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THE FIRST 20 YEARS (1994–2013)

Status and Trends of Northern Spotted Owl Habitats

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Cover Photo: Spotted owl by Jason Mowdy.

Abstract

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This is the third in a series of periodic monitoring reports on northern spotted owl (*Strix occidentalis caurina*) habitat status and trends on federally administered lands since implementation of the Northwest Forest Plan (NWFP) in 1994. The objective of this monitoring is to determine if the NWFP is providing for conservation and management of northern spotted owl (NSO) habitat as anticipated. This report focused on the amount, distribution, and spatial arrangement of NSO habitats across the NWFP area; and how these have changed as a result of disturbance and ingrowth starting with the year of the NWFP analyses in 1993. Results showed a net decrease from 9,089,700 ac to 8,954,000 ac (-1.5 percent) of nesting/roosting habitat on NWFP federal lands. This occurred despite gross losses from wildfire of 5.2 percent (474,300 ac), 1.3 percent from timber harvest (116,100 ac), and 0.7 percent from insects or other causes (59,800 ac), indicating that processes of forest succession have compensated for some of the losses resulting from disturbance. Dispersal habitat on NWFP federal lands increased by 2.2 percent (net change), but dispersal-capable landscapes experienced a 5 percent net decrease owing to habitat losses on the surrounding nonfederal lands. Large wildfires continue to be the leading cause for loss of NSO habitat on federal lands. Most of these losses occurred within the network of large reserves designed for NSO conservation.

Keywords: Northwest Forest Plan, effectiveness monitoring, northern spotted owl, MaxEnt, owl habitat, habitat suitability.

Preface

Northern spotted owl (*Strix occidentalis caurina*) monitoring of the Northwest Forest Plan area was approved by an intergovernmental advisory committee and is consistent with the framework for effectiveness monitoring described in "The Strategy and Design of the Effectiveness Monitoring Program for the Northwest Forest Plan" published in 1999. It follows protocols and guidance in the "Northern Spotted Owl Effectiveness Monitoring Plan for the Northwest Forest Plan" published in 1999. An interagency effectiveness monitoring framework was implemented to meet requirements for tracking the status and trends of older forests, populations and habitats of northern spotted owls and marbled murrelets (*Brachyramphus marmoratus*), watershed conditions, social and economic conditions, and tribal relationships. Monitoring is conducted and reported in 1- to 5-year intervals. Monitoring results for the first 10 and 15 years were documented in a series of general technical reports available online at http://www.fs.fed.us/pnw/publications/gtrs.shtml. This report, and the others in the current series, covers the first 20 years of the plan.

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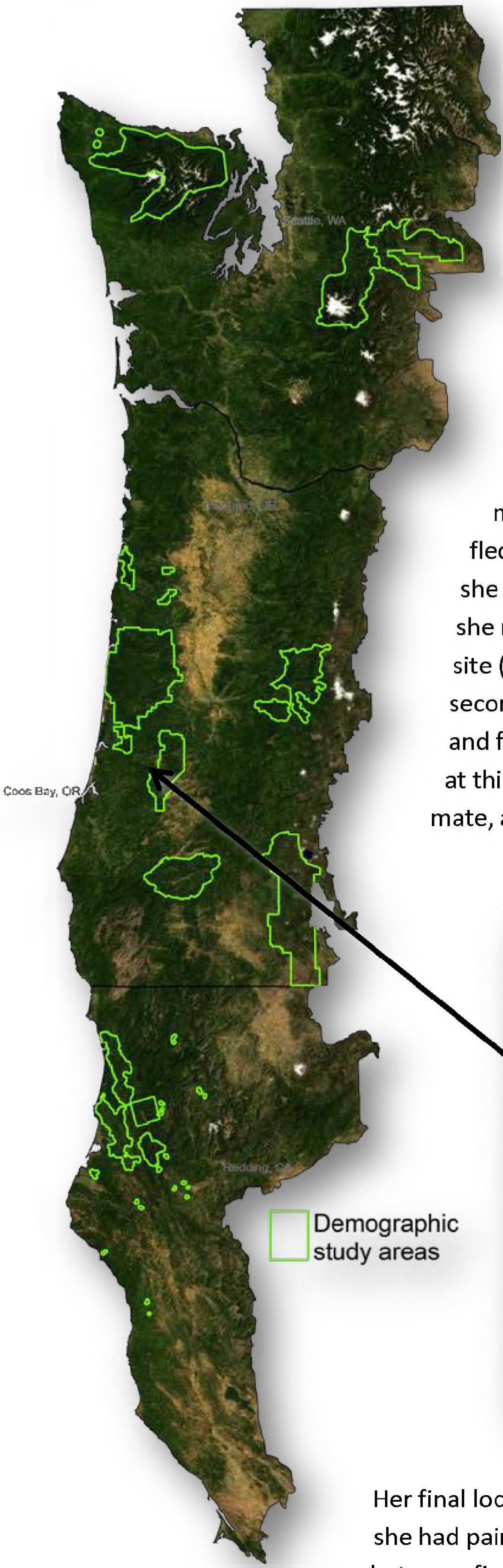
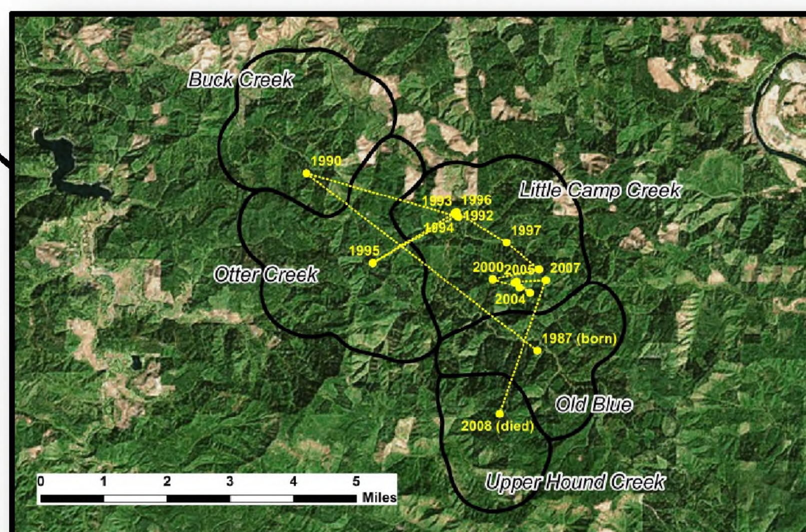


For more than two decades, the northern spotted owl monitoring program has been following the life histories of hundreds of banded northern spotted owls throughout their geographic range in the Pacific Northwest forests of the United States (left). This is a brief accounting of one of those owls that spent her entire life in the coastal forests near Coos Bay Oregon.

Photo by Jason Mowdy

She was hatched in 1987 at an owl territory known as the Old Blue site. She was one of two fledglings. Eventually she dispersed from her natal site to establish a territory of her own in 1990, traveling almost five miles to the northwest. That same year she fledged two owlets with the first of five males she would eventually mate with. Two years later she moved about 2.5 miles to the Little Camp Creek site (below) and fledged two more young with her second mate. There she paired with her third mate in 1993 and for the next 11 years these two owls fledged several more young at this site. In 1995 she briefly moved to Otter Creek with her fourth mate, a 1.5 mile move, but returned the following year.



Her final location at age 21 was in the Upper Hound Creek site in 2008, where she had paired with her fifth mate. After traveling over 16 miles linear distance between five territories, her last known location was about a mile from where she was fledged. We collected data from 17 years of her life and she contributed to the population with at least 8 owls fledged.

Introduction

It has been slightly more than two decades since implementation of the Northwest Forest Plan (hereafter referred to as "NWFP"). The NWFP amended 19 existing Forest Service and 7 Bureau of Land Management resource management plans across three states and two Forest Service regions within the range of the northern spotted owl (*Strix occidentalis caurina*). An interagency effectiveness monitoring framework was implemented in the late 1990s to meet NWFP requirements for tracking the status and trends of late-successional and old-growth forests, northern spotted owl (hereafter referred to as "NSO") populations and habitat, marbled murrelet (*Brachyramphus marmoratus*) populations and habitat, watershed condition, social and economic conditions, and tribal relationships (Mulder et al. 1999). Beginning in 2005, monitoring reports have been published at 5-year intervals and made available at http://www.reo.gov/monitoring/.

This report is the third in the series of NSO monitoring reports outlined by an interagency effectiveness monitoring plan (Lint et al. 1999) and covers the time period from 1993 to 2012. The goal of NSO monitoring is to periodically evaluate the success of the NWFP in arresting downward trends in NSO populations and in maintaining and restoring habitat necessary to support viable NSO populations on federally administered forest lands throughout its range. Specific objectives are to:

1. Assess changes in NSO population trends and demographic rates on federal lands within its geographic range in the United States; and
2. Assess changes in the amount and distribution of NSO habitat on federal lands.

While the first two monitoring reports (Davis et al. 2011, Lint 2005) included chapters addressing both objectives, this report focused only on the second objective (habitat status and trends). Status and trends of population and demographic rates were concurrently covered in a refereed science journal (Dugger et al. 2016.) to eliminate redundancy and to be more cost effective.

Each round of monitoring used new and improved data. While this improved the overall quality of the information provided, it also means that individual reports should not be compared directly without fully understanding the processes used to develop the results. Although we used new data, we mainly followed methods described in the second monitoring report (Davis et al. 2011). For efficiency and to avoid repetitiveness, we summarized methods that did not change and only discussed changes in data or analytical techniques made between the 15-year report and this 20-year report.

As in previous reports, we summarized an assessment of NSO habitat for the 22.1 million acres of federally administered forest lands affected by the NWFP, but also included information on the surrounding 23.8 million acres of nonfederal forest lands to provide a broader landscape context across the 57 million acres that comprise the NSOs geographic range in the United States.

Habitat Monitoring Under the NWFP

Habitat status and trends are estimated every 5 years because it was believed that changes in forest vegetation conditions would not be reliably discernable at more frequent intervals using the Landsat remote sensed vegetation data that this broad-scale monitoring relies upon (Lint et al. 1999).

The intent of habitat effectiveness monitoring is to evaluate assumptions made during development of the NWFP. In particular, the assumption that habitat would not decline faster than the estimated 5 percent per decade (from wildfire and timber harvesting combined) in the NWFP's final environmental impact statement (USDA and USDI 1994). Specific habitat assumptions from Lint et al. (1999) were as follows:

1. Habitat conditions within late-successional reserves (LSRs) would improve over time at a rate controlled by successional processes in stands that currently are not habitat. However, this was not expected to produce any significant changes in habitat conditions for several decades.
2. Habitat conditions outside of reserved land use allocations (LUAs) would generally decline because of timber harvest and other habitat-altering disturbances, but the vegetation structure across the landscape would continue to facilitate NSO movements.
3. Catastrophic events were expected to halt or reverse the trend of habitat improvement in some reserves; however, the repetitive design of reserves would provide resiliency, and not result in isolation of population segments.

The rangewide network of reserved federal lands that was designed to support well-distributed and connected populations of reproducing NSO pairs is central to these assumptions. But, also important is the land between these reserves because it provides for recruitment of NSOs into the territorial populations within reserves (see chapter 2 in Davis et al. 2011) and dispersal and movement of NSOs between larger reserves. To assess these assumptions, the following questions are addressed in habitat monitoring:

1. What proportion of the total forested landscape on federal lands are NSO nesting/roosting and dispersal habitat?

2. What are the trends in amount and changes in distribution of NSO habitat, particularly in large, reserved blocks?
3. What are the trends in amount and distribution of dispersal habitat outside of the large, reserved blocks?
4. What are the primary factors leading to loss and fragmentation of NSO nesting/roosting and dispersal habitat?

We evaluate these questions at three broad geographic scales: (1) by physiographic province, (2) by state, and (3) for the geographic range of the NSO. Within these spatial extents, we assess habitat conditions inside broad federal LUAs representing "reserved" and "nonreserved" landscapes.

As in previous monitoring reports, to answer these questions we produced time series maps of forest stands (regardless of patch size and spatial configuration) that are structurally and compositionally similar to forest conditions known to be used for nesting and roosting by NSOs. We referred to these maps as "nesting/roosting habitat" maps throughout this document. We also produced maps of dispersal habitat based on the definition used in Thomas et al. (1990). We developed these habitat maps for the baseline year (1993) that matches the year that the NWFP was designed and for the end of this monitoring cycle (2012). We referred to the time period maps as "bookend" maps, and the differences between them were used to assess habitat status and trends.

At the time the habitat monitoring plan was designed and written (Lint et al. 1999), barred owls (*Strix varia*) were already present within the NWFP area, but at low levels (rangewide, <10 percent of monitored territories). The habitat monitoring design did not factor in the potential effect that the barred owl (hereafter referred to as "BO") might have on NSO habitat selection. However, this effect was considered in the previous two monitoring reports, as well as this one. In Lint (2005), the decision to use "presence-only" modeling methods was based partially on the potential to get "false absence" data owing to NSO displacement by BOs. In other words, NSOs might be absent from a stand with highly suitable forest structure and species composition solely due to presence of BOs. Likewise, habitat modeling was done using NSO presence data from early in the BO invasion to minimize the potential effects of interspecific competition between NSOs and BOs that could potentially confound NSO habitat selection and use (Davis et al. 2011). In this report, we used NSO presence data from 1993 to develop our habitat models.

Data Sources and Methods

Many, but not all, of the data sources used in this report were initially developed and used for the 10- and 15-year monitoring reports (Davis et al. 2011; Lint 2005; Moeur et al. 2005, 2011). During each 5-year monitoring cycle, previously used data sources are occasionally updated to incorporate new research findings and other information, or to correct errors. More indepth descriptions of these data sources can be found in previous monitoring reports.

Physiographic Provinces

The NWFP boundary was based on the geographic range of the NSO in the United States. Because the range was so large, it was divided into 12 physiographic provinces for analytical purposes (FEMAT 1993, Thomas et al. 1990, USDA and USDI 1994). Physiographic provinces were delineated in an attempt to reduce the complex and diverse nature of the NSO range into broad areas that represented different forest zones, plant communities, and disturbance regimes that differ geographically with climate, topography, soils, and geology. These physiographic provinces were largely based on subdivisions by Franklin and Dyrness (1973). We used the same physiographic province geographic information system (GIS) layer that was used for the 15-year monitoring report (Davis et al. 2011).

Land Use Allocations

Federal LUAs have specific management directions under the NWFP. This report groups LUAs into two broad categories: (1) reserved and (2) nonreserved. Reserved allocations are areas where the restoration and maintenance of older forests are expected to occur under the current land use plans. They included the following LUAs:

- Congressionally reserved areas: Lands reserved by the U.S. Congress such as wilderness areas, wild and scenic rivers, and national parks and monuments.
- Late-successional reserves: Lands reserved for the protection and restoration of late-successional and old-growth forest ecosystems and habitat for associated species; including marbled murrelet reserves and NSO activity core reserves.
- Managed late-successional areas: Areas for the restoration and maintenance of optimum levels of late-successional and old-growth stands on a landscape scale, where regular and frequent wildfires occur. Silvicultural and fire hazard reduction treatments are allowed to help prevent older forest losses from large wildfires or disease and insect epidemics.

- Administratively withdrawn areas: Areas identified in local forest and district plans; they include recreation and visual areas, back country, and other areas where management emphasis does not include scheduled timber harvest.
- Adaptive management area—reserved: Identified to develop and test innovative management to integrate and achieve ecological, economic, and other social and community objectives. Emphasis on restoration of late-successional forests and managed as an LSR.

Nonreserved LUAs were designed for multiple land use objectives including sustained-yield management for timber production. They included:

- Matrix: Federal lands outside of reserved allocations where most timber harvest and silvicultural activities were expected to occur.
- Adaptive management area—nonreserved: Identified to develop and test innovative management to integrate and achieve ecological, economic, and other social and community objectives. Some commercial timber harvested was expected to occur in these areas, but with ecological objectives.

The GIS layer representing these LUAs was originally delineated during the analysis for the NWFP (USDA and USDI 1994). The LUA-GIS layer has since been updated three times. Each update was done prior to a monitoring cycle, including this one. Previous updates were described in the 10- and 15-year monitoring reports (Davis et al. 2011, Lint 2005). The latest update for this report mainly involved the addition of congressionally reserved allocations (364,000 ac) as a result of a few new wilderness designations since the 15-year report. Other updates included land exchanges and acquisitions as well as minor editing to correct errors and clean map features. About 71,000 ac remained without assigned allocations. We attributed these areas as "no data" (ND), which represented about 0.1 percent of the total federal area and were reported as nonreserved in this report. Since NWFP implementation, LUA updates indicate a slight overall increase in federal lands (1.5 percent) with a 0.4 percent increase in reserved LUAs.

As in previous monitoring reports, riparian reserves (another NWFP-LUA consisting of protected strips along the banks of rivers, streams, lakes, and wetlands) were not delineated because of a lack of consistency in defining and delineating the stream network at the NWFP scale and varying site-specific definitions (Moeur et al. 2005). Riparian reserves were also subject to change over time based on results of watershed analysis (FEMAT 1994). Rangewide, riparian reserves were estimated to cover about 32 percent of the nonreserved matrix and AMA LUAs (USDA and USDI 1994). Thus, our estimates for reserved federal lands are biased low, and federal nonreserved estimates are biased higher than they would be if riparian reserves were accounted for.

Forest-Capable Area

Areas capable of developing into forests were delineated using a 30- by 30-m (0.22-ac) resolution GIS raster map covering the NWFP area. This map was developed for the 15-year monitoring report (Davis et al. 2011) and was not updated for this report. We used this map to "mask out" (ignore for analytical purposes) nonforested areas for each time-period map. Area estimates and other analyses in this report only apply to forest-capable areas.

LandTrendr Maps

LandTrendr maps are remotely sensed (Landsat TM) forest vegetation change detection maps that identified where, when, how much, and how long disturbance had occurred between 1993 and 2012 (Davis et al. 2015). They were developed following methods in Kennedy et al. (2010, 2012) and verified for accuracy using the TimeSync method (Cohen et al. 2010). These maps represent three aspects of vegetation change: (1) year of disturbance, (2) magnitude of disturbance, and (3) duration of disturbance. We classified these three maps to produce a single map of where timber harvesting, wildfire, insect and disease, and other natural disturbances (e.g., blowdown, floods, landslides, etc.) have occurred between 1993 and 2012 (app. D in Davis et al. 2015). Where this map overlapped losses of habitat, it helped to explain the causes for habitat loss during the 20 years since the NWFP's implementation.

Gradient Nearest Neighbor Maps

We used Gradient Nearest Neighbor (GNN) maps of forest structure and species composition (Ohmann and Gregory 2002) on forest-capable lands from two different dates, 1993 and 2012. We developed these GNN maps specifically for NWFP monitoring. Earlier versions of these GNN maps have also been used for the 15-year monitoring reports (Davis et al. 2011, Moeur et al. 2011, Raphael et al. 2011) and other broad-scale vegetation analyses across a wide range of forest ecosystems for multiple objectives (Ohmann et al. 2007, 2011, 2012; USDI FWS 2011). Along with each map, a large suite of diagnostics detailing model reliability and map accuracy were provided (app. E in Davis et al. 2015).

For both the 15- and 20-year reports, the GNN maps were developed using Landsat TM time-series data that were temporally normalized using the LandTrendr algorithm (Kennedy et al. 2010, 2012). The LandTrendr methodology removed superfluous signals (noise) in the satellite imagery, captured real trajectories of change through time, and improved consistency of GNN maps across years. This allowed us to better separate real changes in forest structure and composition from false changes owing to satellite imagery differences. For the 20-year report maps, we made several other incremental improvements to our data and methods that are summarized in Davis et al. (2015). From these GNN products, we used the same forest structure and species composition maps as environmental response variables in our habitat modeling (table 1).

Northern Spotted Owl Presence Data

Northern spotted owl pair nesting/roosting location data were needed to train and test the habitat models described below. Demographic study areas provided survey data collected annually for population monitoring. We used the most biologically important pair location based on the following hierarchical ranking: (1) active nest, (2) fledged young, (3) primary roost location, (4) diurnal location, and (5) nocturnal detection from 1993. To address sampling bias in relationship to the larger modeling region background (Fourcade et al. 2014, Phillips et al. 2009), we reduced the geographically clumped nature of these data by using only one location per NSO territory. We then filled in the modeling region spaces between demographic study areas with NSO pair presence data compiled for the 10-year monitoring report (Lint 2005). These supplemental locations were geographically thinned out and spaced using nearest-neighbor distances to randomly select a subset of these points (as described in Davis et al. 2011, pg. 30 and app. B). We did not limit the number of random supplemental locations to match the sample size from the demographic study area. Instead, we used all available location data from the 10-year monitoring report (Lint 2005) that occurred between our study areas. This produced a better spatial (less clumped) distribution of NSO locations throughout each modeling region. All locations were compiled and checked for spatial accuracy.

Habitat Modeling and Mapping

Nesting/Roosting Habitat

Methods used for modeling and making rangewide maps of NSO nesting/roosting habitat have evolved to stay abreast of the science and technology of species distribution modeling (SDM). Given the nature of rangewide NSO location data, presence-only SDM was determined to be the most feasible method for producing rangewide models and maps. Biomapper software (Hirzel et al. 2002, 2004) was used for the 10-year report (Lint 2005). For the 15-year monitoring report, we tested Biomapper with the newly developed MaxEnt software (Phillips et al. 2006, Phillips and Dudík 2008). MaxEnt outperformed Biomapper and was thus used for that reporting cycle (Davis et al. 2011). MaxEnt is now the most widely used software for conducting presence-only SDM (Merow and Silander 2014), and a recent survey of over 300 scientists found MaxEnt software is currently one of the most useful

Table 1—Forest structure and species composition variables used in the nesting/roosting habitat modeling process[a]

Variable	Description and expected habitat relationship	Units	Plot accuracy	Model region used
Forest structure and age:				
Diameter diversity index	A measure of the structural diversity of a forest stand based on tree densities in different diameter at breast height (d.b.h.) classes. Calculation procedures are described in appendix 1 of McComb et al. (2002). Positive relationship with habitat suitability.	Index	0.71 (±0.06)	All
Canopy cover of all conifers	Percentage of conifer cover in the canopy as calculated using methods in the Forest Vegetation Simulator. Positive relationship with habitat suitability.	Percentage	0.77 (±0.04)	All
Stand height	Average height of dominant and codominant trees. Positive relationship with habitat suitability.	Meters	0.64 (±0.10)	All
Mean conifer diameter	Basal area weighted mean d.b.h. of all live conifers. Positive relationship with habitat suitability.	Centimeters	0.56 (±0.12)	All
Density of large conifers	Estimated tree density for all live conifers ≥ 30 in d.b.h. Positive relationship with habitat suitability.	Trees/ha	0.60 (±0.09)	All
Stand age (no remnant)	Average stand age based on field-recorded ages of dominant and codominant tree species, and excluding remnant trees. Positive relationship with habitat suitability.	Years	0.64 (±0.10)	All
Forest species composition:				
Subalpine forest	Stand component of Pacific silver fir (*Abies amabilis* Dougl. ex Forbes), subalpine fir (*A. lasiocarpa* (Hook.) Nutt.), noble fir (*A. procera* Rehd.), Shasta red fir (*A. shastensis* (Lemmon) Lemmon), Alaska cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), Engelmann spruce (*Picea engelmannii* Parry ex Engelm.), whitebark pine (*Pinus albicaulis*, Engelm.), and mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.). Negative relationship with habitat suitability.	Percentage of total basal area	0.40 (±0.02)	221, 222, 224, 225
Pine forest	Stand component of lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Jeffrey pine (*P. jeffreyi* Grev. & Balf.), Bishop pine (*P. muricata* D. Don), and ponderosa pine (*P. ponderosa* Dougl. ex Laws.). Negative relationship with habitat suitability.	Percentage of total basal area	0.39 (±0.05)	222, 224, 225, 226
Oak woodland	Stand component of blue oak (*Quercus douglasii* Hook. & Arn.), Oregon white oak (*Q. garryana* Dougl. ex Hook.), and California black oak (*Q. kelloggii* Newb.). Negative relationship with habitat suitability.	Percentage of total basal area	0.40 (±0.06)	222, 223, 224, 225, 226
Evergreen hardwood	Stand component of Pacific madrone (*Arbutus menziesii* Pursh), tanoak (*Lithocarpus densiflorus* Rehd.), California live oak (*Quercus agrifolia* Née), canyon live oak (*Q. chrysolepis* Liebm.), and California laurel (*Umbellularia californica* (Hook. & Arn.) Nutt.). Positive relationship with habitat suitability at lower levels, then negative at higher levels.	Percentage of total basal area	0.38 (±0.07)	223, 224, 225, 226
Redwood forest	Stand component of redwood (*Sequoia sempervirens* (D. Don) Endl.). Negative relationship with habitat suitability.	Percentage of total basal area	0.60	226

[a] Structure variables were consistently used in all modeling regions. Species composition variables were used in modeling regions where they occur. Plot accuracies for structure variables are shown as mean Pearson correlations with 95-percent confidence intervals shown in parenthesis. Species composition plot accuracies were based on the mean Cohen's kappa statistic.

SDM methods available (Ahmed et al. 2015). For this reporting cycle, we followed habitat modeling and mapping methods used in the 15-year report.

MaxEnt uses a machine learning process to develop algorithms that relate environmental conditions at documented species presence locations to that of the surrounding background environment in which they occurred (Elith et al. 2011, Phillips and Dudík 2008). We used the same set of environmental variables (updated with new GNN maps) and suite of response functions (linear, product, and hinge) as in the 15-year report (Davis et al. 2011). Habitat models were developed using GNN and NSO data from 1993, then model algorithms were applied to GNN data from 2012.

The NSO range was divided into six modeling regions as in the 15-year report. Within each modeling region, 10 replicated habitat models were trained using a random subset of 75 percent of NSO locations and then tested using the remaining 25 percent in a bootstrapping procedure. In each bootstrapped replicate, environmental variables at NSO locations were analyzed against a random sample of 10,000 background locations from within the modeling region. We constrained background samples and model outputs to only forest-capable portions of the modeling region (e.g., nonforested areas such as urban areas, agricultural fields, rocks, meadows, and snow were masked out from the SDM process).

We calibrated each habitat model by evaluating how well it fit the training and testing data by varying MaxEnt's regularization multiplier (RM) setting from 0.25 to 3.0 in increments of 0.25. The regularization multiplier "tightens" (lower RM settings) or "loosens" (higher RM settings) the fit (a.k.a. the gain, which is similar to deviance) of the model output to the data. Usually, if the model fits the training data too tightly, it performs poorly when tested against species locations not used to train the model (e.g., the test gain will be lower than the training gain). During this procedure, we examined the differences between regularized training gain and testing gain. Model overfitting was indicated when training gain was significantly higher than testing gain. We also generated predicted-to-expected (P/E) ratio curves for each model using only the testing data to evaluate its predictive performance based on the shape of the curves and Spearman rank statistics (Hirzel et al. 2006). The shape of the P/E curve was based on the ratio of the proportion of NSO test locations to the proportion of modeled area available within each interval of the predicted species distribution output. A good model was indicated by low P/E ratios where the model predicted lower species occurrence and high P/E ratios where the model predicted higher species occurrence (see Davis et al. 2011 for further details). We then evaluated the predictive performance of each model based on the area under the curve (AUC) statistic (Fielding and Bell 1997), again using only the testing data. The best models were the ones with similar regularized training and testing gain (e.g., overlapping 95 percent confidence intervals), highest test AUCs, and stable P/E curves producing high Spearman rank statistics.

We used the logistic output from MaxEnt as the relative index of habitat suitability (HS) of forest structure and species composition for nesting and roosting by territorial NSO pairs. Habitat suitability ranged from 0 to 1.0, where values closer to zero have environmental conditions that are not similar to those found at NSO locations and higher values have more in common with nesting/roosting habitat. For our final habitat map products, we used the average and standard deviation of the logistic outputs from the 10 bootstrapped replicates to produce maps representing the average and 95 percent confidence intervals. Following procedures from Hirzel et al. (2006), we examined the P/E curve for each averaged model to reclassify the continuous output into four biologically meaningful habitat classes as follows:

- Unsuitable—MaxEnt logistic output from zero to the mean value between zero and the P/E = 1 threshold. This habitat class represents the lowest suitability class, and NSOs will normally avoid using it for nesting and roosting.
- Marginal—MaxEnt logistic output from the mean value between zero and the P/E = 1 threshold to the P/E = 1 threshold. This habitat class represents a condition approaching what NSOs will nest and roost in. Occasionally, these habitat characteristics are associated with nesting and roosting NSOs; however, this could be due to occurrence of legacy habitat features such as large trees, extreme rarity of suitable nesting/roosting habitat, or perhaps interspecific competition with BOs.
- Suitable—MaxEnt logistic output from the P/E = 1 threshold to 0.5. A MaxEnt logistic output value of 0.5 represents the "average" environmental condition associated with the NSO training data. This habitat class represents habitat conditions where the probability of NSO presence is higher than expected by random chance and up to average conditions associated with nesting and roosting.
- Highly suitable—MaxEnt logistic output from 0.5 to the highest output from the habitat model. This habitat class represents the most suitable, or "above average," conditions used by nesting and roosting territorial NSO pairs.

To produce rangewide maps of NSO nesting/roosting habitat, we built mosaics of the reclassified maps from each modeling region for each time period and then removed small pixel noise using a 3- by 3-pixel majority filter. We did not mosaic the continuous outputs from each model region as the HS values with each modeling region were not directly comparable (e.g., the suitable habitat thresholds between models differed). A final evaluation of the rangewide map (1993) was performed using NSO pair locations from the 10-year report (Lint 2005) that were not used in the model building described above, nor within 30 m (one pixel) of NSO locations that were used (n = 6,433).

Dispersal Habitat

Habitat used by dispersing juvenile NSOs moving away from natal areas or by subadults and adults moving between territories was mapped following methods in Davis et al. (2011, pg. 40) and briefly described here. We did not use presence locations and SDM to model dispersal habitat. Instead we developed rangewide dispersal habitat maps for both bookend periods using simple GIS queries of GNN data for mean conifer diameter at breast height (d.b.h.) ≥11 in and conifer cover ≥40 percent (Thomas et al. 1990). We also included the suitable habitat classes from our rangewide nesting/roosting habitat maps (that did not overlap pixels that met the above definition) because NSOs obviously disperse through this habitat. This accounted for just a small percentage (2.8 percent) of dispersal habitat. An examination of where suitable habitat did not overlap with the above definition showed a majority (86 percent) was due to areas where conifer cover was ≥40 percent, but mean conifer diameters were slightly below the 11-in threshold (mean = 7.1 in, standard dev. = 2.1 in). This mainly occurred in the Klamath and California Coast modeling regions where smaller diameter (<11 in d.b.h.) trees are known to make up a larger proportion of stand tree density in nesting habitat compared to other areas of the NSO range (Hershey et al. 1998). In addition, the presence of evergreen hardwoods (table 1) in these modeling regions might be expected to raise the modeled relative HS index above the suitable threshold in these stands (Diller at al. 2007, Meyer et al. 1998). We did not provide means and confidence interval maps for dispersal habitat as we did not use a bootstrap modeling procedure to produce the maps.

Habitat Assessments

Bookend Analysis

To assess habitat change in nesting/roosting and dispersal habitat, we spatially differenced the bookend maps (bookend 2012 – bookend 1993) using ArcGIS Spatial Analyst tools. This allowed us to quantify gross losses and gains as well as net changes in amount of habitat. We emphasized gross losses that were corroborated by the LandTrendr change detection data as the most reliable assessment in these bookend analyses.

Habitat Fragmentation

Following methods from Davis et al. (2011, pgs. 41–43), we used software GUIDOS v1.3 (Soille and Vogt 2009) to conduct a morphological spatial pattern analysis (MSPA) on resampled 100- by 100-m (2.47-ac) resolution binary maps of nesting/roosting habitat ("0" if unsuitable or marginal, "1" if suitable or highly suitable) for both time periods. These binary maps were converted by the MSPA process into maps showing edge, core-edge, and core patterns of habitat that were evaluated for changes using bookend analyses. As in the 15-year report, edge was not quantified as a linear perimeter measure, but instead as the area of the interface (one pixel width or 328 ft) of habitat and nonhabitat. Habitat within this distance of nonhabitat was considered "edge habitat." This distance was similar to that used by Franklin et al. (2000) and Zabel et al. (2003) to define core habitat in their analyses, thus habitat greater than this distance from nonhabitat was considered "core habitat." Habitat pixels along the periphery of core habitat were called "core-edge habitat." The combination of "core" plus "core-edge" habitat formed habitat patches that were at least 22 ac. We assessed nesting/roosting habitat fragmentation using the ratio of habitat patches (core plus core-edge) to the sum of all nesting/roosting habitat (included edge habitat). This ratio served as an index where higher percentages represented more contiguous landscapes. Decreases in this ratio between 1993 and 2012 indicated increased fragmentation of habitat, whereas positive changes in the ratio indicated less fragmentation.

Dispersal-Capable Landscape

Northern spotted owls are capable of dispersing long distances, and gene flow from one part of the range to another can occur in a few generations (Forsman et al. 2002). We used the same approach to detect changes in amounts of dispersal habitat that might affect NSO movement across the landscape as in Davis et al. (2011, pgs. 40 and 41). Briefly, we evaluated dispersal habitat at the NWFP scale using a spatial extent derived from Forsman et al. (2002). Specifically, we used a 15.5-mi radius roving circular analysis window to quantify the percentage of dispersal habitat within it for both bookend periods and included all land ownerships. A threshold of ≥40 percent dispersal habitat within this circle captured 90 percent of documented NSO movements from Forsman et al. (2002). We called areas that met this threshold "dispersal-capable landscapes." A bookend analysis was conducted on binary maps of dispersal-capable landscapes ("0" if less than 40 percent, "1" if greater than or equal to 40 percent).

Results

Habitat Modeling and Mapping

Nesting/roosting habitat models performed fair to good (Swets 1988) with mean testing AUCs ranging from 0.78 to 0.87 and mean Spearman rank correlation coefficients from 0.75 to 0.98 ($P < 0.001$) (table 2). Predicted-to-expected curves are shown in figure 1. Our habitat models produced continuous relative indices of habitat suitability for nesting and roosting. We in turn classified these continuums into discrete habitat classes for monitoring purposes. Nesting/roosting habitat bookend maps are displayed in figures 2 and 3, showing patterns of habitat classes across the range of the NSO. The majority (95 percent) of the subset of the 10-year report (Lint 2005) NSO locations were in or within 100 m (the spatial accuracy of these data) of mapped suitable habitat. About 4.5 percent occurred within marginal habitat, and less than 1 percent occurred within unsuitable habitat. Suitable nesting/roosting habitat in both time periods was concentrated on federally managed lands.

On average, stand structure variables provided most (68 percent) of the explanatory information in the habitat models. The strongest structural variables were density of large conifers and conifer cover (table 1). Conifer cover was particularly strong (31 percent) in the California Coast model. Stand age contributed about 11 percent on average, while species composition variables contributed about 21 percent on average. Species composition was more important in drier modeling regions (e.g., east Cascades and Klamath) and also in the redwood region (California Coast). We summarized forest structure and age attributes to help interpret what map

Table 2—Species distribution modeling bootstrapped replicate (n = 10) results for model fit (gain) and testing statistics (95 percent confidence limits shown in parenthesis)

Modeling region	Training sample size	Testing sample size	RM	Training gain	Testing gain	Testing AUC	Spearman rank
	---- *Number* ----						
Washington Coast and Cascades	250	83	0.25	1.07 (±0.04)	1.02 (±0.05)	0.87 (±0.01)	0.93 (±0.04)
Washington Eastern Cascades	87	28	1	0.93 (±0.06)	0.86 (±1.00)	0.84 (±0.01)	0.75 (±0.15)
Oregon Coast Range	247	82	1.75	0.98 (±0.02)	0.99 (±0.01)	0.86 (±0.01)	0.95 (±0.01)
Oregon and California Cascades	596	198	1.25	0.66 (±0.03)	0.64 (±0.03)	0.80 (±0.01)	0.90 (±0.07)
Oregon and California Klamath	757	252	2	0.53 (±0.01)	0.54 (±0.03)	0.78 (±0.01)	0.98 (±0.02)
California Coast	175	58	1	0.74 (±0.05)	0.62 (±0.09)	0.80 (±0.02)	0.83 (±0.13)

RM = regularization multiplier, AUC = area under the curve.

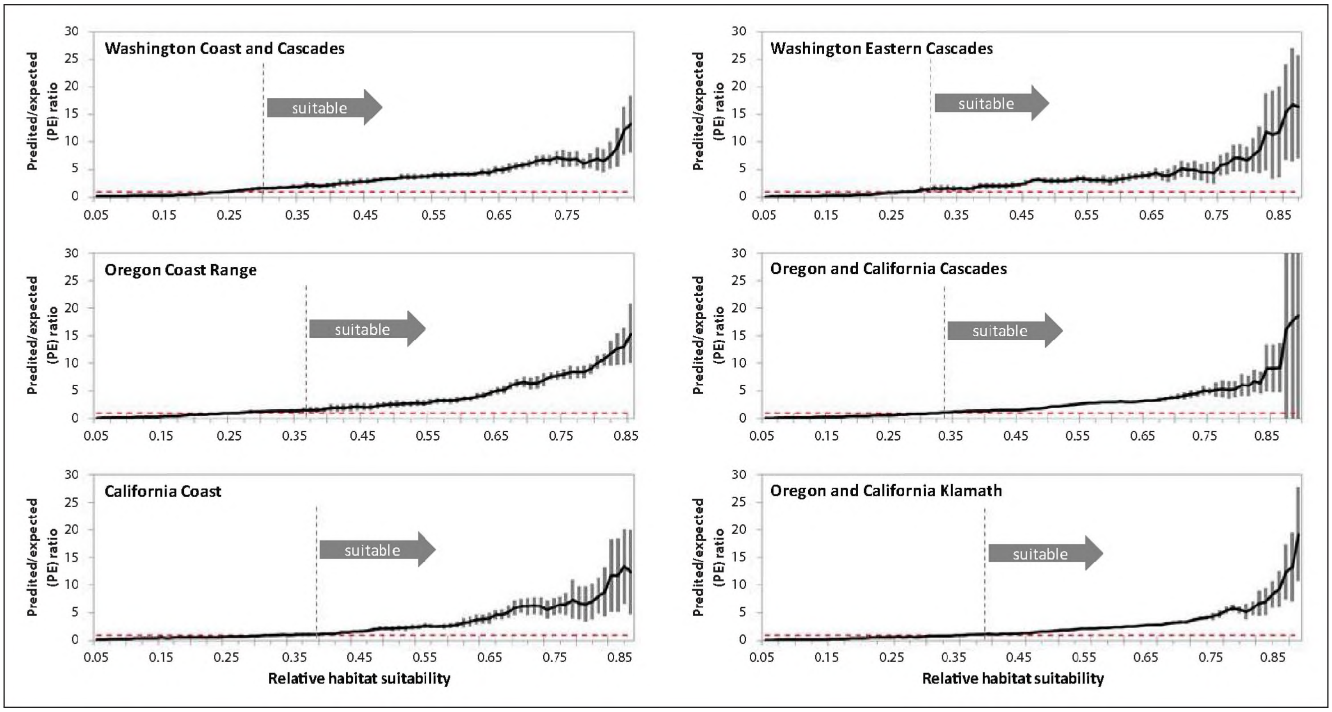


Figure 1—Predicted-to-expected (P/E) ratio curves for northern spotted owl nesting/roosting habitat models. The red dashed line represents P/E = 1 (random model line). The dashed vertical line represents the habitat suitability threshold that denotes habitat suitable for nesting and roosting by northern spotted owls.

habitat classes represent on the ground (table 3 and fig. 4). Relationships between habitat variables and modeled habitat suitability (table 1) were as expected based on examination of response function curves in the MaxEnt outputs and also NSO habitat associations as summarized by Courtney et al. (2004). Consistently, modeled habitat suitability showed positive relationships with stand structure attributes commonly associated with NSO nesting habitat (fig. 4). Stand age showed lower differences between suitability classes in the California Coast modeling region where NSOs have been documented to use younger stands (Diller et al. 2007).

We explored the BO effect on NSO habitat selection by analyzing the change in modeled habitat suitability from the 1993 map and a time series of annual NSO locations from the Tyee density study area. This study area surveys all habitat within its boundary, as opposed to the "territorial study areas" that only survey historical NSO territories that are sometimes separated by large areas of unsurveyed habitat outside of the territory bounds. We detected a strong negative correlation ($r = -0.894$) between the increasing trend in proportion of NSO territories with BO detections and the average habitat suitability at annual NSO locations. The average habitat suitability at NSO sites in 2013 was significantly lower than it was in 1990, when the study began (fig. 5).

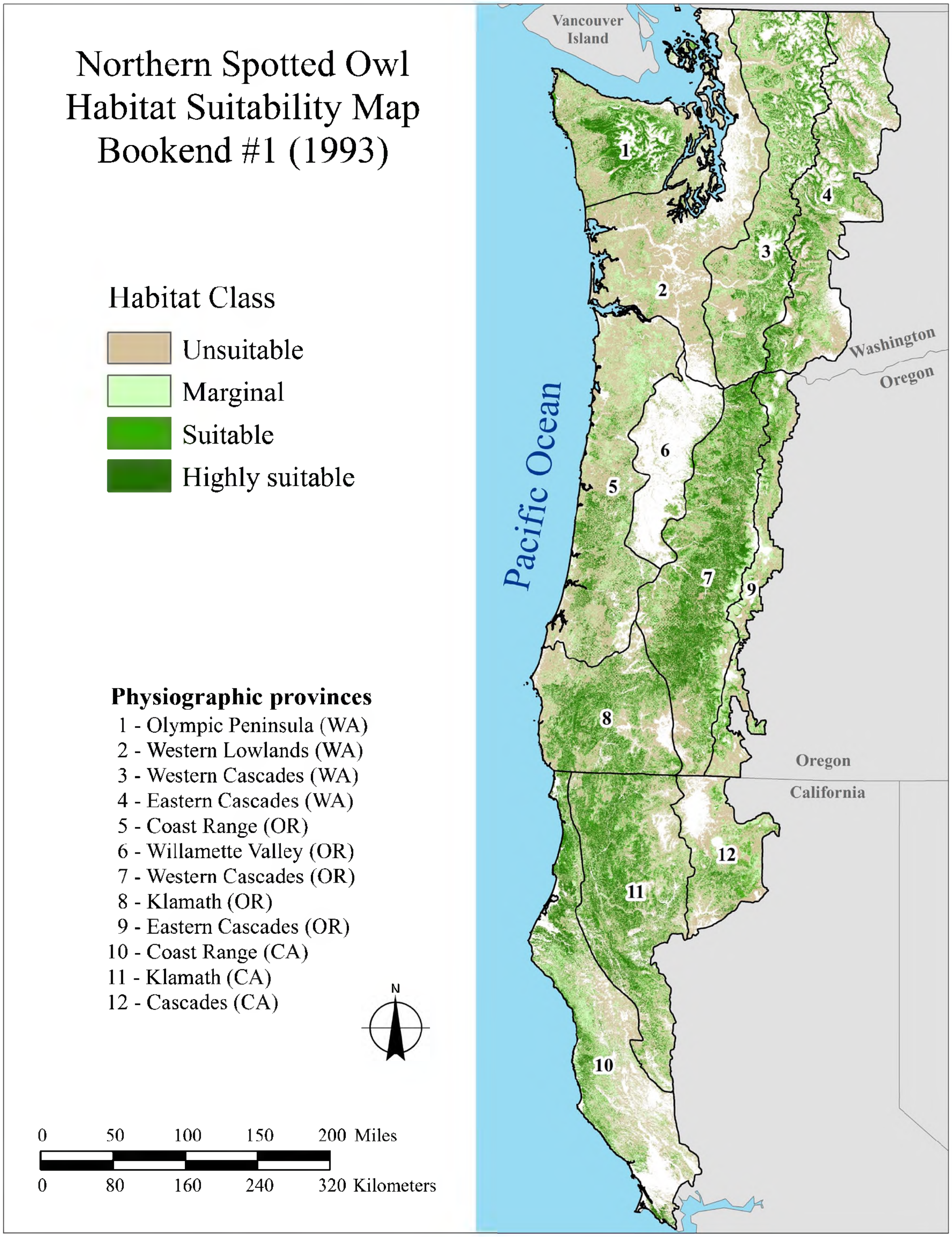


Figure 2—Bookend #1 nesting/roosting habitat map for the Northwest Forest Plan area in Washington (WA), Oregon (OR), and California (CA).

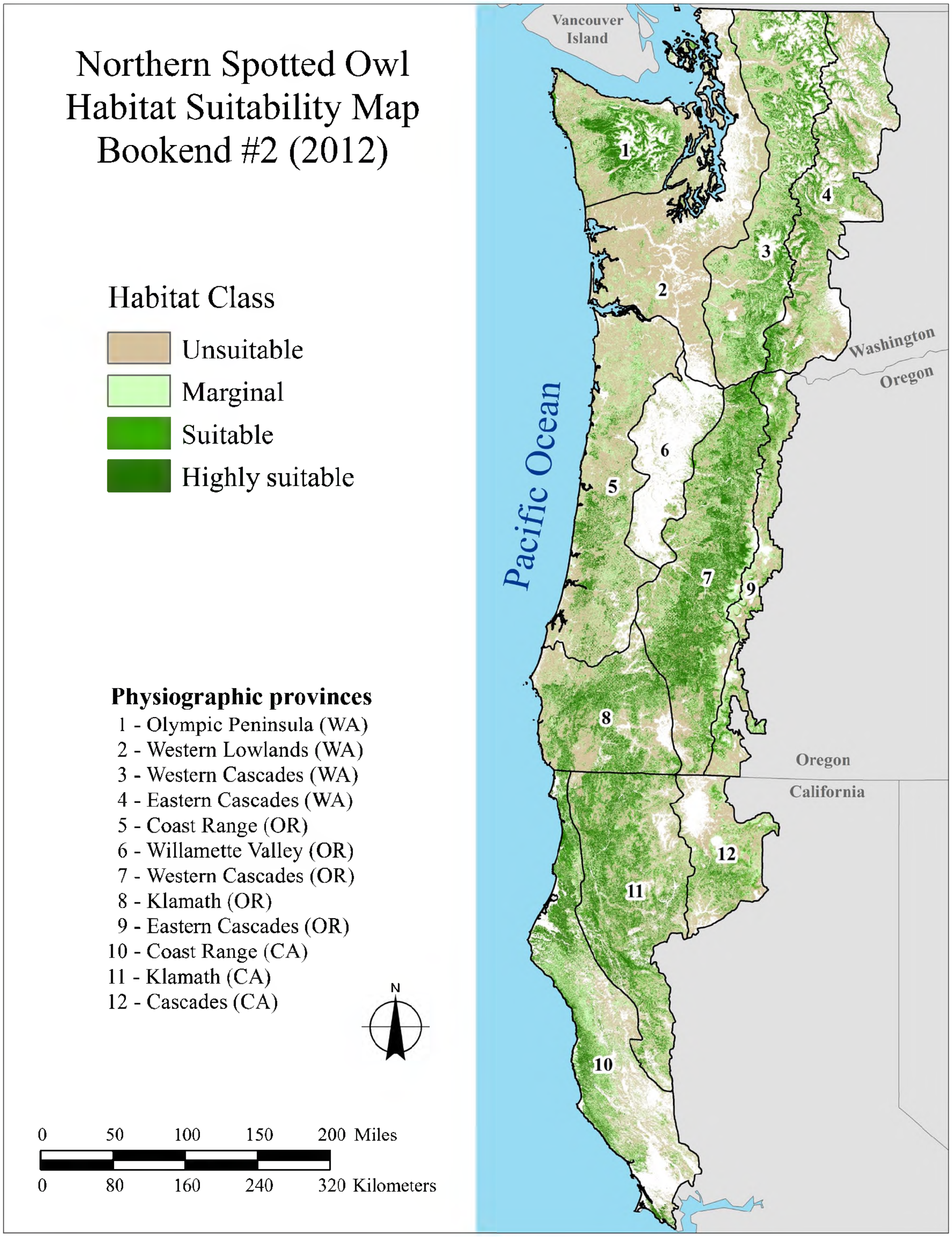


Figure 3—Bookend #2 nesting/roosting habitat map for the Northwest Forest Plan area in Washington (WA), Oregon (OR), and California (CA).

Table 3—Average (standard deviation) forest structure and age (gradient nearest neighbor) attributes for nesting/roosting habitat classes in each modeling region

Modeling region	Habitat class	Habitat suitability	Conifer cover	Average conifer d.b.h.	Large conifer (≥30 in d.b.h.)	Diameter diversity index	Average stand height	Average stand age	Old-growth structure index
			Percent	*Inches*	*Trees/acre*	*Index*	*Feet*	*Years*	*Index*
Washington Coast and Cascades	Unsuitable	0–8	41 (31)	10 (9)	0 (1)	2 (2)	44 (33)	33 (32)	3 (10)
	Marginal	9–30	81 (12)	17 (7)	3 (6)	5 (2)	76 (31)	102 (83)	16 (23)
	Suitable	31–50	84 (11)	26 (11)	10 (9)	6 (2)	95 (35)	192 (109)	40 (25)
	Highly suitable	>50	89 (16)	31 (8)	16 (8)	7 (1)	110 (30)	247 (78)	58 (20)
Washington Eastern Cascades	Unsuitable	0–8	50 (29)	13 (6)	1 (2)	50 (2)	43 (23)	99 (55)	15 (22)
	Marginal	9–31	62 (19)	16 (6)	2 (3)	62 (1)	55 (22)	106 (47)	18 (21)
	Suitable	32–50	70 (14)	18 (6)	3 (4)	70 (1)	72 (19)	125 (58)	23 (23)
	Highly suitable	>50	79 (11)	21 (6)	6 (7)	79 (1)	91 (18)	155 (61)	36 (21)
Oregon Coast Range	Unsuitable	0–12	37 (30)	9 (9)	0 (1)	2 (2)	37 (25)	29 (20)	3 (11)
	Marginal	13–37	68 (18)	20 (8)	2 (3)	5 (1)	84 (20)	60 (22)	10 (18)
	Suitable	38–50	67 (14)	32 (12)	10 (7)	6 (1)	118 (27)	118 (61)	37 (24)
	Highly suitable	>50	71 (11)	35 (7)	18 (8)	7 (1)	141 (26)	159 (56)	55 (18)
Oregon-California Cascades	Unsuitable	0–12	34 (24)	11 (9)	1 (2)	2 (1)	35 (25)	58 (46)	6 (16)
	Marginal	13–33	72 (16)	16 (6)	2 (4)	4 (1)	64 (20)	107 (62)	18 (22)
	Suitable	34–50	76 (12)	21 (6)	5 (5)	6 (1)	88 (23)	132 (65)	30 (23)
	Highly suitable	>50	76 (9)	30 (6)	16 (9)	7 (1)	123 (25)	229 (75)	54 (18)
Oregon-California Klamaths	Unsuitable	0–15	24 (23)	11 (9)	1 (3)	2 (2)	32 (20)	65 (35)	6 (16)
	Marginal	16–37	49 (21)	19 (8)	3 (5)	4 (1)	54 (22)	97 (50)	20 (24)
	Suitable	38–50	60 (18)	26 (9)	7 (7)	6 (1)	74 (29)	139 (68)	40 (21)
	Highly suitable	>50	62 (16)	31 (9)	10 (6)	7 (1)	89 (27)	161 (63)	47 (18)
California Coast	Unsuitable	0–14	17 (20)	10 (11)	0 (1)	3 (2)	37 (13)	63 (24)	12 (22)
	Marginal	15–39	52 (22)	21 (14)	2 (4)	5 (2)	55 (25)	73 (71)	16 (23)
	Suitable	40–50	66 (22)	25 (14)	5 (7)	5 (1)	73 (35)	86 (72)	23 (25)
	Highly suitable	>50	79 (16)	25 (12)	8 (8)	6 (1)	81 (27)	76 (47)	26 (27)

d.b.h. = diameter at breast height.

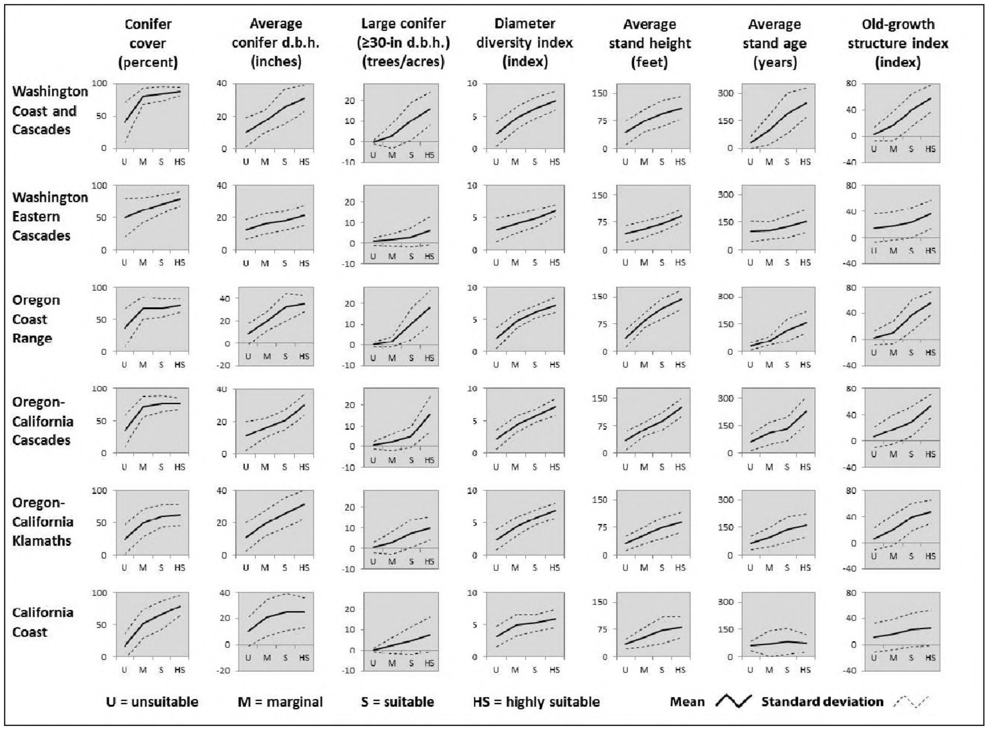


Figure 4—Relationship between nesting/roosting habitat classes with forest structure and age (see table 3). U = unsuitable, M = marginal, S = suitable, HS = highly suitable, d.b.h. = diameter as breast height.

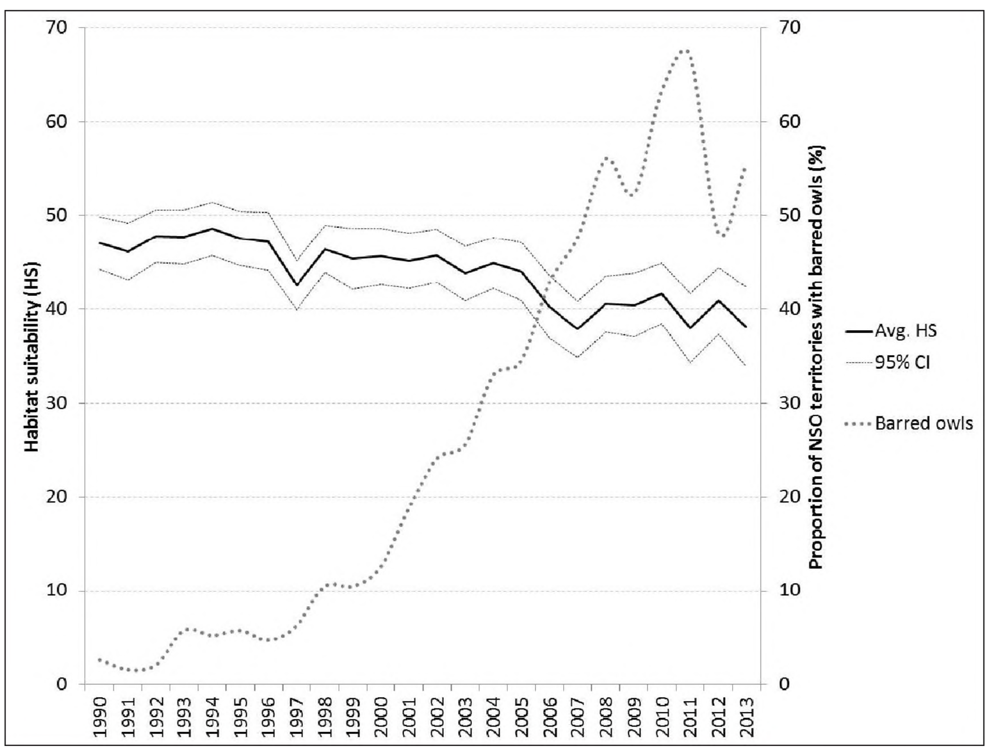


Figure 5— Relationship between barred owl presence and northern spotted owl (NSO) habitat selection. CI = confidence interval.

Table 4—Bookend map areal estimates of nesting/roosting habitat and net changes from 1993 to 2012 on nonreserved federal lands (left), assigned causes for losses from LandTrendr disturbance maps (right)

	Nesting/roosting habitat estimates from bookend maps				LandTrendr disturbance assignment for losses					
State and physiographic province	1993	2012	Net area change	Net percentage change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Acres			*Percent*	*Acres*					*Percent*
Washington:										
Olympic Peninsula	23,000	23,100	100	0.4	300	0	0	0	300	-1.3
Western Lowlands	0	0	0	0	0	0	0	0	0	0
Western Cascades	209,800	212,300	2,500	1.2	3,700	0	100	0	3,800	-1.8
Eastern Cascades	221,600	224,800	3,200	1.4	10,200	10,600	4,700	0	25,500	-11.5
Total	454,400	460,200	5,800	1.3	14,200	10,600	4,800	0	25,500	-6.5
Oregon:										
Coast Range	74,700	79,500	4,800	6.4	4,400	0	100	0	4,500	-6.0
Willamette Valley	5,700	6,100	400	7.0	200	0	0	0	200	-3.5
Western Cascades	1,029,100	1,070,900	41,800	4.1	30,100	11,900	1,600	0	43,600	-4.2
Klamath	361,400	381,700	20,300	5.6	10,400	15,600	700	0	26,700	-7.4
Eastern Cascades	105,500	134,600	29,100	27.6	6,700	3,600	800	0	11,100	-10.5
Total	1,576,400	1,672,800	96,400	6.1	51,800	31,100	3,200	0	86,100	-5.5
California:										
Coast Range	7,300	10,000	2,700	37.0	0	100	0	0	100	-1.4
Klamath	615,100	621,800	6,700	1.1	8,200	41,800	1,100	0	51,100	-8.3
Cascades	84,000	89,300	5,300	6.3	6,100	2,300	800	0	9,200	-11.0
Total	706,400	721,100	14,700	2.1	14,300	44,200	1,900	0	60,400	-8.6
NWFP total	2,737,200	2,854,100	116,900	4.3	80,300	85,900	9,900	0	176,100	-6.4

NWFP = Northwest Forest Plan.

Table 5—Bookend map areal estimates of nesting/roosting habitat and net changes from 1993 to 2012 on reserved federal lands (left), assigned causes for losses from LandTrendr disturbance maps (right)

	Nesting/roosting habitat estimates from bookend maps				LandTrendr disturbance assignment for losses					
State and physiographic province	1993	2012	Net area change	Net percentage change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Acres			*Percent*	*Acres*					*Percent*
Washington:										
Olympic Peninsula	742,900	714,500	-28,400	-3.8	1,400	1,000	700	2,200	5,300	-0.7
Western Lowlands	12,900	12,900	0	0	0	0	0	600	600	-4.7
Western Cascades	947,900	957,200	9,300	1.0	3,100	2,600	800	3,500	10,000	-1.1
Eastern Cascades	611,200	554,600	-56,600	-9.3	14,300	41,500	29,400	3,100	88,300	-14.4
Total	2,314,900	2,239,200	-75,700	-3.3	18,800	45,100	30,900	9,400	104,200	-4.5
Oregon:										
Coast Range	421,300	426,800	5,500	1.3	3,300	100	100	0	3,500	-0.8
Willamette Valley	1,400	1,400	0	0	0	0	0	0	0	0
Western Cascades	1,315,200	1,300,500	-14,700	-1,1	4,800	51,100	900	1,100	57,900	-4.4
Klamath	637,200	550,400	-86,800	-13.6	3,600	116,400	200	200	120,400	-18.9
Eastern Cascades	193,700	205,000	11,300	5.8	1,700	11,200	800	300	14,000	-7.2
Total	2,568,800	2,484,100	-84,700	-3.3	13,400	178,800	2,000	1,600	195,800	-7.6
California:										
Coast Range	106,100	113,800	7,700	7.3	100	1,700	0	500	2,300	-2.2
Klamath	1,245,700	1,142,900	-102,800	-8.3	2,200	158,000	2,200	2,600	165,000	-13.2
Cascades	117,400	120,000	2,600	2.2	1,000	4,900	300	300	6,500	-5,5
Total	1,469,200	1,376,700	-92,500	-6.3	3,300	164,600	2,500	3,400	173,800	-11.8
NWFP total	6,352,900	6,100,000	-252,900	-4.0	35,500	388,500	35,400	14,400	473,800	-7.5

NWFP = Northwest Forest Plan.

Table 6—Bookend map areal estimates of nesting/roosting habitat and net changes from 1993 to 2012 on all federal lands (left), assigned causes for losses from LandTrendr disturbance maps (right)

State and physiographic province	Nesting/roosting habitat estimates from bookend maps: 1993	2012	Net area change	Net percentage change	LandTrendr disturbance assignment for losses: Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Acres			*Percent*	*Acres*					*Percent*
Olympic Peninsula	765,800	737,600	-28,200	-3.7	1,700	1,000	800	2,200	5,700	-0.7
Western Lowlands	12,900	12,900	0	0	0	0	0	600	600	-4.7
Western Cascades	1,157,700	1,169,500	11,800	1.0	6,900	2,600	900	3,500	13,900	-1.2
Eastern Cascades	832,700	779,400	-53,300	-6.4	24,400	52,100	34,000	3,100	113,600	-13.6
Total	2,769,100	2,699,400	-69,700	-2.5	33,000	55,700	35,700	9,400	133,800	-4.8
Oregon:										
Coast Range	496,000	506,200	10,200	2.1	7,700	100	200	0	8,000	-1.6
Willamette Valley	7,000	7,500	500	7.1	300	0	0	0	300	-4.3
Western Cascades	2,344,300	2,371,400	27,100	1.2	34,900	63,000	2,500	1,100	101,500	-4.3
Klamath	998,700	932,100	-66,600	-6.7	14,000	132,000	900	200	147,100	-14.7
Eastern Cascades	299,200	339,600	40,400	13.5	8,400	14,700	1,700	300	25,100	-8.4
Total	4,145,200	4,156,800	11,600	0.3	65,300	209,800	5,300	1,600	282,000	-6.8
California:										
Coast Range	113,300	123,800	10,500	9.3	200	1,800	0	500	2,500	-2.2
Klamath	1,860,800	1,764,700	-96,100	-5.2	10,400	199,800	3,300	2,600	216,100	-11.6
Cascades	201,300	209,300	8,000	4.0	7,200	7,200	1,100	300	15,800	-7.8
Total	2,175,400	2,097,800	-77,600	-3.6	17,800	208,800	4,400	3,400	234,400	-10.8
NWFP total	9,089,700	8,954,000	-135,700	-1.5	116,100	474,300	45,400	14,400	650,200	-7.2

NWFP = Northwest Forest Plan.

Table 7—Bookend map areal estimates of nesting/roosting habitat and net changes from 1993 to 2012 on all (federal and nonfederal) lands (left), assigned causes for losses from LandTrendr disturbance maps (right)

State and physiographic province	Nesting/roosting habitat estimates from bookend maps: 1993	2012	Net area change	Net percentage change	LandTrendr disturbance assignment for losses: Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Acres			*Percent*	*Acres*					*Percent*
Washington:										
Olympic Peninsula	936,200	859,600	-76,600	-8.2	41,400	1,000	2,500	2,200	47,100	-5.0
Western Lowlands	184,500	108,900	-75,600	-41.0	81,200	0	1,400	600	83,200	-45.1
Western Cascades	1,391,700	1,350,600	-41,100	-3.0	71,400	2,900	2,000	3,500	79,800	-5.7
Eastern Cascades	1,181,200	1,068,400	-112,800	-9.5	110,100	58,600	40,500	3,100	212,300	-18.0
Total	3,693,600	3,387,500	-306,100	-8.3	304,100	62,500	46,400	9,400	422,400	-11.4
Oregon:										
Coast Range	788,600	696,500	-92,100	-11.7	137,400	400	1,800	0	139,600	-17.7
Willamette Valley	88,400	70,900	-17,500	-19.8	26,700	0	300	0	27,000	-30.5
Western Cascades	2,820,000	2,710,700	-109,300	-3.9	255,100	65,000	5,100	1,100	326,300	-11.6
Klamath	1,238,900	1,175,300	-63,600	-5.1	85,500	134,400	2,200	200	222,300	-17.9
Eastern Cascades	408,500	438,400	29,900	7.3	37,200	19,300	2,900	300	59,700	-14.6
Total	5,344,400	5,091,800	-252,600	-4.7	541,900	219,100	12,300	1,600	774,900	-14.5
California:										
Coast Range	970,700	1,198,500	227,800	23.5	79,500	5,600	2,900	500	88,500	-9.1
Klamath	2,148,500	2,063,400	-85,100	-4.0	50,100	208,100	5,600	2,600	266,400	-12.4
Cascades	368,500	362,500	-6,000	-1.6	44,700	10,500	3,300	300	58,800	-16.0
Total	3,487,700	3,624,400	136,700	3.9	174,300	224,200	11,800	3,400	413,700	-11.9
NWFP total	12,525,700	12,103,700	-422,000	-3.4	1,020,300	505,800	70,500	14,400	1,611,000	-12.9

NWFP = Northwest Forest Plan.

Habitat Assessments

Nesting/Roosting Habitat

Habitat area net change and loss estimates are shown in tables 4 thru 7. We estimated a rangewide gross loss of about 650,200 ac of nesting/roosting habitat on federal lands (table 6). This amounted to about 7.2 percent of what was present in 1993. Most of the losses (73 percent) occurred within the federally reserved LUAs, or a loss of about 7.5 percent of the habitat reserved by the NWFP. Nonreserved federal LUAs experienced a 6.4 percent rangewide loss of habitat that existed in 1993.

Wildfires were the primary cause of habitat loss since 1993, accounting for about 82 percent of the loss in reserved allocations (388,500 ac) and about half of the loss in nonreserved allocations (85,900 ac). Timber harvesting accounted for about 45 percent of the loss in nonreserved allocations (80,300 ac) and 8 percent within reserved allocations (35,500 ac). Harvests within reserved allocations were due to (1) timber sales that were under contract at the implementation of the NWFP and (2) harvesting that occurred in nonreserved allocations that were subsequently added to reserved allocations (e.g., land exchanges, wilderness designations, etc.). Insects, diseases, and other natural disturbances accounted for a minor proportion (0.7 percent) of habitat loss since 1993.

Relative to the baseline maps based on LandTrendr change-detection data, the physiographic province that experienced the greatest loss of habitat was the California Klamath province (fig. 6). The Oregon and California Klamath physiographic provinces experienced the largest amounts (132,000 to 199,800 ac, respectively) and double digit percentage losses (13.2 and 10.7 percent, respectively) of habitat

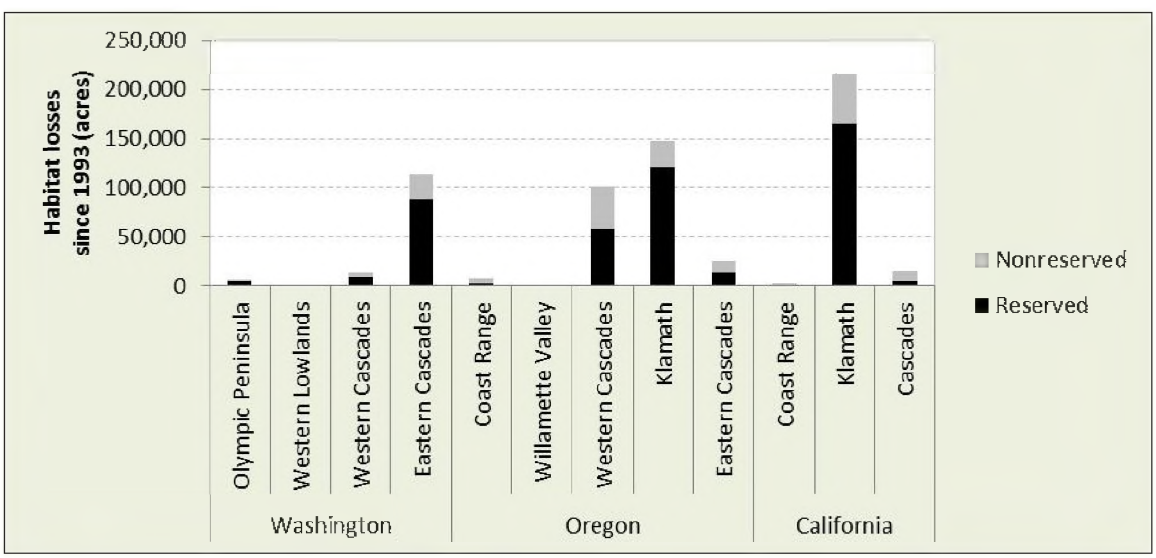


Figure 6—Nesting/roosting habitat losses on federal lands between 1993 and 2012 by physiographic province.

lost owing to wildfires. Other physiographic provinces that experienced significant amounts of habitat loss to wildfire include the Oregon Western Cascades (63,000 ac) and the Washington Eastern Cascades (52,100 ac). Most of these wildfire-related habitat losses occurred in the federally reserved LUAs (fig. 7)

Habitat recruitment estimates have a higher level of uncertainty than estimates of habitat loss for reasons explained in the 15-year monitoring report (Davis et al. 2011, pgs. 48 and 49). However, we used gains and losses to estimate net changes in this report. Considering both gains and losses, we estimated a rangewide net decrease in nesting/roosting habitat of 1.5 percent on all federal lands (table 6). Within the federally reserved allocations, the net change was a 4.0 percent decline (table 5), which was less than the 2.5 percent per decade (5 percent over two decades) loss rate anticipated in the NWFP's design. In nonreserved federal LUAs, we estimated a net increase of 4.3 percent since 1993. Most of the gains occurred in the moister physiographic provinces (e.g., Coast Ranges and Western Cascades); however, we also observed a large gain (13.5 percent) in the Oregon Eastern Cascades. When compared to the results of the concurrent late-successional and old-growth forest monitoring (Davis et al. 2015), which estimated a net decrease of 0.8 to 2.8 percent of older forests defined purely by structural attributes (e.g., old-growth structure index) in the same area, we suspect the reason behind the net gain in NSO habitat was driven by species composition changes (e.g., understory development of Douglas-fir [*Pseudosuga menziesii* (Mirb.) Franco] and grand fir [*Abies grandis* Douglas ex D. Don Lindl.]) that in pine stands would lower the percentage of stand basal area composed of pine (see table 1). Shifts in species compositions in the higher elevations (e.g., silver fir [*Abies amabilis* (Douglas ex Loud) Douglas ex Forbes], mountain hemlock [*Tsuga mertensiana* (Bong.) Carr.], etc.) could have similar results. Regardless, given the uncertainty in our nesting/roosting habitat map estimates, the net habitat changes fell within the 95 percent confidence intervals of our estimates (fig. 8).

Habitat Fragmentation

Rangewide, nesting/roosting habitats have become slightly more fragmented on federal lands (both reserved and nonreserved) with about a 1.1 percent conversion of core habitat to edge habitat. The changes vary by physiographic province (table 8). In Washington, the reserved allocations have become slightly more contiguous (0.1 to 4.5 percent increase), except for the Eastern Cascades, where core/core-edge habitat decreased by 1.7 percent. In Oregon, federal reserves have generally become slightly more fragmented (0.5 to 2.7) with the highest increase in fragmentation in the Oregon Klamath province. However, habitat has become slightly more contiguous in the Oregon Eastern Cascades (4.9 percent). In California, reserved habitat

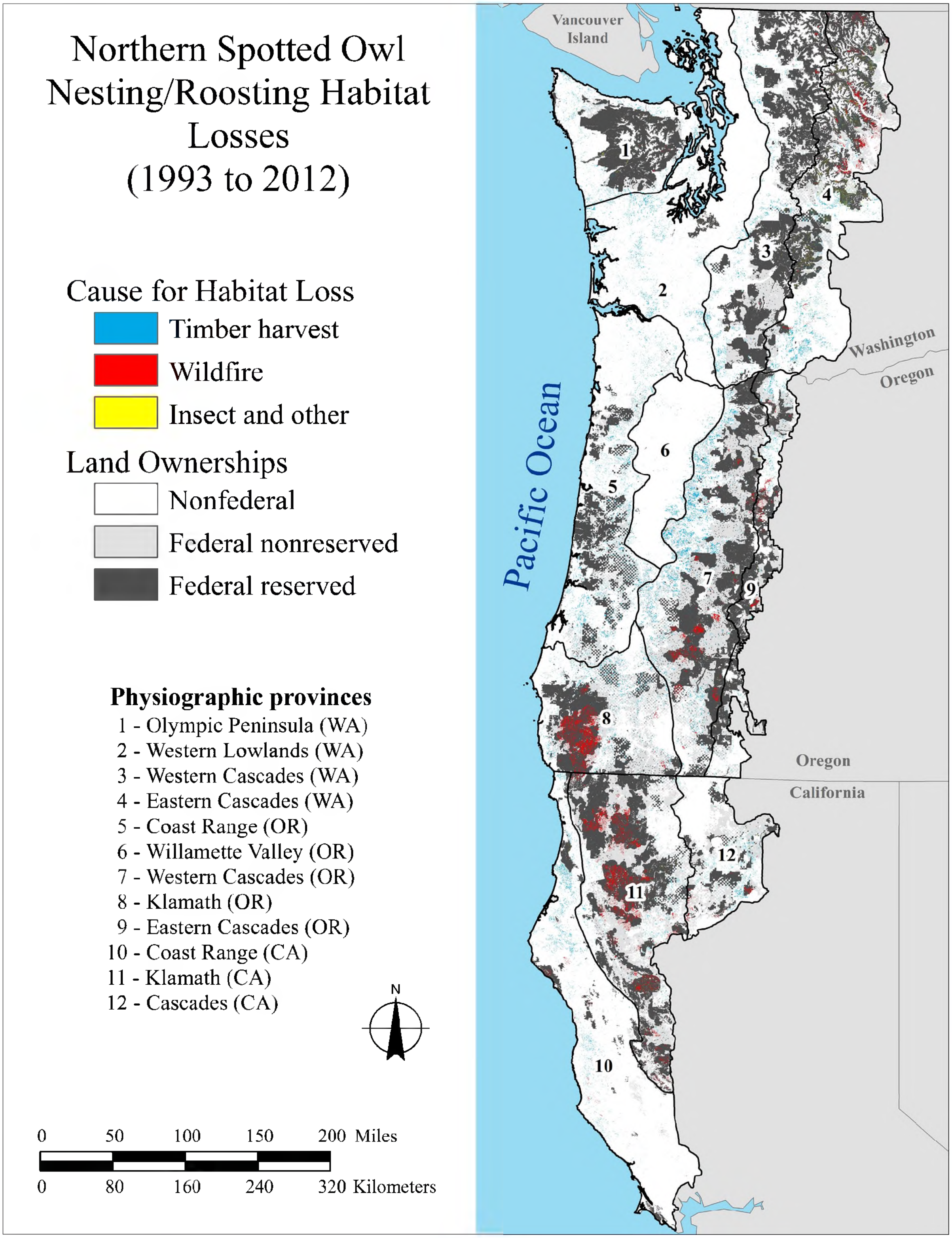


Figure 7—Map of nesting/roosting habitat losses on all lands by disturbance agent between 1993 and 2012 in Washington (WA), Oregon (OR), and California (CA). Note wildfires within federal reserved land use allocations.

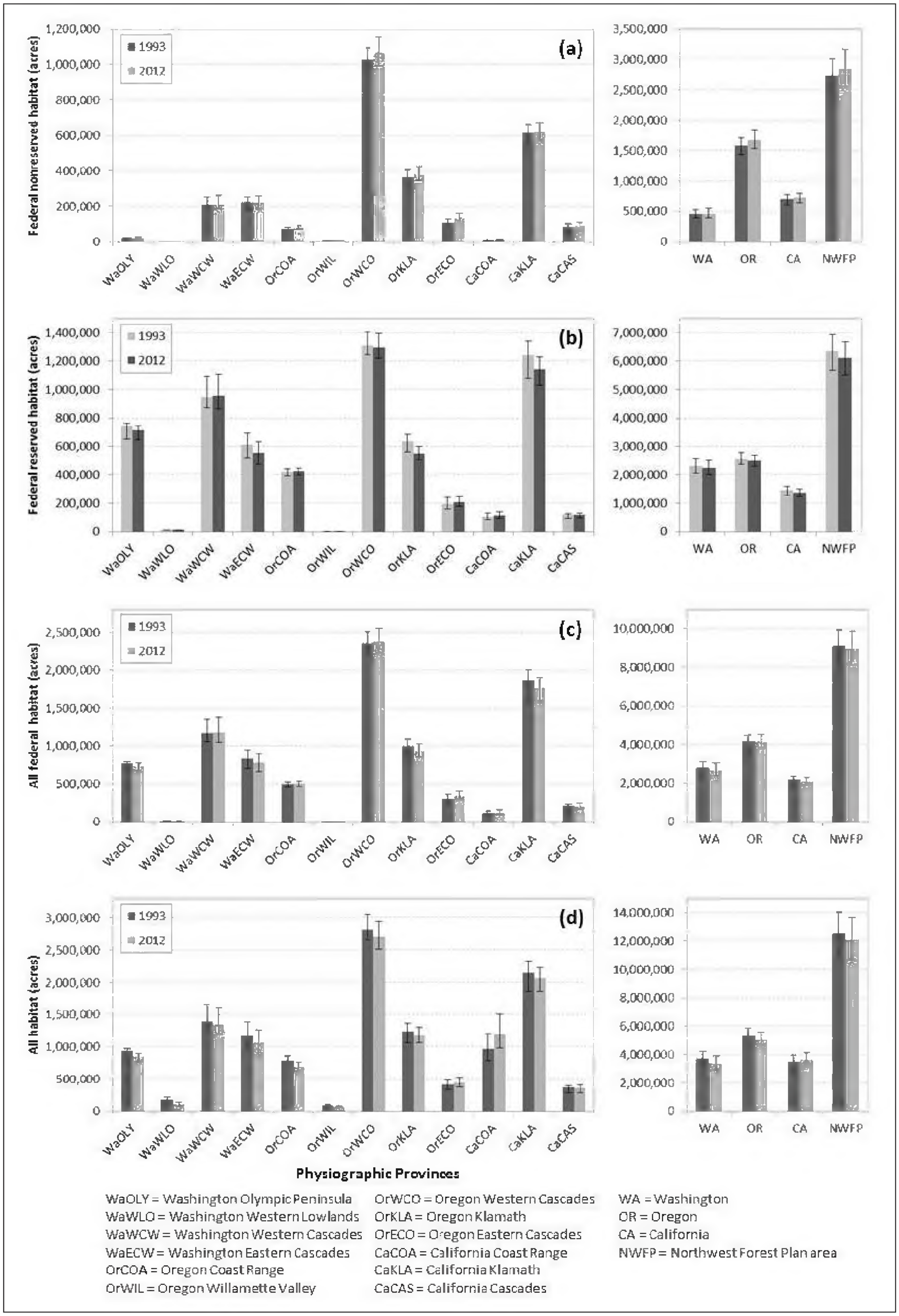


Figure 8—Histogram of nesting/roosting habitat bookend analysis results showing areal estimates of habitat for 1993 and 2012. Error bars represent 95-percent confidence intervals.

Table 8—Nesting/roosting habitat fragmentation bookend analysis

Physiographic province	Reserved			Nonreserved		
	1993	2012	Change	1993	2012	Change
	Percentage					
Washington Olympic Peninsula	85.5	85.6	0.1	39.4	39.0	-0.4
Washington Western Lowlands	18.7	23.2	4.5	0	0	0
Washington Western Cascades	69.4	70.6	1.2	61.0	57.1	-3.9
Washington Eastern Cascades	66.5	64.8	-1.7	59.8	62.7	2.9
Oregon Coast Range	69.7	69.2	-0.5	47.3	43.4	-3.9
Oregon Willamette Valley	56.3	54.7	-1.6	62.4	58.5	-4.0
Oregon Western Cascades	84.3	82.7	-1.6	75.5	74.2	-1.2
Oregon Klamath	74.5	71.7	-2.7	60.8	62.5	1.7
Oregon Eastern Cascades	63.4	68.3	4.9	53.6	56.7	3.1
California Coast Range	76.2	77.0	0.8	51.8	68.9	17.1
California Klamath	72.5	68.7	-3.8	62.2	60.2	-2.0
California Cascades	60.4	61.6	1.2	47.8	49.7	1.9

[a] The level of fragmentation was based on the proportion of all nesting/roosting habitat consisting of patch habitat (core plus core-edge). Lower percentages indicate higher levels of fragmentation.

has become slightly more contiguous in the Coast Range and Cascades (0.8 to 1.2 percent, respectively) and more fragmented in the Klamath province (3.8 percent).

In nonreserved federal LUAs, habitat has generally become more fragmented (0.4 to 3.9 percent) on the west side, and slightly more contiguous on the east side (2.9 percent). In Oregon, the same pattern was observed with more fragmentation in the moister provinces (1.2 to 4.0) and more contiguous habitat in the drier provinces (1.7 to 3.1). In California, as in the reserved allocations, nonreserved federal habitat became more fragmented in the Klamath province and less in the Coast and Cascades provinces.

Habitat Dispersal

Rangewide, we report an estimated gross loss of about 789,500 ac of dispersal habitat on federal lands, most (79 percent) from wildfire (621,900 ac). The causes for dispersal habitat loss were similar to those for nesting/roosting habitat losses, with wildfire being the main cause in reserved allocations and more than half of the loss in nonreserved allocations (tables 9 through 12). Timber harvesting accounted for the 17,800 ac of the loss in nonreserved allocations, and insects and disease account for a small percentage of loss in all allocations. However, these losses were offset by a 1.13-million-ac gross gain in dispersal habitat on federal land from forest succession, resulting in a 2.2-percent overall net gain of dispersal habitat coverage across the NSO's range (table 11). In general, the gains in dispersal habitat were higher in federal nonreserved allocations than in reserved allocations.

At the NWFP scale, we detected a 10 percent gross loss of dispersal-capable landscape, mostly around the periphery of the federal forests. We suspect this may be due to second-rotation regeneration timber harvesting occurring in dispersal habitats on nonfederal lands that border federal lands. Large wildfires on federal lands played a role in this decrease in the eastern Cascade provinces and the Oregon Klamath Mountain province. We also detected a 5 percent gross gain in dispersal-capable landscapes along the periphery of some federal forests caused by forest succession in younger forests, resulting in an overall net decrease of 5 percent in dispersal-capable landscapes since 1993. In general, the dispersal-capable landscape has receded by a few miles into federally managed lands in Washington and Oregon (fig. 9). Some internal losses occurred within large reserves in the Washington Eastern Cascades. California has been resilient to many large wildfires and dispersal-capable lands mostly expanded along the coastal regions owing to rapid growth of redwood forests. The large reserve network remains mostly intact for dispersal, even with many large wildfires occurring within some of them. One notable change is due to the large Biscuit Fire that caused a wide loss of dispersal-capable lands within a large reserve, separating the northern portion from the southern portion by about 15 mi (fig. 9). Other noteworthy changes include the loss of a connection between the Oregon Coast Range and the Oregon Western Cascades, the loss of a connection between the central portion of the Oregon Coast Range physiographic province and its northern end, a widening of the southern connection in the same province, and an increased isolation of the Olympic Peninsula (fig. 9).

Table 9—Bookend map areal estimates of dispersal habitat and net changes from 1993 to 2012 on nonreserved federal lands (left), assigned causes for losses from LandTrendr disturbance maps (right)

	Dispersal habitat estimates from bookend maps				LandTrendr disturbance assignment for losses					
State and physiographic province	1993	2012	Net area change	Net percentage change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Acres			*Percent*	*Acres*					*Percent*
Washington:										
Olympic Peninsula	71,600	84,400	12,800	17.9	600	0	0	0	600	-0.8
Western Lowlands	200	300	100	50.0	0	0	0	0	0	0
Western Cascades	410,800	471,100	60,300	14.7	3,900	0	100	0	4,000	-1.0
Eastern Cascades	387,100	393,800	6,700	1.7	10,100	16,400	3,000	0	29,500	-7.6
Total	869,700	949,600	79,900	9.2	14,600	16,400	3,100	0	34,100	-3.9
Oregon:										
Coast Range	245,300	287,900	42,600	17.4	7,500	0	200	0	7,700	-3.1
Willamette Valley	9,700	10,700	1,000	10.3	200	0	0	0	200	-2.1
Western Cascades	1,384,700	1,507,300	122,600	8.9	24,400	13,700	1,200	0	39,300	-2.8
Klamath	555,900	592,900	37,000	6.7	10,100	23,600	600	0	34,300	-6.2
Eastern Cascades	312,700	366,700	54,000	17.3	10,600	7,900	2,700	0	21,200	-6.8
Total	2,508,300	2,765,500	257,200	10.3				0		-4.1
California:										
Coast Range	20,500	26,000	5,500	26.8	200	400	0	0	600	-2.9
Klamath	898,100	938,100	40,000	4.5	8,700	45,000	1,100	0	54,800	-6.1
Cascades	311,600	335,800	24,200	7.8	8,900	3,200	1,900	0	14,000	-4.5
Total	1,230,200	1,299,900	69,700	5.7	17,800	48,600	3,000	0	69,400	-5.6
NWFP total	4,608,200	5,015,000	406,800	8.8	85,200	110,200	10,800	0	206,200	-4.5

NWFP = Northwest Forest Plan.

Table 10—Bookend map areal estimates of dispersal habitat and net changes from 1993 to 2012 on reserved federal lands (left), assigned causes for losses from LandTrendr disturbance maps (right)

State and physiographic province	Dispersal habitat estimates from bookend maps				LandTrendr disturbance assignment for losses					
	1993	2012	Net area change	Net percentage change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	- - - - - - - - - - - - Acres - - - - - - - - - - -			*Percent*	- - - - - - - - - - - - - - - - - - - *Acres* - - - - - - - - - - - - - - - - - -					Percent
Washington:										
Olympic Peninsula	1,053,900	1,078,100	24,200	2.3	1,000	1,100	400	1,400	3,900	-0.4
Western Lowlands	55,700	59,300	3,600	6.5	0	0	100	1,300	1,400	-2.5
Western Cascades	1,844,200	1,911,900	67,700	3.7	2,700	3,700	700	4,300	11,400	-0.6
Eastern Cascades	1,462,800	1,395,900	-66,900	-4.6	8,600	88[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Total	4,416,600	4,445,200	28,600	0.6	12,300	93[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Oregon:										
Coast Range	713,900	811,000	97,100	13.6	6,200	100	200	200	6,700	-0.9
Willamette Valley	2,300	2,600	300	13.0	0	0	0	0	0	0
Western Cascades	1,887,600	1,877,300	-10,300	-0.5	4,000	75,600	1,700	1,000	82,300	-4.4
Klamath	849,200	750,900	-98,300	-11.6	3,400	137,600	200	300	141,500	-16.7
Eastern Cascades	635,800	632,800	-3,000	-0.5	3,000	33,400	5,500	700	42,600	-6.7
Total	4,088,800	4,074,600	-14,200	-0.3	16,600	246,700	7,600	2,200	273,100	-6.7
California:										
Coast Range	160,300	176,600	13,300	8.3	200	2,900	0	300	3,400	-2.1
Klamath	1,851,500	1,751,900	-99,600	-5.4	1,800	163,500	1,300	2,300	168,900	-9.1
Cascades	255,300	265,200	9,900	3.9	900	4,700	600	500	6,700	-2.6
Total	2,267,100	2,190,700	-76,400	-3.4	2,900	171,100	1,900	3,100	179,000	-7.9
NWFP total	10,772,500	10,710,500	-62,000	-0.6	31,800	511,500	25,000	15,200	583,500	-5.4

NWFP = Northwest Forest Plan.

Table 11—Bookend map areal estimates of dispersal habitat and net changes from 1993 to 2012 on all federal lands (left), assigned causes for losses from LandTrendr disturbance maps (right)

State and physiographic province	Dispersal habitat estimates from bookend maps: 1993	2012	Net area change	Net percentage change	LandTrendr disturbance assignment for losses: Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Acres	*Acres*	*Acres*	*Percent*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Percent*
Washington:										
Olympic Peninsula	1,125,600	1,162,500	36,900	3.3	1,600	1,100	400	1,400	4,500	-0.4
Western Lowlands	55,900	59,600	3,700	6.6	0	0	100	1,300	1,400	-2.5
Western Cascades	2,255,000	2,383,000	128,000	5.7	6,500	3,800	800	4,300	15,400	-0.7
Eastern Cascades	1,849,900	1,789,700	-60,200	-3.3	18,700	105,400	17,300	2,900	144,300	-7.8
Total	5,286,400	5,394,800	108,400	2.1	26,800	110,300	18,600	9,900	165,600	-3.1
Oregon:										
Coast Range	959,300	1,098,900	139,600	14.6	13,700	100	300	200	14,300	-1.5
Willamette Valley	12,000	13,200	1,200	10.0	200	0	0	0	200	-1.7
Western Cascades	3,272,300	3,384,500	112,200	3.4	28,300	89,300	2,900	1,000	121,500	-3.7
Klamath	1,405,100	1,343,900	-61,200	-4.4	13,500	161,200	800	300	175,800	-12.5
Eastern Cascades	948,500	999,500	51,000	5.4	13,600	41,400	8,200	700	36,900	-6.7
Total	6,597,200	6,840,000	242,800	3.7	69,300	292,600	12,200	2,200	375,700	-5.7
California:										
Coast Range	180,800	199,600	18,800	10.4	400	3,300	0	300	4,000	-2.2
Klamath	2,749,600	2,690,000	-59,600	-2.2	10,500	208,500	2,400	2,300	223,700	-8.1
Cascades	566,900	600,900	34,000	6.0	9,800	7,800	2,400	500	20,500	-3.6
Total	3,497,300	3,490,500	-6,800	-0.2	20,700	219,600	4,800	3,100	248,200	-7.1
NWFP total	15,380,900	15,725,300	344,400	2.2	116,800	621,900	35,600	15,200	789,500	-5.1

NWFP = Northwest Forest Plan.

Table 12—Bookend map areal estimates of dispersal habitat and net changes from 1993 to 2012 on all (federal and nonfederal) lands (left), assigned causes for losses from LandTrendr disturbance maps (right)

State and physiographic province	Dispersal habitat estimates from bookend maps: 1993	2012	Net area change	Net percentage change	LandTrendr disturbance assignment for losses: Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Acres			*Percent*	*Acres*					*Percent*
Washington:										
Olympic Peninsula	1,819,800	1,781,500	-38,300	-2.1	190,900	1,200	4,600	1,400	198,100	-10.9
Western Lowlands	1,966,300	1,524,100	-442,200	-22.5	708,700	0	11,000	1,300	721,000	-36.7
Western Cascades	3,290,000	3,359,200	69,200	2.1	296,000	4,300	4,000	4,300	308,600	-9.4
Eastern Cascades	2,737,200	2,516,500	-220,700	-8.1	179,400	120,500	26,400	2,900	329,200	-12.0
Total	9,813,300	9,181,300	-632,000	-6.4	1,375,000	126,000	46,000	9,900	1,556,900	-15.9
Oregon:										
Coast Range	2,783,200	2,589,300	-193,900	-7.0	745,000	800	9,800	200	755,800	-27.2
Willamette Valley	205,600	179,400	-26,200	-12.7	56,400	0	700	0	57,100	-27.8
Western Cascades	4,130,000	4,082,000	-48,000	-1.2	367,700	94,000	6,900	1,000	469,600	-11.4
Klamath	1,984,000	1,918,100	-65,900	-3.3	150,200	165,500	3,100	300	319,100	-16.1
Eastern Cascades	1,275,300	1,307,700	32,400	2.5	72,500	51,000	11,700	700	135,900	-10.7
Total	10,378,100	10,076,500	-301,600	-2.9	1,391,800	311,300	32,200	2,200	1,737,500	-16.7
California:										
Coast Range	1,848,200	2,192,600	344,400	18.6	54,300	9,200	2,300	300	66,100	-3.6
Klamath	3,285,300	3,249,800	-35,500	-1.1	62,600	221,000	5,800	2,300	291,700	-8.9
Cascades	1,004,700	1,029,000	24,300	2.4	61,400	13,600	6,400	500	81,900	-8.2
Total	6,138,200	6,471,400	333,200	5.4	178,300	243,800	14,500	3,100	439,700	-7.2
NWFP total	26,329,600	25,729,200	-600,400	-2.3	2,945,100	681,100	92,700	15,200	3,734,100	-14.2

NWFP = Northwest Forest Plan.

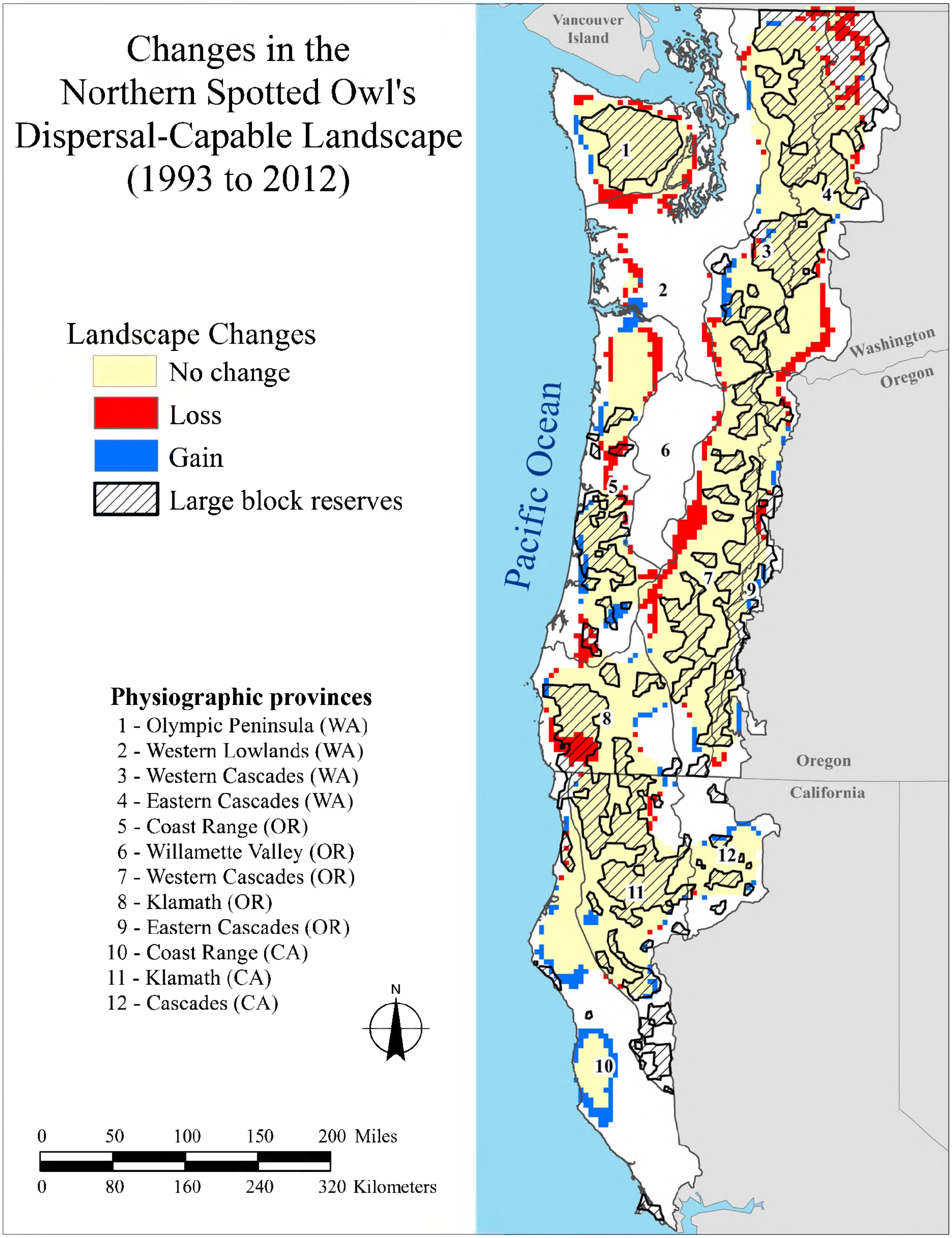


Figure 9—Changes in dispersal-capable landscape in Washington (WA), Oregon, (OR), and California (CA) between 1993 and 2012.

Discussion

Habitat loss for the NSO became a concern in the early 1970s (Forsman 1975, Gould 1974, Mouat and Schrumpf 1974). Slightly less than two decades later, the NSO was listed as threatened under the Endangered Species Act owing to continued chronic habitat loss (USDI FWS 1990). Shortly thereafter, a series of related events led to the implementation of the NWFP (Marcot and Thomas 1997), the boundary of which was defined by the NSO's geographic range in the United States. Since the NWFP's implementation, the rate of nesting/roosting habitat loss with this area has lessened, but still continues to decline (fig. 10). This continued decline in habitat was not unexpected. When the NWFP was designed, rangewide NSO habitat loss on federal lands was projected to be about 5 percent per decade, split evenly between wildfires and timber harvesting (FEMAT 1993, USDA and USDI

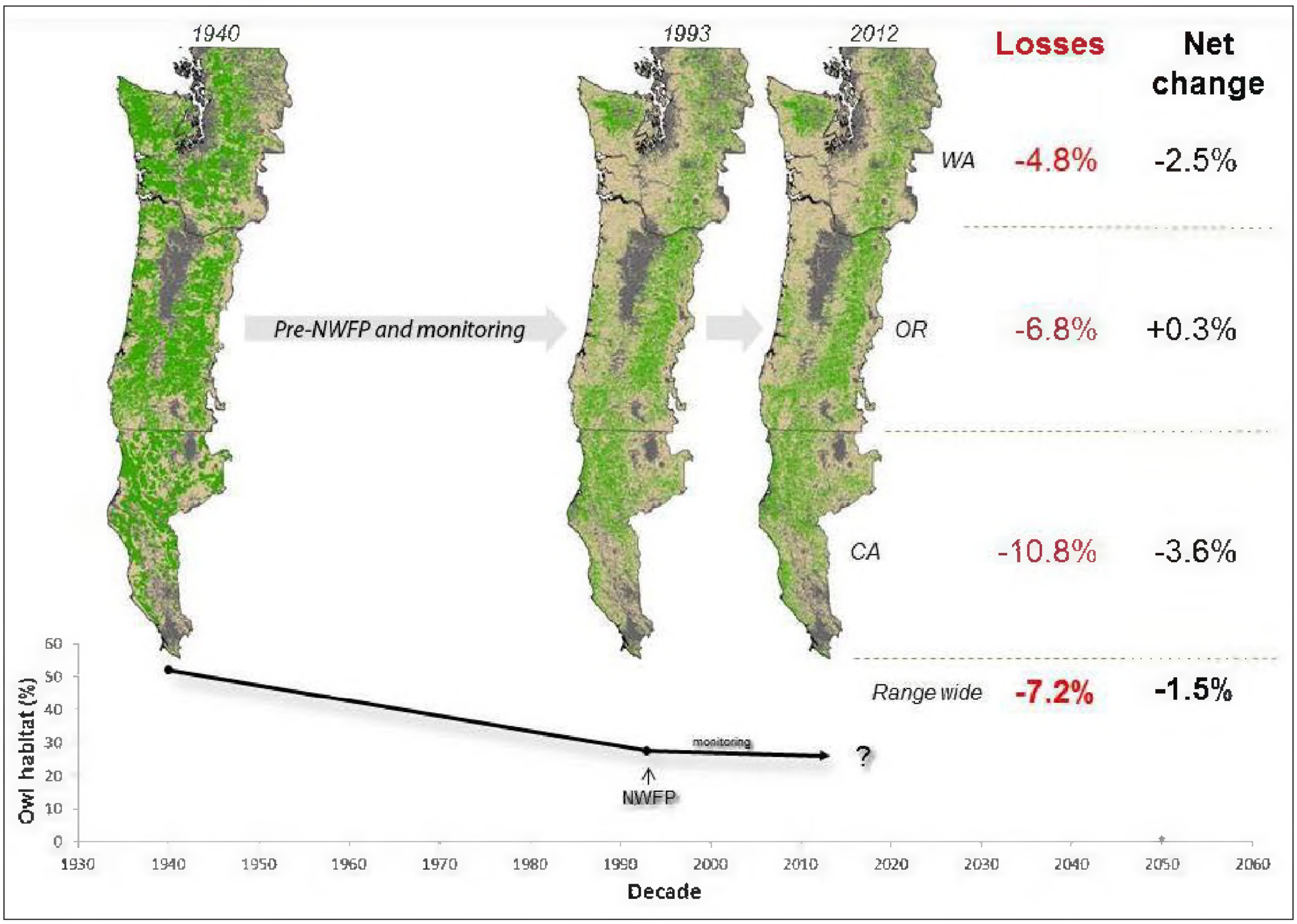


Figure 10—The rate of loss of older forests and northern spotted owl nesting/roosting habitat lessened when the Northwest Forest Plan (NWFP) was implemented in 1994. Since then, nesting/roosting habitat has continued to decline but at a much lower rate. Continued habitat monitoring will inform management of future habitat changes (source of map for 1940 was Andrews and Cowlin 1940) and Weislander and Jensen 1946).

1994). In fact, nesting/roosting habitat was projected to continue to decline for up to 50 years or until about 2044 (USDA and USDI 1994, chap. 3 and 4, pg. 228).

Eventually, habitat recruitment was expected to exceed losses and nesting/roosting habitat within the LSR network would begin to increase and become less fragmented, providing greater benefits for NSOs as well as other late-successional forest species (USDA and USDI 1994, apps. J3-8). Two decades into the NWFP, the amount of nesting/roosting habitat within reserved LUAs rangewide has declined by about 4.0 percent (252,900 ac), primarily owing to wildfire. The losses from wildfire amounted to about 6.1 percent (388,500 ac) of what existed within them when they were reserved. At the range scale, the gross loss of nesting/roosting habitat was slightly higher than the 5.0 percent loss expected over two decades from wildfire. It was two to three times higher in the Klamath physiographic provinces, where most nesting/roosting habitat losses have occurred.

With foresight, the LSRs within fire-prone provinces were designed with wildfire in mind. Late-successional reserves were delineated to be large enough to withstand large wildfire events over 50 years such that unburned portions would maintain a well-connected network of nesting/roosting and dispersal habitat (USDA and USDI 1994, app. J3-8 and 9). However, given the increased frequency of large wildfires within the NWFP area since the turn of this century (Davis et al. 2011 and recent unpublished data), which have far exceeded the area burned in the recent decades leading to the design of the NWFP, this design feature may be challenged in the near future.

Although wildfire losses have occurred episodically, timber harvesting has resulted in more stable annual rates of habitat loss (fig. 11). Timber-harvesting related losses removed less than 10,000 ac of nesting/roosting habitat each year. Within nonreserved LUAs, the percentage loss from timber harvesting was 2.9 percent (80,300 ac) or slightly more than half of what the NWFP had anticipated (2.5 percent per decade or 5.0 percent over two decades). Even though the NWFP allowed for more timber harvesting from federal lands, the debates and litigation surrounding the harvesting of older forests has resulted in federal land managers focusing harvest efforts on younger forests via commercial thinning with multiple resource objectives, including accelerating the development of future NSO habitat as one of them. Losses resulting from insects and disease accounted for a minor amount (<1 percent) of nesting/roosting habitat loss, mostly in the Washington Eastern Cascades where the trend of this loss began to increase on federal lands in the early part of this century (fig. 11).

While there are indications of gains, especially in the moister portions of the range, not enough time has passed to allow for significant recruitment of nesting/

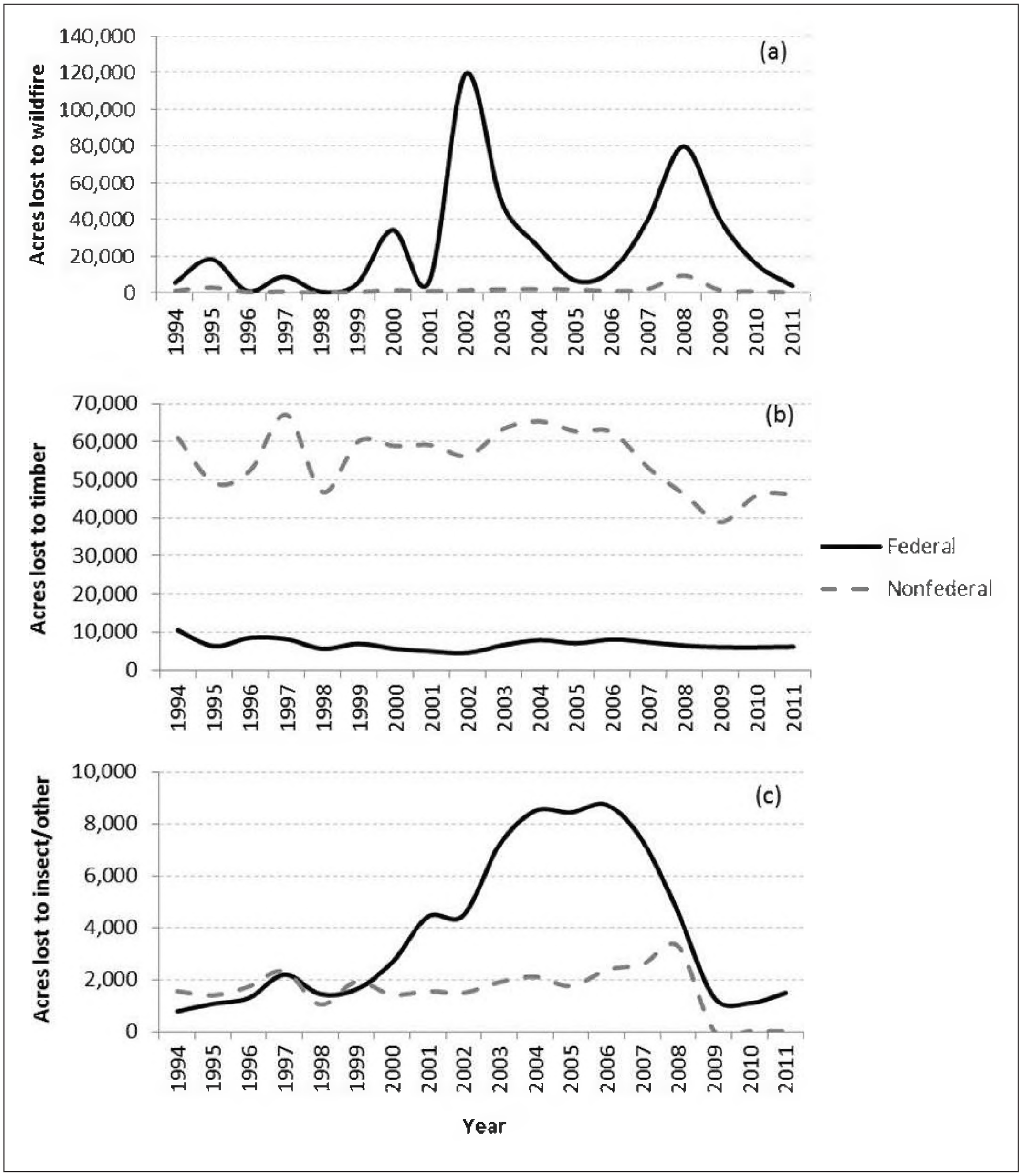


Figure 11—Trends in nesting/roosting habitat losses on federal and nonfederal forest lands by (a) wildfire; (b) timber harvesting; and (c) insects, disease, and other natural disturbances.

roosting habitat (fig. 8). However, we observed a rangewide 2.2 percent net gain in dispersal habitat on federal lands (table 11). But, losses of dispersal habitat on adjacent nonfederal lands resulted in a net decrease of 2.3 percent on all lands (table 12). The result has been a receding of the dispersal-capable landscape by a few miles toward the federal land base with losses of connections to certain portions of the range particularly in the Oregon Coast Range (fig. 9). Habitat gains in the last 20 years were likely due to younger forests of marginal habitat transitioning into slightly older forests that are just becoming suitable for nesting and roosting (app. A). Given past history of timber harvesting in this region (Gale et al. 2012), we anticipate significant recruitment of future habitat, and some of the gains observed in this report may be part of the leading edge of this peak in the harvest history (fig. 12). Another potential cause for habitat gains in this report may be due to changes in forest species composition owing to natural succession or disturbance processes. Our nesting/roosting habitat suitability models included forest species composition variables (table 1), and decreases in subalpine forest, pine forest, or oak woodland basal areas over 20 years could increase habitat suitability. While any changes in forest species composition over two decades were most likely due to disturbances (e.g., wildfire, timber harvest, etc.) or natural succession, the potential for forest species composition changes resulting from changes in climate will need to be considered in future monitoring.

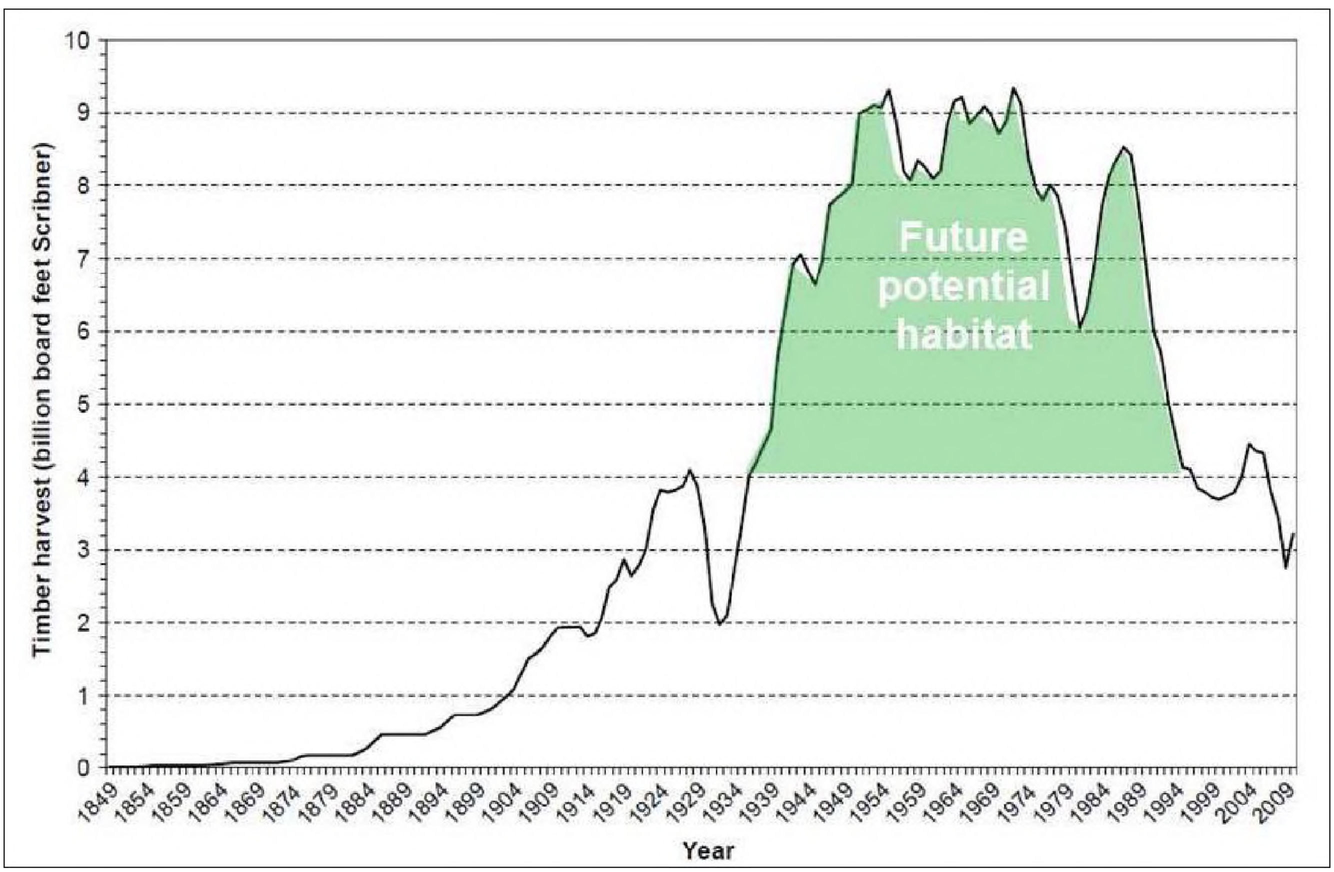


Figure 12—Oregon timber harvest between 1849 and 2010 (fig. 1 from Gale et al. 2012). The shaded area has the potential to become future northern spotted owl habitat by the middle of this century.

The recovery of future NSO habitat may be affected by climate change that could alter the pattern and frequency of large wildfire within the NSO's range. Climate change is also expected to alter forest species composition within the Pacific Northwest by the end of the 21st century (Peterson et al. 2014). Subalpine forests are expected to recede in area while pine-dominated forests will likely expand. Both of these forest types are normally not used for nesting and roosting by NSOs, and these potential changes will affect amounts and distribution of future NSO habitat.

Geographic Pattern of Large Wildfires

The geographic distribution of large wildfires exceeding 1,000 ac (fig. 13) and the habitat loss from wildfire was highest in fire-prone areas of the range as delineated by Davis et al. (2011). Based on total area of habitat lost to wildfire (all federal lands), the Klamath provinces accounted for most (331,800 ac), followed by the Eastern Cascades (66,800 ac). A large amount (63,000 ac) of nesting/roosting habitat was lost to large wildfires in the southern half of the Oregon Western Cascades (table 5). Most of this habitat loss also occurred in the reserved LUAs, which were designed for the restoration and maintenance of older forests and NSO habitat. The physiographic provinces of the Klamath Mountains and Eastern Cascades exceeded the 2.5-percent-per-decade losses projected for reserved allocations (see table 5).

Habitat and Demographic Trends

This report focused on status and trends of NSO habitat; however, the status and trends of NSO populations were the focus of a second report developed concurrently (Dugger et al. 2016). The estimates of nesting/roosting habitat developed in the 15-year report (Davis et al. 2011) were used to explore relationships between habitat conditions and NSO demographic parameters from 11 study areas (8 federal, 3 nonfederal) across the species' range (Dugger et al. 2016). Likewise, we anticipate that the estimates of habitat developed in this report will be used in future demographic analyses. Indeed, the ultimate objective of NSO effectiveness monitoring has always been to link habitat to population demographics with good reliable statistical models, such that future monitoring would rely more on a model-driven, habitat-based approach (Lint et al. 1999). To date, we have not been able to accomplish this objective, and the uncertainties in mapping habitat described in the next section, and perhaps more so, the increased presence of BOs that compete for similar habitat with the result that they exclude NSO (Dugger et al., 2016, Wiens et al. 2014, Yackulic et al. 2014) pose significant challenges in achieving this monitoring objective.

The relationships between habitat and NSO demographic parameters have been varied across the range, from one demographic study area to the next (e.g., Dugger et al. 2016, Forsman et al. 2011). However, when relationships are evident,

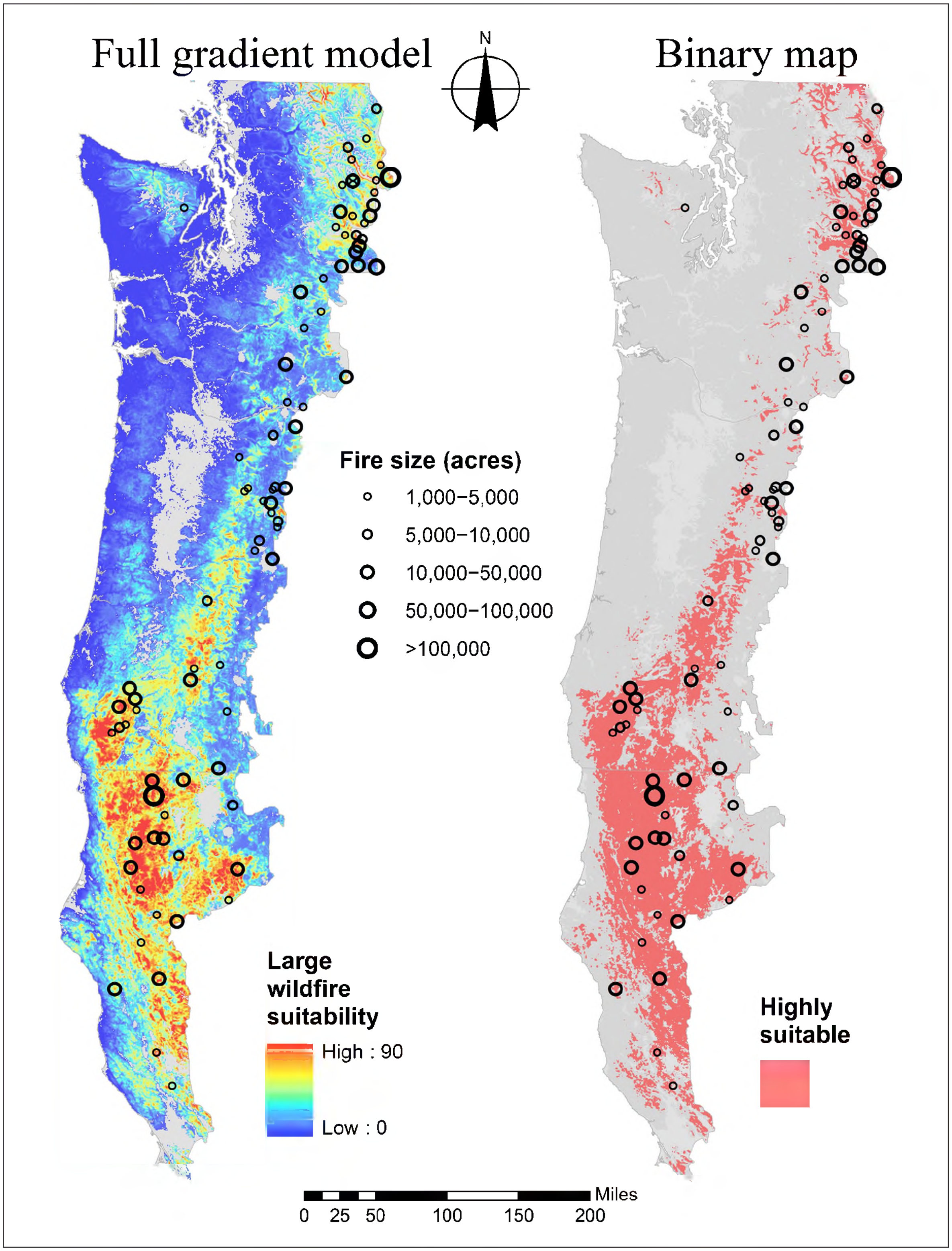


Figure 13—Geographic distribution of large wildfires (≥1,000 ac) that have occurred within the owl's range from 2010 to 2014 in relation to large wildfire suitability modeling done in Davis et al. (2011).

they typically occur in the direction we might predict. For instance, more nesting/roosting habitat (or less habitat loss) has been associated with higher survival (Dugger et al. 2005, 2016; Franklin et al. 2000), fecundity (Dugger et al. 2016), and colonization rates (Dugger et al. 2011, 2016; Yackulic et al. 2014) of NSOs. Some of the strongest links between NSO demographics and habitat have been observed in relation to occupancy dynamics, with more suitable habitat typically associated with higher colonization rates and lower extinction rates, even when BOs are present in the landscape (Dugger et al. 2011, 2016; Yackulic et al. 2014). The results for federal demographic study areas from the most recent population meta-analysis (Dugger et al.2016) are summarized below (table 13).

Table 13—Habitat relationships with northern spotted owl population parameters in federal demographic study areas from top or competitive models in Dugger et al. 2016

Population parameter	Spatial scale of habitat covariates	Amount or percentage of nesting/roosting habitat (HAB)	Percentage of area with >50 percent nesting/roosting habitat within 800-m radius (CORE)	Percentage of nesting/roosting habitat that had ≥30% reduction in canopy cover during prior 3 years (HC)	Percentage of area that interfaced (within 100 m) of nesting/roosting habitat (EDGE)
Reproduction	Individual study area	Strong positive relationships in TYE and NWC. Weak positive relationships in CLE, COA, and HJA	Weak positive relationship in CAS	None found	None found
Survival	Individual study area	None found	Weak positive relationship in KLA	Strong negative relationship in TYE. Weak negative relationship in CAS	Weak positive relationships in CLE and COA
Colonization rates	Individual territories	Strong positive relationships in OLY, COA, TYE, CAS, and NWC	None found	Weak negative relationships in CLE and HJA	Strong positive relationship in KLA
Extinction rates	Individual territories	Strong negative relationship in HJA. Weak negative relationships in OLY, COA, and CAS	Strong negative relationships in KLA, and NWC	None found	None found

Federal study area abbreviations are as follows: CLE = Cle Elum, OLY = Olympic, COA = Coast Ranges, HJA = H.J. Andrews, TYE = Tyee, KLA = Klamath, CAS = South Cascades, NWC = Northwest California

Uncertainty in Habitat Monitoring

Continued monitoring is important for informing managers on the effectiveness of the NWFP in achieving its goals and objectives. Information learned from it can be used in the adaptive management process. With each monitoring cycle, monitoring methods and technology have adapted also. Species distribution modeling for large landscapes is a relatively new science (Phillips et al. 2006) made possible by readily available broad-scale environmental data (e.g., remote sensed data) and advances in computing power. We use presence-only SDM methods because of the nature of the NSO location data available rangewide. Given the newness of these methods, caution has been advised in their use (Loehle et al. 2015, Yackulic et al. 2013). We exercised appropriate caution through the development of our modeling and calibration procedures as well as consideration and critical examination of our data sources, sampling biases, how species occurrence varied with environmental covariates, and the time and resources available for conducting this monitoring.

Monitoring of habitat change across the large geographic range of the NSO was facilitated by the use of remotely sensed data. The habitat monitoring in this report relied heavily on imagery collected "passively" by the National Aeronautics and Space Administration's Landsat satellite program. This imagery was converted into maps of forest structure and species composition by modeling relationships between on-the-ground data collected in forest inventory plots to geospatial environmental data (e.g., climate and topography), but most importantly, light being reflected by the forest canopy. The GNN variables for forest structure that we used had mean-plot accuracies that ranged from 0.56 to 0.77 (Pearson correlations). Forest species composition variables had mean Cohen kappas that ranged from 0.38 to 0.4 (see table 1). Thus, errors in these data were transferred to the habitat models we produced. We tested our habitat models using known NSO locations and indeed, none of them were 100 percent accurate (see table 2). However, our map accuracies were fair to good and useful for broad-scale monitoring purposes. In the future, we may be able to improve map accuracy through the use of light detection and ranging (lidar) data. Lidar is a form of "active" remote sensing that provides direct measurements of forest vegetation and structure versus the inferred measures currently being used. A recent comparison of lidar- versus Landsat-based NSO habitat modeling and mapping showed that while both produced acceptable and similar areal estimates of nesting/roosting habitat, the lidar-based maps were more spatially accurate than Landsat-based maps (Ackers et al. 2015). Currently, lidar data do not provide the spatial or temporal coverage needed for monitoring habitat across the NSO's range.

The reliance of passively collected light measurements in forest mapping poses other monitoring challenges (Davis et al. 2015). This is especially when trying to measure habitat change over time when differences in sun angle, canopy shadowing, and atmospheric haze in imagery of the same area on different dates can result in false change. As described in the 15-year report (Davis et al. 2011, pgs. 48-49), we noted canopy shadowing created through light-intensity disturbances, such as thinning, resulted in erroneous GNN estimates of older forest attributes that were transferred to our habitat models. Uncertainty was highest for gains in older forests that make up nesting/roosting habitat. Gains in dispersal habitat, which includes younger forest, were less uncertain as were gains in the redwood region of the California Coast physiographic province where nesting/roosting habitat can develop rapidly over the course of a few decades. Detection of forest disturbance over two decades is more reliable and thus so was our estimate of habitat losses that were corroborated by the LandTrendr data. There were net gains in nesting/roosting habitat in some physiographic provinces and net losses in others. All net changes in habitat were less than the error in our area estimates, thus considered not statistically significant. While we reported on net changes in this monitoring cycle, we consider habitat losses that were corroborated by forest-disturbance-change-detection data as the most reliable.

Conclusion

During the first two decades of the NWFP, rangewide losses of nesting/roosting habitat on federal lands were estimated at 5.2 percent (474,300 ac) from wildfire; 1.3 percent (116,100 ac) from timber harvesting; and 0.7 percent (59,800 ac) from insects, disease, or other natural disturbances. This accounted for a total rangewide loss of 7.2 percent, but we estimated an overall net decrease of 1.5 percent, owing to new nesting/roosting habitat recruitment. Rangewide, the observed rate of habitat loss on federal lands was less than what was anticipated when the NWFP was designed, mostly as a result of less timber harvesting than was anticipated. Losses from wildfire were slightly higher than anticipated in federal reserved LUAs at the range scale. Insects and disease accounted for less than 1 percent of losses. While dispersal habitat has shown a net increase of 2.2 percent on federal lands, dispersal-capable landscapes have been reduced in area by 5 percent, partially owing to losses of habitat on surrounding nonfederal lands but also owing to large wildfires on federal lands.

One of the goals of the NWFP was to protect and enhance habitat for the NSO on federal lands. The first step in achieving this goal was to reduce the rate at which habitat was being lost. Monitoring shows that the NWFP has been effective at achieving this. Eventually, the NWFP anticipated restoration of habitat within the large reserve network over the course of several decades. Two decades into the NWFP, we report that nesting/roosting habitat is still declining at the NWFP scale, but that recruitment is occurring in portions of the range and beginning to help offset losses. Based on past timber harvesting history (Gale et al. 2012) and current management of old clearcut plantations to accelerate the development of future habitat, significant habitat recruitment will likely be seen by the middle part of this century.

Challenges remain: increasing concentrations of greenhouse gases and resultant climate change may expand the geographic extent and increase the frequency of large wildfires within the NSO range (Westerling et al. 2006). Changing climates may also cause large shifts in forest species compositions (Peterson et al. 2014), which will affect the suitability of forests for future nesting and roosting. And lastly, BOs are displacing NSOs from their historical territories at an increasing rate (Dugger et al., 2016) and may be forcing NSOs to use less suitable and more marginal habitat (Dugger et al. 2011, Wiens et al. 2014, Yackulic et al. 2104).

Acknowledgments

This report is the result of a large group effort over many years focused on monitoring the effectiveness of the NWFP. It would not have been possible without the continued hard work of many dedicated biologists who annually collect the NSO field data used to train and test our habitat models. Wall-to-wall maps of forest structure and species composition that we use as habitat model variables to produce maps of nesting/roosting habitat would not exist without the hard, dedicated work by the Landscape, Ecology, Modeling, Mapping, and Analysis team directed by Dr. Janet Ohmann. The mapping of forest vegetation benefited from the collaborative work with the Laboratory for Applications of Remote Sensing in Ecology research laboratory directed by Dr. Warren Cohen and the work of Dr. Robert Kennedy on the production of the LandTrendr change detection data set. We thank Drs. Peter Singleton, Betsy Glenn, Damon Lesmeister, Joan Hagar, and Katie Dugger for their reviews and constructive comments that resulted in a much improved report.

Metric Equivalents

When you know:	Multiply by:	To find:
Inches (in)	2.54	Centimeters (cm)
Feet (ft)	0.3048	Meters (m)
Acres (ac)	0.405	Hectares (ha)
Square feet per acre (ft^2/ac)	0.2296	Square meters per hectare (m^2/ha)
Square miles (mi^2)	2.59	Square kilometers (km^2)
Trees per acre (trees/ac)	2.47	Trees per hectare (trees/ha)
Tons (ton)	907.0	Kilograms (kg)
Tons per acre (ton/ac)	2.24	Megagrams per hectare (Mg/ha)
Cubic feet per acre (ft^3/ac)	0.07	Cubic meters per hectare (m^3/ha)

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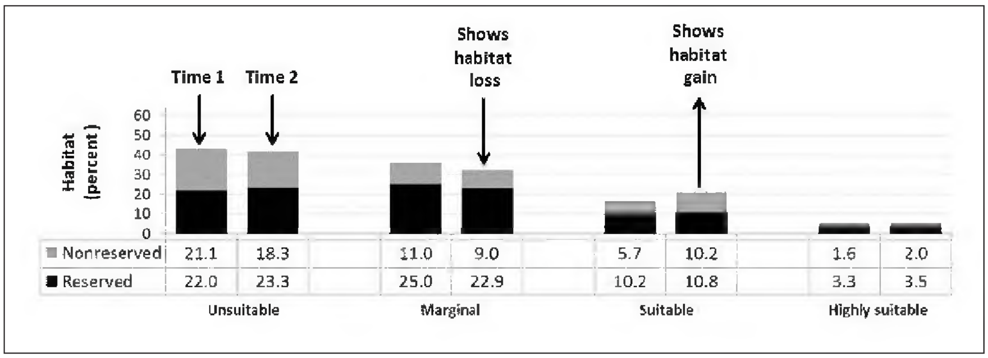
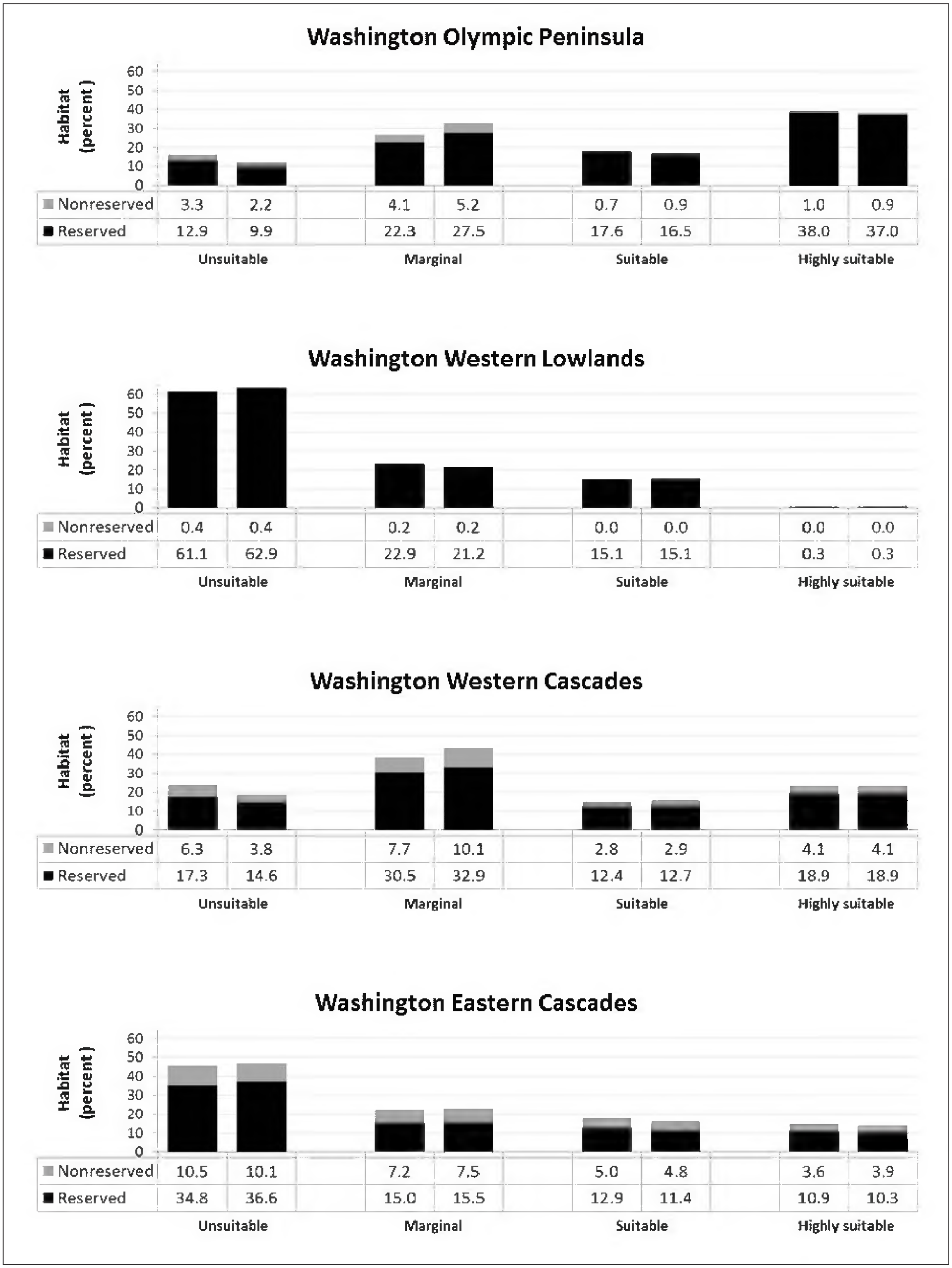
Appendix: Habitat Suitability Histograms

The habitat histograms displayed in this appendix are based on habitat conditions at the time of the Northwest Forest Plan (NWFP) implementation (1993) and at the end of our analysis period in 2012. There are four pairs of histogram bars, one pair per nesting/roosting habitat suitability class. The first bar in the pair shows conditions at time 1 (1993), the second bar shows conditions at time 2 (2012). We provide an example histogram below to help with the interpretation of the histograms provided for each state and each physiographic province.

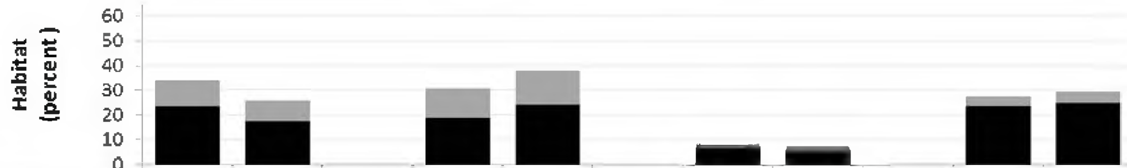


In the example above, we observe a slight decrease in unsuitable habitat between time 1 and time 2. We also observe a larger decrease in marginal habitat class during the same timeframe with a relatively similar increase in the suitable habitat class and very slight increase in the highly suitable habitat class. We can conclude that the decreases in the unsuitable and marginal classes were likely due to two forest successions resulting in increases in the suitable habitat classes. Most of the increase in suitable habitat occurred within the nonreserved land use allocation.

The tables under the graphs show the percentage of forest-capable lands having each habitat class as estimated from the habitat maps for both time periods. The percentages are split into nonreserved and reserved land use allocations. The habitat histograms on the following pages illustrate our best estimates of how habitat has changed since NWFP implementation. These graphs are primarily for interpretive purposes.


Washington Olympic Peninsula
Habitat (percent)
60
50
40
30
20
10
0
Nonreserved 3.3 2.2 4.1 5.2 0.7 0.9 1.0 0.9
Reserved 12.9 9.9 22.3 27.5 17.6 16.5 38.0 37.0
Unsuitable
Marginal
Suitable
Highly suitable
Washington Western Lowlands
Habitat (percent)
60
50
40
30
20
10
0
Nonreserved 0.4 0.4 0.2 0.2 0.0 0.0 0.0 0.0
Reserved 61.1 62.9 22.9 21.2 15.1 15.1 0.3 0.3
Unsuitable
Marginal
Suitable
Highly suitable
Washington Western Cascades
Habitat (percent)
60
50
40
30
20
10
0
Nonreserved 6.3 3.8 7.7 10.1 2.8 2.9 4.1 4.1
Reserved 17.3 14.6 30.5 32.9 12.4 12.7 18.9 18.9
Unsuitable
Marginal
Suitable
Highly suitable
Washington Eastern Cascades
Habitat (percent)
60
50
40
30
20
10
0
Nonreserved 10.5 10.1 7.2 7.5 5.0 4.8 3.6 3.9
Reserved 34.8 36.6 15.0 15.5 12.9 11.4 10.9 10.3
Unsuitable
Marginal
Suitable
Highly suitable

Oregon Coast Range



	Unsuitable		Marginal		Suitable		Highly suitable	
Nonreserved	10.8	8.3	11.7	13.7	1.4	1.4	4.0	4.3
Reserved	23.3	17.5	18.7	24.2	6.7	5.7	23.5	24.9

Oregon Willamette Valley

	Unsuitable		Marginal		Suitable		Highly suitable	
Nonreserved	25.7	19.9	19.4	22.7	22.4	25.2	7.0	6.6
Reserved	14.5	13.0	4.0	5.5	4.5	4.6	2.5	2.4

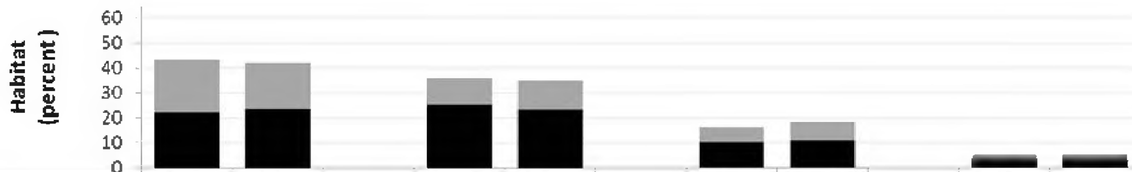
Oregon Western Cascades

	Unsuitable		Marginal		Suitable		Highly suitable	
Nonreserved	14.3	9.5	8.7	12.5	7.6	8.4	16.2	16.3
Reserved	10.3	9.5	12.6	13.7	8.7	8.8	21.6	21.2

Oregon Klamath

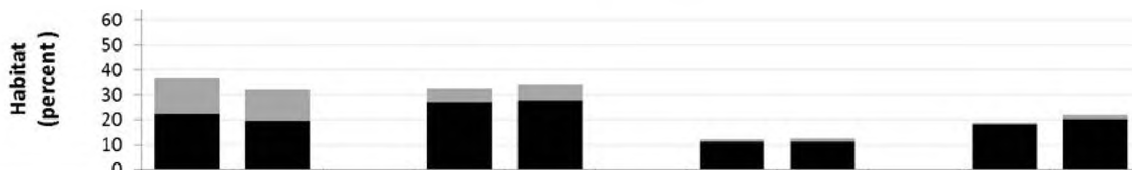
	Unsuitable		Marginal		Suitable		Highly suitable	
Nonreserved	15.0	13.1	10.8	11.8	5.5	5.3	11.8	13.0
Reserved	14.3	18.1	12.2	12.5	7.8	6.2	22.6	20.1

Oregon Eastern Cascades



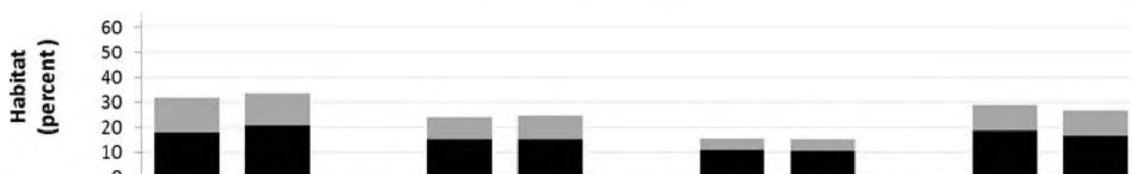
	Unsuitable		Marginal		Suitable		Highly suitable	
Nonreserved	21.1	18.3	11.0	11.8	5.7	7.4	1.6	2.0
Reserved	22.0	23.3	25.0	22.9	10.2	10.8	3.3	3.5

California Coast Range



	Unsuitable		Marginal		Suitable		Highly suitable	
Nonreserved	14.4	12.6	5.5	6.6	1.1	1.1	0.9	1.6
Reserved	22.1	19.4	26.9	27.6	11.0	11.2	18.0	19.9

California Klamath



	Unsuitable		Marginal		Suitable		Highly suitable	
Nonreserved	13.7	13.0	8.9	9.4	4.6	4.8	10.0	9.9
Reserved	18.1	20.6	15.2	15.2	10.7	10.3	18.8	16.8

California Cascades

	Unsuitable		Marginal		Suitable		Highly suitable	
Nonreserved	38.2	36.8	17.1	17.9	6.4	6.9	1.9	2.0
Reserved	13.4	12.5	11.4	12.0	7.3	7.9	4.4	4.0

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