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Northwest Forest Plan—The First 25 Years (1994–2018): Status and Trends of Northern Spotted Owl Habitats

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NORTHWEST FOREST PLAN
THE FIRST 25 YEARS (1994–2018)

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Abstract

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This is the fourth in a series of periodic monitoring reports on status and trends of forests used by northern spotted owls (*Strix occidentalis caurina*; NSO) for nesting, roosting, and dispersal on federally administered lands within the Northwest Forest Plan (NWFP) area (NSO range in the United States) since its implementation in 1994. The objective of this monitoring is to determine if federal forest lands are providing sufficient conservation of forests that are important elements of NSO habitat, and thus populations. Here we present models on the amount, distribution, and spatial arrangement of nesting, roosting, and dispersal forest types across the NWFP area, and losses and gains resulting from disturbance and forest succession, respectively. Forests suitable for nesting and roosting are one of the most critical components of NSO habitat, defined as the area with the full range of environmental conditions necessary to support occupancy, survival, and reproduction. Given the importance of habitat to support population recovery, this is the first monitoring report to model habitat using distribution and amount of suitable nesting/roosting forest at multiple spatial scales, and in combination with abiotic environmental covariates. We used estimates of territory occupancy in conjunction with available habitat to estimate changes in population size and distribution of territorial NSOs on federal lands at the start and end of this monitoring cycle (1993 and 2017).

We found a 3 percent net increase (from 8,890,500 to 9,155,700 ac) of nesting/roosting forest on federal lands between 1993 and 2017. This net gain occurred despite gross losses from wildfire of 7.9 percent (703,700 ac), 2.9 percent from timber harvest (257,700 ac), and 0.9 percent from insects or other causes (83,700 ac), indicating that processes of forest succession more than compensated for the losses resulting from disturbance during the first 25 years of the NWFP. Dispersal forest on federal lands increased by 1 percent, but dispersal-capable landscapes decreased by 9 percent because of forest losses on surrounding nonfederal lands and large wildfires on federal lands. The forest landscape that allowed for owl movement between one reserved area to another became more confined and fragmented. Despite net increases in NSO forests on federal lands during the monitoring period, the population of territorial owls on federal lands decreased by an estimated 61.8 percent. A primary cause for population declines on federal lands was displacement from native habitat by the invasive barred owl (*S. varia*), which highlights the increasing threat to NSO persistence.

Keywords: Northwest Forest Plan, effectiveness monitoring, northern spotted owl, territory occupancy, habitat, barred owl.

Preface

Monitoring northern spotted owl (*Strix occidentalis caurina*) populations and the forests used by them within the Northwest Forest Plan (NWFP) area was approved by an Intergovernmental Advisory Committee. The program is consistent with the framework for effectiveness monitoring described in "The Strategy and Design of the Effectiveness Monitoring Program for the Northwest Forest Plan" and follows protocols and guidance in the "Northern Spotted Owl Effectiveness Monitoring Plan for the Northwest Forest Plan," both published in 1999. The 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 in 1- to 5-year intervals and results are documented in a series of technical reports. This report, and the others in the current series, covers the first 25 years of the NWFP.

Contents

Introduction

More than a quarter century has passed since the design and implementation of the Northwest Forest Plan (NWFP). The NWFP amended 19 U.S. Department of Agriculture (USDA) Forest Service and 7 U.S. Department of the Interior Bureau of Land Management (BLM) resource management plans across three western states and two Forest Service regions within the range of the northern spotted owl (*Strix occidentalis caurina*; NSO) in the United States. As part of the NWFP, an interagency effectiveness monitoring framework was created to track status and trends of late-successional and old-growth forests, NSO populations and habitat, marbled murrelet (*Brachyramphus marmoratus*) populations and habitat, watershed conditions, social and economic conditions, and tribal relationships (Mulder et al. 1999). In 2016, the BLM in western Oregon revised its resource management plans, which adopted the interagency monitoring framework in its entirety (USDI BLM 2016a, 2016b).

This report is the fourth in the series of NSO habitat monitoring reports outlined in Lint et al. (1999). It covers 1993–2018, which marks the year the NWFP was designed (FEMAT 1993) and the following 25 years of NWFP implementation. The goal of this monitoring is to evaluate the success of the NWFP in arresting the downward trends in NSO habitat and populations that preceded its implementation, and in maintaining and restoring forest types necessary to support future NSO populations on federally administered forest lands throughout its range. Specific monitoring objectives are as follows:

- Assess status and trends in NSO demographic rates or population size and distribution on federal lands.
- Assess status and trends in the amount and distribution of NSO forests and habitat on federal lands.

Addressing objective 1, Franklin et al. (2021) provided information on demographic rates from a population meta-analysis of demographic study areas (1993–2018). Here we focused on objective 2 and combined occupancy rates reported by Franklin et al. (2021) in our models to estimate NSO population size and distribution on federal lands.

There has been a long history of inconsistent use of the term “habitat” to describe forest stands (e.g., a stand of “nesting, roosting, foraging habitat”), including its use in previous NWFP monitoring reports. Forest stands of various types, amounts, and spatial configurations are only part of what constitutes habitat. NSO habitat is more accurately defined as the combination of the environmental biotic and abiotic conditions on the landscape necessary to support owl occupancy, survival, and reproduction (see Lesmeister et al. 2018: 250). Here, forest cover type refers to forest structure and tree species composition associated with use by NSOs (e.g., nesting, roosting, foraging, and dispersal), while habitat refers to the combination of forest cover type and the other relevant environmental conditions.

Each monitoring report has used new or revised data and sometimes new or improved analytical methods. For example, in future efforts, Google Earth Engine™ may become the primary platform for monitoring trends in NSO forests and habitat. Given the improvements in analytical tools, the results in every report supersede, and should not be compared to, prior reports. Here we summarized an assessment of NSO forest types and habitat for 22.1 million ac of federally administered forest lands affected by the NWFP. We also included information on the surrounding 23.8 million ac of nonfederal forest lands to provide a broader landscape context across the 57 million ac that comprise the NSO geographic range in the United States.

Habitat Monitoring Under the NWFP

The status and trends of forests used by NSOs have been estimated every 5 years because it was believed that changes in forest vegetation would not be reliably discernible at more frequent intervals using the Landsat remotely sensed vegetation data that this broadscale monitoring program relies upon (Lint et al. 1999). This has proven to be mostly true for changes that result in gains in suitable forest types and habitat as a result of forest succession; however, our ability to detect losses from forest disturbance has now become very reliable and near-real time, thus future monitoring may entail annual updates.

Effectiveness monitoring evaluates assumptions made during development of the NWFP, which included that “habitat” (e.g., suitable forest) likely would not decline faster than the estimated 5 percent per decade (from wildfire and timber harvest combined) in the NWFP’s final environmental impact statement (USDA and USDI 1994).

Assumptions outlined in Lint et al. (1999) were evaluated to determine the following:

- Suitable forest conditions within late-successional reserves (LSRs) would improve over time at a rate controlled by successional processes in forest stands that were not suitable when the NWFP was developed. Given the slow process of old-forest development, these gains were not expected to produce any significant changes in suitable forest conditions for several decades.
- Forest conditions outside of reserved land use allocations (LUAs) were declining because of timber harvest and other habitat-altering disturbances, but many forest stands retained vegetation structure across the landscape to facilitate NSO movements.
- Catastrophic events would likely halt or reverse gains of suitable forest in some reserves, but the repetitive design of reserves would provide resiliency, and not result in isolation of population segments.

Based on these assumptions, we addressed the following questions:

- What proportion of the total forested landscape on federal lands is covered by forest types used for owl nesting, roosting, and dispersal?
- What are the trends in the amount of and changes in distribution of these NSO forest types, particularly in large reserves?
- What are the trends in the amount and distribution of dispersal forest that allow for movement of owls between large reserves?
- What are the primary factors leading to loss and fragmentation of suitable forest types and NSO habitat?
- What are the trends in the estimated number of occupied territories over the duration of the monitoring program?

We evaluated 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 assessed forest types and habitat conditions inside broad federal LUAs representing reserved and nonreserved landscapes.

Phase II Monitoring Under the NWFP

The NSO monitoring plan was designed to occur in two phases. During phase I, NSO populations have been monitored separately by continuing demographic studies using mark-recapture methods on territorial owls in federal study areas and habitat (e.g., forests used by NSO). Thus, appropriate monitoring indicators for phase I have been population demographic rates (e.g., survival, recruitment, population growth) and changes in amount and distribution of suitable forests. Phase II was envisioned as a monitoring program based on predictive models of regional population dynamics driven by landscape-scale amounts and patterns of habitat. Relevant population-level indicators for phase II would then be population size and distribution (Lint et al. 1999).

For the past two decades, the monitoring program has studied relationships between various measures of NSO occupancy and demographic performance with forest conditions (type, quantity, quality, and distribution) at the home range and at landscape scales (Anthony et al. 2006; Dugger et al. 2005, 2016; Forsman et al. 2011; Franklin et al. 2000; Yackulic et al. 2019). These studies have provided critical information on if and what forest conditions could be used to predict owl occupancy, distribution, and demographic performance at a variety of spatial scales. Combining findings from other efforts, Glenn et al. (2017) developed a method to estimate NSO territory density across broad landscapes based on habitat carrying capacity, territorial spacing, and occupancy rate estimates. Here we report on the first application of phase II monitoring to predict population size and distribution on federal lands.

Data Sources

Many, but not all, of the data sources used in this report were initially developed and used in previous monitoring reports (Davis et al. 2011, 2016; Lint 2005). 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 details of these data sources can be found in previous monitoring reports but are briefly described here.

Physiographic Province Map

The NWFP boundary was based on the geographic range of the NSO in the United States. Because the range is large, it was divided into 12 physiographic provinces (fig. 1) to reduce the complexity and diversity of such an extensive

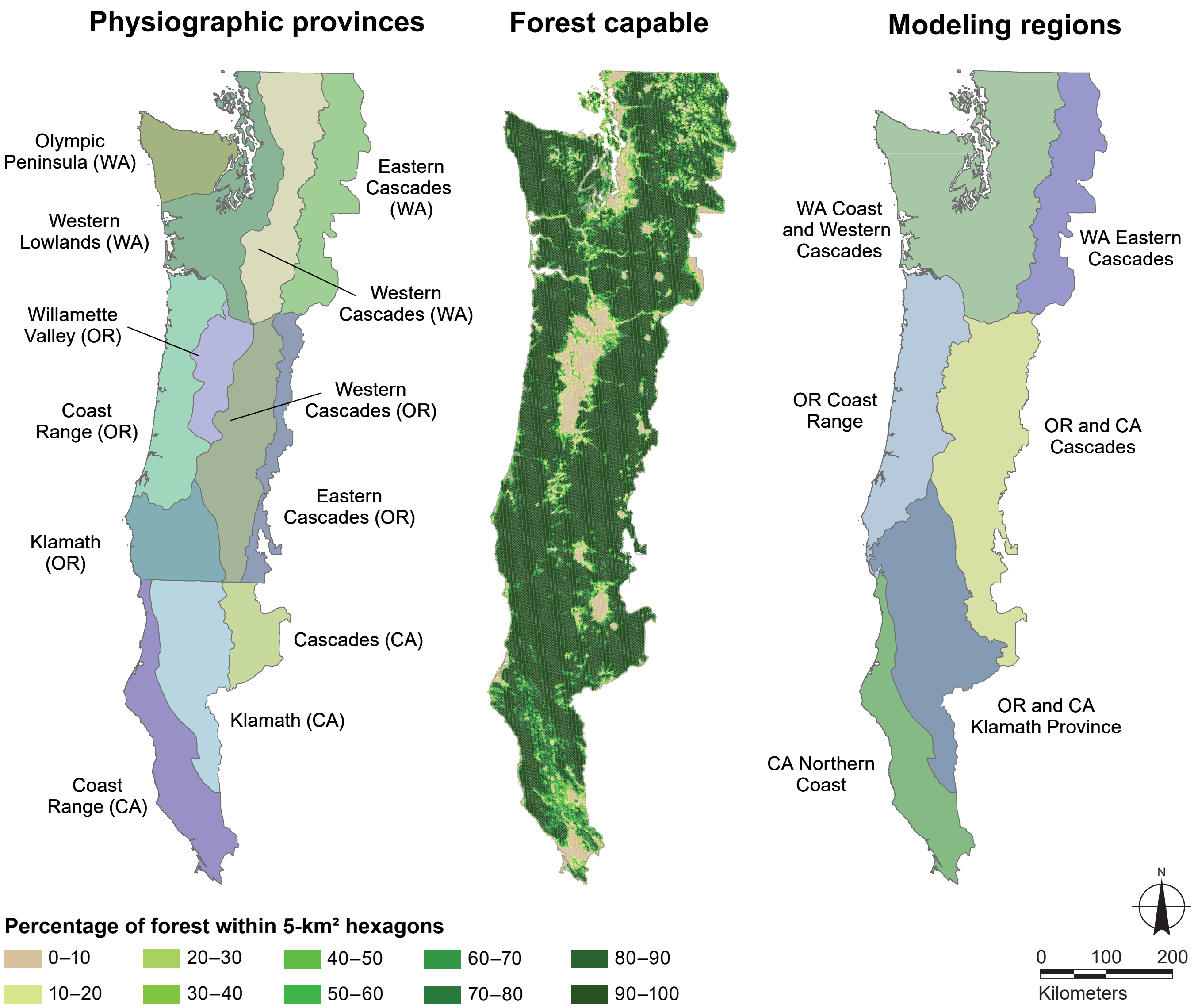

Figure 1—Physiographic provinces, percentage of forest-capable lands within 5-km^2 hexagons, and modeling regions within the range of the northern spotted owl in the United States.

geography, as well as for analytical purposes (FEMAT 1993; Thomas et al. 1990; USDA and USDI 1994). Physiographic provinces represent different forest zones, plant communities, and disturbance regimes that vary geographically with climate, topography, soils, and geology and were largely based on subdivisions by Franklin and Dyrness (1973).

Forest-Capable Area Map

This data source is a 30-m resolution (pixel size) raster map of areas capable of developing into forests (Davis et al. 2011). It is largely based on the U.S. Geological Survey Gap Analysis Program and the "impervious layer" from the National Land Cover Database (Herold et al. 2003, Vogelmann et al. 2001). It excludes urbanized areas, major roads, agricultural areas, water, lands above tree line, snow, rock, and other nonforested features. We used this map to exclude (mask) these areas for modeling, mapping and analytical purposes (fig. 1).

Modeling Regions

The NSO range was divided into six regions to model forest cover types used by the owl and for habitat modeling. They are a modified version of the physiographic provinces described above. Boundary modifications were based on (1) ecological similarities between physiographic provinces and (2) balancing the occurrence and distribution of NSO location data used for model training and testing. We used geographic region information from population monitoring work (Anthony et al. 2006: app. A, Forsman et al. 2011) to combine some provinces and Environmental Protection Agency level III ecoregions (Omernik 1987) to guide final delineations of modeling regions (fig. 1).

Land Use Allocation Map

LUAs describe overarching forest management direction. The geographic information system (GIS) layer representing LUAs was originally delineated when the NWFP was developed (USDA and USDI 1994). It has been updated prior to each monitoring cycle to account for LUA changes that occurred in the prior 5 years as well as minor editing to correct mapping errors. Updates include federal surface ownership boundary adjustments, changes in federal land ownership (e.g., land exchanges, land acquisitions and disposals), and changes owing to forest resource management plan amendments or revisions. Since the last monitoring report, the BLM has revised its LUAs in western Oregon (USDI BLM 2016a, 2016b). However, the management objectives and direction for the new LUAs are similar to those in the NWFP (fig. 2). One noteworthy change in the BLM revision is the division of BLM forests into areas characterized as moist (northwestern and coastal Oregon) and dry (southwestern Oregon) to recognize ecological differences between the historical fire regimes of western Oregon, as well as different habitat treatments that are hypothesized to reduce the risk of loss of suitable habitat in the dry forest types.

Federal LUAs have specific management directions, so we classified these allocations into reserved and nonreserved lands. Reserved allocations are areas where the maintenance and restoration of older forests over time are expected under the current land use plans, including the following (GIS layer attribute codes in parentheses):

- Congressionally reserved areas (CR)—lands reserved by the U.S. Congress, such as wilderness areas, wild and scenic rivers, and national parks and monuments.
- Late-successional reserves (LSRs)—lands reserved for the protection and restoration of late-successional/old-growth (LSOG) forest ecosystems and habitat for associated species; this includes marbled murrelet reserves (LSR3) and NSO activity core reserves (LSR4).
- Managed late-successional areas (MLSAs)—areas for the restoration and maintenance of optimal levels of LSOG forest on a landscape scale where regular and frequent wildfires historically occurred. 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 (AW)—areas identified in local forest and district plans, including recreation and visual retention areas, backcountry, and other areas where management emphasis does not include scheduled timber harvest.
- Adaptive management area in reserves (AMR)—areas 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 the following sustained-yield management for timber production:

- Matrix (other)—federal lands outside of reserved allocations where most timber harvest and silvicultural activities were expected to occur.
- Adaptive management area nonreserved (AMA)—identified to develop and test innovative management to integrate and achieve ecological, economic, and other social and community objectives. Commercial timber harvest was expected to occur in these areas, testing alternative approaches to meet NWFP objectives.

Standards and guidelines in the NWFP and revised BLM resource management plans allow for timber harvesting within LSRs that is designed to benefit the development of late-successional conditions. In the moist forests, stands (generally <80 years old) not currently providing nesting/roosting function for NSOs can be managed to speed the development of, or improve, NSO habitat quality in the long term. On BLM lands, these treatments are not to preclude or delay by 20 years or more the nesting/roosting function of a stand compared to development without treatment (USDI BLM 2016a: 64–67). Management direction for dry

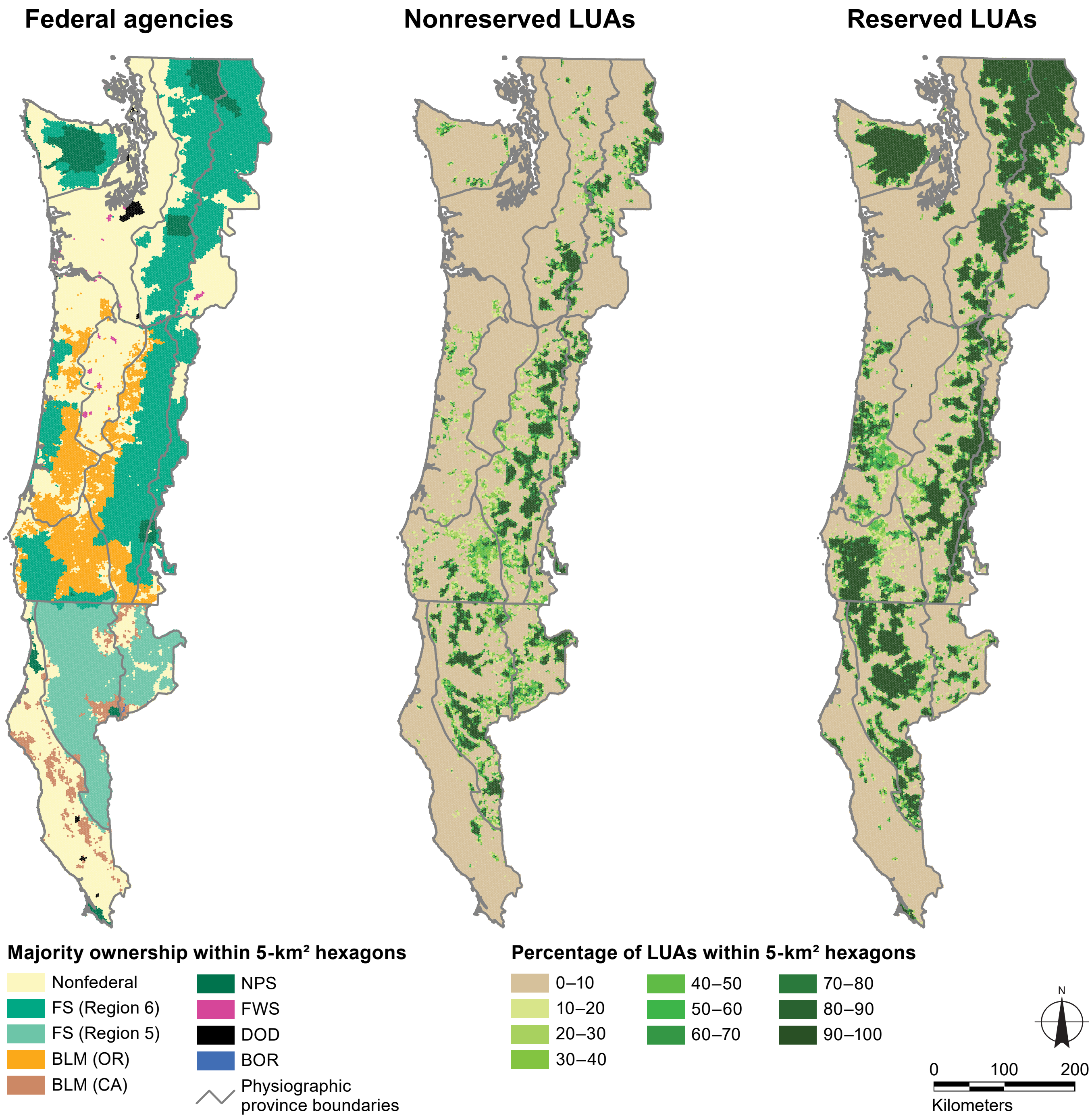

Figure 2—Maps of federal forest management agencies and land use allocations (LAUs) summarized as majority ownership and percentage of area in 5-km² hexagons within the range of northern spotted owls in the United States. FS = Forest Service, BLM = Bureau of Land Management, NPS = National Park Service, FWS = Fish and Wildlife Service, DOD = Department of Defense, BOR = Bureau of Reclamation.

forests is reflective of the more frequent, fire-driven stand and landscape dynamics. Focus is therefore on restoring resistance and resilience against fire, insects, and drought through vegetation treatments. Outside of BLM lands, timber harvesting in LSRs is allowed west of the Cascade crest in stands up to 80 years old (110 years in the Northern Coast Range Adaptive Management Area) regardless of stand origin (e.g., plantations or naturally regenerated) if it benefits the creation, hastens the transition to, or maintains late-successional forest conditions. East of the crest and in the Oregon and California Klamath Physiographic Provinces, silvicultural activities aimed at reducing the risk of large, high-severity wildfires are allowed. The focus of these treatments is to make the reserved forests in fire-prone environments less susceptible to losses from large-scale, high-severity fire. Such management activities are encouraged in LSRs even if a portion of the activities must take place in late-successional forests. Such activities in older stands may also be undertaken in LSRs in other provinces if fire risk is particularly high (USDA and USDI 1994: C-12).

We used the updated LUA layer, as of 2017, to frame the status and trend analyses in this report (fig. 2). Since NWFP implementation, there has been a slight overall increase in federal lands (1.8 percent) with an 8 percent increase in reserved LUAs, largely owing to new LSR designations by the BLM in western Oregon. As in previous monitoring reports, riparian reserves, another NWFP LUA, were not delineated because they were supposed to be delineated based on site-specific analyses.

Forest Disturbance Maps

Annual forest disturbance maps (30-m pixel resolution) were produced for forest-capable lands from 1986 to 2017 using an ensemble LandTrendr methodology (Cohen et al. 2018, Healey et al. 2018). These maps (fig. 3) are part of a larger national dataset produced by the USDA Forest Service Rocky Mountain Research Station's Landscape Change Monitoring System program (USDA FS 2021). Three types of annual maps of forest disturbance were produced:

- Year of detection—image taken the year change was detected. This year does not always represent the year of disturbance. Often, vegetation change caused by a disturbance was detected in the following year; but sometimes it was detected >1 year afterward, depending on Landsat image availability and other factors. Usually, disturbance was detected within 2 years of the disturbance event.
- Duration of disturbance—the duration of a disturbance was based on the number of years of consecutive disturbance segments. Short-duration (usually 1 year) disturbances are associated with events that quickly remove or alter forest vegetation cover (e.g., wildfires, timber harvesting, forest clearings, wind, floods, etc.). Disturbances lasting multiple years represent slow forest change and loss of cover caused by insects, disease, or other physiological stressors (Cohen et al. 2016).
- Severity of disturbance—the relativized difference in the normalized burn ratio (RdNBR) (Miller and Thode 2007) was used as our index of disturbance severity. We classified disturbance severity using class thresholds (low, moderate, high) identified by Reilly et al. (2017) that correlated RdNBR with tree mortality (percentage of live tree basal area change) from pre- and postfire forest inventory plots.

The last step in disturbance mapping was to assign a cause agent (wildfire, timber harvest, insect/disease, etc.) for each disturbance signal for each year. This procedure captured multiple disturbances that occurred in the same area (pixel) over time. Assignment of disturbance agent was based on expert rulesets incorporating the duration of the disturbance, its location in relationship to federal LUAs, relationship to aerial detection survey maps for insects and disease (Coleman et al. 2018, Johnson 2016), spatial relationship to mapped wildfire perimeters (e.g., National Interagency Fire Center, Monitoring Trends in Burn Severity), and when inside wildfire perimeters, the year of detection in relationship to the wildfire year. If a disturbance inside a wildfire perimeter predated the wildfire year by >2 years, it was attributed to some other cause (e.g., insects or timber harvest). We classified disturbance cause agents into four general classes using the rules below:

- Timber harvest—including thinning and regeneration. Classified as abrupt disturbances (duration <4 years) outside of CR lands (e.g., wilderness areas) where timber harvesting is not allowed in the reserved area's

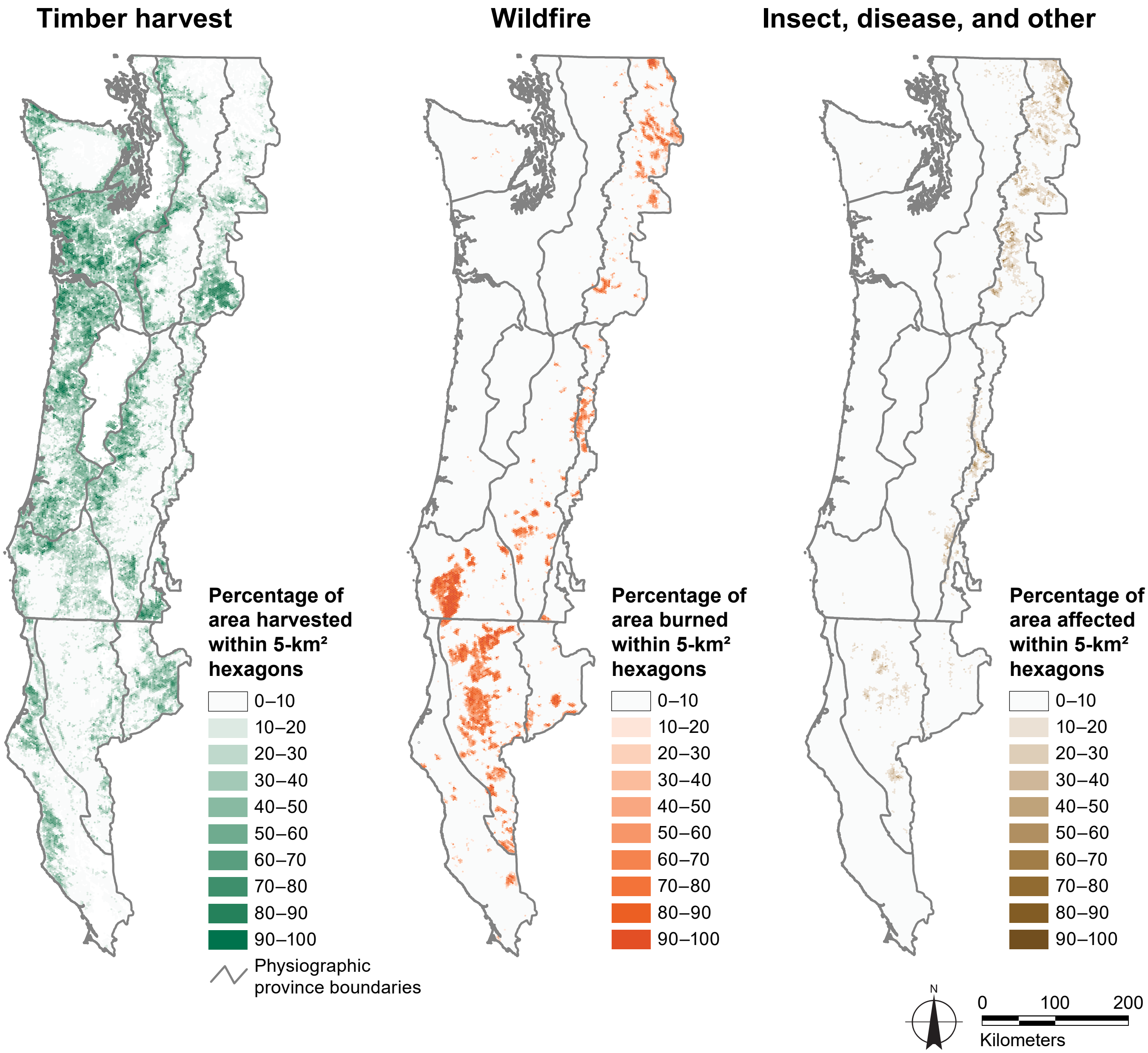

Figure 3—Cumulative forest disturbances over 25 years (1993–2017) summarized as percentage of disturbed area in 5-km^2 hexagons within the range of northern spotted owls in the United States.

management plan. During our monitoring period, new CRs have been designated; and for these, harvest attribution only applied to disturbances prior to the year of designation. Abrupt disturbances within wildfire perimeters were attributed to harvesting if they occurred prior to the fire year.

- Wildfire—a disturbance with duration of 1 year that occurred the same year, or the year following a fire and within a mapped wildfire perimeter.
- Insect and disease—disturbances with long durations (≥4 years, persistent), or more than four (chronic) disturbances detected. Also, this includes small disturbance patches shorter duration (patch size <9 pixels) when they occurred with a "potential insect/disease area" (PIDA). The PIDA was generated using a focal mean analysis on a binary map of pixels exhibiting persistent or chronic disturbance signals (duration ≥4 years or more than four disturbance events). A focal

mean using a 1-km radius (equivalent to a 776-ac area) was compared against aerial detection survey polygons for the region to identify a mapping threshold to represent PIDAs. We observed that when at least 10 percent of this area contained persistent/chronic disturbance signals, it matched well with aerial detection survey data.

- Other disturbance—All detected disturbances not assigned above.

Forest Structure and Species Composition Maps

Annual forest vegetation structure and composition maps (30-m pixel resolution) for forest-capable lands from 1986 to 2017 were generated using the gradient nearest neighbor (GNN) imputation modeling and mapping methodology developed by Oregon State University Department of Forest Ecosystems and Society's Landscape Ecology, Modeling, Mapping, and Analysis program (LEMMA 2020). GNN is a multivariate, nonparametric modeling and mapping framework that inputs forest inventory plot data to individual map pixels based on Landsat surface reflectance and environmental similarity in the gradient space (Ohmann and Gregory 2002). The version of GNN used in our analysis was based on the composite Landsat images produced to map the forest disturbances above, matching plot measurements to Landsat image years (Bell et al. 2021).

Methodological changes, described in detail in the late-successional and old-growth monitoring report (Davis et al., in press), improved the quality of GNN compared to previous monitoring reports. This included using a consistent type of forest inventory plot for imputations, the ensemble LandTrendr imagery described above, imagery stabilization, and bootstrapped approximations utilizing multiple neighbors ($k = 7$) with weighted means proportional to the probability that a bootstrap sample would result in that plot being the nearest neighbor for a pixel (Davis et al., in press).

NSO Presence Data

NSO pair locations from demographic study areas, supplemented with other location data, were used to train species distribution models used for 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 reduce 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 from the late 1980s through the 1990s compiled for the 10-year monitoring report (Lint 2005). We limited our data to those collected prior to extensive barred owl invasion that likely affected NSO forest selection. 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: 30, 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 procedure resulted in a more complete spatial distribution of NSO locations (less clumped) throughout each modeling region. All locations were compiled and checked for spatial accuracy.

Methods

Mapping Nesting/Roosting Forest

Maps of forest types associated with owl nesting and roosting were produced following methods from previous monitoring reports (Davis et al. 2011, 2016), and that methodology is described briefly below. Open-source machine learning software Maxent (Phillips et al. 2006, 2017, 2021) was used to develop a forest cover type model for each modeling region using 10 bootstrapped random samples. We used 75 percent of NSO locations for model training and 25 percent for model testing. Training locations were analyzed against a random sampling of 10,000 background locations from forest-capable pixels within the modeling region.

Based on findings of previous reports and analyses of NSO forest selection (Davis et al. 2011, 2016), we used five GNN forest structure metrics as model predictor variables that co-date the NSO location demography data: density (trees/ha) of large trees >75 cm diameter at breast height (d.b.h.), percentage of live conifer tree canopy cover, average stand height (meters) of live dominant and codominant trees, mean live conifer diameter (centimeter at d.b.h.), and diameter diversity of live trees as an index of structural diversity based on live conifer tree densities in different diameter classes. Forest species composition GNN variables included proportion of total stand basal area comprising high-elevation tree species, pine species, evergreen hardwood species, oak woodland species, and redwood (*Sequoia sempervirens* (Lamb. ex D. Don) Endl.) (depending on the modeling region). Stand age was also included as a predictor variable.

The relative proportion of training locations were fit to each model predictor variable using linear, product, and hinge response functions. Each model maximized the likelihood ratio of average presence to average background (called the gain function) to best contrast environmental conditions at owl sites from background locations. A regularization multiplier function was applied to penalize high variance in model response functions, where higher variance incurred larger penalties (Merow et al. 2013). Model calibration was accomplished by adjusting the regularization multiplier function setting from 0.25 to 5.0 incrementally by 0.25 and evaluating the difference between the training and testing gain. Maxent is prone to overfitting, resulting in predicted distributions that are clustered around location points. Model overfitting was indicated when training gain was significantly higher than testing gain based on nonoverlapping 95 percent confidence intervals.

We evaluated model predictive performance using the area under the curve (AUC) statistic (Fielding and Bell 1997) based on the held-out test locations and by examining the ratio of the proportion of correctly predicted test locations to the proportion of available area within a moving window of modeled suitability—the predicted-vs-expected (P/E) curve as described in Hirzel et al. (2006). The best model was indicated by having the highest AUC, a monotonically increasing P/E curve with a high Spearman rank statistic, and similar training and testing gain (e.g., overlapping 95 percent confidence intervals).

All replicate model algorithms (Maxent lambda files) from the best model were coded into Google Earth Engine (GEE), where annual model predictor variables were uploaded, to produce a time series of maps based on their mean.[1] This monitoring cycle marks the first use of GEE to demonstrate automated analysis and map production for NSO monitoring. GEE is a cloud platform for massively parallel spatial analyses and computation and has provided many benefits in model development in terms of rapid comparison, visualization, and attribute calculation (Gorelick et al. 2017). Our use of GEE resulted in a considerable savings in time and effort that would normally be required for data management and analyses of such a large quantity of spatial data. Although we produced 31 years of maps (1986–2017) using Landsat 5, 7, and 8 image collections freely available in GEE, the following analyses focused on the years from 1993 to 2017 between which the analyses were bookended.

We used the logistic model output as the relative index of forest suitability for nesting and roosting by NSO pairs. The forest suitability index ranged from 0 to 1.0, where values closer to zero represent forest structure and species composition unsimilar to that found at NSO locations and higher values are more similar. Following procedures from Hirzel et al. (2006), we used the P/E curve to reclassify the continuous suitability index into four biologically meaningful map classes as follows:

- Unsuitable—Maxent logistic output from zero to the mean value between 0 and the P/E = 1 threshold. This map class represents forest types that NSOs normally avoid using for nesting and roosting.
- Marginal—Maxent logistic output from the unsuitable threshold to the P/E = 1 threshold, resulting in a map class that represents forest types approaching what NSOs will nest and roost in.
- Suitable—Maxent logistic output from the P/E = 1 threshold to 0.5. This map class represents forest types where nesting and roosting occurred 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 suitability index value. This map class represents forest types with above-average conditions found at nesting and roosting locations.

[1] The use of trade or firm names in this publication is for reader information and does not imply endorsement by the U.S. Department of Agriculture of any product or service.

To produce rangewide maps of NSO nesting/roosting forest, we applied these mapping thresholds to the Maxent logistic outputs in GEE, producing mosaics of the reclassified maps from each modeling region for each year. The "suitable" and "highly suitable" map classes were combined to analyze trends in nesting/roosting forest.

Pixels can be misclassified as nesting/roosting forest following a high-severity disturbance (e.g., stand-replacing event) because rapid green up of ground vegetation creates surface reflectance in Landsat imagery that is similar to old forest (Bright et al. 2019). These misclassifications can produce errors in the forest vegetation maps used as modeling variables that are transferred to the forest type models and thus cause artificial gains in nesting/roosting forest. To correct for errors in these trends, we used high-severity disturbance maps from the Landscape Change Monitoring System program to mask out unrealistic recruitment of nesting/roosting forest in our time series as it takes decades, not a few years, for a stand-replaced forest to redevelop back into a nesting/roosting forest. Specifically, once a pixel of nesting/roosting forest was lost because of a high-severity disturbance, it was maintained as nonnesting for the remainder of the time series.

Forest Fragmentation Analysis

We used modified methods described by Soille and Vogt (2009) that were coded into GEE to conduct morphological spatial pattern analyses of the time series of nesting/roosting forest maps. These maps were classified into two spatial pattern types (fig. 4):

- Interior—30-m pixels classified as nesting/roosting forest (combined suitable and highly suitable classes) and >1 map pixel from unsuitable or marginal forest. The smallest patch containing interior consisted of a 3-by-3 pixel configuration (2 ac) with the center pixel classified as interior.
- Edge—30-m pixels classified as nesting/roosting forest and directly adjacent to unsuitable or marginal pixels.

Microclimate of interior forest pixels is expected to be similar to intact old forest because patches as small as 2.4 ac have similar microclimates as large intact forest conditions (Heithecker and Halpern 2007). Fragmentation results in lower amounts of interior forest and higher amounts of edge and can occur through two different processes: (1) severe forest disturbances that remove interior forest, or (2) forest succession where a nonnesting forest begins to transition into nesting/roosting forest.

Dispersal-Capable Landscape Analysis

Forest cover types 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: 40) and is briefly described here. We developed rangewide maps of suitable dispersal forest that included the extent of nesting/roosting forest classes (suitable and highly suitable) and all pixels of GNN data representing mean conifers ≥11 inches d.b.h. and canopy cover ≥40 percent (Thomas et al. 1990). Many of the forests classified as "suitable" dispersal forest may not meet dispersal forest requirements because dispersing juveniles use similar forests as nesting/roosting forests (Sovern et al. 2015) but do serve as an effective measure of landscape forest cover.

NSOs 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, Jenkins et al. 2019). Ninety percent of natal NSO movements from the Forsman et al. (2002) dispersal study occurred within 15.5 mi of the natal site, when the surrounding landscape was covered with ≥40 percent dispersal forest (Davis et al. 2011). Thus, we used a 15.5-mi radius roving circular analysis window to quantify the percentage of dispersal forest for both bookend periods (1993 and 2017), including all forest landownerships. We quantified the percentage of a 15.5-mi radius roving circular window that contained dispersal forest for both bookend periods and considered any pixel with ≥40 percent dispersal forest within the window part of the "dispersal-capable landscape."

Habitat Modeling for Estimating Number of Occupied Territories

Here we followed methods for habitat modeling and estimating density of occupied territories that were developed by Glenn et al. (2017), who reported high predictability based on independent data. Using estimates of occupied territory density, we calculated the likely number of territories occupied (TEROCC) within each demographic study area.

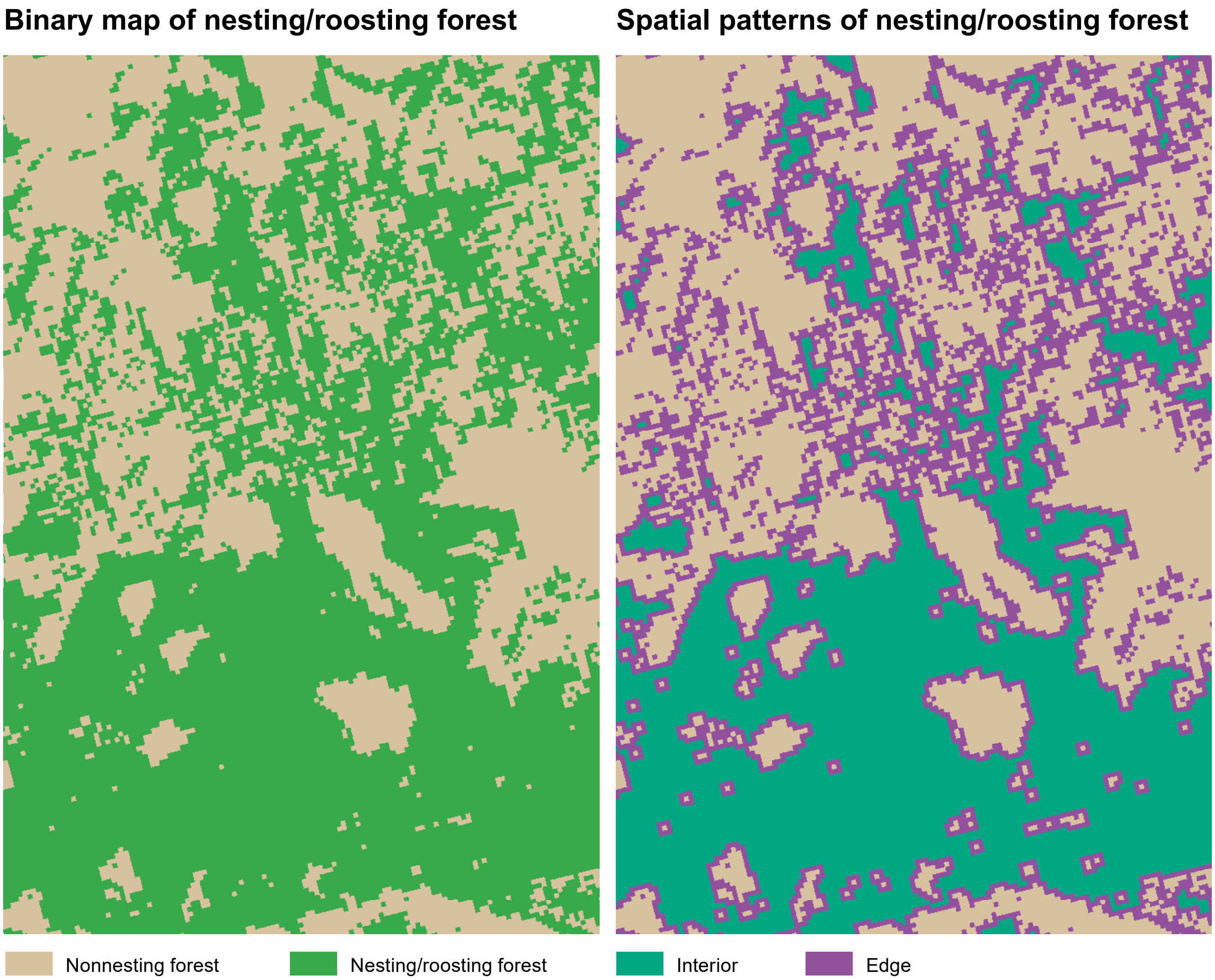

Figure 4—Nesting/roosting forest spatial pattern types produced by the morphological spatial pattern analysis.

We modeled the relationship between territorial owl pair locations and abiotic and biotic environmental conditions at multiple spatial scales (as opposed to the pixel scale used for forest type modeling) using Maxent. Nesting/roosting forest is an essential component of an owl pair's territory, so we used it as the basis for four model predictor variables spatially summarized in four ways: (1) percentage within a nest patch radius (200-m [0.2-mi] radius), (2) percentage within a territory radius (600- to 1900-m [0.4- to 1.2-mi] radii, depending on the modeling region), (3) percentage of edge nesting/roosting forest within a territory radius, and (4) distance (kilometers) from a patch of interior nesting/roosting forest. Abiotic predictor variables included elevation, topographic position index (the difference between a pixel's elevation and mean elevation within a 450-m [0.3-mi]radius), average annual precipitation, average monthly maximum temperature for August, and average monthly minimum temperature for December. All climate variables were based on the 1981–2010 climate normal (PRISM 2015).

Modeling, calibration, evaluation, and reclassification methods were identical to those described above (except that quadratic response functions were used instead of hinge). Model outputs represented a landscape-scale relative suitability index for use by territorial owl pairs and was reclassified into two map classes:

- Unsuitable—Maxent logistic output from 0 to the P/E = 1 threshold. This map class represents the biotic and abiotic conditions normally avoided for nesting and roosting.

- Suitable—Maxent logistic output from the P/E = 1 threshold to the highest suitability index. This map class represents the biotic and abiotic conditions normally used for nesting and roosting.

We produced habitat maps for the start and end (bookend) years of the monitoring period (1993 and 2017) and estimated habitat carrying capacity and TEROCC by pairs for both years. This method relied on two forms of monitoring information: (1) habitat-based estimates of territory density using median nearest neighbor distance (NND) data, and (2) occupancy rate information provided by the population meta-analyses. We first produced estimates of habitat carrying capacity using 20 random replicates of territory centers within "suitable" habitat and spaced no nearer than the NND. We used a random point generator in open-source software QGIS (QGIS 2021) to fill the suitable habitat footprint for each modeling region until no more centers could be fit, thus an estimate of habitat carrying capacity. We calculated the mean and 95 percent confidence intervals for each point replicate to estimate habitat carrying capacity for each modeling region. To estimate TEROCC, we adjusted the habitat carrying capacity using occupancy rates reported in the latest population meta-analysis (Franklin et al. 2021) that included the effects of other environmental variables that affect occupancy, such as the presence of barred owls. To ensure that our TEROCC estimates were reasonable, we compared them to territory occupancy and realized population change estimates for all eight federal demographic study areas (Franklin et al. 2021).

We calculated change in TEROCC estimates between 1993 and 2017 TEROCC and compared those to realized population change estimates reported by Franklin et al. (2021). For our modeling time period, we calculated change in habitat carrying capacity and TEROCC on all federal lands and within reserved lands.

Results

Mapping Nesting/Roosting Forest

The nesting/roosting forest models had mean testing AUCs ranging from 0.78 to 0.92 and mean Spearman rank correlation coefficients from 0.87 to 0.98 ($P < 0.001$) (table 1).

Nesting/roosting forest was concentrated on federal lands at the beginning of the monitoring period (71.9 percent) and slightly more so at the end (72.5 percent). We estimated a rangewide gross loss of about 1,045,100 ac of nesting/roosting forest on federal lands since the NWFP was implemented (app. 1). This amounted to about 11.8 percent of what was present in 1993. Most of the losses (69.4 percent) occurred within the federally reserved LUAs, roughly in proportion to the amount of nesting/roosting

Table 1—Nesting/roosting forest modeling results for model calibration and testing statistics

Modeling region	Training sample	Testing sample	RM	Training gain	Testing gain	Testing AUC	Spearman rank
Washington coast and Cascades	250	83	0.50	1.15 (±0.03)	1.15 (±0.05)	0.88 (±0.01)	0.97 (±0.01)
Washington eastern Cascades	87	28	1.75	0.90 (± 0.05)	0.93 (±0.13)	0.85 (± 0.02)	0.87 (±0.07)
Oregon Coast Range	247	82	0.75	1.46 (±0.04)	1.48 (±0.07)	0.92 (±0.01)	0.93 (±0.04)
Oregon and California Cascades	596	198	2.75	0.70 (±0.01)	0.73 (±0.03)	0.80 (±0.01)	0.97 (±0.01)
Oregon and California Klamath	757	252	0.75	0.53 (±0.02)	0.52 (±0.03)	0.78 (±0.01)	0.98 (±0.01)
California coast	175	58	0.50	0.83 (±0.04)	0.69 (±0.12)	0.80 (±0.02)	0.90 (±0.06)

Means with 95 percent confidence intervals are shown in parenthesis.
RM = regularization multiplier setting, AUC = area under the curve.

forest that is reserved. Figure 5 shows the spatial pattern of net losses and gains of nesting/roosting forest within the owl's range on all forest lands.

On federal lands, wildfires accounted for 67.3 percent (703,700 ac) of nesting/roosting forest losses. Timber harvesting accounted for 24.7 percent (257,700 ac), while insects, disease, and other disturbances (e.g., blowdown, floods, etc.) accounted for 8 percent (83,700 ac). Considering both losses and gains from forest succession, we estimated a rangewide net increase in nesting/roosting

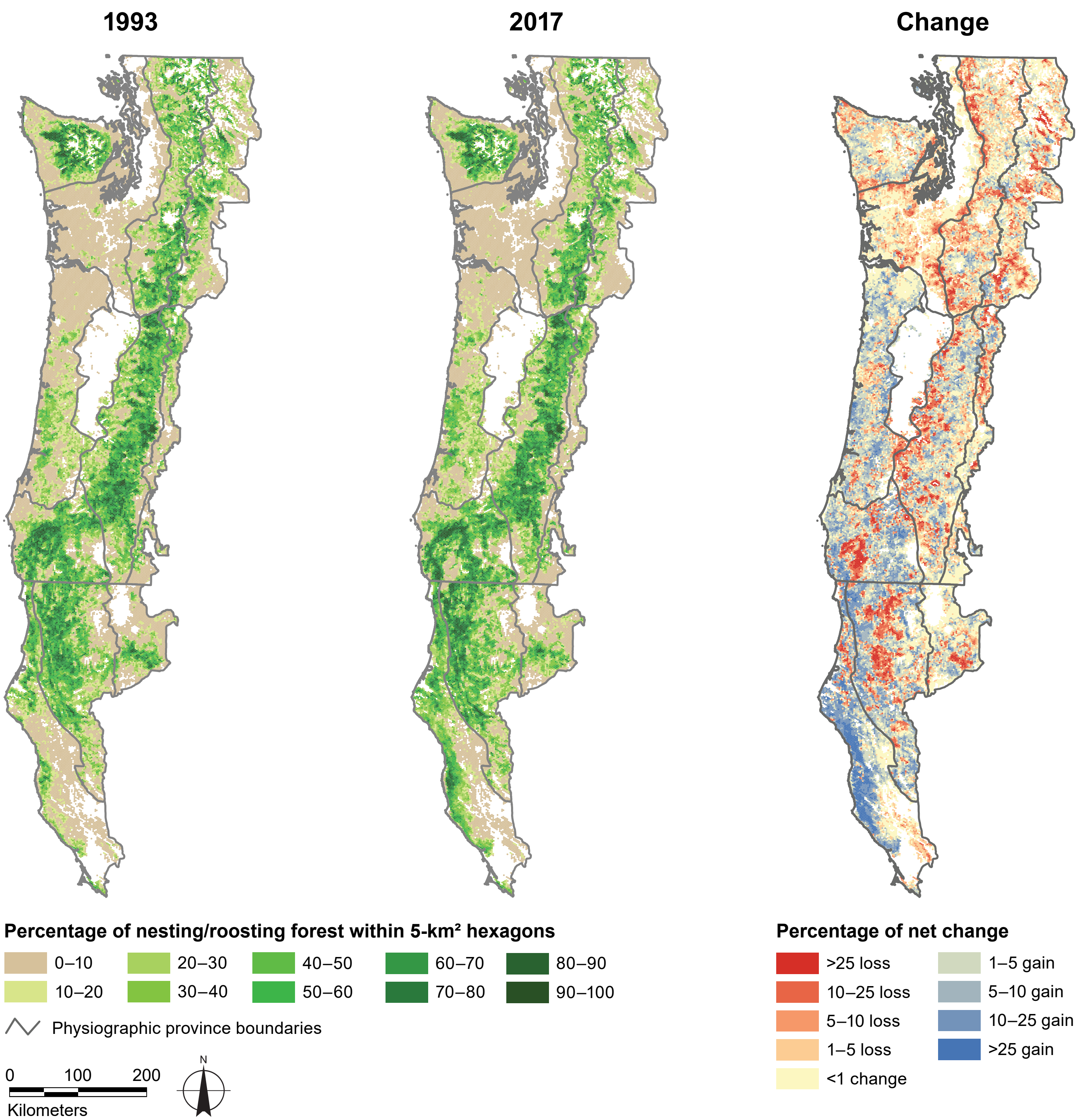

Figure 5—Bookend and change maps of nesting/roosting forest and patterns of change for the first 25 years of Northwest Forest Plan implementation within the range of the northern spotted owl in the United States.

forest of 3 percent on federal lands. The linear trend between bookend years on federal lands was positive, with an average of 12,400 ac (about 0.12 percent) recruited annually. On federally reserved LUAs, the trend was essentially stable with net increase of 0.1 percent (fig. 6).

The 2002 wildfire season caused the largest annual loss of nesting/roosting forest (≈180,000 ac, or ≈1-percent loss), most of this (86 percent) was in reserved LUAs. The period 2009–2012 showed the highest annual gains (about 53,500 ac per year, or 0.6-percent recruitment), with about half of that occurring in reserved LUAs. Most of the gains occurred closer to the Pacific coast and moister physiographic provinces (e.g., coast ranges and western Cascades). Reasons for the net gain were mainly owing to recruitment from old stand-replacing fires that burned in those areas during the mid- to late-1800s.

The physiographic province that experienced the greatest net loss of nesting/roosting forest on federal lands was the Washington Eastern Cascades (fig. 7). The California and Oregon Klamath physiographic provinces experienced the largest gross losses (394,200 and 220,600 ac, respectively) as a result of wildfires, but gains offset losses in both provinces (app. 1). Net gains were seen in 8 of the 12 physiographic provinces with the largest net gains occurring in the Oregon Coast Range and western Cascades (fig. 7). For more details on nesting/roosting forest net change and gross losses, see appendix 1.

Habitat Fragmentation Analysis

Although we estimated a net increase in nesting/roosting forests on federal lands rangewide, these forests have become slightly more fragmented with a rangewide, 2.6-percent increase in the proportion of edge. This varied by physiographic province (fig. 8).

The Oregon western Cascades had the most intact nesting/roosting forest and the western lowlands of Washington had the most fragmented forest. Rangewide, nesting/roosting forest was 5 percent less fragmented on federal reserved LUAs compared to nonreserved forest lands. The most intact reserved allocations were on Washington's Olympic Peninsula, with 30 percent more interior forest on reserved than nonreserved LUAs. The only province with more fragmented nesting/roosting forest on reserved LUAs than nonreserved LUAs was the eastern Cascades of Washington, which increased from 2 to 3.5 percent more fragmented between 1993 and 2017.

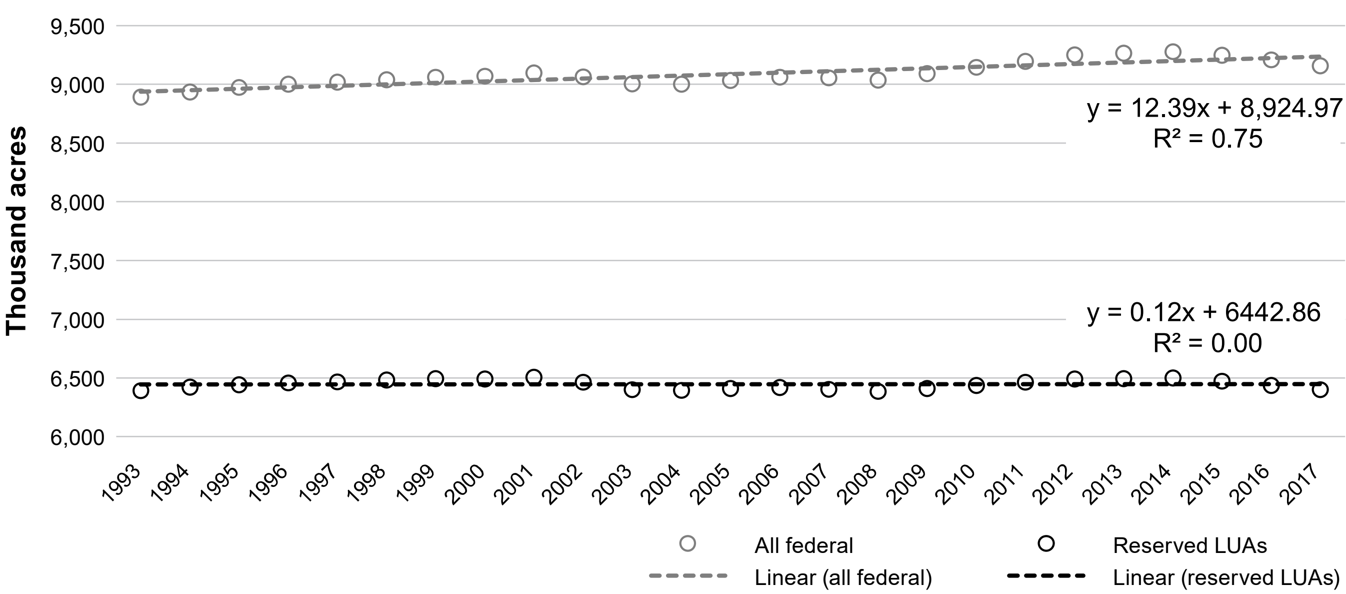

Figure 6—Trends of nesting/roosting forest on federal lands between 1993 and 2017. The *x*-axis values used in the regression are the sequential index of the years starting with 1993 (year 1) and indexed to 2017 (year 25), which represent the first 25 years since the design and implementation of the Northwest Forest Plan. LUAs = land use allocations.

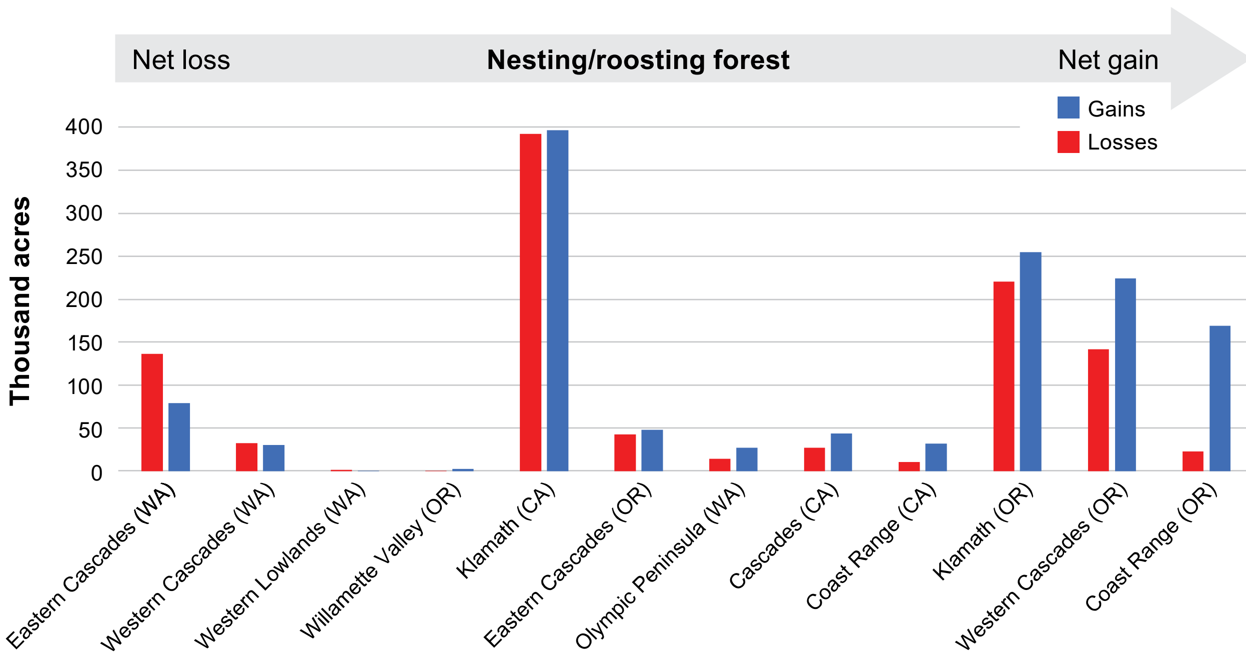

Figure 7—Bookend losses and gains in nesting/roosting forest on federal lands. Physiographic provinces are ordered by net gain (least to most) from left to right.

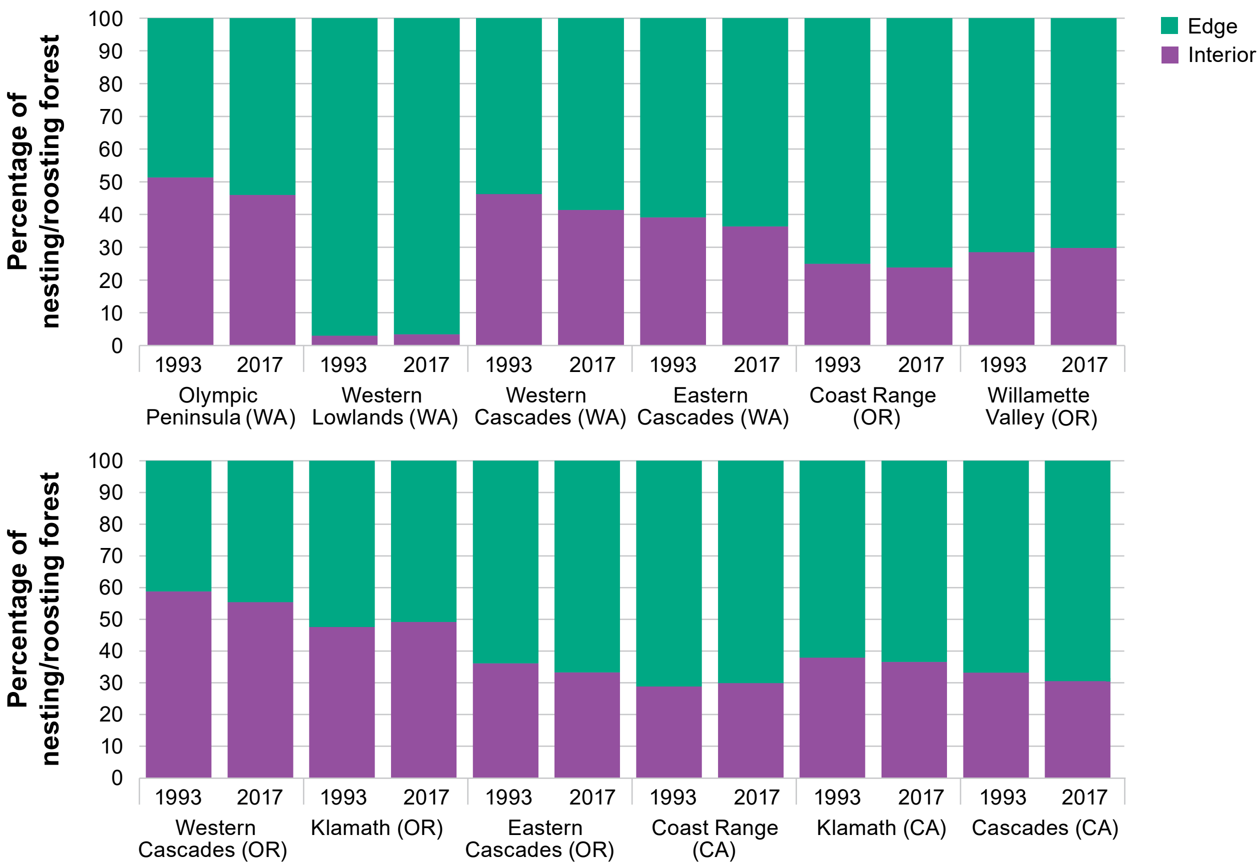

Figure 8—Bookend changes in nesting/roosting forest spatial patterns by physiographic province.

Dispersal-Capable Landscape Analysis

Rangewide, we report an estimated gross loss of about 1.47 million ac of dispersal forest on federal lands, about 9.4 percent of what was present in 1993 (app. 2). Similar to the pattern of loss for nesting/roosting forest, 69.3 percent of dispersal forest losses occurred on reserved LUAs. On federal lands, wildfires accounted for 67.9 percent (998,300 ac) of dispersal forest losses. Timber harvesting accounted for 23.3 percent (343,200 ac), while insects, disease, and other disturbances accounted for 8.7 percent (128,600 ac). Losses were offset by a 1.63-million-ac gross gain in dispersal forest from forest succession on federal land, resulting in a 1-percent overall net gain; however, a 1.9-percent net decrease remained in the reserved LUAs. The trend in dispersal forest has been positive for all federal lands, with an annual recruitment of about 7,800 ac per year since 1993. The trend on reserved LUAs was negative, with average losses of about 9,700 ac per year (fig. 9).

The physiographic province that experienced the greatest net loss of dispersal forest on federal lands was the Washington Eastern Cascades (fig. 10). All eastern Cascades and Klamath physiographic provinces, which occur in the most fire-prone portions of the range, experienced net losses of dispersal forests largely because of wildfires. Net gains were seen in six physiographic provinces, with the largest net gains occurring in the western Cascade and Coast Ranges (fig. 10). For more details on dispersal forest net change and gross losses, see appendix 2.

Rangewide, we estimated a 15-percent net decrease in dispersal forests on nonfederal lands, and a 5.8-percent net decrease on all lands combined. These losses resulted in a 12.4-percent gross loss in the dispersal-capable landscape, largely because of second-rotation regeneration timber harvesting on bordering nonfederal lands and large wildfires. We detected a 3.4-percent gain caused by forest succession in younger forests along the periphery of some federal forests, but mainly on nonfederal lands within the redwood region of the California Coast Range physiographic province. The result was an overall net decrease of 9 percent of the dispersal-capable landscape since 1993 (fig. 11).

In general, the dispersal-capable landscape continues to recede into federally managed lands in Washington and Oregon. Extremely large wildfires such as the 2002 Biscuit Fire created large internal gaps within federally managed lands. Notable losses of connectivity between physiographic provinces occurred at the pinch point between the Oregon Coast Range and the western Cascades. A connection was also lost within the Oregon Coast Range province, with the northern portion of this province becoming isolated from the southern portions (fig. 11).

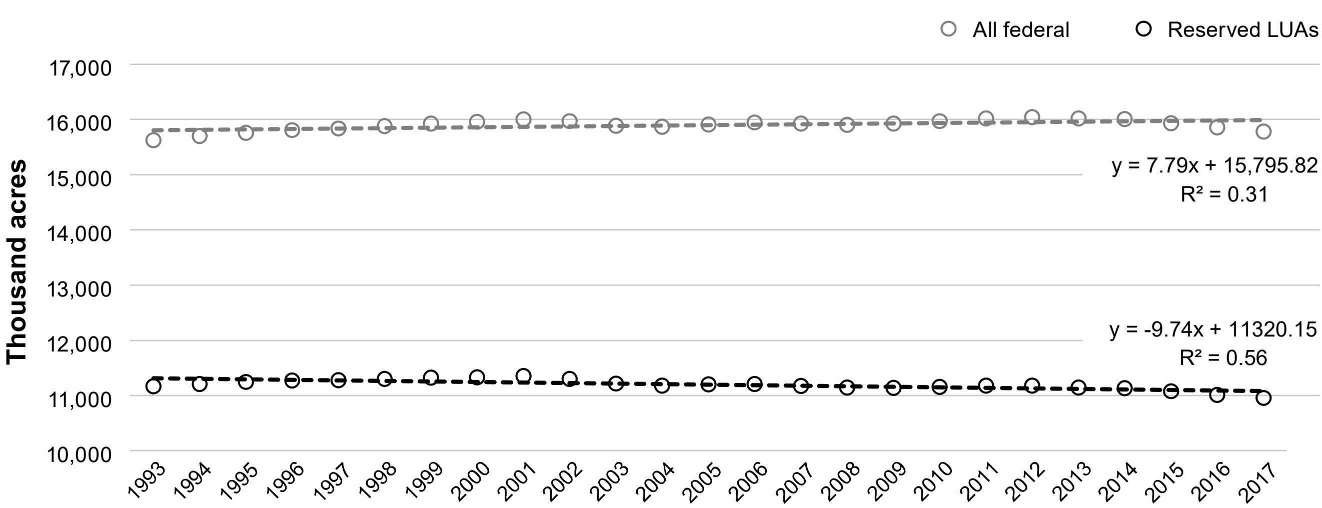

Figure 9—Trends of dispersal forest on federal lands between 1993 and 2017. The *x*-axis values used in the regression are the sequential index of the years starting with 1993 (year 1) and indexed to 2017 (year 25), which represent the first 25 years since the design and implementation of the Northwest Forest Plan. LUAs = land use allocations.

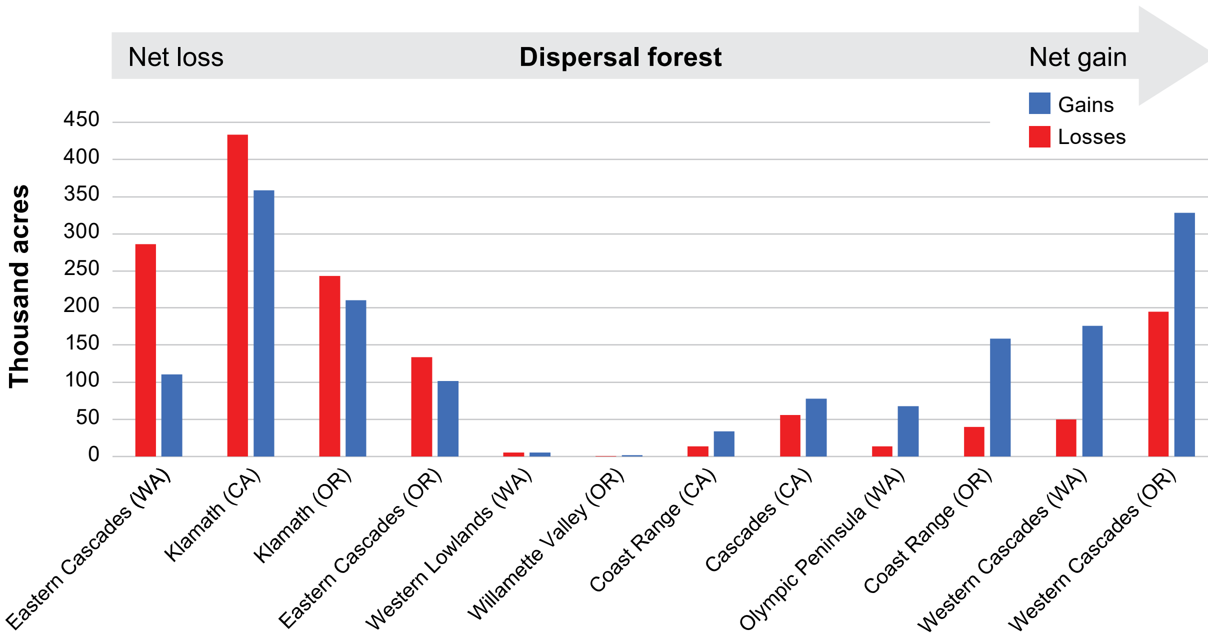

Figure 10—Bookend losses and gains in nesting/roosting forest on federal lands. Physiographic provinces are ordered by net gain (least to most) from left to right.

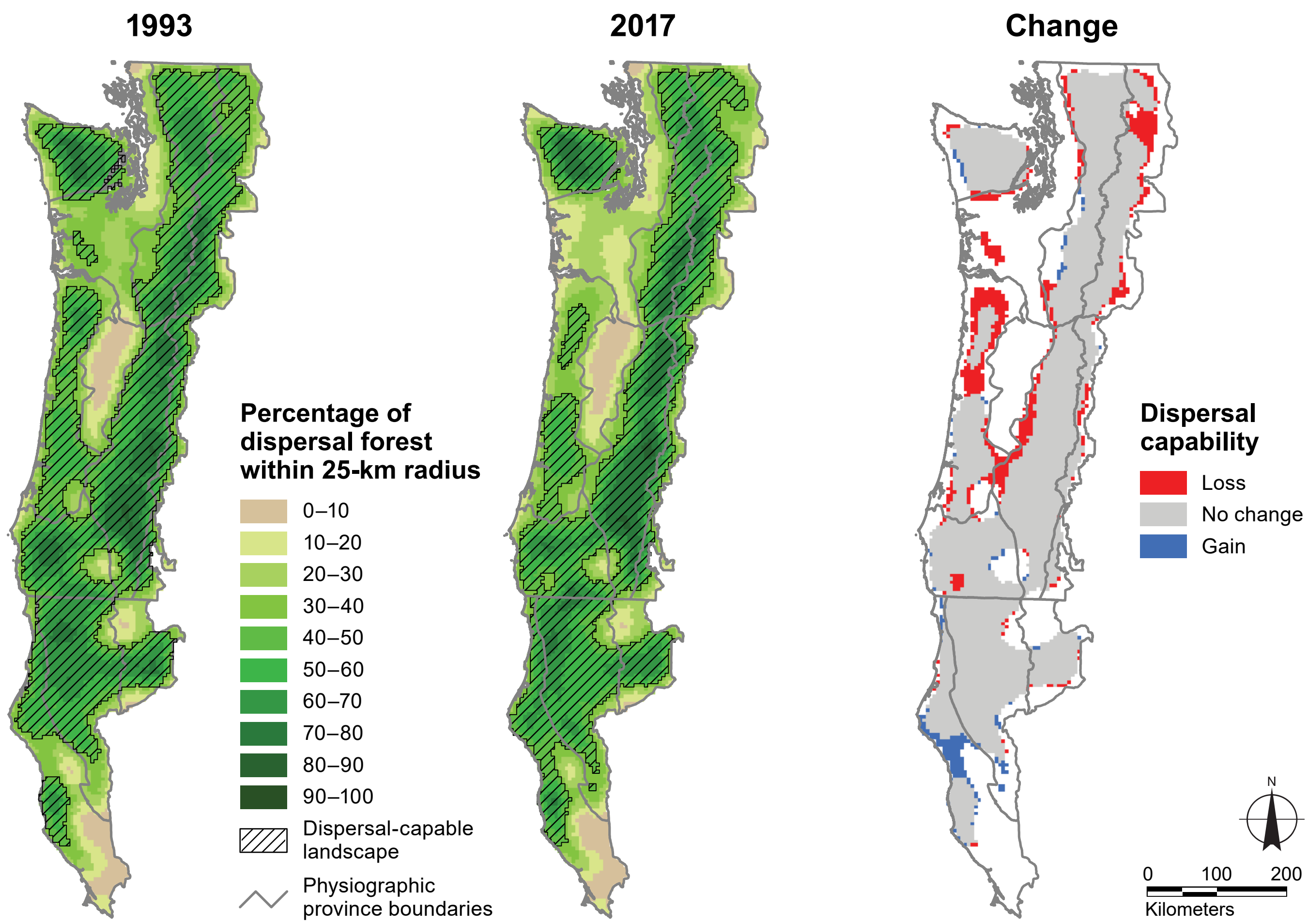

Figure 11—Bookend and change maps of the dispersal-capable landscapes and patterns of change for the first 25 years of Northwest Forest Plan implementation.

Habitat Modeling for Estimating Number of Occupied Territories

Habitat models performed well, with mean testing AUCs ranging from 0.82 to 0.92 and mean Spearman rank correlation coefficients ranging from 0.91 to 0.99 ($P < 0.001$) (table 2).

Our TEROCC point estimates for 1993 and 2017 were generally lower, but with overlapping 95 percent confidence intervals, than those estimated from the most recent meta-analysis (app. 3, Franklin et al. 2021). We suspect that this may be due to the use of an averaged NND based on the NNDs from all study areas within a modeling region for spacing of randomly generated territories. For example, within the Oregon and California Cascades modeling region, the NND for the H.J. Andrews study area is 2 km (1.24 mi) and 3.5 km (2.17 mi) for the southern Cascades study and pair territory estimates for H.J. Andrews were lower for both time periods (app. 3). Changes in TEROCC and Franklin et al. (2021) realized population change estimates had overlapping 95 percent confidence limits (except for the Oregon Klamath study area) and the mean owl pair territory estimates were mostly within the confidence limits of the realized population change (table 3).

On all federal lands at the range scale, habitat carrying capacity increased on federal lands by 3.4 percent, but TEROCC decreased by 61.8 percent (fig. 12). In federal reserved lands, habitat carrying capacity increased by 0.4 percent, but TEROCC decreased by 64.5 percent (fig. 12). On federal lands, the proportion of TEROCC in reserve lands decreased from 70 percent in 1993 to 65 percent in 2017. The opposite trajectories between habitat carrying capacity and TEROCC were mainly due to increased presence of the invasive barred owl. Mean NSO occupancy rates in federal demographic study areas ranged from 46 to 91 percent in 1993 to 7 to 38 percent in 2017 (Franklin et al. 2021). Barred owls displace NSOs from existing and recruited forest habitat. Abundant habitat helps to mitigate the negative effect of barred owls on NSO occupancy but does not reverse it (Franklin et al. 2021, Yackulic et al. 2019).

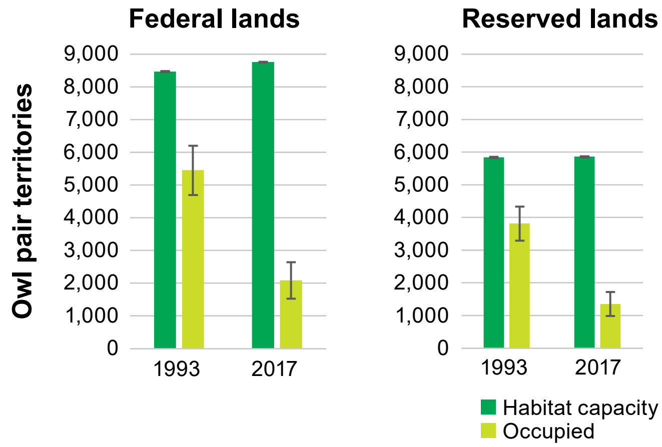

Figure 12—Northern spotted owl pair territory estimates on federal forests for the bookend periods.

Table 2—Habitat modeling results for model calibration and testing statistics

Modeling region	Training sample	Testing sample	RM	Training gain	Testing gain	Testing AUC	Spearman rank
Washington coast and Cascades	250	83	1.00	1.50 (±0.03)	1.52 (±0.05)	0.92 (±0.004)	0.97 (±0.01)
Washington eastern Cascades	87	28	5.00	1.10 (± 0.09)	1.31 (±0.10)	0.90 (± 0.01)	0.91 (±0.02)
Oregon Coast Range	247	82	2.00	1.49 (±0.07)	1.51 (±0.14)	0.91 (±0.01)	0.97 (±0.01)
Oregon and California Cascades	596	198	3.00	0.83 (±0.02)	0.84 (±0.02)	0.84 (±0.004)	0.98 (±0.01)
Oregon and California Klamath	757	252	4.50	0.68 (±0.02)	0.73 (±0.03)	0.82 (±0.004)	0.99 (±0.003)
California coast	175	58	2.50	0.94 (±0.04)	1.03 (±0.099)	0.86 (±0.01)	0.96 (±0.02)

Means with 95 percent confidence intervals are shown in parenthesis.

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

Table 3—Comparison of population change using the Glenn et al. (2017) method for estimating pair territory densities against realized population change estimates (for all individuals detected regardless of pair status) from the latest population meta-analysis

Demographic study area	Pair territory change (1993–2017)	Realized population change (1995–2017)
	Percentage population decrease (mean and 95% CL)	
Washington Olympic	83.7 (80.4–88.4)	83.9 (74.2–91.1)
Washington Cle Elum	90.4 (86.9–95.5)	84.3 (71.1–93.2)
Oregon Coast Ranges	78.6 (75.4–82.7)	81.1 (73.5–87.0)
Oregon H.J. Andrews	52.1 (47.1–57.9)	63.4 (53.6–71.9)
Oregon Tyee	61.7 (58.6–66.1)	66.2 (53.9–75.7)
Oregon Klamath	47.7 (43.7–53.2)	76.8 (68.2–83.6)
Oregon south Cascades	51.1 (46.8–56.7)	64.6 (51.5–75.1)
Northwest California	47.2 (42.6–53.7)	46.0 (23.4–64.2)

CL = confidence limits.

Source: Franklin et al. 2021.

Discussion

In the early 1970s, the downward trend of old-growth forests resulting from timber harvesting raised concerns for the future of the NSO (Forsman 1975, Gould 1974, Mouat and Schrumpf 1974). Less than two decades later, the owl 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 design and implementation of the NWFP (FEMAT 1993, Marcot and Thomas 1997), the boundary of which was defined by the NSO geographic range in the United States. A major goal of the NWFP is to stop the downward trend in NSO populations and to maintain and restore forest conditions necessary to support viable populations on federally administered forest lands throughout its range.[2] The recovery of old-forest conditions was anticipated to happen gradually over several decades.

Here we report on monitoring forest structure and composition that are suitable for NSO nesting and roosting; and we demonstrate continued improvements in the process and speed of this monitoring that result in models that performed better than previous monitoring efforts. We expect that future monitoring efforts will improve on our methods to provide near-real-time assessments of status and detailed patterns in annual change. Differing from previous reports, our results indicated a positive trend and net gain in nesting/roosting forest on federal lands that have more than compensated for gross losses caused mainly by wildfires as well as from timber harvesting, insects, disease, and other forest disturbances. Within reserved LUAs, nesting/roosting forest was stable and most of the gains occurred in the nonreserved allocations, contrary to the NWFP assumption that habitat would improve within reserves and decline outside of them. The LSR network was designed (in part) to support NSO metapopulations and dispersal between them across federal lands. As an added measure of assurance for achieving this objective, LSRs were delineated to be large enough to withstand wildfires for up to 50 years (USDA and USDI 1994: apps. J3-8 and 9). In half this time, losses from wildfires have exceeded the anticipated 2.5-percent loss per decade within some LSRs in the fire-prone portions of the range (Davis et al. 2011, Spies et al. 2018). However, some LSRs have remained stable (<1-percent change) and others have shown gains (fig. 13).

There has been a slight increase in the fragmentation of nesting/roosting forests. Not all of it is a result of forest disturbance, it is also owing to the development of younger forests into older forests. These newly recruited nesting/roosting forests tended to occur in small patches, thus increasing the measure of fragmentation. Further, recent studies indicate that interior NSO forest is normally less prone to burning at high severity compared to fragmented (edge) or nonnesting forest types (Lesmeister et al. 2019, 2021b). In addition, it appears to dampen an increasing trend in high-severity wildfire that is occurring in nonnesting forests, and to a lesser extent in edge forests (Lesmeister et al. 2021b). This leads to the conclusion that large patches of interior nesting/roosting forest are

[2] Although the BLM has adopted new resource management plan for BLM land within the range of the NSO, it has retained contributing to the conservation of the NSO as a major objective.

more resilient to wildfires and may serve as fire refugia by normally burning at lower severity than other forest types. Further, these findings highlight the resilience of nesting/roosting forests to wildfire, and these forests are critical in postfire landscapes by providing biological legacies of live and dead large trees as well as logs.

Dispersal forests have increased slightly on federal lands, but losses on nonfederal lands due to timber harvesting

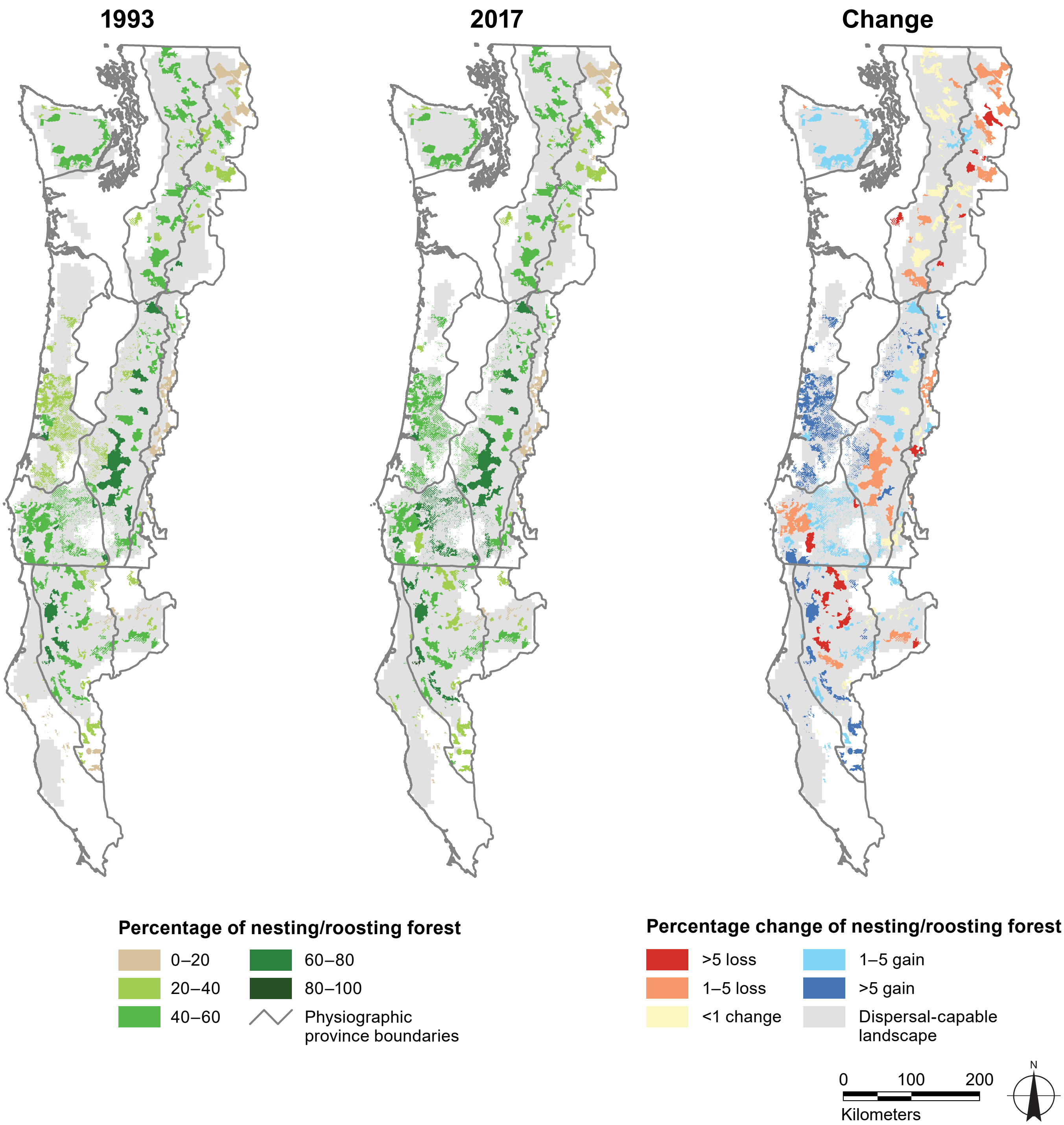

Figure 13—Bookend and change maps of the current large late-successional forest reserve network overlaid on the dispersal-capable landscape maps.

and on federal lands from large wildfires has resulted in a constriction of the dispersal-capable landscape. As a result of past forest management and the ongoing barred owl invasion, NSO populations on federal lands are becoming smaller and more widely dispersed. The decreased, narrowing footprint of dispersal-capable landscapes limits the movement of owls between remnant populations and conceivably makes it harder for recruitment from the floater NSO population (single, nonterritorial birds).

In the previous habitat monitoring report, sufficient time had not yet passed to allow for detectable recruitment of nesting/roosting forest (Davis et al. 2016). Enough time has since passed for old stand-replaced fire patches from the mid- to late-1800s to cross the threshold into suitable nesting/roosting forest conditions. The annual time series maps of nesting/roosting forest allowed us to see this occur as suitable forest pixels began to aggregate as edge-type forest, eventually forming patches of interior forest. More time is needed before we can observe significant recruitment of nesting/roosting forest from the hundreds of thousands of acres of regeneration harvest units that occurred prior to the NSO listing and implementation of the NWFP on federal lands. Given the history of timber harvesting in this region (Gale et al. 2012), this recruitment should begin to peak by around 2040, assuming that setbacks in forest succession do not occur at higher than expected rates as a result of future high-severity wildfires or timber harvest. These assumptions may not fully hold given increased occurrence of wildfires and changes in timber management plans in the region. For example, in 2020, five megafires burned about 812, 977 ac in Oregon and more than 321,236 ac was at high severity.

Despite positive trends in owl forests, NSO populations continue to decline (Franklin et al. 2021), and now the subspecies warrants reclassification to endangered (USDI FWS 2020). The declines have been attributed to continued forest loss and the invasive barred owl that are displacing NSOs from their native habitat. Although increasing amounts of suitable nesting/roosting forest help to mitigate declines in NSO occupancy, it is not expected to reverse the trend by itself (Franklin et al. 2021, Yackulic et al. 2019). The predicted increase in frequency and extent of large wildfires (Davis et al. 2017) will make the NWFP goal of stabilizing NSO habitat and populations more challenging. In addition, the occurrence of large megafires that burn large areas at high severity that results in extensive losses of nesting/roosting forest, as witnessed in 2020, puts isolated populations at risk of rapid extirpation.

Finally, in the short term, climate change is likely to contribute to changes in prey populations and, in the long term, alter future forest species composition, geographic distributions, and extent by the end of the 21st century (Peterson et al. 2014). As the fire-prone footprint expands, fire-susceptible tree species (e.g., *Tsuga heterophylla* (Raf.) Sarg.) may recede and fire-associated species (e.g., *Pinus* spp.) may expand in distribution. Subalpine forests are expected to recede in area, while Douglas-fir forests will likely expand into higher elevations. How these long-term changes unfold remains uncertain, as does the effect on future owl forests.

Conclusion

One of the main goals of the NWFP was to reduce the rate at which owl nesting/roosting forests were being lost on federal lands and to eventually restore them to within a natural range to support viable populations of NSO, especially within the LSR network. A quarter century into the NWFP, the latest monitoring shows that it has been effective at reducing the preceding rate of loss. We also report that recruitment is beginning to occur, but mostly in the nonreserved LUAs.

We estimated rangewide gross losses of nesting/roosting forest on federal lands at 7.9 percent (703,700 ac) from wildfire, 2.9 percent (257,700 ac) from timber harvesting, and 0.9 percent (83,700 ac) from insects, disease, or other natural disturbances. However, we also documented development of about 1.3 million acres through succession, so an overall 3-percent net increase of nesting/roosting forest. All but 0.1 percent of this net gain occurred on nonreserved LUAs. While there was a net gain, a slightly larger proportion of nesting/roosting forest was fragmented, compared to 1993.

Rangewide, the observed rate of loss on federal lands was less than what was anticipated when the NWFP was designed, mostly because of less timber harvest. Losses from wildfire were higher (8.5 vs. 6.25 percent; based on a 2.5-percent loss per decade) than anticipated in federal reserved LUAs at the range scale. Insects and disease accounted for less than 1 percent of gross losses. Although dispersal forest increased by 1 percent on federal lands, it decreased by 1.9 percent on reserved LUAs. Large losses primarily from timber harvest on surrounding nonfederal lands and large wildfires reduced the footprint of the dispersal-capable landscape by 9 percent. What remains, as of 2017, is more confined to federal forest lands, and the connection between the Oregon Coast Range and the western Cascades through "checkerboard" BLM land has been broken.

Although we observed gains in nesting/roosting forest through mid-2017, there have been four big wildfire seasons (2017, 2018, 2020, and 2021) since the end of this monitoring cycle. Significant challenges remain, as witnessed by the 2020 wildfire season, where decades of forest recruitment can be set back in 1 year by extremely large and severe wildfires—the type that have historically occurred within the infrequent, high-severity fire regime (Spies et al. 2018). Climate change is predicted to increase the extent and frequency of large wildfires, with the largest changes occurring along the western Cascades of Oregon and Washington, which defines the leading front of change (Davis et al. 2017). Changing climates may also cause direct drought-related mortality of large trees that are important nesting/roosting structure (Gutiérrez et al. 2017), as well as large shifts in the forest types that recover (or not) after a stand-replacing event (Halofsky et al. 2020, Peterson et al. 2014). The use of increasing remote sensing and GEE technologies will allow us to monitor NSO forest in near-real time, with annual updates instead of every 5 years. To be successful at managing to maintain and restore nesting/roosting forests into the future, it will be critical for forest managers to track and foresee the "when" and "where" of forest changes that may occur because of climate change. Fire refugia in forested landscapes can be defined as forest stands that remain unburned, burn less frequently, or burn at lower severity than the surrounding landscape (Meddens et al. 2018). Old forest classified as nesting/roosting forest is an important component of fire refugia (Lesmeister et al. 2021b), but further research is needed to identify areas within old forest that could be persistent fire refugia, spatially and temporally, through multiple fires.

Lastly, the long-term goal of the monitoring program to transition to a model-driven, habitat-based approach (phase II) for population monitoring (Lint et al. 1999) is feasible and in progress (Lesmeister et al. 2021a). The gains in nesting/roosting are encouraging, but unfortunately the increases in available forest has not translated into recruitment of new owl pair territories. On the contrary, largely because of the invasion of the barred owl, the number of occupied pair territories has dropped significantly since 1993. A key advantage of phase II monitoring will be the ability to conduct prospective modeling of future change as opposed to being limited to retrospective assessments conducted thus far. As described in the NSO monitoring plan for the NWFP, "the latter leaves us only the option to patch and recover as opposed to the prospective approach, which provides opportunity to set the trajectory for desired outcomes through model-driven insights of the future." (Lint et al. 1999: 21).

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Metric Equivalents

When you know:	Multiply by:	To find:
Inches	2.54	Centimeters (cm)
Feet (ft)	0.3048	Meters (m)
Acres (ac)	0.405	Hectares (ha)
Miles (mi)	1.61	Kilometers
Trees per acre (trees/ac)	2.47	Trees per hectare (trees/ha)

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Appendix 1—Bookend Map Area Estimates of Nesting/Roosting Forests

Table A1-1—Bookend map area estimates of nesting/roosting forests on federal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Nesting/roosting forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net percent change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	719.0	732.3	13.3	1.9	3.6	3.4	0.3	6.7	14.1	-2.0
Western Lowlands	12.3	10.9	-1.4	-11.1	1.8	0.0	0.0	0.0	1.8	-14.4
Western Cascades	1,382.4	1,380.2	-2.2	-0.2	14.9	5.8	1.8	10.2	32.7	-2.4
Eastern Cascades	730.4	673.5	-56.9	-7.8	31.3	75.2	22.7	7.4	136.7	-18.7
Total	2,844.1	2,797.0	-47.1	-1.7	51.6	84.4	24.9	24.2	185.2	-6.5
Oregon:										
Coast Range	413.6	559.4	145.8	35.3	22.9	0.2	0.0	0.1	23.3	-5.6
Willamette Valley	6.2	8.8	2.6	42.0	0.5	0.0	0.0	0.0	0.5	-8.6
Western Cascades	2,251.2	2,333.7	82.5	3.7	68.5	68.0	2.1	3.3	141.8	-6.3
Klamath	1,087.6	1,121.6	34.0	3.1	40.3	178.6	0.3	1.4	220.6	-20.3
Eastern Cascades	283.9	288.9	5.0	1.7	19.6	20.0	2.7	1.0	43.4	-15.3
Total	4,042.5	4,312.3	269.8	6.7	151.9	266.8	5.1	5.8	429.6	-10.6
California:										
Coast Range	106.8	128.5	21.7	20.3	2.6	7.7	0.0	0.3	10.6	-9.9
Klamath	1,722.9	1,727.2	4.3	0.2	40.6	329.3	7.5	14.9	392.4	-22.8
Cascades	174.2	190.7	16.5	9.4	11.0	15.5	0.8	0.1	27.4	-15.7
Total	2,003.9	2,046.4	42.4	2.1	54.2	352.5	8.3	15.3	430.3	-21.5
NWFP total	8,890.5	9,155.7	265.1	3.0	257.7	703.7	38.3	45.3	1,045.1	-11.8

NWFP = Northwest Forest Plan.

Table A1-2—Bookend map area estimates of nesting/roosting forests on federal reserved lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

State and physiographic province	Nesting/roosting forest area estimates from bookend maps				LCMS disturbance explanation for losses					
	1993	2017	Net area change	Net percent change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	692.5	700.0	7.5	1.1	2.9	3.4	0.3	6.7	13.3	-2.0
Western Lowlands	12.3	10.9	-1.4	-11.1	1.8	0.0	0.0	0.0	1.8	-14.4
Western Cascades	1,112.4	1,101.9	-10.4	-0.9	7.9	5.7	1.8	10.2	25.6	-2.4
Eastern Cascades	525.4	467.5	-57.9	-11.0	14.4	62.6	19.2	7.2	103.4	-18.7
Total	2,342.6	2,280.4	-62.2	-2.7	26.9	71.7	21.3	24.1	144.0	-6.1
Oregon:										
Coast Range	372.7	483.1	110.4	29.6	15.3	0.2	0.0	0.1	15.6	-4.2
Willamette Valley	1.7	2.0	0.3	19.7	0.1	0.0	0.0	0.0	0.1	-8.2
Western Cascades	1,353.2	1,354.5	1.3	0.1	16.8	53.5	1.5	3.2	75.0	-5.5
Klamath	791.7	771.1	-20.6	-2.6	19.0	154.6	0.2	1.3	175.0	-22.1
Eastern Cascades	177.5	175.8	-1.6	-0.9	5.1	13.1	1.8	0.9	20.9	-11.8
Total	2,696.8	2,786.6	89.8	3.3	56.3	221.4	3.4	5.6	286.7	-10.6
California:										
Coast Range	98.5	117.1	18.6	18.9	2.2	7.6	0.0	0.3	10.1	-10.3
Klamath	1,142.2	1,099.7	-42.5	-3.7	14.6	233.7	6.6	14.7	269.6	-23.6
Cascades	111.4	114.7	3.3	3.0	4.3	11.0	0.4	0.1	15.8	-14.2
Total	1,352.1	1,331.6	-20.5	-1.5	21.1	252.3	7.0	15.1	295.5	-21.9
NWFP total	6,391.4	6,398.6	7.1	0.1	104.3	545.4	31.7	44.8	726.2	-11.4

NWFP = Northwest Forest Plan.

Table A1-3—Bookend map area estimates of nesting/roosting forests on nonfederal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Nesting/roosting forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net percent change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	- - - - - *Thousand acres* - - - - -			*Percent*	- - - - - - - - - - - - *Thousand acres* - - - - - - - - - - - - -					*Percent*
Washington:										
Olympic Peninsula	151.7	137.7	-14.0	-9.2	74.2	0.0	0.5	0.1	74.7	-49.2
Western Lowlands	222.4	135.0	-87.4	-39.3	152.8	0.0	0.3	0.0	153.1	-68.8
Western Cascades	407.2	272.8	-134.4	-33.0	164.5	0.4	0.3	0.0	165.2	-40.6
Eastern Cascades	285.7	219.2	-66.5	-23.3	122.9	13.9	5.5	0.1	142.4	-49.8
Total	1,067.0	764.7	-302.3	-28.3	514.4	14.4	6.5	0.2	535.5	-50.2
Oregon:										
Coast Range	277.9	325.2	47.3	17.0	264.8	0.3	0.4	0.0	265.5	-95.5
Willamette Valley	82.7	76.8	-5.9	-7.2	48.8	0.0	0.1	0.0	48.9	-59.0
Western Cascades	448.7	295.4	-153.3	-34.2	339.4	2.2	0.5	0.0	342.0	-76.2
Klamath	340.3	365.0	24.7	7.3	188.7	13.7	0.4	0.1	202.9	-59.6
Eastern Cascades	98.4	68.9	-29.5	-30.0	46.9	9.5	0.7	0.1	57.2	-58.2
Total	1,248.0	1,131.2	-116.7	-9.4	888.6	25.6	2.0	0.3	916.5	-73.4
California:										
Coast Range	681.6	1,050.6	369.1	54.2	232.0	9.0	0.1	0.0	241.1	-35.4
Klamath	315.6	381.6	66.0	20.9	87.5	23.3	0.6	0.1	111.5	-35.3
Cascades	164.4	143.6	-20.7	-12.6	75.4	9.8	1.0	0.0	86.2	-52.5
Total	1,161.5	1,575.8	414.3	35.7	395.0	42.0	1.8	0.1	438.9	-37.8
NWFP total	3,476.5	3,471.8	-4.7	-0.1	1,797.9	82.0	10.3	0.6	1,890.8	-54.4

NWFP = Northwest Forest Plan.

Table A1-4—Bookend map area estimates of nesting/roosting forests on all lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Nesting/roosting forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net percent change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	870.7	870.1	-0.7	-0.1	77.8	3.4	0.8	6.7	88.8	-10.2
Western Lowlands	234.7	145.9	-88.8	-37.8	154.5	0.0	0.3	0.0	154.9	-66.0
Western Cascades	1,789.6	1,653.0	-136.5	-7.6	179.4	6.2	2.1	10.2	198.0	-11.1
Eastern Cascades	1,016.1	892.7	-123.4	-12.1	154.3	89.2	28.2	7.5	279.1	-27.5
Total	3,911.1	3,561.7	-349.4	-8.9	566.0	98.8	31.4	24.4	720.7	-18.4
Oregon:										
Coast Range	691.5	884.6	193.1	27.9	287.8	0.5	0.4	0.1	288.8	-41.8
Willamette Valley	89.0	85.6	-3.3	-3.8	49.3	0.0	0.1	0.0	49.4	-55.5
Western Cascades	2,699.9	2,629.1	-70.8	-2.6	407.8	70.2	2.5	3.3	483.8	-17.9
Klamath	1,427.8	1,486.5	58.7	4.1	229.1	192.2	0.7	1.5	423.5	-29.7
Eastern Cascades	382.3	357.7	-24.6	-6.4	66.5	29.5	3.5	1.2	100.6	-26.3
Total	5,290.5	5,443.6	153.1	2.9	1,040.4	292.4	7.1	6.1	1,346.1	-25.4
California:										
Coast Range	788.4	1,179.1	390.8	49.6	234.6	16.6	0.1	0.3	251.7	-31.9
Klamath	2,038.5	2,108.8	70.3	3.4	128.2	352.6	8.1	14.9	503.9	-24.7
Cascades	338.6	334.3	-4.3	-1.3	86.4	25.3	1.8	0.1	113.6	-33.5
Total	3,165.4	3,622.2	456.8	14.4	449.2	394.6	10.1	15.4	869.2	-27.5
NWFP total	12,367.0	12,627.5	260.5	2.1	2,055.7	785.7	48.6	45.9	2,935.9	-23.7

NWFP = Northwest Forest Plan.

Appendix 2—Bookend Map Area Estimates of Dispersal Forests

Table A2-1—Bookend map area estimates of dispersal forests on federal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Nesting/roosting forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net percent change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	1,109.7	1,164.1	54.4	4.9	3.8	3.9	0.5	5.3	13.5	-1.2
Western Lowlands	58.8	59.0	0.2	0.3	5.5	0.0	0.0	0.0	5.5	-9.4
Western Cascades	2,286.0	2,411.6	125.6	5.5	19.2	9.2	5.3	16.5	50.2	-2.2
Eastern Cascades	1,927.0	1,751.5	-175.6	-9.1	39.1	205.3	28.0	14.1	286.4	-14.9
Total	5,381.5	5,386.2	4.7	0.1	67.6	218.3	33.8	35.9	355.7	-6.6
Oregon:										
Coast Range	911.3	1,030.1	118.8	13.0	39.4	0.3	0.0	0.1	39.9	-4.4
Willamette Valley	12.7	14.0	1.3	10.3	0.7	0.0	0.0	0.0	0.7	-5.2
Western Cascades	3,350.1	3,483.8	133.7	4.0	67.5	112.5	7.4	7.5	194.9	-5.8
Klamath	1,436.9	1,403.9	-33.0	-2.3	41.5	200.1	0.3	1.4	243.4	-16.9
Eastern Cascades	1,015.8	983.9	-31.9	-3.1	41.7	72.4	14.0	5.4	133.5	-13.1
Total	6,726.8	6,915.8	189.0	2.8	190.8	385.2	21.8	14.4	612.3	-9.1
California:										
Coast Range	189.4	209.9	20.5	10.8	3.5	9.6	0.0	0.3	13.5	-7.1
Klamath	2,703.8	2,629.4	-74.5	-2.8	44.7	367.2	7.8	13.1	432.9	-16.0
Cascades	620.9	643.5	22.6	3.6	36.6	17.8	1.2	0.2	55.8	-9.0
Total	3,514.2	3,482.7	-31.4	-0.9	84.8	394.7	9.0	13.6	502.1	-14.3
NWFP total	15,622.5	15,784.7	162.2	1.0	343.2	998.3	64.7	63.9	1,470.0	-9.4

NWFP = Northwest Forest Plan.

Table A2-2—Bookend map area estimates of dispersal forests on federal reserved lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Nesting/roosting forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net percent change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	1,036.8	1,074.7	37.9	3.7	2.4	3.9	0.5	5.3	12.1	-1.2
Western Lowlands	58.5	58.6	0.1	0.2	5.5	0.0	0.0	0.0	5.5	-9.4
Western Cascades	1,872.4	1,930.4	58.1	3.1	9.9	9.1	5.2	16.5	40.8	-2.2
Eastern Cascades	1,505.7	1,332.0	-173.7	-11.5	15.9	172.6	24.1	13.8	226.5	-15.0
Total	4,473.3	4,395.8	-77.6	-1.7	33.8	185.6	29.9	35.6	284.9	-6.4
Oregon:										
Coast Range	746.5	829.7	83.2	11.1	25.2	0.2	0.0	0.1	25.6	-3.4
Willamette Valley	2.8	2.9	0.1	3.6	0.2	0.0	0.0	0.0	0.2	-8.9
Western Cascades	2,030.0	2,026.3	-3.8	-0.2	17.8	91.3	5.8	7.3	122.3	-6.0
Klamath	1,006.3	942.0	-64.4	-6.4	17.9	170.1	0.2	1.3	189.4	-18.8
Eastern Cascades	683.0	629.8	-53.1	-7.8	12.8	54.6	9.9	5.0	82.2	-12.0
Total	4,468.6	4,430.6	-37.9	-0.8	73.9	316.2	15.9	13.8	419.7	-9.4
California:										
Coast Range	165.5	184.0	18.5	11.2	2.5	8.4	0.0	0.3	11.2	-6.8
Klamath	1,790.5	1,676.2	-114.3	-6.4	13.7	254.4	6.8	12.9	287.8	-16.1
Cascades	267.8	268.5	0.7	0.3	5.2	9.9	0.4	0.2	15.6	-5.8
Total	2,223.7	2,128.7	-95.1	-4.3	21.4	272.7	7.2	13.4	314.7	-14.2
NWFP total	11,165.6	10,955.1	-210.6	-1.9	129.1	774.4	53.0	62.8	1,019.3	-9.1

NWFP = Northwest Forest Plan.

Table A2-3—Bookend map area estimates of dispersal forests on nonfederal lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

	Nesting/roosting forest area estimates from bookend maps				LCMS disturbance explanation for losses					
State and physiographic province	1993	2017	Net area change	Net percent change	Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	576.2	520.4	-55.7	-9.7	296.6	0.0	1.1	0.1	297.8	-51.7
Western Lowlands	1,939.6	1,412.1	-527.6	-27.2	1,110.0	0.1	2.3	0.0	1,112.4	-57.4
Western Cascades	1,072.4	923.6	-148.8	-13.9	465.9	0.7	0.6	0.0	467.2	-43.6
Eastern Cascades	888.6	719.4	-169.2	-19.0	312.4	44.3	7.6	0.2	364.4	-41.0
Total	4,476.8	3,575.5	-901.3	-20.1	2,185.0	45.0	11.5	0.3	2,241.9	-50.1
Oregon:										
Coast Range	1,883.1	1,378.1	-505.0	-26.8	1,169.7	0.8	1.9	0.0	1,172.4	-62.3
Willamette Valley	234.0	182.2	-51.8	-22.1	107.9	0.0	0.1	0.0	108.1	-46.2
Western Cascades	969.0	695.9	-273.1	-28.2	588.5	6.1	0.8	0.1	595.5	-61.5
Klamath	665.9	604.4	-61.6	-9.2	313.6	16.5	0.6	0.2	330.9	-49.7
Eastern Cascades	328.2	260.5	-67.7	-20.6	148.9	26.4	2.7	0.3	178.3	-54.3
Total	4,080.3	3,121.2	-959.1	-23.5	2,328.6	49.8	6.2	0.5	2,385.2	-58.5
California:										
Coast Range	1,874.2	1,994.3	120.1	6.4	259.2	22.2	0.2	0.0	281.7	-15.0
Klamath	586.5	641.8	55.2	9.4	126.0	33.6	0.9	0.1	160.6	-27.4
Cascades	497.0	457.2	-39.8	-8.0	126.2	14.5	2.0	0.0	142.8	-28.7
Total	2,957.7	3,093.3	135.6	4.6	511.4	70.4	3.2	0.1	585.1	-19.8
NWFP total	11,514.8	9,790.0	-1,724.8	-15.0	5,025.1	165.2	20.9	1.0	5,212.1	-45.3

NWFP = Northwest Forest Plan.

Table A2-4—Bookend map area estimates of dispersal forests on all lands and explained losses from Landscape Change Monitoring System (LCMS) disturbance maps

State and physiographic province	Nesting/roosting forest area estimates from bookend maps: 1993	2017	Net area change	Net percent change	LCMS disturbance explanation for losses: Harvest	Wildfire	Insect	Other	Total explained loss	Percentage loss from 1993
	Thousand acres			*Percent*	*Thousand acres*					*Percent*
Washington:										
Olympic Peninsula	1,685.9	1,684.5	-1.3	-0.1	300.5	3.9	1.6	5.4	311.3	-18.5
Western Lowlands	1,998.4	1,471.1	-527.4	-26.4	1,115.5	0.1	2.3	0.0	1,117.9	-55.9
Western Cascades	3,358.4	3,335.2	-23.2	-0.7	485.1	9.9	5.9	16.6	517.5	-15.4
Eastern Cascades	2,815.6	2,470.9	-344.7	-12.2	351.5	249.5	35.6	14.3	650.9	-23.1
Total	9,858.3	8,961.7	-896.6	-9.1	2,252.6	263.4	45.4	36.2	2,597.6	-26.3
Oregon:										
Coast Range	2,794.4	2,408.3	-386.1	-13.8	1,209.1	1.0	1.9	0.1	1,212.2	-43.4
Willamette Valley	246.8	196.3	-50.5	-20.5	108.6	0.0	0.1	0.0	108.8	-44.1
Western Cascades	4,319.1	4,179.7	-139.4	-3.2	656.0	118.6	8.2	7.6	790.4	-18.3
Klamath	2,102.8	2,008.2	-94.6	-4.5	355.1	216.7	1.0	1.5	574.3	-27.3
Eastern Cascades	1,344.0	1,244.5	-99.6	-7.4	190.6	98.7	16.7	5.7	311.8	-23.2
Total	10,807.1	10,036.9	-770.1	-7.1	2,519.5	435.0	28.0	15.0	2,997.4	-27.7
California:										
Coast Range	2,063.6	2,204.2	140.6	6.8	262.7	31.9	0.3	0.3	295.1	-14.3
Klamath	3,290.4	3,271.1	-19.2	-0.6	170.7	400.9	8.8	13.2	593.5	-18.0
Cascades	1,117.9	1,100.7	-17.2	-1.5	162.8	32.3	3.2	0.2	198.5	-17.8
Total	6,471.9	6,576.1	104.2	1.6	596.2	465.1	12.2	13.7	1,087.2	-16.8
NWFP total	27,137.3	25,574.7	-1,562.6	-5.8	5,368.3	1,163.5	85.5	64.9	6,682.2	-24.6

NWFP = Northwest Forest Plan.

Appendix 3—Estimating Northern Spotted Owl Pair Territories

Modeling parameters used to estimate owl pair territories following methods in Glenn et al. (2017) relied primarily on demographic data from population meta-analyses information from Dugger et al. (2016) and Franklin et al. (2021). Demographic parameters were averaged when more than one study area occurred within a modeling region (table A3-2).

Table A3-1—Data summary from demographic studies that informed the models

Demographic study areas	½ median nearest neighbor distance[1]	Occupancy rate (1993)[2]	Occupancy rate (2018)[2]	Number of territories (Thiessen polygons)[2,3]
	Kilometers	*Mean (95% CL)*	*Mean (95% CL)*	*1993/2017*
OLY	1.75	0.77 (0.64–0.90)	0.12 (0.07–0.18)	98
RAI[4]	1.50	0.85 (0.72–0.98)	0.11 (0.05–0.16)	NA
CLE	1.75	0.65 (0.53–0.77)	0.07 (0.03–0.11)	92
COA	1.25	0.72 (0.63–0.81)	0.15 (0.11–0.19)	172
HJA	1.00	0.91 (0.81–1.00)	0.27 (0.21–0.33)	11/185
TYE	1.00	0.46 (0.39–0.54)	0.17 (0.13–0.22)	160
CAS	1.75	0.70 (0.61–0.80)	0.23 (0.18–0.29)	113/169
KLA	1.25	0.68 (0.58–0.78)	0.20 (0.16–0.25)	91/158
NWC	0.75	0.76 (0.63–0.88)	0.38 (0.28–0.48)	99
GDR[4]	0.60	0.97 (0.92–1.00)	0.35 (0.27–0.44)	NA

[1] From Dugger et al. (2016, table 3).

[2] From Franklin et al. (2021).

[3] Two numbers for study area expansions between 1993 and 2017.

[4] Not a Northwest Forest Plan monitoring program demographic study area.

OLY = Olympic (WA), RAI = Mt. Rainier (WA), CLE- = Cle Elum (WA), COA = Coast Ranges (OR), HJA = H.J. Andrews (OR), TYE = Tyee (OR), CAS = South Cascades (OR), KLA = Klamath (OR), NWC = Northwest (CA), GDR = Green Diamond Resources (CA). CL = confidence limits.

Table A3-2—Modeling parameters used to generate estimates of owl pair territories

Modeling region	Demographic study areas	Minimum spacing	Occupancy rate (1993)	Occupancy rate (2017)
		Kilometers	*Mean (95% CL)*	*Mean (95% CL)*
WA Coast and Western Cascades	OLY, RAI	3.2	0.81 (0.68–0.94)	0.12 (0.06–0.17)
WA Eastern Cascades	CLE	3.8	0.65 (0.53–0.77)	0.07 (0.03–0.11)
OR Coast Range	COA, TYE	2.4	0.59 (0.51–0.67)	0.16 (0.12–0.20)
OR and CA Cascades	HJA, CAS	2.8	0.80 (0.71–0.90)	0.25 (0.20–0.31)
OR and CA Klamath Mountains	KLA, NWC	2.0	0.48 (0.40–0.55)	0.29 (0.22–0.37)
CA Coast Range	GDR	1.2	0.97 (0.92–1.00)	0.35 (0.27–0.44)

WA = Washington, OR = Oregon, CA = California, OLY = Olympic (WA), RAI = Mount Rainier (WA), CLE- = Cle Elum (WA), COA = Coast Ranges (OR), HJA = H.J. Andrews (OR), TYE = Tyee (OR), CAS = South Cascades (OR), KLA = Klamath (OR), NWC = Northwest (CA), GDR = Green Diamond Resources (CA), CL = confidence limits.

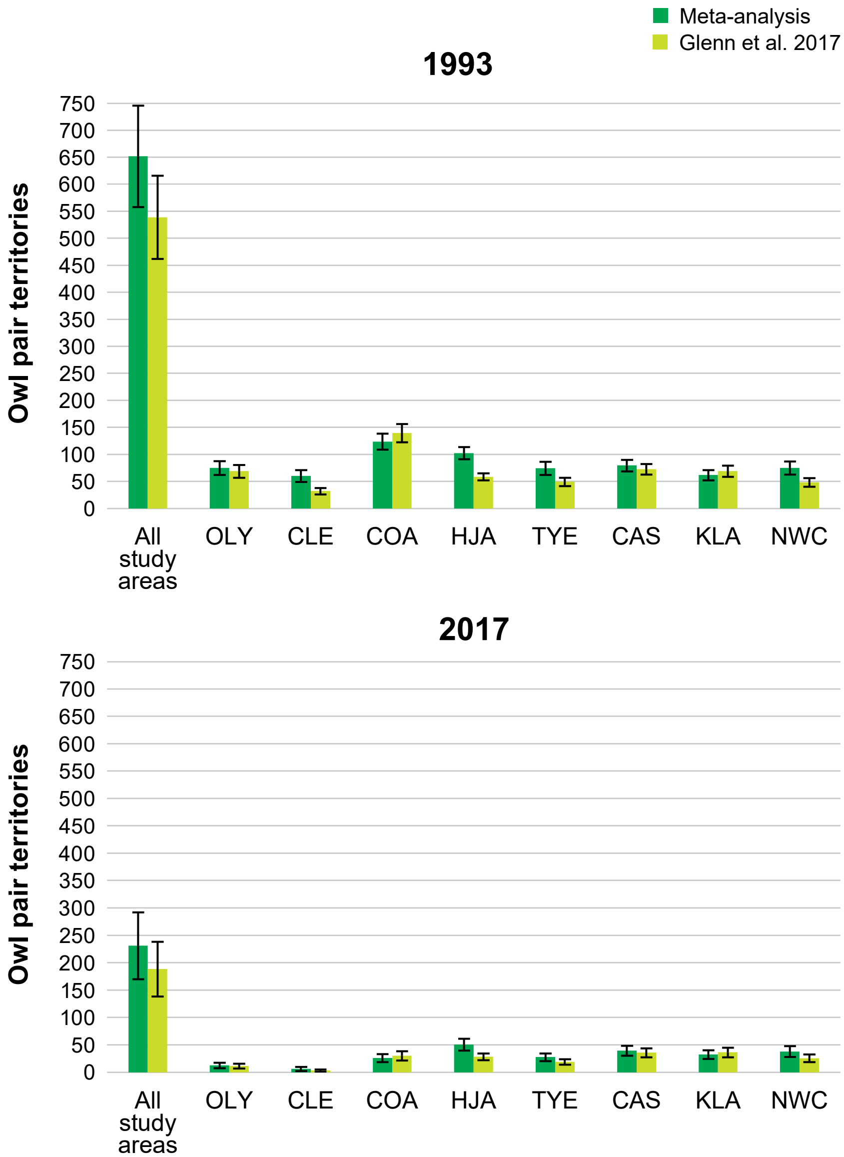

Figure A3-1—Comparison (means and 95% confidence limits) of owl occupied owl territory estimates for the bookend time periods using the Glenn et al. (2017) method to occupancy analysis estimates from the last population meta-analysis applied to the number of Theisen polygons on each demographic study area (Franklin et al. 2021). OLY = Olympic (WA), CLE = Cle Elum (WA), COA = Coast Ranges (OR), HJA = H.J. Andrews (OR), TYE = Tyee (OR), CAS = South Cascades (OR), KLA = Klamath (OR), NWC = Northwest (CA).

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