	1,226,605	1,107,891	2,334,496

Appendix B. (continued)

Total acres in study area **inside** HCP landscape, divided into geographic zone, relation to SOSEAs, and relation to Spotted Owl management circles.

		Inside SOSEA			Outside SOSEA	
Zone	Own Group	Inside Circle	Outside Circle	Inside SOSEA Total	Inside Circle	Grand Total
East Cascades	State-Local	40,850	45,006	85,857	22,130	107,986
	Private	42,945	23,857	66,802	795	67,597
East Cascades Total		83,796	68,863	152,659	22,924	175,583
North Cascades	State-Local	32,690	80,789	113,478	18,890	132,369
	Private	36,453	22,894	59,347	18	59,365
North Cascades Total		69,143	103,682	172,825	18,908	191,733
Olympic	State-Local	144,796	56,947	201,743	91,379	293,123
	Private	320	231	551	14,383	14,934
Olympic Total		145,116	57,178	202,294	105,763	308,057
South Cascades	State-Local	51,007	40,268	91,276	18,420	109,696
	Private	11,252	43,533	54,785	113	54,899
South Cascades Total		62,259	83,802	146,061	18,534	164,595
Southwest	State-Local	0	0	0	52,945	52,945
	Private	0	0	0	6,532	6,532
Southwest Total		0	0	0	59,477	59,477
Grand Total		360,314	313,526	673,839	225,607	899,446

Appendix C. Report Information Sources and Spatial Data Processing Software

Spatial Data Processing Software Resources

Environmental Systems Research Institute (ESRI) Inc. Copyright © 1995-2005 ESRI. ArcInfo 9.0.
http://www.esri.com/
380 New York Street, Redlands, California 92373-8100, USA.

Environmental Systems Research Institute (ESRI) Inc. Copyright © 1982-2002 ESRI. ArcInfo 8.3
http://www.esri.com/
380 New York Street, Redlands, California 92373-8100, USA.

Leica Geosystems Geospatial Imaging. Copyright © 1991-2003 Leica Geosystems GIS & Mapping LLC.
ERDAS Imagine 8.7.
http://gis.leica-geosystems.com
5052 Peachtree Corners Circle, Norcross, GA 30092, USA.

Northern Spotted Owl Locations and Emphasis Areas

Owl Observation Data

Source: Washington Dept. of Fish & Wildlife
Data Type: point
Description: owl locations obtained from private, state, and federal sources.
Data distribution is restricted under sensitive data release rules.

Spotted Owl Special Emphasis Areas (SOSEA)

Source: Washington Dept. of Natural Resources
Data Type: polygon
Description: ten special emphasis areas mapped in eastern and western Washington.
Publication date is May 1996. Data and metadata located at:
http://www.dnr.wa.gov/forestpractices/data/

Spotted Owl Project Area

Source: Washington Dept. of Fish & Wildlife
Data Type: raster
Description: the Spotted Owl area of interest was generated from SOSEA boundaries, spotted owl circles, and Fire Management Area Zones (FMAZ). The selected Spotted Owl circles were merged with the SOSEAs. The FMAZ boundaries were originally compiled by the U.S. Forest Service for fire control purposes on the Wenatchee National

Forest and vicinity. Most of FMAZ zone 5 delineated the boundary between the East Cascades and North Cascades Zones.

Landscape Change

Stand Replacement

Source: U.S. Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon
Data Type: raster
Description: 1972 to 2004 stand replacement covering the Forest Ecosystem Management Assessment Team (FEMAT) area. Landscape change (harvest, fire, volcanic) data developed from Landsat Multspectral Scanner, Thematic Mapper, and Enhanced Thematic Mapper imagery.

Partial Canopy Change

Source: U.S. Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon
Data Type: raster
Description: partial canopy change mapping covering two processing areas in eastern Washington and part of Skamania County. Landscape change data developed from Thematic Mapper and Enhanced Thematic Mapper imagery. The data are in continuous (non-categorical) form. Basal area and crown cover were modeled as percent relative change and in absolute units.

Combined Stand Replacement and Partial Canopy Change

Source: Washington Department of Fish & Wildlife
Data Type: raster
Description: in Geographic Zones Olympics, Southwest, North Cascades, and South Cascades, stand replacement data provided the only landscape change source. Partial canopy change data and stand replacement data were applied in the East Cascades Zone. Crown cover criteria were applied to the 1996 and 2004 Forestry Sciences Lab raster cover data. Table 8 in the Washington State Spotted Owl Habitat Assessment Report lists the crown cover thresholds. Partial canopy change data were applied inside of forest practice polygons. Outside of forest practice polygons, partial canopy change data were applied in areas where stand replacement indicated no-change.

Landcover

Seral Strata

Source: Washington Dept. of Natural Resources

Data Type: raster/polygon
Description: mapping was performed across all Washington forested Water Resource Inventory Areas (WRIA) using 1988 Landsat Thematic Mapper imagery. The seral stage data were derived from federal and state contracts with Pacific Meridian Resources. U.S. Forest Service lands were mapped into crown cover and size/structure themes. On Washington state lands, a coarser mapping was performed, generating four forest categories. The U.S. Forest Service classification was generalized to fit the broader Washington State classification. The combined forest cover and forest age data were mapped into late seral, mid-seral, early seral, and other lands in forested areas. A nonforest class was added from the 1:250,000-scale, 1976 U.S Geological Survey land use/land cover data set. The nonforest class includes urban, agriculture, rangeland, barren, glaciers, etc. Washington Dept. of Natural Resources updated harvest activities in the seral stage map to 1991/93 conditions using Landsat imagery.

Interagency Vegetation Mapping Project (IVMP)

Source: USDA Forest Service/USDI Bureau of Land Management
Data Type: raster
Description: map products cover the Forest Ecosystem Management Assessment Team (FEMAT) area. Four map themes were produced using ca. 1996 Landsat Thematic Mapper 5 imagery: vegetation cover, conifer cover, broadleaf cover, and quadratic mean diameter (QMD). The themes were mapped over four Washington provinces: Olympics, Western Washington Lowlands, West Cascades, and East Cascades.

Sample Plots

Spotted Owl Project Field Plots

Source: Washington Dept. of Fish & Wildlife
Data Type: polygon.
Description: 10-acre and 4-acre field sample plot boundaries compiled for the Spotted Owl habitat assessment project.

Partial Canopy Change Field Plots

Source: U.S. Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon
Data Type: point/polygon
Description: one-hectare plot locations for thinning and crown cover model estimates.

Stand Replacement Accuracy Assessment Plots

Source: U.S. Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon
Data Type: point
Description: data compiled from visual inspection of Landsat imagery.

Partial Canopy Change Accuracy Assessment Plots

Source: U.S. Forest Service, Forestry Sciences Laboratory, Corvallis, Oregon
Data Type: point/polygon
Description: plot data compiled from field and airphotos.

Forest Management and Planning

Forest Resource Inventory System (FRIS)

Source: Washington Dept. of Natural Resources
Data Type: polygon
Description: land cover mapping on Washington Dept. of Natural Resources trust lands. The maps depict relatively homogeneous areas of vegetation or similarly variable vegetation and non-forest conditions in polygons with an average size of about 50 acres. Map update is ongoing.

Forest Practice and Review System (FPARS)

Source: Washington Dept. of Natural Resources
Data Type: polygon
Description: forest practice application (FPA) spatial and attribute data maintained statewide. Data update is ongoing. The Eastside forest practice data used in the 1996 to 2004 non-federal lands assessment were obtained on 30 March 2005. Westside FPA data were acquired from the WDNR website http://www.dnr.wa.gov/forestpractices/data/ The website FPA publication date was January 2004.

Habitat Conservation Plan (HCP)

Source: US Fish & Wildlife Service Pacific Region
Data Type: Polygon
Description: HCP polygons for Boise Cascade, City of Seattle, Daybreak-Storedahl, Murry Pacific, Plum Creek, Port Blakely, Scofield Corp., Simpson, Tacoma Public Utilities, and Washington Dept. of Natural Resources. The HCP data were obtained in April 2004.

Owl Habitat Modeling

Logistic Regression

Source: Washington Dept. of Fish & Wildlife
Data Type: raster.
Description: logistic regression habitat model output. Model output generated from IVMP layers and FRIS. Habitat threshold values were applied from Table 27 Summary of Performance for each IVMP region.

Ecological Niche Factor Analysis (ENFA)

Source: Washington Dept. of Fish & Wildlife
Data Type: raster
Description: Biomapper habitat model output. Model output generated from IVMP layers and FRIS. Threshold values were applied from Table 24 Habitat Suitability Model results from Ecological Niche Factor Analysis using Biomapper, according to four Washington State IVMP regions.

Land Ownership and Transportation

Major Public Lands

Source: Washington Dept. of Natural Resources, Washington Dept. of Fish & Wildlife
Data Type: polygon
Description: 100:000-scale ownership ca. 1996 and ca. 2004. Land ownership input to cross tabulation summaries and other procedures.

Transportation

Source: Washington Dept. of Natural Resources
Data Type: line
Description: 1:24,000-scale transportation network. These data facilitated ground plot access and cartographic map layout.

Aerial Photography

Digital Orthophotography

Source: Washington Dept. of Natural Resources
Data Type: raster
Description: color and black/white orthophotos. Pixel size is equal to three feet. An index map to current orthophoto missions can be found at:
http://www.dnr.wa.gov/dataandmaps/maps/pdf/color_ortho_nu.pdf

Latest available mission years:
Color orthophotos used in the project were from the 2002 and 2003 mission years.
Black/white orthos were available for mission year 2000 for the Olympic Peninsula area.

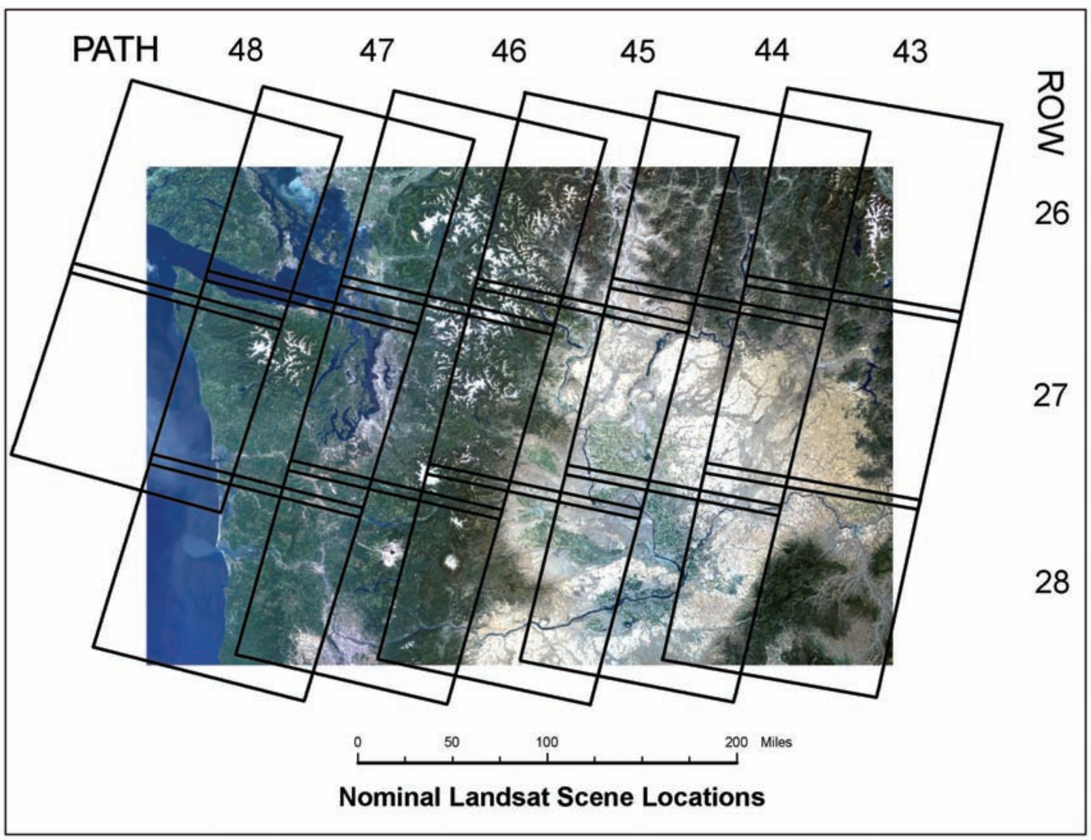
Historical mission years:
Black/white orthophoto mission years 1993 to 1998.

Aerial Photo Prints

Source: Washington Dept. of Natural Resources
Data Type: 9-inch x 9-inch prints
Description: 1:12,000-scale black/white photo prints. Acquisition years were 1999 and earlier.

Landsat Satellite Imagery Acquisitions

Source: EROS Data Center, U.S. Geological Survey
http://edc.usgs.gov/
Data Format: raster
Description: the stand replacement and partial canopy change mapping utilized Landsat satellite imagery acquired in 1996, 1997, 1998, 2000, 2002, and 2004. The data are indexed by acquisition path and row. See the Washington index map below. Due to persistent cloud cover in 1996 over the Olympic Peninsula area, a 1995 Landsat image (48/26, with approximate 40% shift south) was used. Duplicate scenes within a given year of acquisition were purchased to minimize cloud cover. The table below lists the path, row, month, day, and year of the Landsat images used.



List of Landsat Imagery

Path	Row	Month	Day	Year
48	26	9	18	1995
45	26	7	13	1996
45	27	7	13	1996
45	28	7	13	1996
46	26	8	21	1996
46	27	8	21	1996
46	28	8	21	1996
47	26	8	12	1996
47	27	8	21	1996
47	28	7	11	1996
48	26	5	18	1997
45	26	8	4	1998
45	27	8	4	1998
45	28	8	4	1998
46	26	8	27	1998
46	27	8	27	1998
46	28	8	27	1998
47	26	8	2	1998
47	27	8	2	1998
47	28	8	2	1998
48	26	7	19	1999
45	26	8	17	2000
45	27	8	9	2000
45	27	8	17	2000
45	27	10	4	2000
45	28	8	9	2000
45	28	8	17	2000
45	28	10	4	2000
46	26	8	8	2000
46	27	7	7	2000
46	28	7	7	2000
46	28	6	21	2000
47	26	7	30	2000
47	27	7	30	2000
47	28	7	30	2000
48	26	8	22	2000
48	27	6	3	2000
45	26	9	8	2002
45	27	7	22	2002
45	28	9	24	2002
46	26	8	14	2002
46	27	8	14	2002

Path	Row	Month	Day	Year
46	28	6	11	2002
47	26	9	22	2002
47	27	9	22	2002
47	28	9	22	2002
48	26	8	26	2002
48	27	6	3	2002
45	26	8	20	2004
45	27	8	20	2004
45	27	9	21	2004
45	28	8	20	2004
46	26	8	11	2004
46	27	7	26	2004
46	27	8	11	2004
46	28	7	26	2004
46	28	8	11	2004
47	26	7	17	2004
47	27	7	17	2004
47	27	9	22	2004
47	28	6	15	2004
48	26	7	24	2004

Appendix D. Stand Replacement Methodology

Excerpt from: *Forest Disturbance and Spatial Pattern: Remote Sensing and GIS Approaches* Wulder,M. and Franklin, S., eds. Taylor Press / CRC. Chapter 5: Remotely sensed data in the mapping of forest harvest patterns

Sean P. Healey, Warren B. Cohen, Yang Zhiqiang, and Robert E. Kennedy

Case study in harvest detection: stand-replacing harvests in the Pacific Northwest

Background and Methods

The Northwest Forest Plan (the Plan) was a 1994 amendment to the management plans of federal forestlands within the range of the Spotted Owl (*Strix occidentalis caurina*) in California, Oregon, and Washington. The aim of this plan was to balance the maintenance and restoration of older forest ecosystems with a predictable and sustainable level of harvest. Effectiveness monitoring was an important component of the plan, and, among other measures, monitoring programs were established to assess trends in old growth forest ecosystems, habitat of Spotted Owls and Marbled Murrelets (*Brachyramphus marmoratus*), and the socioeconomic status of people in timber-dependent towns. Although a system of re-measured inventory plots has provided region-wide estimates of the net loss or gain of different forest types in the region, a spatially explicit record of significant disturbances was needed to assess changes to older forests and to owl habitat (Moeur et al., 2005; Lint et al., 2005). Furthermore, historical context was desired regarding harvest levels both before and after the Plan was enacted.

It was decided that stand-replacing harvests and fires in Oregon and Washington from 1972 to 2002 would be mapped at approximately four-year intervals using composite analysis with Landsat MSS, TM, and ETM+ data. Change detection in California was approached differently

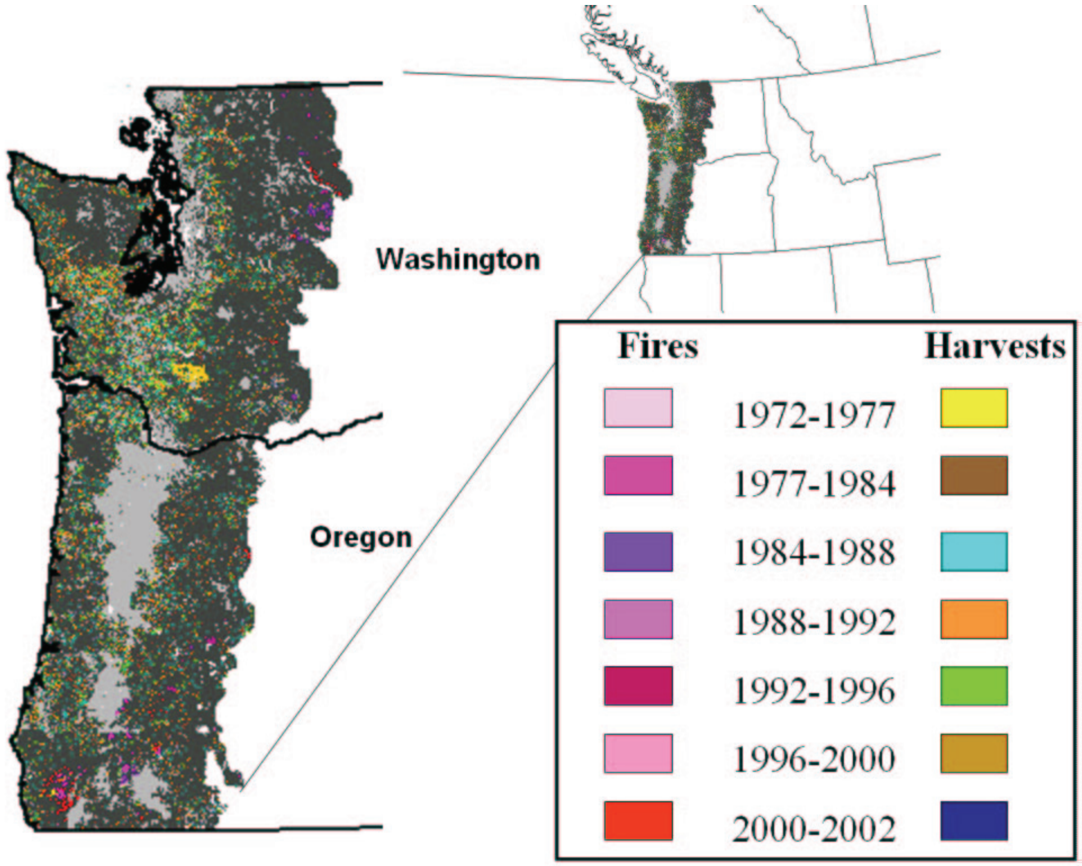


Figure 1. Map of stand-replacing harvests and fires within the range of the Northern Spotted Owl in Oregon and Washington from 1972-2002.

(Levien et al., 2003) and will not be discussed here. Methods used in Oregon and Washington were chosen in consideration of project needs. Landsat data was used because it satisfied the need for historical data, and because its moderate spatial resolution struck a balance between a large study area (14.5 million hectares, see Figure 1) and the need for accurate spatial referencing of disturbances. Also, the spectral resolution of the Landsat satellites, particularly TM and ETM+ which provide SWIR information, has been useful in several vegetation mapping projects in the region (Cohen and Goward, 2004). The mapping interval minimized image acquisition and processing costs while offering sufficient temporal resolution for the detection of clearings in the Pacific Northwest (Cohen et al., 1998).

The “stand-replacing” harvest attribute (the detection of fires will not be discussed here) met the study’s need to identify cuttings that removed all or nearly all of a stand’s trees.

It should be noted that, silvicultural definitions notwithstanding, the "stand-replacing" designation used here does not apply to gradual shelterwood cuts that leave a large percentage of resident trees. In fact, harvests leaving a large canopy component (partial harvests) were intentionally excluded from the map. The identification and labeling of harvested pixels was accomplished through the use of composite analysis, a process by which a multi-temporal "stack" of image data is classified to identify relevant changes.

Accurate cross-date spatial co-registration is essential in this process (Coppin and Baeur, 1996), and an automated tie-point program (Kennedy and Cohen, 2003) was used to carefully co-register the images. Other data preparation, detailed by Cohen et al., (2002), included masking out non-forest areas using a land cover layer prepared for the Plan area (Fassnacht et al., 2005) and subsetting Landsat images along general ecosystem boundaries to reduce ecological variation in the spectral signal. Composite analysis was chosen because it was judged to be an accurate and efficient means of isolating pixels displaying multi-temporal spectral signatures consistent with stand-replacing harvest (Cohen and Fiorella, 1998). Supervised classification, where spectral properties of disturbed and undisturbed pixels are identified in advance, was chosen for this analysis.

An informal study (Figure 2) indicated that such a process, when used with a maximum likelihood classifier, is more efficient at isolating clearcut pixels than unsupervised classification. Unsupervised classification relies on analyst interpretation of feature space clusters and can be time-consuming when clusters are not well-aligned with the boundaries of desired classes.

Prior to composite analysis, the Tasseled Cap transformation was performed on the Landsat data for purposes of data reduction and feature emphasis (see Data Considerations section). A further transformation was performed on the Tasseled Cap indices to produce a single band per image/date called the disturbance index (DI). This index quantifies the degree to which a pixel fits a profile that is presumed to match the position of clearcuts in Tasseled Cap space. Specifically, pixels with high Tasseled Cap brightness and low Tasseled Cap greenness and wetness values have high DI values.

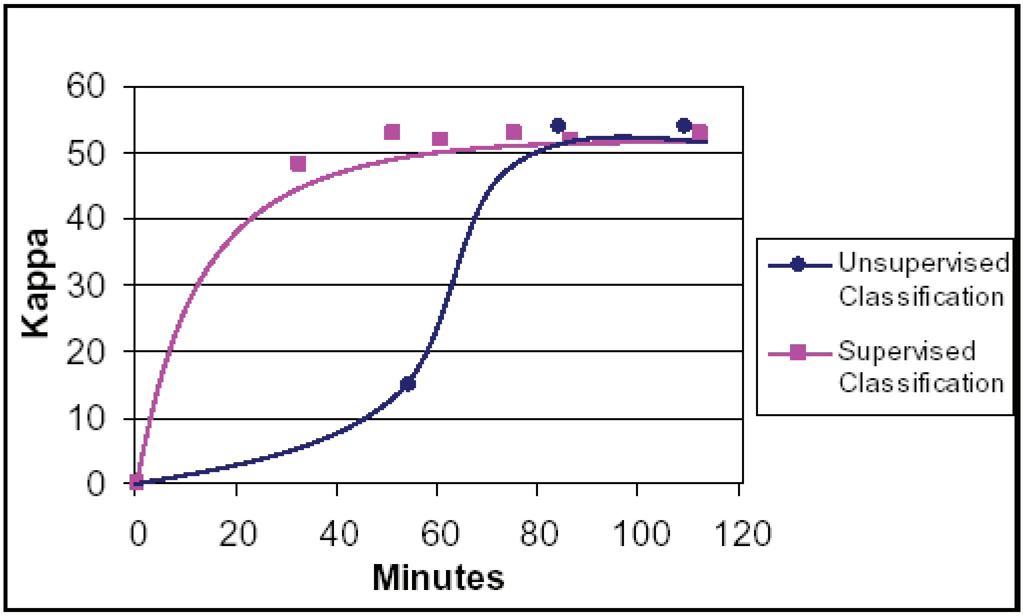


Figure 2. Pilot study of efficiency of composite analysis using unsupervised and supervised classification to detect stand-replacing harvests. Both approaches were applied in a 500,000-hectare study area in Eastern Washington to create maps identifying harvest over two four-year intervals using Tasseled Cap-transformed Landsat TM data. Resulting maps were evaluated against the Landsat imagery, allowing iterative adjustment of classification parameters. Kappa accuracy of successive maps was measured against hand-digitized disturbance maps and plotted over processing time. Reported times do not reflect pre-processing procedures that were common to both approaches.

Details of the transformation can be found in Healey et al. (in press). Disturbed pixels are identified by the classifier because they move suddenly from low to high DI values. Composite analysis in different regions has shown DI-transformed imagery to produce results comparable to Tasseled Cap-transformed data (Healey et al., in press). Further, reduction to a single band allows visualization of multi-temporal imagery in a single monitor. Figure 3 shows a three-date display of DI images that identifies the standreplacing harvests from a given period in a distinct color. This ready identification of the date of each clearing facilitated the selection of training polygons for supervised composite analysis. Post-processing included the mosaicing of all of the mapped segments together and the removal of all mapped cuts and "islands" of retained tress that were less than two hectares in size. The latter measure was intended to remove small areas of error introduced by spatial mis-registration.

Results and Analyses

The map that was created through this process displayed stand-replacing harvests larger than two hectares and identified the time period in which they occurred. Map error was assessed at approximately 2500 randomly selected points through a sampling strategy described by Cohen et al. (2002). Accuracy was found to be acceptable for the analyses described below. In general, the earlier dates, which were mapped with lower-resolution MSS data, were less accurate than TM-mapped dates.
On the pixel-level, most errors resulted from either spatial mis-registration or confusion of partial harvests with stand-replacing harvests. A variety of analyses were performed with the map in support of the Plan's vegetation monitoring program. First, the map was considered in conjunction with a variety of GIS layers to identify harvest trends over ecological provinces, ownerships, and federal land use designations. Figure 4 shows harvest trends by ownership. Notable in the graph is the dramatic reduction in harvest on federal Forest Service and BLM (Bureau of Land Management) lands during the time that has coincided with the Northwest Forest Plan. A second type of analysis focused on the average size of harvest units for each ownership over time; in general, stand-replacing harvests on private land were larger than those on public land over all time periods.

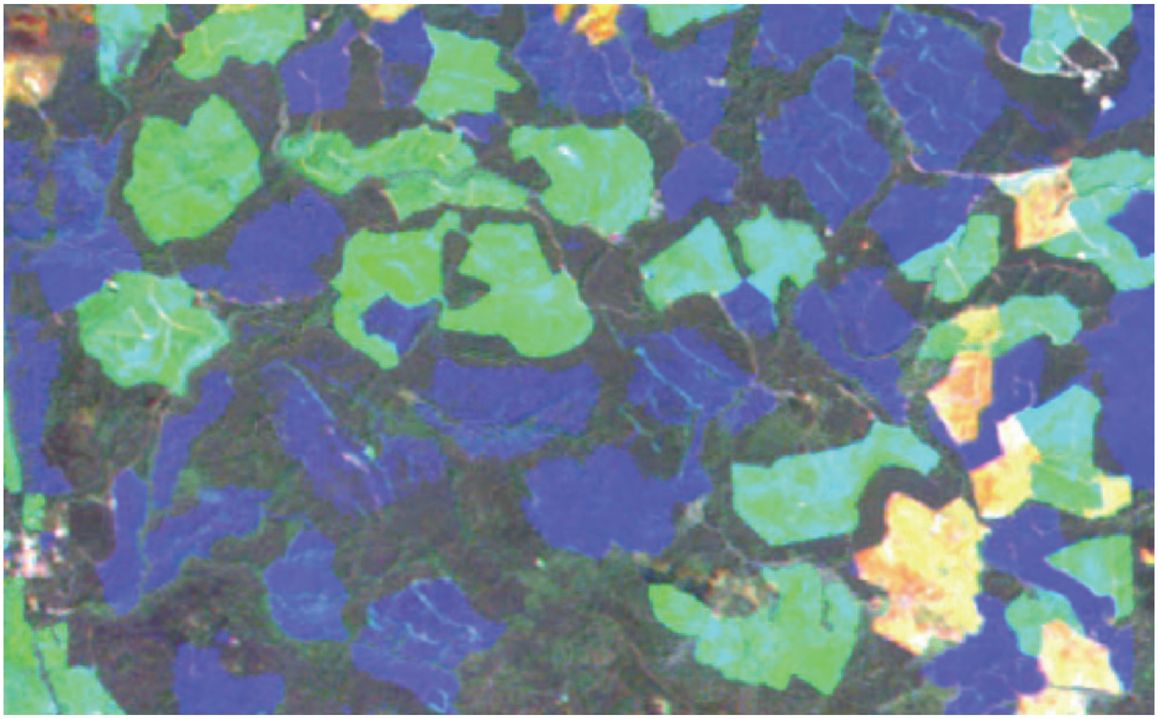


Figure 3. Three dates of DI as viewed in a typical RGB monitor. The first date (1988) is plotted in the red color gun, the second (1992) in the green, and the third (1996) in the red. Using the assumption that DI is high in disturbed areas, additive color logic can be used to interpret this multi-temporal image. Cyan-colored areas are high in both the second and third dates, indicating a change between the first and second dates. Blue pixels have a high DI only in the third date, indicating disturbance between the second and third dates. The yellowish colors, high in the red and green color guns and lower in the blue, indicate stands disturbed before the first date that are becoming re-vegetated by the third date.

The relatively high spatial and temporal resolution of the map make it useful for updating regional-scale maps of forest resources. In support of the Plan, the map was combined with circa-1996 maps of older forests and owl habitat to identify recent changes in those resources. Summaries of these analyses can be found in Moeur et al., (2005) and Lint et al. (2005). A similar update of Spotted Owl habitat is planned by the Washington Department of Fish and Wildlife. The map is also being used to calibrate a continentalscale
carbon accounting model (Potter et al., in press). The synoptic and spatially explicit

nature of satellite-derived maps of disturbance have become a useful complement to more traditional plot-based statistical estimates of change.

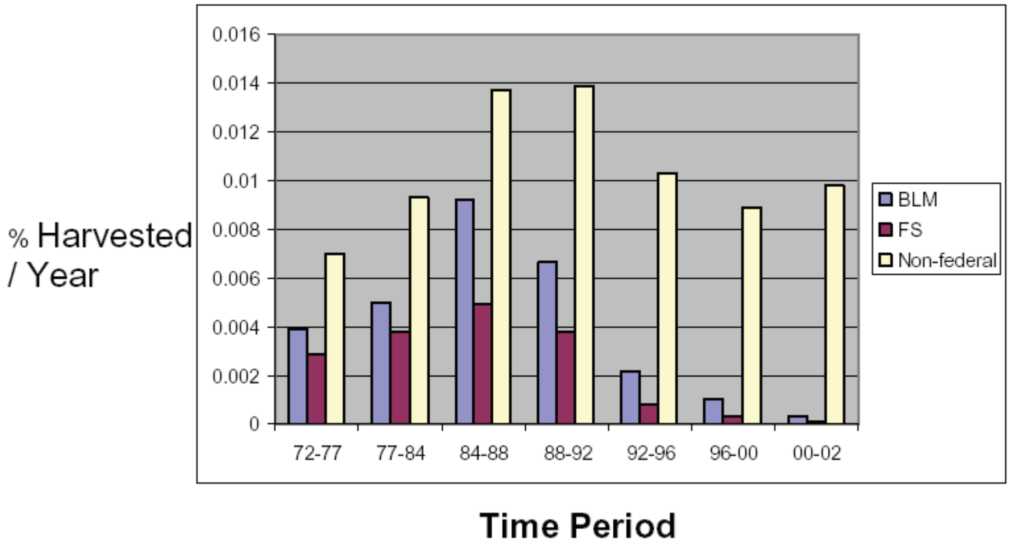


Figure 4. Percent of federal and non-federal forestland harvested in the Plan area of Oregon and Washington, 1972-2002

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Appendix E. Partial Harvest Methodology

Application of two regression-based methods to estimate the effects of partial harvest on forest structure using Landsat data

Sean P. Healey[1], Yang Zhiqiang[2], Warren B. Cohen[3], and John Pierce[3]

1.0 Abstract

Although partial harvests are common in many forest types globally, there has been little assessment of the potential to map the intensity of these harvests using Landsat data. In our Pacific Northwest, USA study area (central Washington), we modeled basal area removal and percent cover change using biennial Landsat imagery with historical aerial photography and a system of inventory plots as reference data,. First, we assessed the correlation of various Landsat spectral bands and derived indices with measured levels of forest change. Shortwave infrared (SWIR) bands (5 and 7) and those strongly influenced by SWIR reflectance (Tasseled Cap Wetness, the Disturbance Index, and to a lesser extent the Normalized Difference Moisture Index) were the variables most closely associated with the forest change variables. Bands and indices associated with near-infrared reflectance (band 4, Tasseled Cap Greenness, and the Normalized Difference Vegetation Index) were only weakly correlated with forest change. Two regression-based methods of estimating forest loss were tested. The first, termed "state model differencing" (SMD), involves creating a model representing the static relationship between inventory data from any date and corresponding, cross-normalized spectral data. This "state model" is then applied to two dates, with the difference between the two estimates taken as estimated change. The second approach, which we called "direct change modeling" (DCM), involved modeling forest structure changes in re-measured inventory plots with spectral differences from corresponding image pairs. In a leave-one-out cross-validation process, DCM-derived estimates of harvest intensity had approximately 5% lower root mean square error for relative basal area removal and 10% lower for relative cover change. The higher measured accuracy of DCM in this project must be weighed against several operational advantages of SMD relating to less restrictive reference data requirements and more specific resulting estimates of change.

2.0 Introduction

Forest harvests that remove only a part of the canopy are common throughout much of the world. In addition to allowing the extraction of saleable forest products, partial harvests may also address a range of other silvicultural goals. These goals may include: improving the ability of retained trees to grow vigorously, providing seed and ameliorating conditions for a new cohort of trees, and increasing the stand's value as wildlife habitat (Smith et al., 1997). Partial cutting has also traditionally been used in the management of tree density in young stands and has increasingly been considered as a means of reducing fire risk (Brown et al., 2004; Fight et al., 2004). The Pacific Northwest of the United States, like other regions (e.g. Sader et al., 2003), has seen an increase over the last several years in the frequency of partial harvest (McNeel and Dodd, 1996; Oregon Department of Forestry Annual Reports, 1989-2003).

As in other regions composed of a variety of forest owners, satellite-based monitoring is likely the most realistic means of mapping forest harvests in the Pacific Northwest. While public agencies routinely publish spatially referenced harvest practice information, private landowners often consider such data proprietary. Information about harvest practices on private land is available from tax records, but is provided in a spatially generalized format (e.g. Oregon Department of Forestry Annual Reports provides harvest practice information by owner only at the county level). Because of its synoptic and historical nature, Landsat satellite data has been a useful source of forest disturbance information at the regional scale (Cohen and Goward, 2004). Landsat data has been used to create relatively accurate regional-scale maps of stand-clearing harvests in the Pacific Northwest (Cohen et al., 2002; Moeur et al., 2005), but no work has extended the use of Landsat data to the identification of partial harvests in the region. We investigated two regression-based approaches to estimating the intensity of partial harvests occurring in central Washington from 1996 to 2004. In doing so, we also explored the relative ability of various transformations of Landsat data to predict removal of cover and basal area in this area.

2.1 Background

The Washington Departments of Fish and Wildlife (WDFW) and Natural Resources (WDNR) were interested in reviewing the spatial patterns and effects of harvests occurring between 1996 and 2004 in and around sensitive habitat for the northern Spotted Owl (*Strix occidentalis caurina*). The most useful existing source of information for harvest locations was a spatially referenced database of harvest permits granted during the period in question. This database had some shortcomings with respect to estimating the effects of harvest on habitat, however. First, not all permitted activities were actually carried out, and of those that were, harvests rarely filled out the entirety of delimited permit boundaries. Also, the database did not address harvest intensity. Depending on the structural effects of a harvest, a stand may or may not retain characteristics that meet Spotted Owl habitat requirements (Washington Administrative Code 222-16-085). WDFW therefore required a spatially referenced map of harvest intensity that could be used to address harvest effects on owl habitat. Remote sensing was seen as a potential means to map harvests in WDFW's large and varied area of interest in a uniform and retrospective way. Landsat data has had a significant role in such studies (Cohen and Goward, 2004), and several studies have suggested the potential of Landsat data to map partial canopy removals (Franklin, 2001).

Changes in percent cover and basal area were chosen as measures of harvest intensity because these structural variables were relevant to owl habitat definitions and because previous studies have shown them to be correlated with Landsat data (Franklin, 1986; Cohen and Spies, 1992; Cohen et al., 1995). Mapping efforts were focused on two areas in central Washington (Figure 1) that contained a high concentration of recognized Spotted Owl Special Emphasis Areas (Federal Register, 1996; WAC 222-10-041).

Ultimately, harvest maps were used to assess the degree to which management activities have impacted the extent and configuration of owl habitat in the region (Pierce et. al 2005).

2.2 General spectral characteristics of partial harvest

A relatively thorough dataset comprised of historical photos, management records, and field plots permitted estimation of harvest intensity as the change in two forest attributes, basal area and canopy cover. Changes were modeled as continuous variables, which not only increased the precision of the variable selection process, but it also produced flexible model outputs capable of being binned into categories appropriate for a range of objectives. Two modeling approaches were explored. The first, hereafter called “state model differencing” or SMD, was based upon the construction of a date-invariant relationship between the spectral variables and the forest inventory variables. Assuming acceptable relative radiometric normalization among image dates, this approach allowed prediction of the state of a particular area in terms of basal area or cover at different times. The predictions for successive dates could then be compared in order to produce an estimate of change. The other approach, “direct change modeling” (DCM), involved regression of changes in basal area and cover at different dates against differences in spectral values for corresponding dates.

There were two primary lines of inquiry in this study: (1) comparison of Landsat-derived bands for use in support of partial harvest measurement; and (2) assessment, through a leave-one-out cross-validation procedure, of how well each of the above modeling approaches (DCM and SMD) were able to predict the measured changes in our reference data. In regards to the first question, several studies have noted that the general spectral response to canopy reduction involves increased reflectance in the visible and shortwave-infrared (SWIR) portions of the electromagnetic spectrum and decreased reflectance in the near-infrared (NIR) range (Hame, 1991; Olsson, 1994; Franklin et al., 2000). This response is consistent with certain physical changes in the stand that may be expected upon partial canopy loss: higher soil and litter reflectance in relation to canopy reflectance, lower water absorption, and greater shadow fraction (Franklin et al., 2000). However, slash patterns (Nilson et al., 2001), understory and residual tree growth response (Franklin et al., 2000), and shifts in species composition (Olsson, 1994) may mitigate the expected spectral response after a stand is thinned. In characterizing the intensity of partial harvests, it is therefore important to choose spectral variables that are sensitive to the canopy removal of interest but that are relatively insensitive to site-specific factors.

Prior studies have emphasized the importance of SWIR in differentiating partial canopy removal. Olsson (1994) found that bands 5 and 7 were the most effective Landsat bands for predicting basal area removal. Spectral composite indices featuring SWIR have also been used effectively to detect partial forest removals. Tasseled Cap wetness (TCW) (Crist and Cicone, 1984), which emphasizes SWIR reflectance, has been identified as a reliable indicator of both forest structure and forest structure change (Cohen et al., 1995; Collins and Woodcock, 1996; Franklin et al., 2000; Skakun et al., 2003). Jin and Sader

(2005) found that NDMI, which contrasts SWIR and NIR reflectance, to be at least as accurate as TCW in detecting disturbance intensity in Maine. In the present project, these and other Landsat-derived spectral variables were compared according to their relationship with four forest inventory variables: basal area, percent cover, relative basal area removal, and percent cover change. Only single-variable models were considered because of strong multicollinearity between most of the spectral indices with respect to the variables predicted.

Independent of the spectral variable selection process, cross-validation was used to assess the relative error rates of the SDM and DCM change detection approaches. The relative change in basal area and percent cover was predicted for each plot using both SMD and DCM using information from all other plots as training data. So that cross-validation results would be directly comparable, plots that did not have the multi-temporal reference measurements needed for DCM were dropped from both approaches. Since cross-validation used only a portion of the dataset, this cross-validation procedure was used only to compare SMD and DCM, not to compare spectral variables. Together, it was hoped that the variable selection and cross-validation processes would lead to insight both into the basic effect of partial harvest in the region on surface reflectance and into the ability of two change detection approaches to quantify the effects of those harvests.

3.0 Methods

3.1 Study Area

The boundaries of the study area were chosen to include several designated Spotted Owl Special Emphasis Areas (Figure 1). Forests in this region are coniferous, dominated primarily by Douglas-fir (*Pseudotsuga me*nziesii) and ponderosa pine (*Pinus ponderosa*), with ponderosa pine being replaced by western hemlock (*Tsuga* heterophylla) in the western part of the southern study area and by grand fir (*Abies grandis*) in the upper elevations. Elevations range from 500 m above sea level near the Columbia River to approximately 2800 m near the crest of the Cascade Mountains. Topography influences the amount of rainfall in the area, with average precipitation ranging from 600 to 3000 mm/year across the two areas (Spatial Climate Analysis Service, 2005). The northern study area is centered at 47.3° N / 120.9° W, and the southern area is centered at 45.9° N / 121.5° W.

Forest cover in the area ranges from relatively open to complete closed, with canopy structure ranging from relatively uniform monoculture plantations to mature older forests with highly complex canopy structures. The area has a long history of timber management, and numerous permits for both even- and uneven-aged harvests were granted for each 2-year interval in the 1996-2004 study period (*Forest Practice and Review System (FPARS),* Washington Dept. of Natural Resources, 2004). Although the area is located in a region where stand-replacing fires are common, a Landsat-based map of stand-replacing disturbances (created following Cohen et al., 2002) showed no such fires in the area from 1996-2004. Aerial sketch mapping of insect activity (WDNR, 2003) showed a few areas of mortality in the study area between 1996 and 2003.

However, the density of attacked trees was quite low (typically fewer than 10 trees/hectare) in our study area, and insect activity was therefore not explicitly considered in the modeling process.

3.2 Reference Data

Three types of reference data were used to train and then cross-validate the spectral models for partial harvest: a harvest permit database, field plots, and historical aerial photos. This permit database was compiled by WDNR and was used to identify likely sites of harvest activity between the years 1996 and 2004. Two field crews were dispatched in the summer of 2004 to sites on accessible land in the study area where harvest permits had been granted in the previous eight years. Land was deemed accessible if it was under state, federal or municipal ownership or if it belonged to cooperating private companies. Recent Landsat images for target stands were visually inspected, and plots were sited in areas within the stand that displayed relatively uniform spectral change. Five plots were also sited in accessible stands where harvest permits had been granted but where no activity was visible from the imagery. Each one-hectare plot was composed of nine fixed-radius subplots (Figure 2). The radius for the subplots in a given plot was fixed at 5, 10, or 12.5 meters, depending on the density of the stand: smaller subplots were used in plots that had more live trees and stumps.

A number of inventory measurements were recorded at each subplot, including: the diameter at breast height (DBH), species, and canopy class of all trees with DBH greater than 10 cm. The diameter of all stumps at a height of 14 cm was also recorded. Further, the height and basal diameter (diameter measured at a height of 14 cm) was recorded for a representative tree for each canopy class (dominant, co-dominant, intermediate, suppressed) found in the subplot. The ratio of basal diameter to DBH for all such trees (Figure 3) was later used to estimate the DBH and basal area of the trees removed from the stand. The percentage basal area removed from a plot was calculated as the basal area of the stumps divided by basal area of the combined stumps and live trees in the plot. No attempt was made to back-calculate the basal area of live trees at the time of harvest, which may have occurred up to 8 years prior to the stand survey.

Eighty-four plots were established in which live tree basal area information was recorded. For 40 of these plots, basal area change was not calculated because local harvest records indicated that multiple partial harvests had occurred in the last 20 years and that not all of the stumps could be attributed to the time period of interest.

Percent canopy cover was estimated for most plots in both 1998 and 2002 using 1:15,000 nominal scale black and white aerial photographs (1998) and 1-meter orthophotos (2002). Photo coverage was available for only 83 and 77 plots in 1998 and 2002, respectively. Estimates were made using a percent tree cover key that exhibited a variety of different clumping arrangements for each of 10 (10% cover) classes from 5% to 95% canopy cover. The value for a given plot for a given year was determined as the average among three photointerpreters who estimated percent cover in 5% increments using the key as a guide. The canopy cover change between 1998 and 2002 was calculated as the difference between the cover estimates between the two dates.

To summarize, current basal area was measured at each plot, basal area removal was measured in plots where existing stumps could confidently be attributed to harvests in the study period, and photo-based percent cover estimates were made at two dates in cases where supporting photography was available.

3.3 Spectral Data

Five late-summer Landsat TM and/or ETM+ images in two-year intervals were acquired for both the north and the south study areas (Table 1). Biennial or annual image acquisition has been recommended to combat the potentially ambiguous effects of forest re-growth following harvest (Jin and Sader, 2005). For each study area, the 1996 image was chosen as a geospatial reference, and all other images were co-registerd to that image using the automated approach developed by Kennedy and Cohen (2003). All the images were resampled to 25 m resolution during this process, using the UTM projection and WGS84 datum. The 1998 path 45 / row 27 scene was used as the reference for radiometric calibration. For this, the COST atmospheric correction model of Chavez (1996) was applied to that image to convert digital counts to reflectance. Then, the other four images from row 27 were relatively normalized to it using the multivariate alteration detection (MAD) method of Canty et al. (2004), adapted by Schroeder et al. (in review). The 1998 row 48 image was then normalized to the row 27 reference image using the image overlap area and the remaining four images of row 28 were subsequently normalized to the row 28 1998 image.

In addition to the Landsat reflectance bands (1-5, 7), several other Landsat derived indices were computed. Tasseled Cap brightness (TCB), greenness (TCG), and wetness (TCW) images were created using coefficients published by Crist (1985). Also derived were Disturbance Index (DI) images, which have been used to detect stand replacing disturbances (Healey et al, in press; Masek, 2005). In this transformation, Tasseled Cap components are first re-scaled to standard deviations above or below a forest mean condition, and are then linearly combined in a way that approximates their spectral similarity to clearcuts (which are assumed to have high brightness, and low greenness and wetness). This combination (eq. 2),

$$DI = \text{brightness}_{\text{re-scaled}} - (\text{greenness}_{\text{re-scaled}} + \text{wetness}_{\text{re-scaled}}), \qquad (1)$$

typically produces high positive values in highly-disturbed areas and values near zero in most other forested areas. The DI has not been tested in partial harvest situations.

The normalized difference vegetation index (NDVI), a measure of the ratio of NIR to red reflectance, was also calculated (eq. 2) for each image, using:

$$NDVI = (NIR - red) / (NIR + red) \qquad (2).$$

Further, the normalized difference moisture index (NDMI), was also calculated (eq. 3). This index takes advantage of the canopy structure information in one of the SWIR channels (band 5; Jin and Sader, 2005) using the equation:

NDMI = (NIR – SWIR) / (NIR + SWIR) (3).

For each plot center, a 16-pixel (1-hectare) neighborhood (see Figure 2) of pixel values was extracted from each of the spectral bands and indices. The average spectral value in this neighborhood was the spectral signature associated with each plot for a given time and band. In some cases, pixels were removed from this averaging operation because they contained unanticipated heterogeneity (new roads, clouds). Since plots were the modeling unit in this project, it was desirable to use plots that were as structurally and spectrally homogenous as possible. Subplots were removed from the database if they overlapped with any of the removed pixels.

<u>3.4 Modeling the relationship between spectral and forest inventory variables</u>

In this project, SMD and DCM were used to estimate the partial harvest intensity in terms of reductions in forest canopy cover and basal area. Accordingly, there were four regression-based modeling efforts: creation of date-invariant models of cover and basal area for SMD, and models of basal area and cover change for DCM. Regression analysis has been a popular empirical method of modeling the relationship between spectral data and forest attributes (e.g. Butera 1986, Turner et al. 1999). However, traditional (i.e. ordinary least squares, OLS) methods of regression are not sufficient when resulting biophysical surfaces derived from remote sensing are subsequently used to drive ecosystem process models or characterize habitat. This is because with OLS regression, the variance of the predictions is commonly compressed relative to the variance of the observations (Curran and Hay, 1986, Cohen et al. 2003). The degree of compression is a function of the correlation between the spectral data and the biophysical variable of interest; low correlation, much compression, and vice versa. In this study, the orthogonal RMA (reduced major axis) regression method was used. Cohen et al. (in press) recently demonstrated the value of RMA relative to OLS regression to predict tree cover and leaf area index across a number of sites in the western hemisphere.

Preliminary bivariate-plots showing the relationships between all possible 2-way combinations of spectral values for the inventory plots suggested strong multicollinearity among the spectral measures under investigation. Further, forward step-wise regression suggested that a second spectral variable rarely made a significant contribution in explaining the variance in the forest inventory data. For simplicity's sake, therefore, only models using a single spectral term were further considered. In the variable-selection process, spectral bands were assessed in their relationship to the inventory data using their respective coefficients of determination (r^2). This process is outlined below for the four primary inventory variables (basal area, cover, basal area change, cover change).

For the SMD approach, the static relationship between basal area and the spectral variables was determined using basal area measured in 2004 and the mean spectral value of those plots (up to 16 pixels). The static relationship between percent cover and spectral data was derived from the percent cover estimates obtained from 1998 1:15,000 nominal scale black and white aerial photographs and corresponding 1998 images. In both cases, some plots had to be discarded either because disturbances occurred between the date of the reference information and the date of the imagery or because of heterogeneous conditions within the plot that prevented unambiguous interpretation of the mean spectral value. This left 71 plots for basal modeling and 76 plots for cover modeling.

For the DCM models, relationships between spectral changes and changes in the inventory variables were assessed using reference data from two or more dates in concert with contemporaneous spectral differences. Cover change was assessed at 54 plots by combining the 1998 photo data with a similar interpretation of 2002-era color orthophotos. Linear models using the absolute difference in cover between these two dates (Cover98 – Cover02) were consistently weaker than models using relative cover change ((Cover98 – Cover02) / Cover98). Accordingly, cover change throughout this paper is expressed in terms relative to the original percent cover. Basal area change was likewise better captured in relative terms ((Basal Area $_{\text{pre-removal}}$ – Basal Area $_{\text{post-removal}}$) / Basal Area $_{\text{pre-removal}}$); thus, removals of basal area (as measured with stump data) were expressed as percentage decreases relative to the starting amount. The spectral change associated with each harvest operation was calculated by taking the difference of the dates immediately preceding and following harvest. Harvest dates were determined in consideration of the harvest database and through visual interpretation of the time series of Tasseled Cap images for each plot.

No plots in our dataset displayed relative basal area removal of 60-80 percent. A similar phenomenon was found in the dataset of Olsson (1994), and it is possible that removals of this magnitude are uncommon in our study area. It also appeared that although the relationship between spectral change and basal area change was linear (with logarithmic transformation) for all spectral variables up to 60% removal, different relationships occurred above 80% removal. Thus, it was decided to limit this model to values between 0 and 60% removal; only plots in that range (a total of 42) were used to create the basal area DCM model, and only that range of prediction was considered in the variable selection process.

The strength of the linear or log-linear RMA relationship between each of the spectral bands was assessed for each inventory variable (basal area, basal area change, percent cover, percent cover change). Comparison of the r^2 values of each of these relationships was the basis for evaluating the general potential of each spectral band or index for supporting prediction of harvest intensity.

3.5 Cross-Validation

The above variable-selection process did not address the larger question of how well SMD and DCM predict relative basal area and cover removal. This question was the focus of a leave-one-out cross validation analysis. For each plot, comparable DCM and

SMD estimates of relative basal area and cover change were developed with data from all other plots. Estimates were then compared plot-wise with change information from re-measured reference data and the root mean square error (RMSE) for each approach was calculated. So that SMD and DCM would be directly comparable, the absolute estimates resulting from DCM were transformed to relative terms to match the output of DCM, and only those plots with reference information supporting both SMD and DCM were used.

In the leave-one-out process, both SMD and SCM were used to predict the measured cover change between 1998 and 2002, and the basal area of the stumps measured in 2004 and attributed to harvest in one of four 2-year intervals (1996-1998, 1998-2000, 2000-2002, and 2002-2004). Forty-two plots were available to support this cross-validation procedure for basal area, and 54 plots were available for cover. Cross-validation was repeated using each of the spectral variables under study (bands 1-5, 7, TCB, TCG, TCW, DI, NDVI, and NDMI).

3.6 Using SMD to map owl habitat loss

Harvest mapping methods investigated here were intended to be integrated into a larger analysis carried out by WDFW and WDNR of how harvests have affected Spotted Owl habitat in the last several years (Pierce et. al 2005). WDFW and WDNR used SMD estimates of cover loss to identify harvests resulting in the loss of owl habitat. A description of this process is included here to illustrate a practical application of the methods under investigation. While it is out of the scope of this paper to detail how WDFW and WDNR defined and identified owl habitat in the region, the use of SMD cover change estimates to update habitat maps followed relatively simple rules. If previously mapped owl habitat dropped either from above 70% canopy cover to below 70% cover, or from above 50-70% to below 50% cover, it was assumed that the structural elements needed to support owl populations had been removed. SMD was used to identify harvests because of the need for absolute estimates of both pre- and post-harvest cover. A "state" model for percent cover was developed with photo-based estimates of 1998 cover in conjunction with 1998 TCW values. This model was then applied to each Landsat scene, and estimated cover values from successive dates were compared to identify areas in which cover was estimated to drop below the 70 and 50% thresholds. A masking step was devised to minimize spurious identification of such pixels. Each Tasseled Cap-transformed image pair was submitted to an independent supervised classification to differentiate "changed" from "unchanged" pixels. Only pixels identified as "changed" in this classification were permitted to be labeled as harvest by SMD.

Errors in this map product were assessed by comparing photo-interpreted cover values of field plots from 1998 and 2002 with state model estimates of cover for the same dates. For 10 plots disturbed between 1996 and 1998, it was possible to use earlier 1993 1-meter color orthophotos to determine "pre-harvest" cover conditions. Plots thinned after the latest (2002) photo mission, as well as plots in which no harvest occurred, were estimated for the 1998-2002 interval. In all, there were 74 plots for which repeated photos were available. At these locations, it was possible to assess how accurately the state models had identified stands that had crossed the habitat-critical 50% and 70% cover thresholds for the re-measured 1998 (or 1996) to 2002 period.

4.0 Results

4.1 Spectral variable selection

The coefficients of determination (r^2) for the relationships between the 12 spectral variables under consideration and the inventory variables forming the basis for SMD (basal area and percent cover) and DCM (relative basal area and cover removal) are shown in Table 2. Coefficients were not comparable among inventory variables because a different number of observations was available for each. Furthermore, relative basal area removal was only predicted in a range of 0 to 60%. Nevertheless, coefficients were comparable within each forest inventory measure, and certain general trends were apparent. First, spectral variables dominated by SWIR (band 5, band 7, wetness, and, to a lesser extent, NDMI) showed the closest relationship to all forest and forest change variables. DI may be put into this category because further exploration showed that DI was highly correlated with wetness in this dataset. In general, the two untransformed SWIR bands (5 and 7) were equally effective in predicting cover and basal area change as their derivative indices. The weakest relationships with the forest change variables were shown by band 1, band 4, and TCG. The dataset also showed an apparently negative effect of NIR (band 4) in the indices into which it is integrated. For example, NDMI is a ratio of bands 4 and 5, and while it was more correlated to the forest and forest change variables than band 4, it was less correlated, in all variables except basal area change, than band 5 alone. The same presumed negative effect of band 4 was observed in NDVI, a combination of bands 3 and 4. Likewise, TCG, in which band 4 is strongly weighted, displayed only weak relationships with the forest structure variables. In general variable selection highlighted the importance of SWIR, as the indices strongly influenced by SWIR – i.e. wetness, DI, band 7 and band 5 – had the most explanatory power for the forest change variables.

4.2 Cross-validation

While the variable selection phase of the project considered simple relationships between spectral and the forest inventory measures, the cross-validation integrated these relationships into estimates of forest removal based upon the SMD and DCM approaches. DCM produced lower root mean square error (RMSE) for prediction of both percent cover loss and percent basal area reduction (Figure 4). However, SMD-based estimates using the most effective spectral variables (TCW, DI, band 5, band 7, and NDMI) were only approximately 5% lower for basal area loss and 10% lower for cover change, relative to DCM models.

An extremely high error rate was noted for bands 1 and 2 in cross-validation for basal area SMD. This likely occurred as the errors involved with two applications of a weak model were compounded through their combination to produce a change estimate. The fact that this phenomenon was not seen with other variables such as band 4 and TCG, which according to the variable selection results were also weakly correlated with basal area, was possibly a factor of sample size. As plots were dropped from the original dataset to enable direct comparison of cross-validation results, the impact of spectral outliers increased either by their retention or exclusion. Thus, because this cross-validation generally incorporated fewer samples and was designed only to compare the relative error rates between SMD and DCM, it was considered a less appropriate means of comparing spectral variables than the variable-selection process. Nevertheless, the overall trend of SWIR-dominated indices producing better estimates of change that was noted in the variable selection procedure was also apparent in cross-validation.

4.3 SMD-based maps to support study in owl habitat change

Modified SMD maps depicting harvests reducing cover from above 70% to below 70% and from 50-70% to below 50% were used by WDFW and WDNR to analyze trends in owl habitat. While discussion of this analysis is not within the scope of this paper, an example of one of the cover change maps used is shown in Figure 5. These maps depicted, for each 2-year interval, areas identified as unchanged by an independent supervised classification (light grey), areas that were estimated to have greater than the 50% cover in the first date but less in the second (black), and areas where classification indicated that harvests did occur but where cover was not estimated to move from above 50% to below. An error matrix was constructed (Table 3) for the two classes, those areas that did and those that did not cause undergo changes in percent cover that were consistent with the loss of Spotted Owl habitat, that resulted from the SMD process. Fifty-six out of 74 re-measured plots (76%) were correctly placed into these classes using SMD.

5.0 Discussion

5.1 Which spectral variable are the most sensitive to forest structure changes associated with partial harvest?

The general spectral response to forest removal has been relatively consistent across several studies: visible and SWIR reflectance increases and NIR reflectance decreases (Franklin, 2001). However, few studies have assembled datasets designed to support the modeling of forest harvest effects as a continuous variable. Thus, there is little information on how consistently and with what order of detail these general spectral trends can be used to estimate degrees of harvest intensity. In this context, our results provide information about which Landsat-based variables are most sensitive to forest structure changes that accompany partial harvests in the Pacific Northwest.

The relative performances of the spectral bands considered in the variable selection phase of this study have two broad implications. First, SWIR, as represented by bands 5 and 7, TCW, DI, and potentially NDMI, is the most useful range of the Landsat spectrum for characterization of forest structure change. This corroborates results obtained both in studies classifying tree mortality/removal data into general levels of intensity (Franklin et al., 2000; Skakun et al., 2003; Jin and Sader, 2005) and in those measuring forest change as continuous variables (Olsson, 1994; Collins and Woodcock, 1996). The relative value of the various data transformations in predicting harvest intensity varied slightly among inventory variables, and would likely vary further in different forest systems and with different harvest practices. However, it would seem that for harvest characterization in our study area, the benefits of processing data beyond the original Landsat SWIR bands are minimal. For projects involving large areas and multiple dates, this may offer a considerable reduction in processing time. The value of indices relative to SWIR bands alone should be tested in the future for consistency in other regions. .

The second implication of our results is that the relationship between NIR and forest structure change is relatively inconsistent. TCG, in which NIR is heavily weighted, and band 4 were both weakly correlated with the forest structure variables in the variable selection exercise, and NDVI and NDMI, which incorporate NIR in ratios with red and SWIR respectively, also produced relatively poorer results. The apparently inconsistent relationship between NIR and harvest effects underscores findings of other studies that suggest the general relationship between forest condition and NIR can be compromised by factors like understory conditions (Danson and Curran, 1993), slash patterns (Nilson et al., 2001), and species differences (Olsson, 1994). Thus, whereas SWIR bands show relatively strong and consistent relationships with measures of forest removal, the relationship between our ground data and the NIR bands was more tenuous.

5.2 Approaches to modeling harvest intensity

The primary objective of this study was to test two change estimation approaches, DCM and SMD, in their ability to measure partial harvest with multi-temporal Landsat data. The leave-one-out cross-validation process was developed to assess and compare errors involved with predictions produced through these two approaches. In our study area, DCM and SMD both produced estimates of relative forest change with reasonably low RMSE when using SWIR-based spectral bands and indices. The RMSE of DCM estimates was approximately 5% lower than those from SMD for basal area change and 10% lower for cover change. The lower error rates associated with DCM were expected because relative change was modeled as a single variable with a single error term instead of the difference of two independently modeled “state” estimates, each with their own error term.

However, there are a number of practical advantages to SMD that, depending on the resources and needs of a project, may counterbalance the measured increase in error. First, SMD has simpler reference data needs than DCM since it is concerned only with identifying the static relationship between spectral data and forest condition. As long as cross-date radiometric normalization is reliable, one can pull reference data from any date, match it to contemporaneous spectral data, and use it to build a state model. That state model can then be applied to appropriate imagery for the dates of interest. This flexibility, along with the elimination of the need to re-measure each plot, represents a significant operational advantage. Furthermore, unlike in DCM, SMD does not require pre-selection of disturbed areas for determining plot locations. Such areas may be rare, which may limit the number of available plot locations, and their identification may add considerable pre-processing time. For validation, multi-date reference data are still needed, but this requires a considerably lower volume of such data.

Another advantage involves the specificity of SMD results. Theoretically, DCM can provide an estimate of absolute change by focusing on absolute changes in stand condition with spectral changes. However, in our dataset, the relationship between spectral data and absolute change was inconsistent because of the lack of a reference point; for example, a reduction from 90% cover to 65% cover resulted in a much different spectral change than from 25% to 0% cover. So in our study, DCM could only accurately be modeled in terms of relative change (change as a percent of the starting value). Because SMD provides an estimate of forest condition for both before and after a harvest, harvest effects are estimated in absolute terms.

Moreover, SMD provides definite reference points for estimates of change, whereas DCM does not. This latter advantage of SMD was critical in the mapping of our study area to meet WDFW's needs. The mere application of either SMD or DCM to a series of normalized Landsat imagery does not necessarily constitute a map. These approaches, rather, provide raw estimates to be used in a map in light of the needs and tolerances of the user. WDFW was concerned primarily about identifying harvests that removed stands from pre-defined, cover-based definitions of owl habitat. The need for specific cover estimates for both before and after harvest necessitated the use of SMD. Flexibility to conform to varying classes of interest is one of the strengths of modeling changes as a continuous variable as opposed to committing to a single classification scheme. Although both the DCM and SMD processes may produce continuous estimates of change, the flexibility of SMD is augmented by the reference points implicit in its estimates.

Our results suggested that in the conifer-dominated forests of the Pacific Northwest, relatively strong relationships exist between SWIR-dominated spectral bands and measures of harvest intensity. Further, both DCM and SMD can be used with these bands to produce estimates of relative basal area and cover removal with less than 25% RMSE. Although DCM estimates of harvest intensity were more accurate than SMD estimates, the SMD's more flexible reference data requirements and model output may be better suited to the resources and needs of some mapping projects.

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Table 1. Landsat images used in this study.

Landsat Scene (WRS2)	Acquisition Date	Landsat Sensor
Path 45, Row 27	Aug. 14, 1996	5
Path 45, Row 27	Aug. 4, 1998	5
Path 45, Row 27	Aug. 9, 2000	5
Path 45, Row 27	Jul. 22, 2002	7
Path 45, Row 27	Sep. 21, 2004	5
Path 45, Row 28	Aug. 14, 1996	5
Path 45, Row 28	Aug. 4, 1998	5
Path 45, Row 28	Aug. 9, 2000	5
Path 45, Row 28	Sep. 24, 2002	7
Path 45, Row 28	Aug. 20, 2004	5

Table 2. Variable selection results. Values represent the coefficient of determination (r^2) for simple linear or log-linear relationships between reference data and contemporaneous spectral data. These relationships form the basis for both SMD (the Basal Area and Cover variables) DCM (Relative Cover Change and Relative Basal Area Removal) change estimation approaches. The number of observations (N) for each relationship was dependent upon the availability of reference data. Since variable selection was conducted within, not across, change detection approaches, there was no need for equivalent sample sizes. Subsequent cross-validation analyses, which did involve comparisons across approaches, used equal sample sizes.

	Basal Area, 2004 N=71	Cover, 1998 N=76	Relative Cover Change, 1998-2002 N=54	Relative Basal Area Removal, Variable Dates N=42
TM1	0.055	0.476	0.185	0.086
TM2	0.315	0.662	0.447	0.313
TM3	0.388	0.736	0.357	0.502
TM4	0.071	0.064	0.209	0.057
TM5	0.548	0.745	0.636	0.618
TM7	0.566	0.759	0.647	0.601
TCB	0.367	0.264	0.551	0.317
TCG	0.000	0.226	0.044	0.288
TCW	0.579	0.762	0.635	0.630
DI	0.555	0.761	0.636	0.645
NDVI	0.221	0.632	0.204	0.475
NDMI	0.434	0.695	0.492	0.641

Table 3. Error matrix for classes of interest to WDFW and WDNR. Significant harvest was defined as overstory removal resulting in cover conditions below state forest practices criteria for Spotted Owl habitat. Observed values came from repeated photo measurements for 74 plots, and estimated values were derived from SMD using contemporaneous imagery.

	Modeled Prediction		
Verified Condition	No Significant Harvest	Significant Harvest	Total
No significant harvest detected	36	7	43
Significant harvest detected	11	20	31
Total	47	27	74

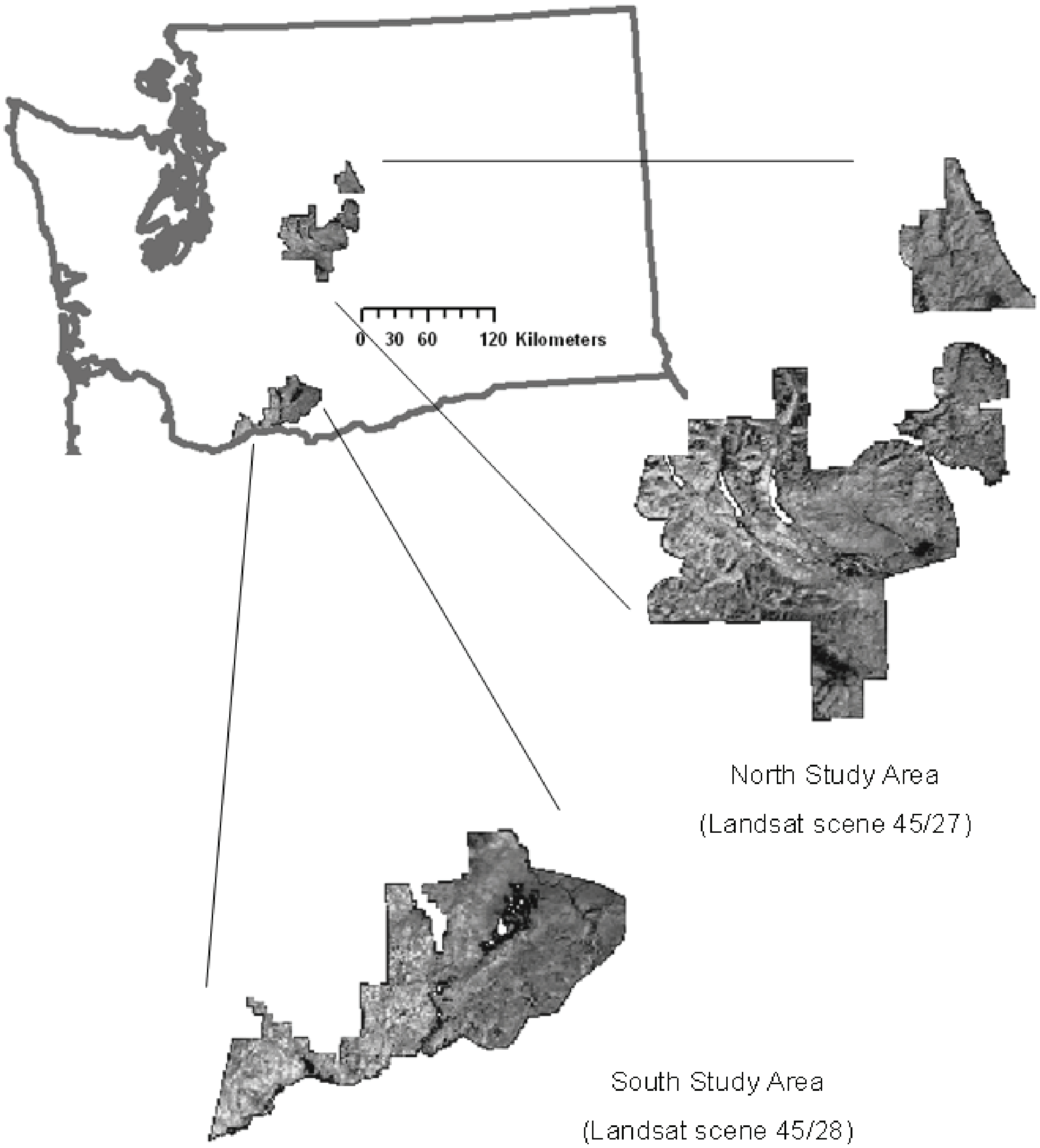


Figure 1. Location of study areas in western Washington, USA. The Tasseled Cap brightness of the study areas is displayed.

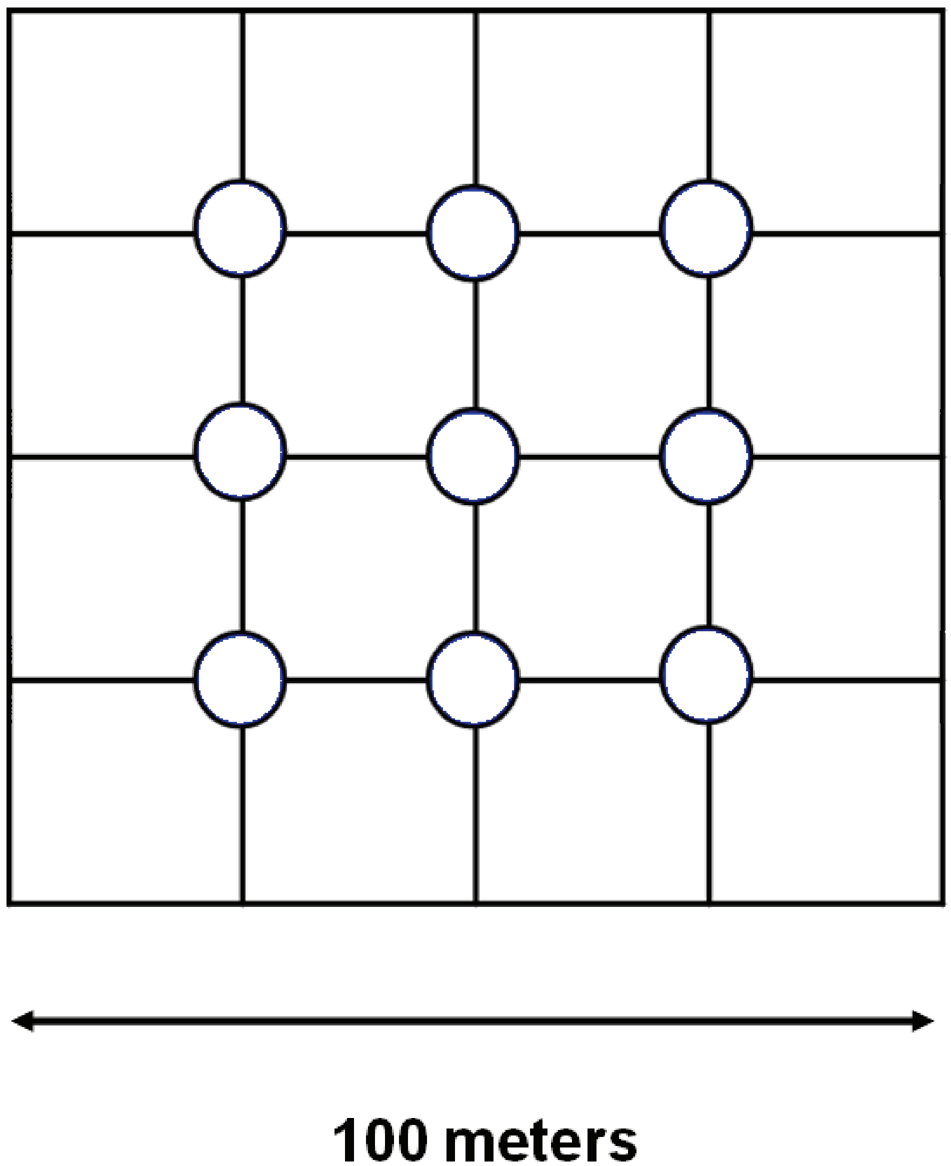


Figure 2. Field plot layout, showing the location of subplots and scale of re-sampled 25-meter Landsat pixels within each 1-ha plot. The radius of each sub-plot was fixed for each plot at 5, 10, or 12.5 meters, depending on the density of the measured stand.

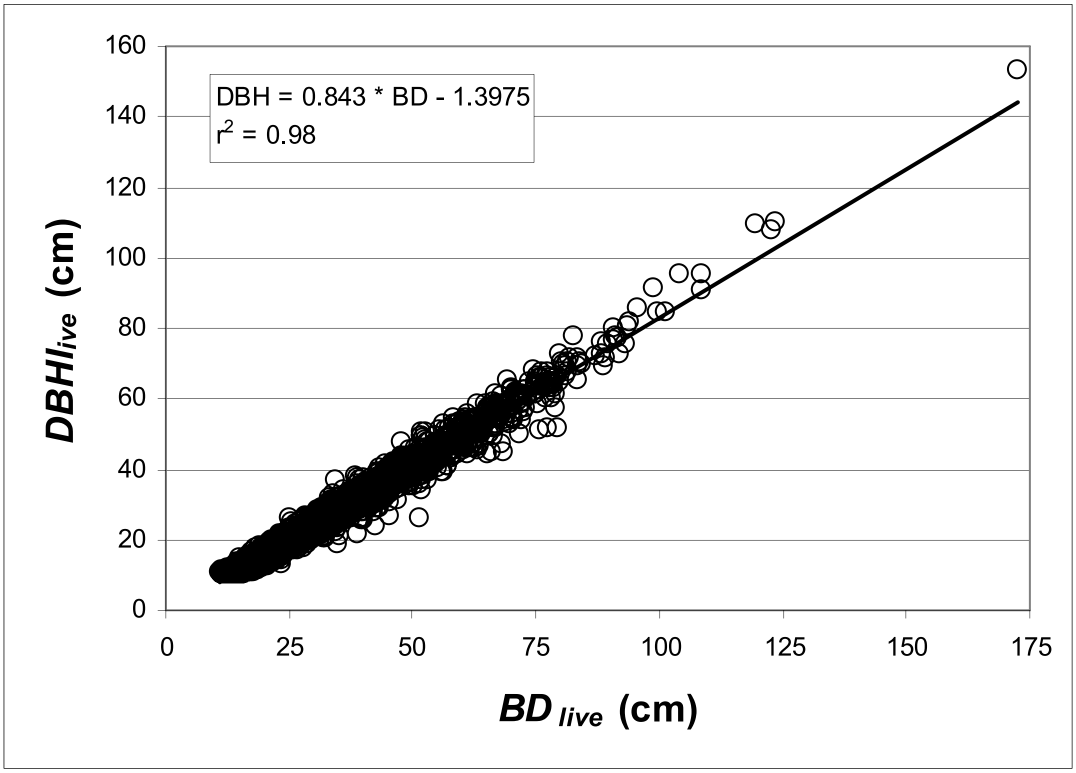


Figure 3. The relationship between basal diameter (BD) at 14 cm height and diameter at breast height (DBH) for all live trees in which basal diameter was measured (N=1983). This relationship was used to estimate the DBH and basal area of harvested trees from stump diameter measurements.

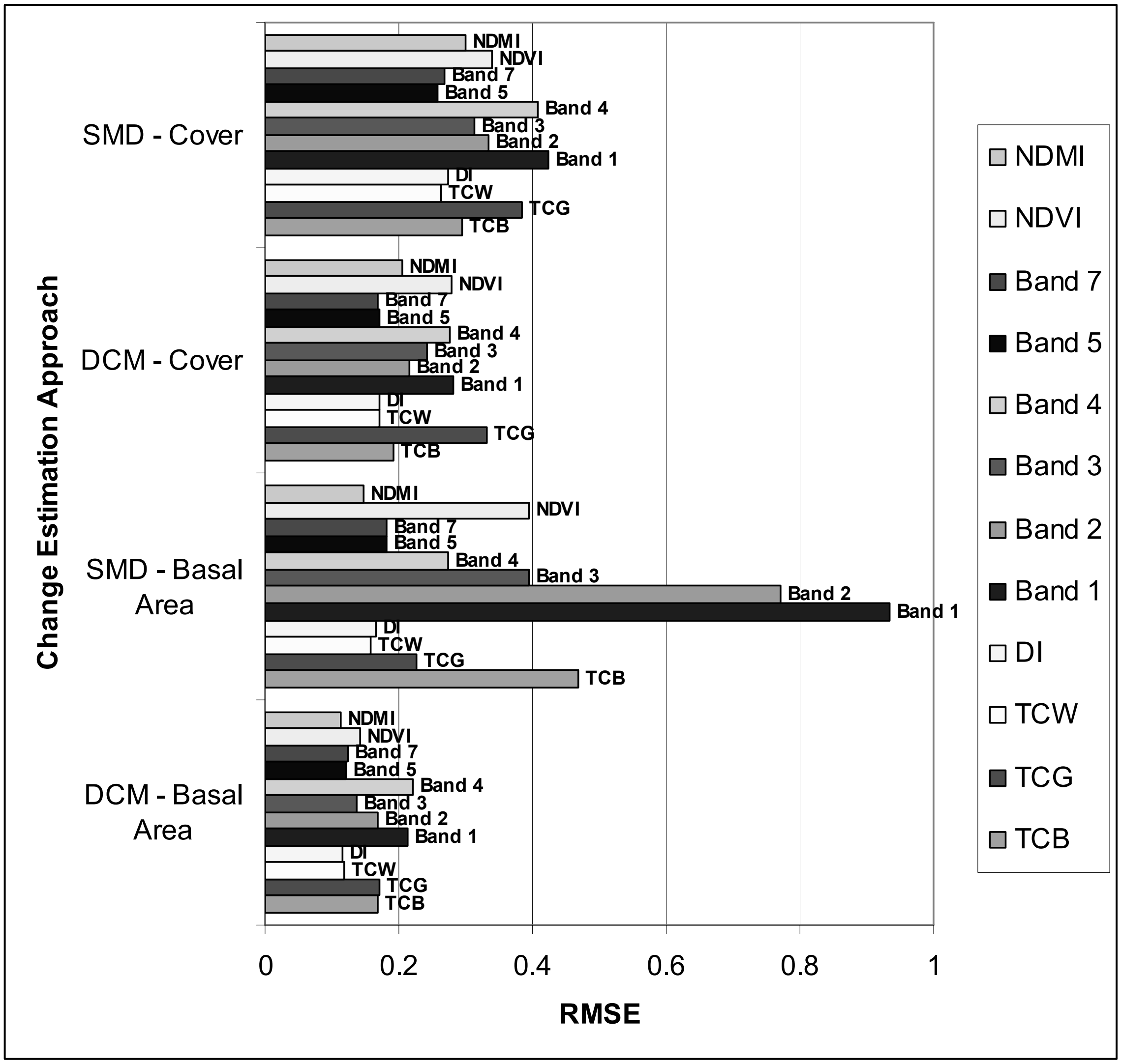


Figure 4. Root mean squared error (RMSE) for leave-one-out predictions of relative basal area and percent cover change using DCM and SMD. SWIR-influenced spectral variables (Bands 5 and 7, TCW, DI, NDMI) produced more stable estimates of change than those not featuring SWIR (Bands 1-4, TCB, TCG, NDVI). DCM estimates using SWIR-based variables produced estimates having approximately 5% lower RMSE than SMD estimates for basal area removal (using 42 plots) and 10% lower for cover change (54 plots).

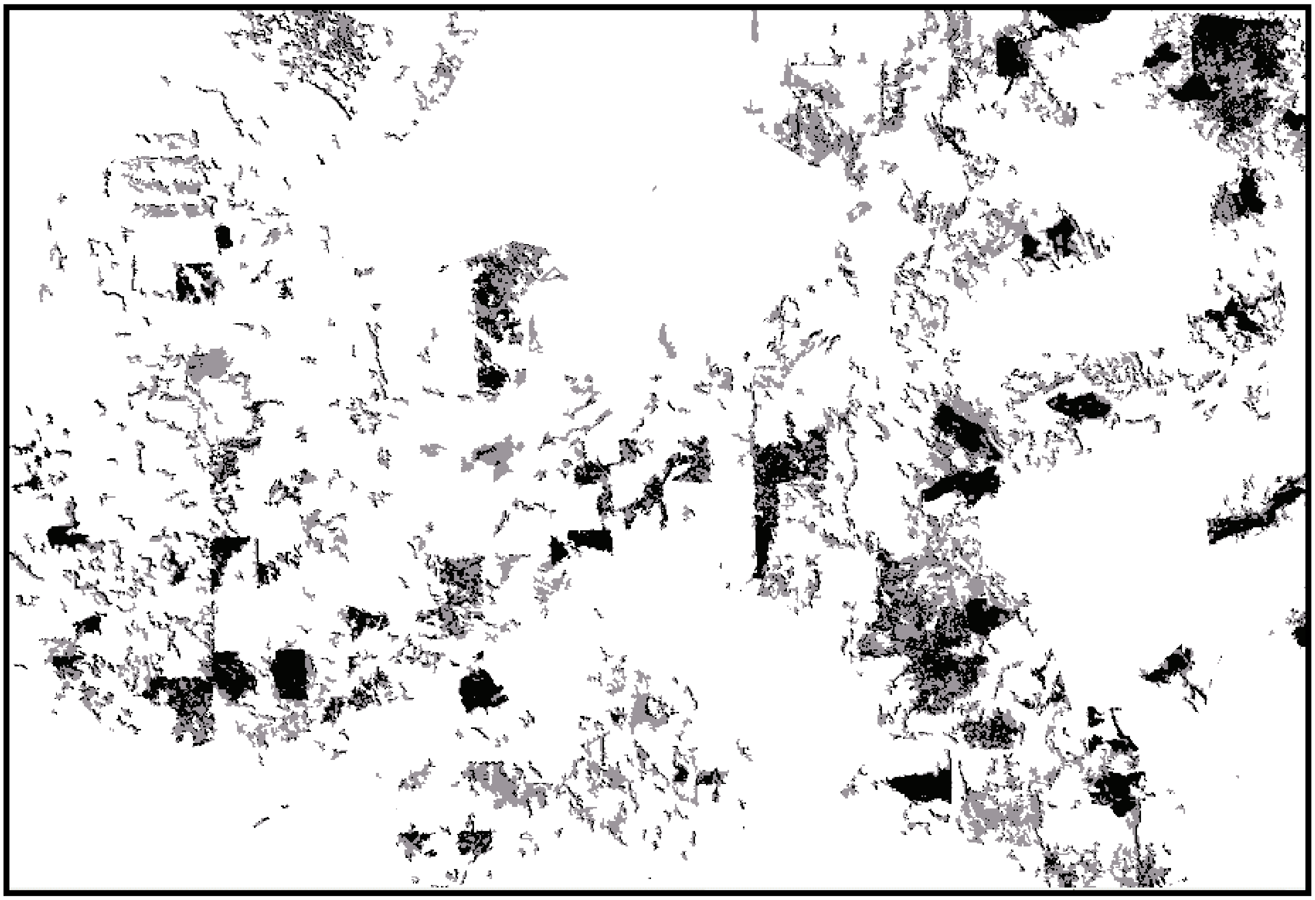


Figure 5. Detail of a map of harvest impacts on owl habitat between 1998 and 2000 in the southern focus area. Areas in white were classified as “no change” in a preliminary multi-temporal supervised classification. Of areas identified as “changed,” classes for habitat loss (black) and no habitat loss (grey) were created by binning SMD results to match Washington forest practices criteria.

Appendix F. Identifying Potential Northern Spotted Owl Habitat Using Washington State Department of Natural Resources Forest Inventory Data

The Washington State Department of Natural Resources (DNR) has mapped land cover across the state for DNR Trust Lands. The data maps relatively homogeneous areas of vegetation or similarly variable vegetation and non-forest conditions into polygons with an average size of about 50 acres. Field sampling has been completed over a period of many years and has resulted in about two-thirds of these areas having had field sampling completed and processed into stand level information. In order to have the inventory data reflect current stand conditions, the data are periodically updated to reflect completed timber harvest and pre-commercial thinning activities, and grown to the current date using Forest Vegetation Simulator (FVS). While all Forest Inventory Units (FIUs) have descriptive stand summary information, some FIUs have not been grown and are reported as observed.

The FIUs exist as geographic information system (GIS) data and is associated with two related tables that provide detailed information about each FIU. The primary FIU table contains the stand level attributes described above. The FIU tree data table contains information about each FIU by species and each 1" diameter class. Only field sampled FIUs have data in this table. Records in this table have been updated to reflect completed Timber Harvest and PCT activities, and grown to the current date using FVS.

The FIU stand level and tree data attributes can be evaluated in terms of meeting requirements for northern spotted owl habitat as defined in Washington Administrative Code (WAC) Chapter 222-16. The code defines suitable spotted owl habitat as forest stands which meet the description of old forest habitat, sub-mature habitat or young forest marginal habitat. These three habitats are characterized by tree size and density, canopy structure, the presence of abiotic elements such as dead standing and down woody material, and biotic elements such as mistletoe and shrubs. Tables 2-4 provide a description of the WAC habitat parameters with notes about the FRIS data used to identify corresponding habitat elements.

The FRIS polygons were imported into an ESRI Personal Geodatabase as a single polygon feature class. An ESRI Personal Geodatabase is maintained in a Microsoft Access database. In Access, the FIU Main table was joined to the feature class table and additional fields added to represent habitat elements described in the WAC and to support other habitat attribution. Many of these fields were formatted as a simple binary data type and used to flag records meeting the habitat element described by the field. Other fields represent descriptive data to summarize combinations of the binary fields and relate to the codified habitat descriptions.

Data Analysis Methods

The DNR has compiled GIS data to represent a dividing line between eastern and western Washington, which generally follows the Cascade Mountains crest. This GIS layer was used to attribute the geographic position of each FIU relative to this dividing line. WAC 222-16 differentiates between habitat in eastern and western Washington and this GIS processing provided the basis for that attribute.

Old forest habitat means habitat that provides for all the characteristics needed by Northern Spotted Owls for nesting, roosting, foraging, and dispersal, described as stands with:

(i) A canopy closure of 60% or more and a layered, multispecies canopy where 50% or more of the canopy closure is provided by large overstory trees (typically, there should be at least 75 trees greater than 20 inches DBH (diameter breast height) per acre, or at least 35 trees 30 inches DBH or larger per acre); and

(ii) Three or more snags or trees 20 inches DBH or larger and 16 feet or more in height per acre with various deformities such as large cavities, broken tops, dwarf mistletoe infections, and other indications of decadence; and

(iii)More than two fallen trees 20 inches or greater per acre and other woody debris on the ground.

The FRIS data do not directly classify canopy cover for FIUs or vertical canopy layering. However, the Northern Spotted Owl habitats WAC does allow for the use of Relative Density (Curtis 1982) or basal area per acre for canopy cover, both are supported attributes within FRIS. Relative Density (RD) in FRIS is calculated by expanding live, all species sample trees observed on plots taken at sample points in a population (e.g. FIU [Forest Inventory Unit], Timber Sale Unit [TSU], or stand) by aggregating the basal area per acre and trees per acre parameters of each sample tree for live, all tree species 3.5+ inches DBH. RD is calculated by dividing the live basal area per acre by the square root of live QMD (quadratic mean diameter). Since Relative Density is used as an index of stand stocking in silvicultural thinning prescriptions and regeneration harvest determinations, a more accurate representation of the forest canopy is found by limiting the RD calculation to trees larger than 3.5 inches DBH. QMD is calculated by taking the square root of the sum of live basal area (BA), all species divided by the sum of the trees per acre (TPA), which is then divided by 0.005454 (QMD = SQRT{(BA/TPA) / 0.005454 }. For the RD calculation, QMD was calculated by restricting BA and TPA to live trees greater than 3.5 inches diamter.

The Old Forest category in the Northern Spotted Owl habitats WAC does not suggest a RD value or a basal area value to use in lieu of canopy cover, however the stands that met the stocking and diameter requirements for Old Forest exceeded the value expressed for the RD parameter of Sub-Mature habitat (eastside). Sub-Mature habitat for eastside stands requires a RD of 44. Westside stands for Sub-Mature habitat use a BA value of 100. In all cases where stands qualified as Old Forest on the basis of diameter and stocking, they exceeded 100 square feet of BA per acre. Additionally, all Old Forest stands had well over 50% of the BA in trees greater than 20 inches QMD.

The Northern Spotted Owl habitats WAC establishes threshold values for snags for each of the habitats described for both eastern and western Washington. The FIU Tree table was used to build a table expressing the number of dead trees per acre that are greater than or equal to 16 inches DBH and 16 feet in height. This table was used to toggle the snag related binary fields for old forest, sub-mature and young forest marginal habitat where the threshold values are met.

Snag/Cavity Trees Parameters

Old Forest – 3 or more dead trees greater than 20" DBH and 16 feet in height.

Western Washington

Sub-Mature – 3 or more dead trees greater than 20" DBH and 16 feet in height.

Young Forest Marginal – 2 or more dead trees greater than 20" DBH and 16 feet in height.

Eastern Washington

Sub-Mature – 3 or more dead trees greater than 20" DBH and 16 feet in height.

Young Forest Marginal - Closed – N/A

Young Forest Marginal - Open – 2 or more dead trees greater than 20" DBH and 16 feet in height.

Habitat Description

Sub-mature habitat provides all of the characteristics needed by Northern Spotted Owls for roosting, foraging, and dispersal. Young forest marginal habitat provides some of the characteristis needed by Northern Spotted Owls for roosting, foraging, and dispersal. Sub-mature habitat and young forest marginal habitat stands can be characterized based on the forest community, canopy closure, tree density and height, vertical diversity, snags and cavity trees, dead and down wood, and shrubs or mistletoe infection. The FRIS data was used to evaluate each stand for achieving the threshold values for sub-mature and young forest marginal. Eastern and western washington stands where analyzed separately.

Forest Community

Western Washington stands must be composed of conifer dominated or conifer hardwood mixed stands with at least 30% conifer cover. The FIU Tree table was used to determine the percent conifer composition for each stand. Stands in western Washington meeting the 30% threshold where flaged. Live BA for conifer species was divided by total live BA to establish the percent conifer.

Eastern Washington stands must be composed of at least 40% fir (Douglas-fir and true fir). The FIU Tree table was used to determine the percent fir composition for each stand.

Stands in eastern Washington meeting the 40% threshold where flaged. Live BA for fir was divided by total live BA to establish the percent fir.

Structure

Tree density and height, vertical diversity and canopy closure are identified in the Northern Spotted Owl habitats WAC to describe the vertical and horizontal structure of forested areas. The WAC describes stand stocking levels at diameter and height thresholds or canopy layers with dominant and codominant height thresholds to identify sub-mature and young forest marginal habitat. Eastside and westside stands are described differently. The FRIS data do not sumarize canopy layers or canopy position by height and diameter classes.

The WAC does provide an alternative to these values by the following criteria:

Western Washington

- The values for canopy closure and tree density may be replaced with a quadratic mean diameter of greater than 13 inches and a basal area of greater than 100

Eastern Washington

- The values indicated for canopy closure and tree density may be replaced with the following:
  - For sub-mature habitat, a quadratic mean diameter of greater than 13 inches and a relative density of greater than 44;
  - For young forest marginal a quadratic mean diamter of greater than 13 inches and a relative density of greater than 28.

The FRIS data support these attributes in the FIU Main table. Western Washinton stands flagged with at least 30% conifer composition, a QMD greater than 13 inches and a live basal area of greater than 100 square feet per acre were flagged for meeting these criteria. Eastern Washington stands with at least 40% fir composition were flagged separately for the two relative density values where the QMD was greater than 13 inches.

The DNR processes sample plot tree data to attribute the FIU Main table with the mean height of the 40 live trees with the largest DBH values in the FIU. This provides a reasonable value of the average height of dominant and codiminant trees in a stand. The Northern Spotted Owl habitats WAC sets height thresholds for eastern and western Washington stands that are used to differentiate between sub-mature and young forest marginal habitat. Three different height thresholds were evaluated for stands that met the forest community criteria and their geographic location. Three binary fields were used to flag records that met these height criteria.

For eastern Washington, the Northern Spotted Owl habitats WAC differentiates between open and closed young forest marginal habitat. However the stated alternative for using QMD and RD only differentiate between sub-mature and young forest marginal, with no RD differentiation between open and closed stands. The canopy closure threshold value for both sub-mature and young forest marginal closed is 70%, since the RD value for sub-mature is 44, this value was used to identify closed young forest marginal habitat.

Abiotic and Biotic Elements

Western Washington young forest marginal habitat provides for the combination of down woody material and shrub cover as a way to evaluate habitat potential. Eastern Washington uses severity of mistletoe infection together with snags as habitat criteria. FRIS does not summarize percent shrub cover or percent of ground cover occupied by down woody material. Down woody material is summarized as weighted average cubic volume per acre (all decay classes combined and individually); there is no way to relate cubic volume per acre to percent of ground covered with woody material. Mistletoe infection is recorded but there is no severity of infection rating. Shrub cover and down wood were not factored into this analysis since these data were not available. Eastern Washington stands that met all other habitat criteria were classified accordingly (such as young forest marginal open) but were separated into two categories that recognize the presence or absence of mistletoe in the stand according to the stand level attributes.

A similar approach was used for snags. Snags are rarely evenly distributed throughout a stand and may not be adequately represented statistically along with the other stand attributes that the sample design was targeted to collect. Again, stands that met all other criteria except snags were attributed in either of two ways.

After each of the key parameters were attributed in the database, the data was processed to produce the owl habitat attribute codes listed in Table 1.

Table 1 – Owl Habitat Coding Description

Code	Description
0	Not habitat
5	Stands Older than 50 years ('96) - WAC Requirements Not Met
10	Old Forest - (Legacy LULC Age GT 70)
11	Old Forest - (Snag Requirement Met)
20	Sub-mature - Westside (Snag Requirement Met)
21	Sub-mature - Westside (Snag Requirement Not Met)
30	Marginal - Westside (Snag Requirement Met)
40	Sub-mature - Eastside (Snag Requirement Met)
41	Sub-mature - Eastside (Snag Requirement Not Met, W/ Mistletoe)
50	Marginal Closed - Eastside (90' Ht - < 3 Snags-Mistletoe Not Used)
51	Marginal Closed - Eastside (Snags/Mistletoe Not Used)
52	Marginal Open - Eastside (Snag Requirement Met and Mistletoe Used)
53	Marginal Open - Eastside (Snag Requirement Met - No Mistletoe)
54	Marginal Open - Eastside (Snag Req. Not Met - Mistletoe Not Used)

Codes 11 and greater represent the application of the Northern Spotted Owl habitat WAC parameter values using the FRIS data. To assist with informing additional analysis, code 5 was added to identify stands not meeting other criteria but over fifty years in age. Code

10 stands are legacy stands without stand level data to support the application of the Northern Spotted Owl habitat WAC parameter values. The DNR EIS analysis for spotted owl habitat included these legacy stands where the average stand age was greater than seventy years.

1996 to 2003 Growth Adjustment

The FRIS database used for this analysis has been modeled to account for growth and management activities through 2003. Some stands flagged as being habitat using 2003 stand values may not have been habitat in 1996. In order to identify these stands it was necessary to make some generalizations about growth rates. The FIU Main table has a productivity index for most FIUs that was determined by a sample of height and age. The index value is a height age relationship of dominant and co-dominant trees established to predict stand growth. These relationships are derived for silver fir, Douglas-fir, western hemlock, and red alder. The need to develop a reasonably simple approach to identifying the difference in height and diameter growth for stands in 1996 versus the current inventory date of 2003 was recognized and addressed. Where FIU site index was listed for a species other than Douglas-fir it was converted to Douglas-fir site index (base 50) using the Universal Species Library for the Forest Projection System Growth Model library (Arney, J.D. 1999). A weighted average and standard deviation for site index for Douglas-fir Site Index was calculated from the FRIS database for both eastern and western Washington. A weighted average and standard deviation of age was also calculated. The weighted average for both site index and height was restricted to those stands identified as habitat using 2003 values.

The values for these weighted averages and standard deviation are:

	Weighted Average Site Index	Std. Dev Site Index	Weighted Average Age	Std. Dev Age
Westside	117	18	66	34
Eastside	86	18	88	35

A table was created and populated with the weighted average site index, and plus and minus one standard deviation of the average. The standard deviation for age was also added to the weighted average age, and plus and minus one standard deviation of the average.

This table was used to input age and site index values into the British Columbia Ministry of Forests *SiteTools* application (Version 3.2m). This application calculates height for a given site index and age. Each pairing of site index and age from the above table was input into the application to calculate height by age and site index. Coastal Douglas fir as the species and King's (1966) equation was used to do the calculation. The application defaults to Nigh's (1996) growth intercept equation. These calculations were recorded back into the above table to produce the following resultant table.

Height By Age and Site Index (Feet) – Year 2003

SI	Age @ Breast Height					
	32	53	66	88	100	123
135	98	140	159	184	195	212
117	85	121	138	159	168	182
104	76	108	122	140	148	160
99	73	103	116	133	141	152
86	63	89	101	115	121	131

In order determine the rate of growth from 1996 to 2003 a similar table was generated by decrementing age values by seven years. The values were run through Site Tools to produce the following table:

Height By Age and Site Index (Feet) – Year 1996

SI	Age @ Breast Height					
	25	46	59	81	93	116
135	80	128	149	177	189	207
117	70	111	129	153	163	178
104	62	99	115	135	144	157
99	59	94	109	128	137	149
86	48	82	95	111	118	128
68	41	65	75	87	92	100

The difference between these two tables represents the potential height growth for dominants and co-dominants in free to grow stands for the seven year period.

Height Growth Between 1996 and 2003 (Feet)

SI	Age @ Breast Height					
	25 - 32	46 - 53	59 - 66	81 - 88	93 - 100	116 - 123
135	18	12	10	7	6	5
117	16	10	8	6	5	4
104	14	9	7	5	4	3
99	13	9	7	5	4	3
86	15	7	6	4	3	3
68	9	6	4	3	3	2

The average rate of growth is 10 feet for the westside and 5 feet for the eastside when the values are averaged separately for eastside/westside site index and age.

The other growth parameter that needed to be evaluated was diameter growth. Empirical Growth and Yield Tables for the Douglas-fir Zone (Chambers, C.J., DNR Report No. 41) were used to estimate average diameter growth. The site index for these yield tables is incremented by five feet from 60 to 160. The site index values used for the height growth calculations above were used as a guide to identify the closest site index in the yield tables. Additionally, the breast height age found in the yield tables are not found in standard increments across the range of site indices and do not relate to the breast height age used for height growth calculations. The closest age to the corresponding site index was used.

Yield Table Diameters by site index and age

SI	Age @ Breast Height				
	33	53	67	89	93
135	13.2	16.9	19.2	22.6	23.1
115	12.1	15.1	16.9	19.6	20.0
105	11.5	14.2	15.8	18.0	18.4
100	11.2	13.7	15.2	17.3	17.6
85	10.4	12.3	13.5	15.0	
70	9.6	11.0	11.9	12.8	

Using the same yield tables, age was decremented by seven years to establish the potential diameter in 1996. This produced the following table.

SI	Age @ Breast Height				
	25	45	59	81	85
135	11.7	15.1	17.9	21.4	22.0
117	10.9	13.9	15.9	18.7	19.1
104	10.4	13.2	14.9	17.3	17.7
99	10.2	12.8	14.4	16.6	17.3
86	9.6	11.5	12.9	14.8	
68	9.0	10.5	11.4	12.5	

The difference between these two tables produces diameter growth that would potentially occur in stands with a similar site index and age.

Average diameter growth rate by site index and age for a seven-year period.

SI	Age @ Breast Height				
	25 - 33	45 - 53	59 - 67	81 - 89	85 - 93
135	1.5	1.8	1.3	1.2	1.1
115	1.2	1.2	1.0	0.9	0.9
105	1.1	1.0	0.9	0.7	0.7
100	1.0	0.9	0.8	0.7	0.3
85	0.8	0.8	0.6	0.2	-
70	0.7	0.6	0.5	0.3	-

The average seven-year growth increment across all site indices and ages is 0.9 inch. If separated into westside/eastside categories that relate to the weighted average site index and age calculated for this project, westside stands grow 1.0 inch over the seven-year period and eastside stands grow 0.4 inch.

After reviewing this analysis and acknowledging the goal of avoiding over prediction of habitat, a decision was made to apply two inches as a QMD adjustment value and fifteen feet as a height adjustment. For example, westside sub-marginal habitat requires a QMD of 13 inches with dominants and co-dominants averaging 85 feet in height. Adding two inches to QMD and fifteen feet to height requirements means that in order for a stand to be considered as habitat in 1996 a QMD of 15 and a height for dominants and co-dominants must be at least 100 feet in the 2003 inventory. Two fields were used to establish 1996 and 2003 habitat values. Additionally, to address the potential sampling inaccuracies of snags and mistletoe, records that met all other criteria but not snags or mistletoe (where required) were flagged differently to recognize the associated uncertainty. These stands represent potential habitat. The following table summarizes the results of this analysis. Values equaling zero are not habitat, 1 equals habitat, and 2 equals potential habitat.

Analysis Summary

Owl Habitat Description	Habitat 2003	Habitat 1996	Acres
Not classified as owl habitat	0	0	824,402
Stands Older than 50 years ('96) Requirements Not Met	0	0	78,648
Stands Older than 50 years ('96) Requirements Not Met	2	2	215,077
Old Forest - (Legacy LULC Age GT 70)	2	2	47,665
Old Forest - (Snag Requirement Met)	1	0	58
Old Forest - (Snag Requirement Met)	1	1	435
Sub-mature - Westside (Snag Requirement Met)	1	0	54,651
Sub-mature - Westside (Snag Requirement Met)	1	1	167,181
Sub-mature - Westside (Snag Requirement Not Met)	2	0	75,792
Sub-mature - Westside (Snag Requirement Not Met)	2	2	90,577
Marginal - Westside (Snag Requirement Met)	1	0	34,354
Marginal - Westside (Snag Requirement Met)	1	1	68,742
Sub-mature - Eastside (Snag Requirement Met)	1	0	1,497
Sub-mature - Eastside (Snag Requirement Met)	1	1	8,620
Sub-mature - Eastside (Snag Requirement Not Met, W/ Mistletoe)	1	0	207
Sub-mature - Eastside (Snag Requirement Not Met, W/ Mistletoe)	1	1	298
Marginal Closed - Eastside (90' Ht - < 3 Snags-Mistletoe Not Used)	1	0	2,696
Marginal Closed - Eastside (90' Ht - < 3 Snags-Mistletoe Not Used)	1	1	4,963
Marginal Closed - Eastside (Snags/Mistletoe Not Used)	2	0	296
Marginal Closed - Eastside (Snags/Mistletoe Not Used)	2	2	831
Marginal Open - Eastside (Snag Requirement Met and Mistletoe Used)	1	0	22
Marginal Open - Eastside (Snag Requirement Met and Mistletoe Used)	1	1	203
Marginal Open - Eastside (Snag Requirement Met - No Mistletoe)	1	0	89
Marginal Open - Eastside (Snag Requirement Met - No Mistletoe)	1	1	328
Marginal Open - Eastside (Snag Req. Not Met - Mistletoe Not Used)	2	0	2,022
Marginal Open - Eastside (Snag Req. Not Met - Mistletoe Not Used)	2	2	1,749

Table 2 Western Washington Spotted Owl Sub-Mature and Young Forest Marginal Habitat Characteristics

Characteristic	Sub-Mature		Young Forest Marginal	
	WAC	FRIS	WAC	FRIS
Forest Community	conifer-dominated or conifer-hardwood (greater than or equal to 30% conifer)	tree table used to identify stands with at least 30% of total live basal area in conifer	conifer-dominated or conifer-hardwood (greater than or equal to 30% conifer)	tree table used to identify stands with at least 30% of total live basal area in conifer
Canopy Cover	greater than or equal to 70% canopy cover		greater than or equal to 70% canopy cover	
Tree Density and Height	115-280 trees/acre (greater than or equal to 4-inches dbh) with dominants and codominants greater than or equal to 85 feet high OR	The values for canopy closure and tree density were replaced with a quadratic mean diameter (QMD) of greater than 13 inches and a basal	115-280 trees/acre (greater than or equal to 4-inches dbh) with dominants and codominants greater than or equal to 85 feet high OR	The values for canopy closure and tree density were replaced with a quadratic mean diameter (QMD) of greater than 13 inches and a basal
Vertical Diversity	dominants and codominants greater than or equal to 85 feet high with 2 or more layers and 25 - 50% intermediate trees	area of greater than 100 (WAC 222-16-085 (i))	dominants and codominants greater than or equal to 85 feet high with 2 or more layers and 25 - 50% intermediate trees	area of greater than 100 (WAC 222-16-085 (i))
Snags/CavityTrees	greater than or equal to 3 per acre (greater than or equal to 20 inches dbh and 16 feet height)	FIU Tree data was summarized for dead trees >=20" and > 16'and used to evaluate each stand.	greater than or equal to 2 per acre (greater than or equal to 20 inches dbh and 16 feet height) OR	FIU Tree data was summarized for dead trees >=20" and > 16'and used to evaluate each stand.
Dead, Down Wood	N/A		greater than or equal to 10% of the ground covered with four	
Shrubs	N/A		inch diameter or larger wood, with 15-60% shrub cover	

Table 3 Eastern Washington Spotted Owl Sub-Mature Habitat Characteristics

Characteristic	Sub-Mature	
	WAC	FRIS
Forest Community	greater than or equal to 40% fir	FRIS tree table used to identify stands with at least 30% of total live basal area in conifer
Tree Density and Height	110-260 trees per acre (greater than or equal to 4 inches dbh) with dominants and codominants greater than or equal to 90 feet high OR dominants and codominants >= to 90 feet high with 2 or more layers and 25-50% intermediate trees 25 - 50% intermediate trees	The values for canopy closure and tree density were replaced with a quadratic mean diameter (QMD) of greater than 13 inches and a relative density area of greater than 44 (WAC 222-16-085 (ii -A)) Tree Height was evaluated for stands with an average height of the top top 40 trees greater than 90'.
Vertical Diversity		
Canopy Cover	greater than or equal to 70% canopy cover	
Snags/CavityTrees	greater than or equal to 3 per acre (greater than or equal to 20 inches dbh and 16 feet height) OR moderate mistletoe infection.	FIU Tree data was summarized for dead trees >=20" and > 16'and used to evaluate each stand. Stands with mistletoe were noted.
Mistletoe		
Dead, Down Wood	greater than or equal to 5% of the ground covered with 4 inch diameter or larger wood.	FRIS data is not attributed in a way that supports this criteria. Not applied.

Table 4 Eastern Washington Spotted Owl Young Forest Marginal Habitat Characteristics

Characteristic	Young Forest Marginal - Closed		Young Forest Marginal - Open	
	WAC	FRIS	WAC	FRIS
Forest Community	greater than or equal to 40% fir	FRIS tree table used to identify stands with at least 40% of total live basal area is in true fir or Douglas-fir	greater than or equal to 40% fir	FRIS tree table used to identify stands with at least 40% of total live basal area is in true fir or Douglas-fir
Tree Density and Height	100 - 300 trees/acre (greater than or equal to 4 inches dbh)	The values for canopy closure and tree density were substituted with a quadratic mean diameter (QMD) of greater than 13 inches and a relative density of greater than 44 (WAC 222-16-085 (ii -B)) Tree Height was evaluated for stands with an average height of the top 40 trees greater than 70 feet.	100 - 300 trees/acre (greater than or equal to 4 inches dbh)	The values for canopy closure and tree density were substituted with a quadratic mean diameter (QMD) of greater than 13 inches and a relative density of greater than 28 (WAC 222-16-085 (ii -B)) Tree Height was evaluated for stands with an average height of the top 40 trees greater than 70 feet.
Vertical Diversity	dominants and codominants greater than or equal to 70 feet high with 2 or more layers. 25 - 50% intermediate trees		dominants and codominants greater than or equal to 70 feet high with 2 or more layers. 25 - 50% intermediate trees	
Canopy Cover	greater than or equal to 70% canopy cover		greater than or equal to 50% canopy cover	
Snags/CavityTrees	N/A	FIU Tree data was summarized for dead trees >=20" and > 16' and used to evaluate each stand. Stands with mistletoe were noted.	greater than or equal to 2 per acre (greater than or equal to 20 inches dbh and 16 feet height) OR	FIU Tree data was summarized for dead trees >=20" and > 16' and used to evaluate each stand. Stands with mistletoe were noted.
Mistletoe	N/A		High or Moderate infection	
Dead, Down Wood	N/A		N/A	

Literature Cited

Arney, J.D. (1999). Universal Species Library for the Forest Projection System Growth Model. *Forest Biometrics Report No. 8*.

Chambers, C.J. (1980). Empirical Growth and Yield Tables for the Douglas fir Zone, *Washington State Dept. of Natural Resources Report No. 41*.

Curtis, R.O. (1982). A simple index of stand density. *Forest Science*. 28:92-94.

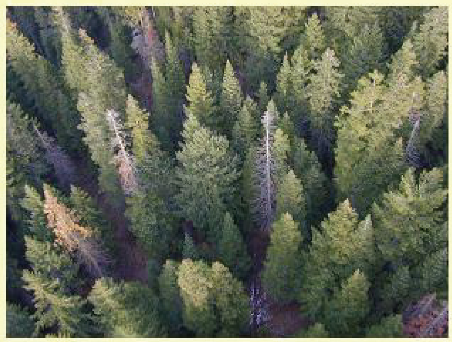
King, J.E. (1996). Site Index Curves for Douglas-fir in the Pacific Northwest. Weyerhaeuser Co., *For Res. Cent. For. Pap. 8.8.* 49p.

Nigh, G.D. (1996). Growth intercept models for species without distinct annual branch whorls western hemlock. *Can. J. For. Res*. 26:8, 1407-1415.

Washington Administrative Code, 222-16-085, Northern spotted owl habitats.

Appendix G. Slide Presentation given to the Forest Practices Board Spotted Owl Workshop, August 9, 2005. (Data updated to match statistics in final report).

AN ASSESSMENT OF SPOTTED OWL HABITAT ON NON-FEDERAL LANDS IN WASHINGTON BETWEEN 1996 AND 2004



D. John Pierce, Joseph B. Buchanan, Brian L. Cosentino, and Shelly Snyder

Washington Spotted Owl Habitat Analysis Study 08/03/2005

In Collaboration with Washington Department of Natural Resources

DNR Staff - **Lenny Young, Tim Gregg, Carl Harris, Walt Obermeyer, Stephen Harmon, and Regional Office Staff**

WDFW Staff - **Jeff Foisy, Marc McCalmon, Greg Falxa, Lori Salzer, Wan-Ying Chang and Rajbir Deol**

USFS GIS Lab – **Warren Cohen, Sean Healy, and Yang Zhiqiang**

Marshall & Associates – **Norm Roller, John Cowell, Brian Scott, and Emily Silverman**

Washington Spotted Owl Habitat Analysis Study 08/03/2005

Technical Review Process

Version 1 Review (May 2005):

Version 2 Review (June-July 2005):

Blind Peer Review

Dr. John Marzluff, University of Washington

3 Anonymous Reviewers

D. Eric Harlow, Washington Forest Law Center

Dave Werntz, Northwest Ecosystem Alliance

Craig Hansen and Jim Michaels, U.S.F.W.S.

Washington Spotted Owl Habitat Analysis Study 08/03/2005

Outline of Presentation

- Study Objectives
- Overview of the Methods
- Significant Results
- Limitations of Results
- Overall Conclusions
- Recommendations

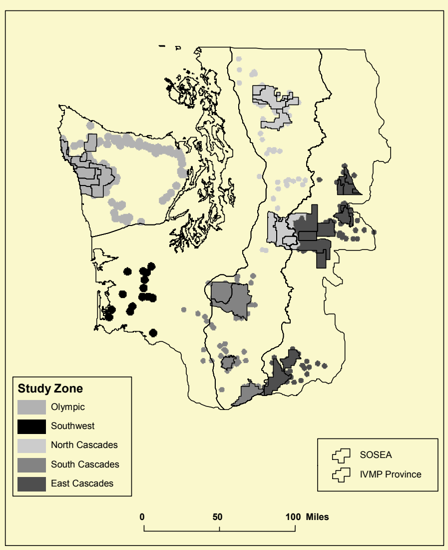
Washington Spotted Owl Habitat Analysis Study 08/03/2005

Spotted Owl Habitat Analysis Study Objectives:

1. Estimate the amount of suitable habitat in 2004 on landscapes affected by state and private forest practices
2. Estimate the amount of suitable habitat harvested on state and private lands from 1996 to 2004
3. Estimate the relative change in suitable habitat on state and private lands since rule adoption in 1996

Washington Spotted Owl Habitat Analysis Study 08/03/2005

Spotted Owl Habitat Assessment Study Area



Washington Spotted Owl Habitat Analysis Study 08/03/2005

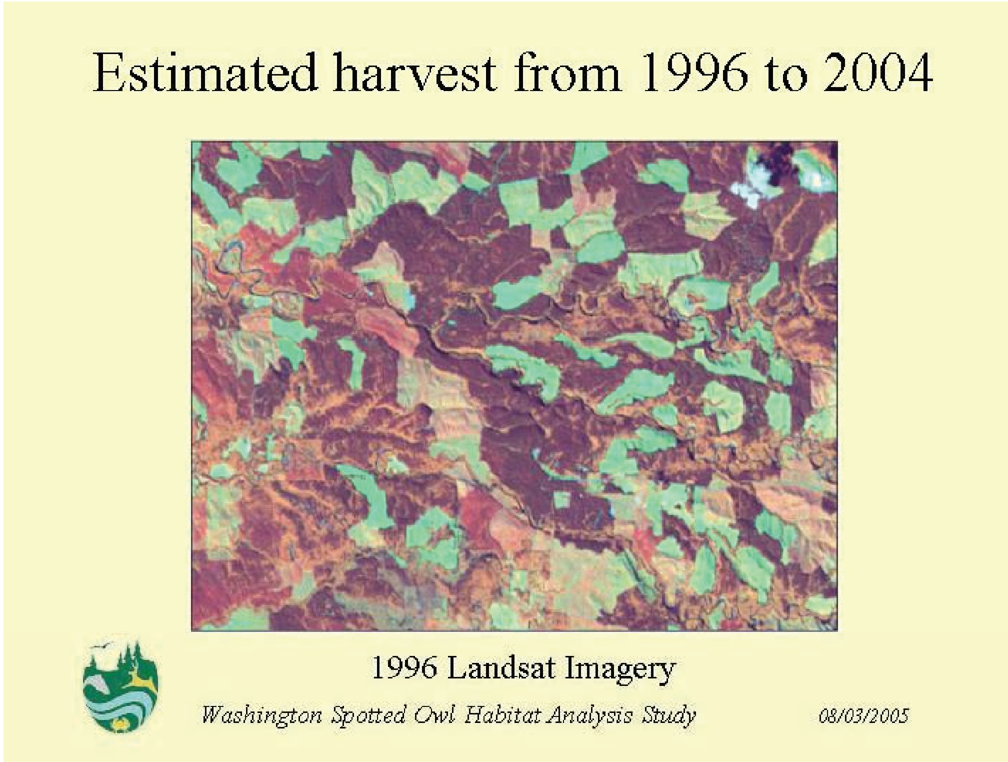
Estimating Spotted Owl Habitat in 2004

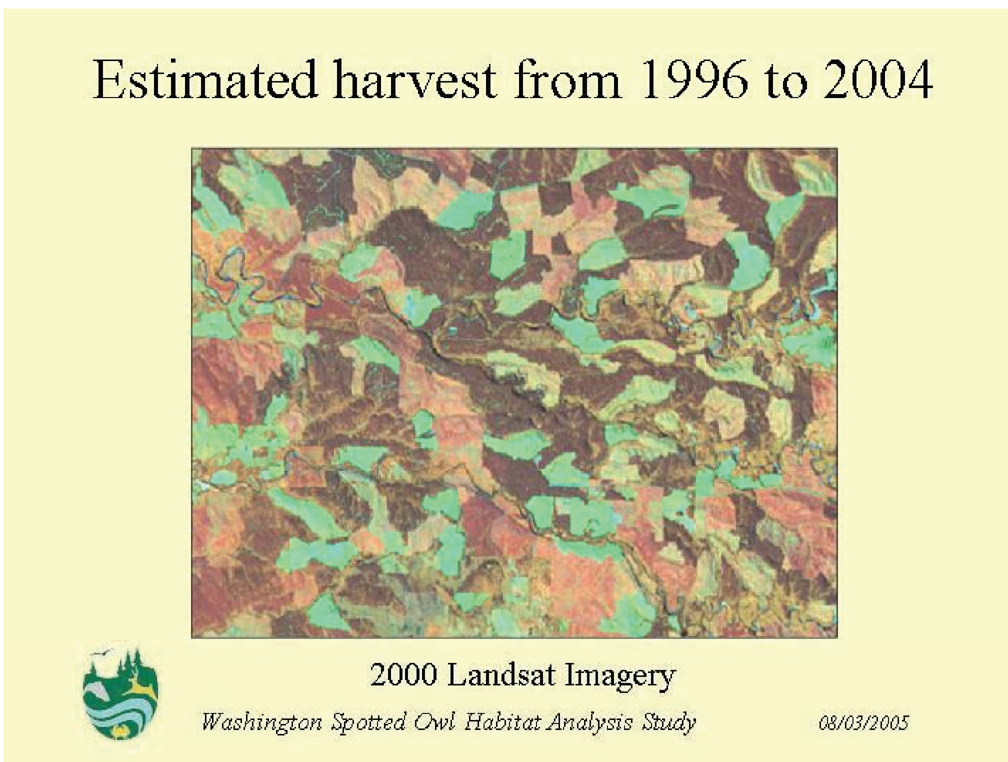
Westside 10 acre plots, Eastside 4 acre plots

Washington Spotted Owl Habitat Analysis Study 08/03/2005

Helicopter Sampling Examples

Washington Spotted Owl Habitat Analysis Study 08/03/2005


Estimated harvest from 1996 to 2004
1996 Landsat Imagery
Washington Spotted Owl Habitat Analysis Study
08/03/2005


Estimated harvest from 1996 to 2004
2000 Landsat Imagery
Washington Spotted Owl Habitat Analysis Study
08/03/2005

Estimated Habitat harvested from 1996 to 2004

- Interagency Vegetation Mapping Project-1996 data
- DNR Forest Stand Inventory
- Biomapper
- Logistic Regression

Washington Spotted Owl Habitat Analysis Study 08/03/2005

Model Uncertainty

"If we knew what we were doing, it wouldn't be called research, … would it?"

Albert Einstein (1879-1955)

Washington Spotted Owl Habitat Analysis Study 08/03/2005

Model Uncertainty

- Federal Land Harvest
- Stand replacement ground sampling
- Partial Harvest Estimates
- Owl status changes during 1996-2004

Washington Spotted Owl Habitat Analysis Study *08/03/2005*

Results are Summarized in Tables

1. Within SOSEAs inside and outside circles on non-HCP lands
2. HCP Lands
3. Outside of SOSEAs inside circles on non-HCP lands

Washington Spotted Owl Habitat Analysis Study *08/03/2005*

Non-HCP Lands Inside SOSEAs

Zone	State-Local	Private	Federal	Tribe	Grand Total
East Cascades	11,508	210,833	294,743	491	517,574
North Cascades	3,996	153,966	130,316	0	288,279
Olympic	1,392	125,019	48,776	961	176,148
South Cascades	5,394	184,491	54,718	0	244,603
Southwest	0	0	0	0	0
Grand Total	22,291	674,309	528,553	1,452	1,226,605

Percent Total	2%	55%	43%	0%

Washington Spotted Owl Habitat Analysis Study *08/03/2005*

Non-HCP Lands Inside SOSEAs

Zone	Total Area	2004 Habitat (B)	1996-2004 Harvest	Habitat Harvested (A)	RCI	% Habitat
East Cascades	517,574	158,096	28,872	8,605	5%	31%
North Cascades	288,279	58,805	17,066	6,243	10%	20%
Olympic	176,148	28,393	9,484	2,992	10%	16%
South Cascades	244,603	31,931	16,418	3,503	10%	13%
Southwest	0	0	0	0	0%	0%
Grand Total	1,226,605	277,225	71,840	21,344	7%	23%

Percent Total	22.60%	5.86%	29.71%

$$RCI = \frac{A}{A+B}$$

Washington Spotted Owl Habitat Analysis Study *08/03/2005*

Non-HCP Lands Inside SOSEAs

Owl Circle	Total Landscape	Habitat	Total Harvest	Habitat Harvested	R.C.I.
Inside	587,484	162,185	22,198	7,081	4.18%
	Percent Total	27.61%	3.78%	31.90%	

Owl Circle	Total Landscape	Habitat	Total Harvest	Habitat Harvested	R.C.I.
Outside	639,122	115,040	49,642	14,263	11.03%
	Percent Total	18.00%	7.77%	28.73%	

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HCP Lands

Zone	State-Local	Private	Federal	Tribe	Grand Total
East Cascades	107,986	67,597	0	0	175,583
North Cascades	132,369	59,365	0	0	191,733
Olympic	293,123	14,934	0	0	308,057
South Cascades	109,696	54,899	0	0	164,595
Southwest	52,945	6,532	0	0	59,477
Grand Total	696,119	203,327	0	0	899,446

Percent Total	77%	23%	0%	0%

Washington Spotted Owl Habitat Analysis Study *08/03/2005*

HCP Lands

Zone	Total Area	2004 Habitat	1996-2004 Harvest	Habitat Harvested	RCI	% Habitat
East Cascades	175,583	49,804	15,017	5,671	10%	28%
North Cascades	191,733	41,353	8,322	3,652	8%	22%
Olympic	308,057	61,620	8,169	3,220	5%	20%
South Cascades	164,595	39,356	6,585	2,213	5%	24%
Southwest	59,477	8,379	3,878	1,331	14%	14%
Grand Total	899,446	200,512	41,971	16,087	7%	22%

Percent Total	22.29%	4.67%	38.33%

Washington Spotted Owl Habitat Analysis Study *08/03/2005*

HCP Lands

Owl Circle	Total Landscape	Habitat	Total Harvest	Habitat Harvested	R.C.I.
Inside	585,920	138,874	27,399	11,084	7.39%
	Percent Total	23.70%	4.68%	40.46%	

Owl Circle	Total Landscape	Habitat	Total Harvest	Habitat Harvested	R.C.I.
Outside	313,526	61,638	14,573	5,003	7.51%
	Percent Total	19.66%	4.65%	34.33%	

Washington Spotted Owl Habitat Analysis Study *08/03/2005*

Non-HCP Lands Outside SOSEAs

Zone	State-Local	Private	Federal	Tribe	Grand Total
East Cascades	5,582	83,642	102,777	13,373	205,373
North Cascades	506	21,839	139,766	0	162,111
Olympic	3,398	97,357	353,674	10,628	465,057
South Cascades	1,470	71,042	86,723	0	159,235
Southwest	256	115,671	188	0	116,115
Grand Total	11,212	389,551	683,127	24,001	1,107,891

Percent Total	1%	35%	62%	2%

All lands are inside owl
management circles

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Non-HCP Lands Outside SOSEAs

Zone	Total Area	2004 Habitat	1996-2004 Harvest	Habitat Harvested	RCI	% Habitat
East Cascades	190,627	60,175	16,003	4,527	7%	32%
North Cascades	154,236	55,611	1,825	635	1%	36%
Olympic	448,111	157,291	14,295	5,103	3%	35%
South Cascades	164,279	42,658	11,243	3,577	8%	26%
Southwest	123,646	8,344	19,290	6,604	44%	7%
Grand Total	1,080,900	324,079	62,656	20,445	6%	30%

Percent Total	29.98%	5.80%	32.63%

All lands are inside owl
management circles

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Conclusions

Inside SOSEAs on Non-HCP Lands

- Relative amount of habitat inside owl circles appear to be below recommended levels for viability (40%)

  Average = 28% (95% CI = 25% – 31%)

- Relative habitat loss inside owl circles 1996-2004

  Average = 4% (95% CI = 3% – 5%)

- Relative habitat loss outside owl circles 1996-2004

  Average = 11% (95% CI = 9% – 13%)

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Conclusions

HCP vs Non-HCP Lands

- HCP - State Lands (77%) vs. Non-HCP – Private (46%) Federal (52%)
- HCP – Habitat loss outside circles = Habitat loss inside circles vs. Non-HCP – Habitat loss outside circles > 2 X Habitat loss inside circles
- Circle RCI HCP = 7% vs. Circle Non-HCP RCI = 4%

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Recommendations

- ***Conserve habitat through landscape planning*** -- Amounts and patterns of habitat loss within SOSEAs suggest that stronger incentives for conserving spotted owl habitat at the landscape level may be needed.

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Recommendations

- ***Develop high-quality habitat maps*** -- Spatially accurate habitat maps based on habitat definitions in the Forest Practices Rules are essential both for day-to-day rule implementation (i.e., review of Forest Practices Applications) and for policy evaluation (i.e., monitoring habitat change over time).

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