Assessing the Compatibility of Fuel Treatments, Wildfire Risk, and Conservation of Northern Spotted Owl Habitats and Populations in the Eastern Cascades: A Multi-scale Analysis.

2013

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Martin G. Raphael
mraphael@fs.fed.us

Paul Hessburg
USDA Forest Service

Rebecca Kennedy
USDA Forest Service

John Lehmkuhl
USDA Forest Service

Bruce G. Marcot
USDA Forest Service

See next page for additional authors

Authors
Martin G. Raphael, Paul Hessburg, Rebecca Kennedy, John Lehmkuhl, Bruce G. Marcot, Robert Scheller, Peter Singleton, and Thomas Spies

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Final Report: JFSP Project 09-1-08-31

Project Website: https://sites.google.com/a/pdx.edu/vegetation-fire-owl/home

Principle Investigator:
Dr. Martin G. Raphael, USDA Forest Service, Pacific Northwest Research Station, 3625 93rd Ave SW, Olympia WA 98512. mraphael@fs.fed.us

Co-Principal Investigators:
Dr. Paul Hessburg, USDA Forest Service, Pacific Northwest Research Station, Wenatchee WA
Dr. Rebecca Kennedy (retired), USDA Forest Service, Pacific Northwest Research Station, Corvallis OR
Dr. John Lehmkuhl, USDA Forest Service, Pacific Northwest Research Station, Wenatchee WA (retired)
Dr. Bruce G. Marcot, USDA Forest Service, Pacific Northwest Research Station, Portland OR
Dr. Robert Scheller, Portland State University, Portland OR
Dr. Peter Singleton, USDA Forest Service, Pacific Northwest Research Station, Wenatchee WA
Dr. Thomas Spies, USDA Forest Service, Pacific Northwest Research Station, Corvallis OR

Research Assistants and Technicians:
Mr. Erik Haunreiter, Oregon State University, Corvallis OR
Mr. James Dickinson, USDA Forest Service, Pacific Northwest Research Station, Wenatchee WA
Mr. Michael Cibicki, USDA Forest Service, Pacific Northwest Research Station, Wenatchee WA
Mr. Shiloh Halsey, Portland State University, Portland, OR

This research was sponsored in part by the Joint Fire Science Program. For further information go to www.firescience.gov

I. Abstract

National Forests in the dry forest provinces on the east-side of the Oregon and Washington Cascades have been managed under the guidelines of local Forest Plans and the Northwest Forest Plan (NWFP), both of which specify large areas of late-successional reserves (LSRs). In contrast, the recently-released USDI Fish and Wildlife Service Revised Recovery Plan (RRP) for the Northern Spotted Owl (NSO) calls for development of dynamic and shifting mosaics in the dry forests, and retention of LSRs in moist forests of eastern Cascades of Oregon and Washington, to address NSO habitat and wildfire concerns. Our objectives in this study were to develop and evaluate several key management approaches intended to reduce fire risk and conserve NSO habitat and to assess the relative merit of alternative management strategies in fire-prone stands and landscapes. We first sought to determine the current area and successional status of east-side forests across eastern Cascade forests in Oregon and Washington. Next, we simulated succession, wildfire, and fuel treatments using a state-and-transition model, *LADS*. Finally, we translated forest cover types into three levels of NSO habitat suitability (poor, moderate, and good) and applied an NSO population simulation model to investigate response of the NSO to vegetation trajectories over a 100-yr time series. To do so, we developed a spatially explicit, individual-based population model using HexSim software that integrated habitat maps with information on spotted owl population dynamics. We then compared the outcomes of several landscape management scenarios: no restoration management, restoration management under the Northwest Forest Plan reserve network, and several whole-landscape scenarios that vary the area and intensity of treatments without regard for current reserve allocations. All of our simulations assumed a wildfire regime that reflects the past 15 years of fire history, including the potential for large, rare fire events.

NSO population changes through time generally tracked changes in total NSO habitat (the combined amount of good and moderate NSO habitat) and showed similar patterns for the Wenatchee analysis area and the Deschutes NSO population scenarios without BDOW displacement. Decadal lambda (rate of population change was approximately stationary (lambda ~1) from simulation years 0 to 30 for most scenarios excepting the large-area, high-intensity treatments, which resulted in decadal NSO population decline (lambdas <1) for those years. NSO population bottlenecks (temporary periods of lower than average population levels) generally occurred in both analysis areas around year 30, after treatments had been applied but before the steep accumulation of good habitat in years 30-50. All of the NSO population modeling scenarios showed a spike in decadal lambda from years 30 to 60 in response to a steep, synchronous increase in the modeled amount of good and moderate habitat.

Higher-intensity, larger-area treatment scenarios created short-term NSO habitat and population bottlenecks, but had mixed effects on end-century NSO population sizes. Particularly for the Wenatchee analysis area, we did not find larger ending NSO population sizes from aggressive fuel reduction treatments relative to the No Treatment scenario. The presence of both good and moderate habitat contributed substantially to the suitability of an area for occupancy by a territorial NSO pair based on our analysis of habitat conditions surrounding documented NSO activity centers. Active fuel reduction activities in moderate habitat

contributed to substantial short-term (simulation years 0 to 30) population declines under the larger area, higher intensity scenarios. However, our landscape-scale analysis may have failed to detect local benefits of targeted fuel reduction treatments for habitat sustainability and recruitment in specific areas. More refined, finer-scale analysis may reveal more local benefits of fuel reduction treatments for recruiting and maintaining NSO habitat.

II. Background and Purpose

Land managers are faced with a conundrum when tasked with maintaining threatened northern spotted owl (*Strix occidentalis caurina*, NSO) populations, while reducing wildfire risk in dry, fire-prone forests of the Inland Northwest. Historical surface-fire-dominated regimes have given way to crown-fire-dominated regimes, with high rates of old forest loss, and potentially dire consequences for the multi-storied stands that are NSO habitat (Spies et al. 2006; Hessburg et al. 2005). Substantial areas of dry forest need to be treated to reduce fire risk and restore dry forest structure, but treatments can adversely impact NSO habitat quality and population viability. In addition, NSO populations appear to be declining in much of their range in part due to competitive interactions with recently established barred owls (*Strix varia*, BDOW; Gutierrez et al. 2004, Forsman et al. 2011).

At present, there remains high uncertainty and controversy over east-side (east of the Cascades crest) forest management and NSO population outcomes, especially with regard to effects of fuel treatments on NSO and reserve vs. non-reserve landscape strategies (TWS 2008, SCB and AOU 2008). To date, National Forests in the dry forest provinces on the east-side have been managed under the guidelines of local Forest Plans and the Northwest Forest Plan (NWFP), both of which specify large areas of late-successional reserves (LSRs). In contrast, the recently-released USDI Fish and Wildlife Service (USFWS) Revised Recovery Plan (RRP) for the Northern Spotted Owl (USFWS 2011) calls for development of dynamic and shifting mosaics in the dry forests, and retention of LSRs in moist forests of eastern Cascades of Oregon and Washington, to address NSO habitat and wildfire concerns. The RRP suggests that approximately a third of the total dry forest land area should be maintained in late-successional and old forest (LSOF) structural conditions of sufficient patch size and spatial distribution to provide for breeding pairs of NSOs. However, the spatial allocation and temporal dynamics of these forests has not been determined, nor is it described by the RRP. Complicating the successful implementation of Plan guidelines are the adverse effects from the BDOW (Livezey 2007), whose influence challenges the success of any NSO recovery plan based solely on vegetation or habitat characteristics.

We developed and evaluated several key management approaches intended to conserve NSO habitat, and reduce fire risk, at stand and landscape scales, throughout a large portion of the east-side NSO range (10 million ac), to assess risk of NSO habitat loss and related population processes. The goal of this project was to assess the relative merit of alternative management practices and conservation strategies to maintaining habitat and populations of the NSO in fire-prone stands and landscapes. Our study is unique in that it focuses not only on fire and fuels management effects on NSO habitat, but also on NSO population viability and influences of the Barred Owl (BDOW) on NSO population processes.

III. Study Description and Location

Project Overview

We used a multi-model framework to simulate forest growth and disturbance dynamics, and NSO population responses, to evaluate the effect of different forest management treatment scenarios on NSO habitat and populations in the eastern Cascades. We also investigated various assumptions regarding competitive interactions with BDOWs, as well as habitat contributions from non-federal lands. We quantified landscape-scale habitat associations of NSOs and BDOWs by analyzing vegetation and topographic characteristics surrounding documented activity centers for each species (Singleton 2013). We used state-of-the-art fire spread models and existing fuels data to determine current burn probability and probable flame length in the vicinity of NSO habitats. Predicted burn probability and flame length maps were used along with topographic and other data to define fuels management treatment locations in the vicinity of NSO habitats for the purpose of their protection. We used a forest state-and-transition model (*LADS*: Wimberly 2002, Wimberly and Kennedy 2008) to simulate forest growth and disturbance processes over a 100-year period. We then used a spatially explicit individual-based population model (HexSim: Schumaker 2012) to simulate NSO population dynamics based on habitat maps derived from the forest growth and disturbance modeling. We compared the various forest management scenarios using the following metrics: (1) ending and minimum amounts of good and moderate NSO habitat, (2) ending and minimum NSO population sizes, (3) rate of NSO population change over 100 years (simulation-duration lambda), and (4) running 10-year rates of NSO population change (decadal lambdas) over each 100-year NSO population simulation.

Analysis Areas

We conducted our modeling in two analysis areas: the Wenatchee analysis area, and the Deschutes analysis area (Figure 1). These areas encompassed portions of the Okanogan-Wenatchee National Forest and Deschutes National Forest, respectively, within the range of the NSO, and included adjacent areas that had the potential to support NSOs. The Wenatchee analysis area was approximately 1.6 million ha characterized by rugged, mountainous topography, with elevations ranging from 210 to 2900 m (700 to 9500 ft). The Deschutes analysis area encompassed 0.4 million ha, dominated by volcanic landforms including broad pumice plains, cinder cones, and overall more gentle terrain than the Wenatchee. Elevations range from 600 to 3150 m (2000 to 10300 ft). Vegetation communities in both areas are influenced by the strong moisture gradient associated with the rain-shadow effect of the Cascade Range, with wetter areas near the crest of the range on the west and drier areas in the east.

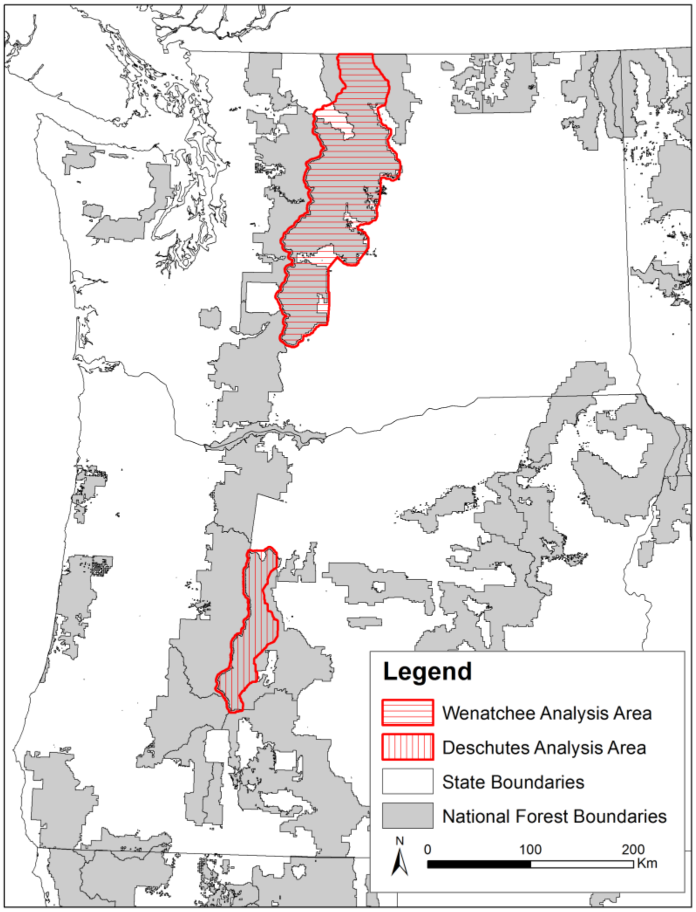


Figure 1. Analysis area locations within Washington and Oregon.

Our objectives were to develop and evaluate several key management approaches intended to reduce fire risk and conserve NSO habitat and to assess the relative merit of alternative management strategies in fire-prone stands and landscapes. We first sought to determine the current area and successional status of east-side forests across the eastern Cascade in Oregon and Washington. Next, we simulated succession, wildfire, and fuel treatments using a state-and-transition model, *LADS* (Wimberly 2002). We then compared the outcomes of several landscape management scenarios: no restoration management, restoration management under the Northwest Forest Plan reserve network, and several whole-landscape scenarios that vary the area and intensity of treatments without regard for current reserve allocations. All of our simulations assumed a wildfire regime that reflects the past 15 years of fire history, including the potential for large, rare fire events. We simulated 100 years of landscape change and structure to determine whether and when the landscape will become more or less heterogeneous.

<u>*Vegetation simulations*</u>

Our study sites occur in the eastern Cascade physiographic provinces designated by the RRP as areas potentially suitable for whole-landscape treatments. Vegetation in the study area consists of Ponderosa pine (*Pinus ponderosa*), mixed conifer, and mountain hemlock (*Tsuga mertensiana*) forest types. Fire regimes range from low to high severity with frequencies ranging from <10 to >150 years. Vegetation is similar in type and current condition to the surrounding landscapes. Results derived from this research will be broadly applicable to surrounding forests in the range of the NSO. Resource managers on these forests have expressed a great interest in developing management approaches that will be conducive to recovering NSO populations.

Fire modeling

Wildfire risk analysis examines for a resource of interest (here, NSO habitat), the susceptibility of that resource to loss or damage by fire, and the probability of the loss. In this work, we used the underlying algorithms from *FlamMap* (Finney 2002) and *Randig* (Ager et al. 2012) to model wildfire ignitions, burn probability and flame lengths, and the Forest Vegetation Simulator (FVS) and stand table (tree list) data from the GNN database (Ohmann 2002) to simulate risk of loss to owl habitats.

On the Wenatchee and Deschutes analysis areas we used 150,000 and 50,000 (respectively) random ignitions to simulate the spread of a large number of fires across the study landscapes. The proportion of times a pixel burned in all fires and its predicted flame length at each occurrence were stored for later creation of burn probability and probable flame length maps (Ager et al. 2012). We used FVS to calculate flame length thresholds needed to make substantive changes in NSO habitat, and to determine whether those thresholds had been achieved in *FlamMap*. Results of this risk analysis were mapped and later used to assign fuels treatments in the vicinity of NSO habitats. Wildfire risk analyses for the Deschutes and Wenatchee were similar, except for local differences in weather and topography and locally established fuels data (Table 1).

The Wenatchee analysis used a fuels map created on national forests by local fuels specialists resampled to 90m to represent the 13 surface fire behavior fuel models (FBFMs, Anderson 1982). The Deschutes used *Landfire* (www.landfire.gov) fuels data, which is based on the Scott and Burgan (2005) 40 FBFMs. To predict crown fire ignition and spread potential and more realistically simulate surface fire behavior, additional raster layers defining the existing crown bulk density, canopy base height, canopy closure, and average canopy height were used to initialize the fire spread model. Elevation, slope and aspect were also used to account for topographic effects on pre-combustion heating and moisture content of fuels. Fuel moistures were assigned by particle size and time-lag class, assuming 97th percentile fire weather burn conditions (Table 1). We used Remote Automatic Weather Station (RAWS) weather data combined with local fire manager experience to establish wind parameter files for the wildfire simulations. The wind parameter file specifies the prevailing wind directions, speed, and duration, which are probabilistically drawn (Table 1) and assigned to each simulated ignition. To ensure that the simulations were capturing realistic fire sizes, we compared simulated fire sizes with recorded fire size data using methods of Ager et al. (2012).

Table 1: Summary of environmental variables used in fire simulation modeling for the Wenatchee and Deschutes study areas.

Wenatchee	Wind				Fuel Moisture (%)		
	Direction (◦)	Speed (k h^{-1})	Probability		Size Class	-	All fuel models
	290	32.18	0.70		1-h	-	3
	290	32.18	0.25		10-h	-	4
	290	32.18	0.05		100-h	-	7
					Live Herbaceous	-	50
					Live Woody	-	80
Deschutes	Wind				Fuel Moisture (%)		
	Direction (◦)	Speed (k h^{-1})	Probability		Size Class	Fuel Model GR2	All other fuel models
	270	40.2	0.35		1-h	1	1
	335	40.2	0.35		10-h	2	2
	225	32.2	0.25		100-h	5	5
	90	32.2	0.05		Live Herbaceous	60	40
					Live Woody	90	60

Vegetation Modeling (LADS)

We used the *LADS* state-and-transition model for all simulations of landscape change (Wimberly 2002, Kennedy and Wimberly 2008). *LADS* treats a landscape as a grid of interacting cells; each cell is associated with a dominant cover type and a fire zone. *LADS* simulates the transition of dominant cover type to larger sizes and higher cover class through time with transition times determined through empirical analysis and/or expert inputs. Simulated fires regimes are unique to each fire zone although an individual fire event can spread among zones. After a fire event is initialized, fire severity is determined by the probability of low, medium, and high fires associated with each combination of cover type, size class, and cover class (details below). Fuel treatments are simulated as events that alter the size and cover class (cover type is immutable) and have unique fire severity and spread rates. Fuel treatments are transitory and after a predefined duration revert back to an appropriate size and cover class (Wimberly 2002).

Our simulated successional trajectories were bounded by the dominant cover at the landscape scale, i.e., dominant cover type at a given location could not change. Nevertheless, our simulations indicate broad successional changes on the landscape that varied among the dominant cover types, among scenarios, and between the two landscapes.

NSO Population Modeling (HexSim)

We developed a spatially explicit, individual-based population model using *HexSim* software (version 2.4, Schumaker 2012) that integrated habitat maps with information on spotted owl population dynamics. Breeding pairs are the fundamental unit of population function for most large raptors, including spotted owls (Anthony et al. 2006, Forsman et al. 2011). We used a female-only, single-sex model structure, where territorial females were surrogates for breeding pairs. The general model structure was based on the work of Dunk et al. (2012, also see USFWS 2011: Appendix C), but was modified for our study area and questions. We adjusted NSO vital rate parameters to reflect local demographic information (Forsman et al. 2011), and we adjusted space use parameters (i.e., core area and home range sizes) to correspond to findings from local NSO radiotelemetry studies (Eric Forsman, USFS PNW Research Station, unpublished data).

Spatially explicit habitat maps formed the basis for the NSO population simulations. Each analysis area landscape was represented as a grid of 86.6 ha (1 km diameter) hexagons. Each hexagon was assigned a habitat resource value based on the amount of good and moderate NSO habitat within the hexagon. Hexagon resource values were updated at 10-year intervals based on the *LADS* landscape modeling outputs. During each annual time step in our simulations, animals moved through the landscape, attempted to establish territories, then reproduced and survived at rates influenced by the habitat quality within their territories (Figure 2).

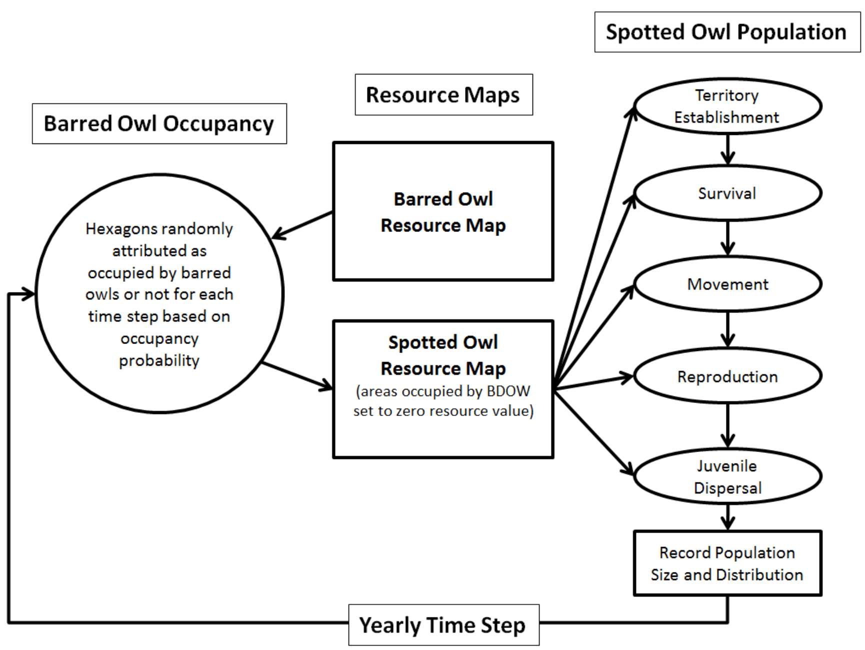


Figure 2. The NSO population model event sequence. The NSO *HexSim* population model simulated territory establishment, survival, reproduction, and movement for female spotted owls during each annual time step for our 100-year simulation period. Resource maps were updated at 10-year intervals based on habitat maps from *LADS* landscape modeling simulations.

Our habitat classification rules were based on habitat patterns observed around NSO activity centers as described by Singleton (2013). We identified areas with vegetation (i.e., tree size, canopy cover, and dominant tree species) and topographic characteristics (i.e., topographic position and slope) that corresponded to areas used by NSOs more than available, or in proportion to availability, within the analysis area landscapes (classified as good or moderate habitat respectively). Using the approach of Dunk et al. (2012), we employed maximum entropy models (*Maxent*: Phillips et al. 2006) to convert habitat characteristics within a hexagon into a single resource value for each hexagon in the *HexSim* base map (Singleton 2013). We then conducted additional spatial analyses so that habitat patterns within modeled NSO territories corresponded to observed habitat patterns around actual NSO activity centers documented in our analysis areas (Singleton 2013).

<u>Model Experiments</u>

We evaluated 12 landscape management scenarios and 4 NSO population scenarios. The landscape management scenarios included a No Treatment scenario, and 11 combinations of 3 strategies for spatial allocation of treatment, 3 sizes of areas treated, and 3 intensities of fuel reduction (Table 2). The 3 strategies for spatial allocation of treatment were: (1) Structured – no treatment in existing good NSO habitat, other areas were prioritized by fire risk and proximity to owl habitat (representing an integration of a critical habitat approach with an effort to create fire-breaks around existing habitat); (2) Naïve – treatment units were prioritized by existing fire risk only, with no consideration for owl habitat (representing aggressive management focused on minimizing fire risk); and (3) Reserve – areas within Late Successional Reserves identified by the Northwest Forest Plan were excluded from treatment, and treatment units outside of reserves were prioritized based on existing fire risk (representing a reserve-based approach, but not including management activities within reserves as provided for under the Northwest Forest Plan).

Table 2. Treatment scenario codes and descriptions.

Code	Strategy	Wen Treated ha	Des Treated ha	Intensity
NoTrt	No Treatment	None	None	None
N10H	Naïve	40553	16152	High
N10L	Naïve	40553	16152	Low
N20M	Naïve	80604	32242	Moderate
N40H	Naïve	161311	64616	High
N40L	Naïve	161311	64616	Low
S10H	Structured	40326	16079	High
S10L	Structured	40326	16079	Low
S20M	Structured	80806	32390	Moderate
S40H	Structured	127017	64530	High
S40L	Structured	127017	64530	Low
NWFP	Reserve	130320	59020	High

The three simulated fuel treatment intensities reduced fuel loads and retained large trees within the treated stands. High intensity treatments resulted in stands moving from a closed canopy (>60%) to an open (<40%) canopy condition and had the largest reduction in fuel, representing typical forest restoration thinning treatments. Light intensity treatments moved stands from closed (>60%) to moderate (40-60%) canopy closure and resulted in less reduction in fuel load, representing light thinning from below and removal of ladder fuels. Medium intensity treatments resulted in an intermediate impact on canopy and fuel load.

USFS lands were considered to be available for treatment if they were not in wilderness or administratively withdrawn (e.g., roadless) status, within 500 m of existing roads, and dominated by a forest type appropriate for fuel reduction treatment (e.g., subalpine fir and mountain hemlock types were not considered for treatment). The simulated treatments were only applied in areas that are currently available for treatment. The total treatable area for the Wenatchee analysis area was 402,769 ha. The total treatable area for the Deschutes analysis area was 161,150 ha. Three areas of treatment (approximately 10%, 20%, and 40% of the available area) were applied for several combinations of treatment intensity and allocation strategy (Table 2). Each treatment scenario landscape simulation was replicated 20 times in *LADS* to capture variation in outcomes resulting from stochastic disturbance events.

We evaluated four NSO population modeling scenarios to evaluate the range of potential population outcomes with and without interactions with competitive BDOWs, as well as with and without habitat contributions from non-federal lands. For the NSO population scenarios with BDOW interactions, hexagons attributed as occupied by BDOWs were set to zero resource value to simulate the effects of exclusion of NSOs from areas occupied by territorial BDOWs (Singleton 2013). We attributed hexagons as occupied by BDOWs or not based on the amount of good BDOW habitat in the area. BDOW habitat definitions and occupancy probability were based on Singleton (2013). We also conducted NSO population simulations with and without non-federal lands contributing NSO habitat resource values. The purpose of these scenarios was to evaluate the range of potential NSO population outcomes that might result from different approaches to habitat conservation on non-federal lands. We conducted 3 population scenario replicates in *HexSim* for each *LADS* landscape realization.

IV. Key Findings

<u>Vegetation</u>

Our results indicated that despite intense prior logging and the risk of very large fires (Irland 2013), there is considerable successional inertia on both landscapes that will eventually transition much of both landscapes to larger diameter classes and more closed canopy conditions. However, the transition from small/medium to large/very large sized trees varies widely depending upon dominant cover type, stochastic variation due to wildfires, and landscape management. There is further uncertainty in that we assumed that logging would remain at its current very low rates (Healey et al. 2008) and that climate change (Westerling et al. 2006) would not substantially alter fire regimes from their recent (1985-2008) patterns. Nevertheless, our simulated transitions are robust and appear likely within a broad spectrum of future conditions and drivers.

At the landscape scale, fuel treatment altered forest transitions for select dominant cover types, primarily when the area treated within the treatment zone was at or close to 5% per year with high intensity (e.g., under the Northwest Forest Plan). By reducing fire severity, fuel treatments enabled individual cells to transition to larger and more fire resilient size and cover classes before the next wildfire occurred. Because of the stochastic nature of wildfire, the process itself is highly variable and the effect can appear relatively minor. Nevertheless, for some dominant cover types, fuel treatments accelerated transitioning from mid- to larger- tree size classes after 30 years.

Treatment effectiveness (Figure 3) is primarily limited by the small area treated in total. Given the relatively small area available for treatment, optimized treatment effects to reduce fire flow through the landscape could not be achieved (Finney et al. 2007). This suggests that current restrictions on the fuel treatment placement may be impeding managers ability to protect against wildfire and improve habitat. Faster transitions could be achieved and across more forest types if the treatable area was larger. Doing so would also reduce 'treatment pressure' on a subset of the landscape and the landscape would more broadly respond to the treatment 'shadow' effect (Finney et al. 2007, Schmidt et al. 2008).

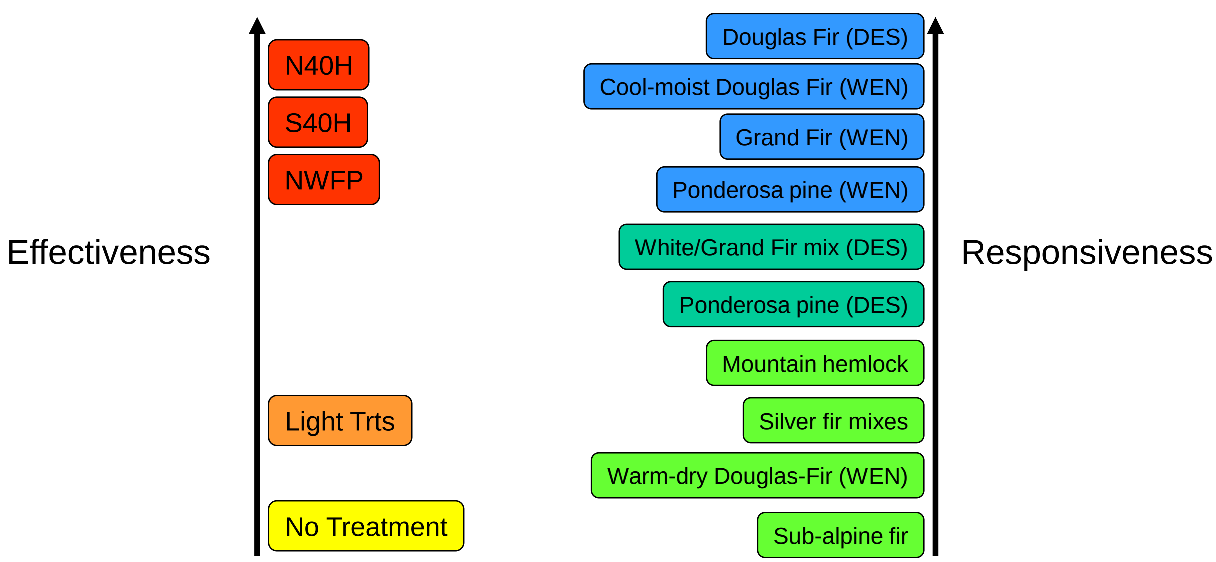


Figure 2. Relative treatment effectiveness and dominant cover type responsiveness for two study landscapes: Deschutes (DES) and Wenatchee (WEN). If location is not listed, the dominant cover type behaved similarly across both landscapes.

Treatment trajectories appeared to be a function of both the constant goal for level and intensity of treatment and the initial vegetation class distribution. We observed a bottleneck in area treated (i.e., the treatment area dropped to zero) between year 15 and 30 in all scenario runs (especially the N40H runs). This pattern appeared to be a function of the initial distribution of vegetation conditions. Initially, the conditions were more synchronized and concentrated in small and medium closed conditions. Fuel treatments over the first 10 years reduced the amount of closed forest so that by year 20 most of the area was in an open condition, which was not eligible for treatment. Over time, this area of medium-open and large-open forest got larger and denser, so that by year 30 there was a fair amount of medium and closed forest which was eligible for treatment. In subsequent years, there was a large area of very large closed forest that never got fully treated and wildfires created a constant supply of younger and smaller forest vegetation classes that grew into pole and small and medium-closed classes that were eligible for treatment.

Our treatment scenarios were not designed to spatially optimize fuel conditions to significantly interrupt fire flow on the Wenatchee landscape; approximately three-quarters of the landscape was exempt from treatment due to existing land allocations or ownerships. Our most aggressive fuel treatment scenario treated 40% of 25% available area, netet 10% of the Wenatchee analysis area was treated. Thus, our treatment scenarios did not produce substantial changes in fire patterns relative to the No Treatment scenario. This result is consistent with the experimental work of Finney *et al.* (2007).

In conclusion, to varying degrees under all management scenarios we analyzed, the two landscapes examined will be subjected to two countervailing trends: landscape successional inertia that will transition the forests to larger, closed-canopy conditions and landscape disturbance that will reset succession. Given the known processes and rates that we emphasized (as compared to less well-known processes including climate change and its cascading effects), the net balance will be an increase in late successional forest as compared to contemporary conditions. Fuel treatments can directly accelerate these transitions through active management and indirectly accelerate these transitions by protecting against the highest severity fires, although their effectiveness is currently limited by the relatively scant area available for treatment.

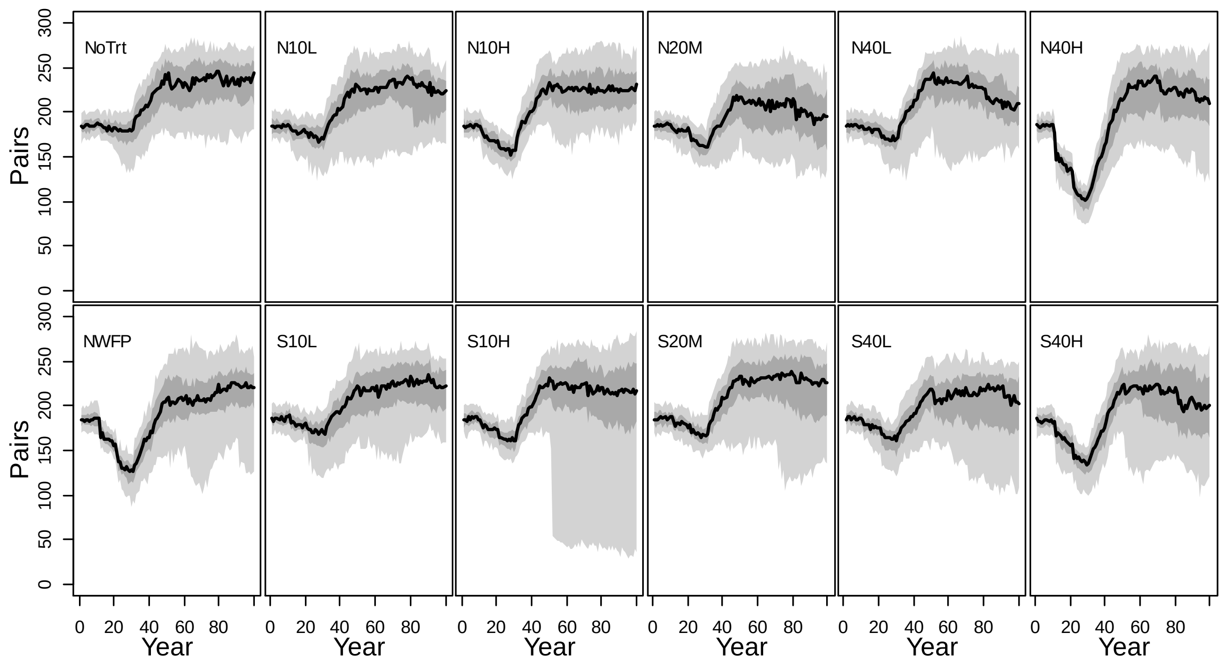
Spotted Owl Habitat and Populations

The amount of good NSO habitat increased over the 100-year simulation period for both analysis areas, but it increased much more in the Wenatchee analysis area than it did in the Deschutes. For the Wenatchee analysis area, the No Treatment scenario ended with average 275,318 ha of good NSO habitat (233% of the starting amount, averaged over 20 *LADS* model replicates). For the Deschutes analysis area, the No Treatment scenario ended with average 34,948 ha of good habitat (117% of starting), also averaged over 20 *LADS* model replicates.

Active treatment scenarios ended with more good quality NSO habitat than did the No Treatment scenario in the Deschutes analysis area, but not in the Wenatchee. The ending amount of good habitat under the treatment scenarios in the Wenatchee analysis area ranged from 235,064 ha (treatment scenario N20M: 200% of starting) to 265,779 ha (N10H: 226% of starting). The ending amount of good habitat under the treatment scenarios in the Deschutes analysis area ranged from 35,509 ha (S40H: 119% of starting) to 41,078 ha (S10L: 138% of starting). The amount of moderate habitat increased over the simulation period on the Deschutes and decreased on the Wenatchee.

Owl populations did not increase at a rate corresponding to the increase in the amount of good habitat in the Wenatchee analysis area because of commensurate declines in the amount of moderate habitat impacted by fuels treatments (figure 3). Simulation-duration lambda (an index depicting rate of population change; lambda =1 indicates a stationary population; lambda < 1 indicates declining and lambda > 1 indicates increasing) was approximately 1.2 for the No Treatment scenario (without BDOW interactions) in the Wenatchee analysis area – that is, the 133% increase in the amount of good NSO habitat resulted in about 20% increase in the NSO population. In the Deschutes analysis area, NSO population growth corresponded more closely to the increase in the amount of good NSO habitat (figure 4). Simulation-duration lambda was 1.1 for the No Treatment scenario (without BDOW interactions) in the Deschutes analysis area – that is, the 17% increase in the amount of good NSO habitat resulted in a 10% increase in the NSO population.

No Barred Owls, with Private Lands, Wenatchee Analysis Area



With Barred Owls, with Private Lands, Wenatchee Analysis Area

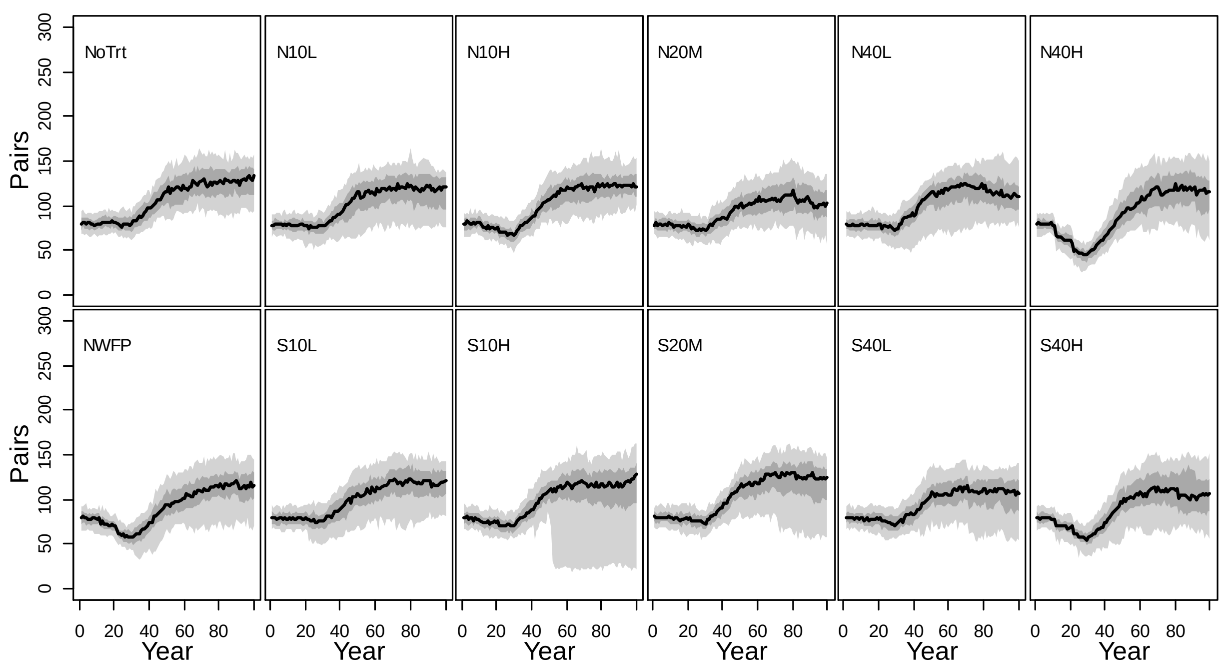
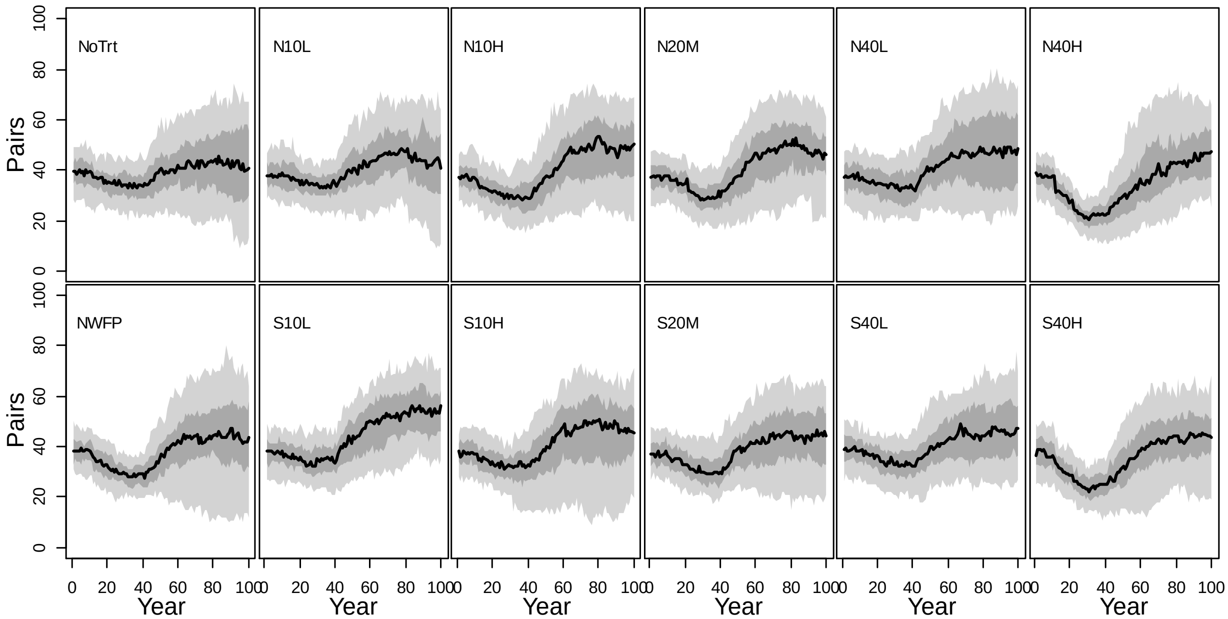


Figure 3. Simulated northern spotted owl population trajectories in the Wenatchee analysis area. Lines depict median (black line), 50% quantile range (dark grey shade), and 90% quantile range (light grey shade) of the estimated number of owls through the simulation for 60 *HexSim* replicates for each treatment scenario (see Table 2) with and without effects of barred owls.

No Barred Owls, with Private Lands, Deschutes Analysis Area



With Barred Owls, with Private Lands, Deschutes Analysis Area

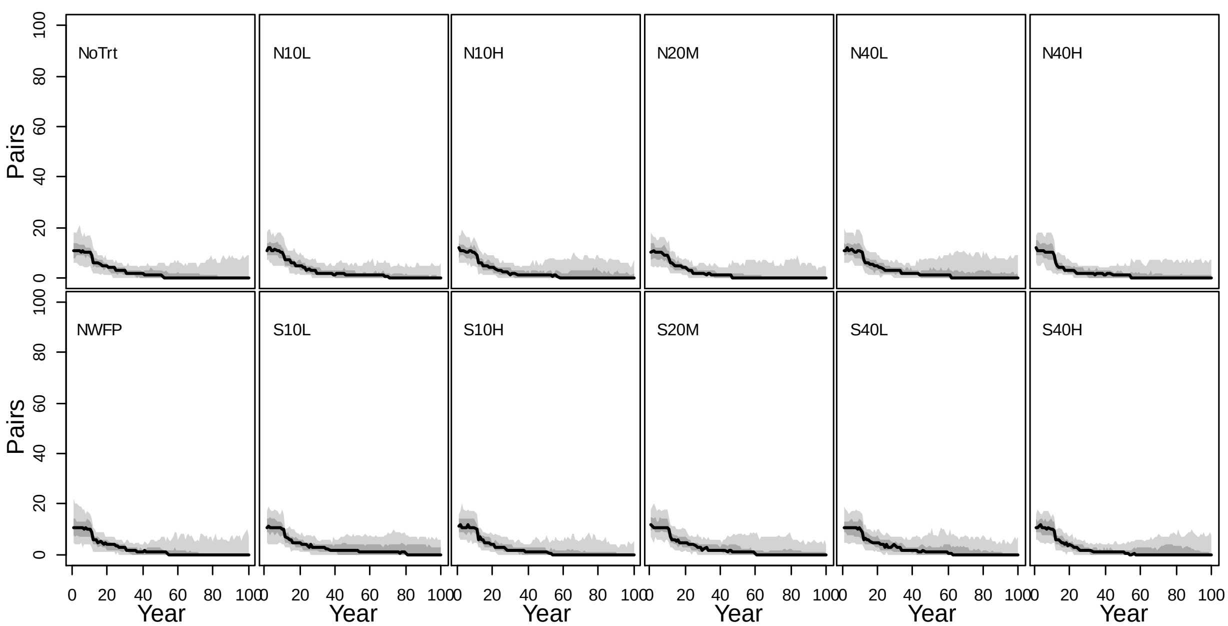


Figure 4. Simulated northern spotted owl population trajectories in the Deschutes analysis area. Lines depict median (black line), 50% quantile range (dark grey shade), and 90% quantile range (light grey shade) of the estimated number of owls through the simulation for 60 *HexSim* replicates for each treatment scenario (see Table 2) with and without effects of barred owls.

Last decade NSO population sizes broadly overlapped across the treatment scenarios, but minimum NSO population sizes were substantially different across scenarios. Last decade NSO population sizes were slightly smaller for the treatment scenarios as compared to the No Treatment scenario in the Wenatchee analysis area, and slightly larger for the Deschutes than for the Wenatchee. Minimum NSO population sizes were substantially different across treatment scenarios for all of the Wenatchee NSO population scenarios (ANOVA $p < 0.01$) and for the NSO population scenarios without BDOW interactions in the Deschutes analysis area (ANOVA $p < 0.01$). The larger-area, higher-intensity treatment scenarios (N40H, S40H, and NWFP) all had smaller minimum NSO population sizes across all of the NSO population scenarios. The N40H scenario produced the lowest minimum NSO population size of any treatment scenario for the Wenatchee analysis area and NSO population scenarios without BDOW interactions in the Deschutes. Minimum NSO population sizes were not different across treatment scenarios (ANOVA $p > 0.05$) for the Deschutes population scenarios with BDOW interactions because NSO populations went to extinction for most replicates of those scenarios.

NSO population changes through time generally tracked changes in total NSO habitat (the combined amount of good and moderate NSO habitat) and showed similar patterns for the Wenatchee analysis area and the Deschutes NSO population scenarios without BDOW displacement. Decadal lambda was approximately 1 from simulation years 0 to 30 for most scenarios excepting the large-area, high-intensity treatments (N40H, S40H, and NWFP) which resulted in decadal lambdas <1 for those years. NSO population bottlenecks (temporary periods of lower than average population levels) generally occurred in both analysis areas around year 30, after treatments had been applied but before the steep accumulation of good habitat in years 30-50. All of the NSO population modeling scenarios showed a spike in decadal lambda from years 30 to 60 in response to a steep, synchronous increase in the modeled amount of good and moderate habitat.

V. Management Implications

The total area treated never exceeded 10% of each landscape analysis area, so the effects of fuel treatments on the landscape were limited by that fact alone. When we compared No Treatment with N40H for Wenatchee, we found a net reduction of about 7% in the amount of high severity fire for areas within 1 km of treatment areas. That means that the treatments, which reduce fire severity within the treated area also have the effect of reducing severity in the areas surrounding the treatments. This outcome makes sense, given the way the fire spread algorithm operates in *LADS* as a cellular automata approach that seeks to meet a fire area and size objective, and in which fuel treatments become a barrier to fire spread, creating wildfire “shadows” around treatments. *LADS* does not include time or weather conditions so it will not include decreases in fire behavior associated with longer-flow paths of fire through the landscape. Thus, our fire model cannot fully account for processes(weather and fire suppression) that would reduce fire spread, and potentially reduce fires severity, when fuel treatments are present in the landscape.

Initial landscape conditions strongly define the forest structural conditions that develop as suitable NSO habitat in the future. For example, mid-20th century selective harvesting practices in the Wenatchee analysis area resulted in relatively large areas of young forest with medium-sized trees. These areas of moderate NSO habitat in the Wenatchee analysis area became good NSO habitat over the duration of our simulations (much of it from simulation years 30 to 50). This pattern also occurred in the Deschutes analysis area, but did not produce as pronounced an increase in good NSO habitat because of the abundance of forest cover types that capable of growing into moderate but not good NSO habitat classes (e.g., ponderosa pine and mountain hemlock forests).

Higher-intensity, larger-area treatment scenarios created short-term NSO habitat and population bottlenecks, but had mixed effects on end-century NSO population sizes. Particularly for the Wenatchee analysis area, we did not find larger ending NSO population sizes from aggressive fuel reduction treatments relative to the No Treatment scenario. The presence of both good and moderate habitat contributed substantially to the suitability of an area for occupancy by a territorial NSO pair based on our analysis of habitat conditions surrounding documented NSO activity centers. Active fuel reduction activities in moderate habitat contributed to substantial short-term (simulation years 0 to 30) population declines under the larger area, higher intensity scenarios. However, our landscape-scale analysis may have failed to detect local benefits of targeted fuel reduction treatments for habitat sustainability and recruitment in specific areas. More refined, finer-scale analysis may reveal more local benefits of fuel reduction treatments for recruiting and maintaining NSO habitat.

The combination of BDOW interactions and high-intensity, larger-area treatments contributed to the most substantial NSO population bottlenecks. The combined effects of aggressive fuel reduction treatment approaches and interactions with BDOWs have the potential to contribute to increased extinction risk for NSOs in both analysis areas. We urge caution in the interpretation of our BDOW interaction modeling for the Deschutes analysis area. Due to the lack of empirical information on BDOW habitat associations in the Deschutes, we applied our BDOW habitat models from the Wenatchee analysis area to the Deschutes analysis area. Our finding that NSOs frequently became extinct under all of the scenarios that included BDOW interactions in the Deschutes analysis area suggests cause for concern regarding the effects of interactions of NSOs with BDOWs in this area. Additional information on BDOW habitat associations and interactions with NSOs in this area will be required.

Barred owl interactions had more impact on NSO population performance than treatment scenarios or assumptions regarding habitat values on non-federal lands, but NSO population growth rates (simulation-duration lambda) were higher for scenarios including BDOW interactions in the Wenatchee analysis area partly because initial NSO population sizes were much smaller, so fewer additional NSO pairs were required to have a proportionately larger effect on its population growth rate. However, our results do suggest that widespread recruitment of NSO habitat could have the potential to enhance the chances of NSO population persistence in the face of detrimental effects of competitive interactions with barred owls in some landscapes (as also suggested by Dugger et al. 2011 and Forsman et al. 2011).

VI. Relationship to other recent findings and ongoing work

Our models show that treatments have opposite effects in the two study areas on the amount of good and moderate NSO habitat over the last decade. In the Wenatchee, the No Treatment scenario resulted in more good and moderate NSO habitat than all the treatments. In the Deschutes the story is reversed, where treatments generally resulted in more NSO habitat than under no treatments. One possible explanation may have to do with the initial vegetation structural class conditions. If the Wenatchee initially has significant areas in younger (non-habitat) vegetation that have potential to grow into NSO habitat, then the treatments, which would concentrate in non-habitat areas might be taking out potential future NSO habitat. Evidence for this interpretation is supported in our analysis of NSO habitat trends, which shows a steep increase in the amount of good NSO habitat on the Wenatchee (from a 100k to an average of more than 250k ha) during the first 7 decades and an equally steep decrease in moderate NSO habitat, which must be growing into good habitat. The relative change in the Deschutes of good habitat is much less (from 30k to an average of about 33k ha), and there is relatively little change in the amount of moderate habitat. The data from the Deschutes suggest that succession is producing relatively little new habitat and that most of the non-habitat that is treated is in environments or forests types that do not have potential to develop into owl habitat through succession. If these interpretations are correct then we may have discovered an important aspect of NSO habitat dynamics—namely the initial vegetation age and size structure of the landscape and the target of treatments relative to future NSO habitat. Ager (2007) (see below) did not grow NSO habitat and evaluted only the Deschutes. Our results are consistent with his for the Deschutes. Roloff et al. (2005) (see below) allowed treatments in owl habitat and found that that active management was not consistent with owl habitat production in that particular case. It appears that management regimes that take out owl habitat through treatments (either current or potential future) do not reduce the amount of habitat that is lost to wildfire enough to make up for the habitats lost through treatments.

Ager et al. 2007 found that fuel treatments would reduce expected loss of owl habitat when the treatment area reached at least 20% of the landscape. The reduction in expected loss of owl habitat in that study went from about 2.4% to 1.3% between 0% treated and 20% of landscape treated. The Ager analysis did allow treatment in areas that were defined as owl habitat and did not assume that succession or stand development would occur (static vegetation).

Roloff et al. 2005 modeled active and no-management in fire prone landscapes in SW Oregon. They found that active management in owl foraging areas reduced owl habitat compared with no management (only losses to wildfire). They attributed the lack of effect of active management in part on the limited area available at landscape scales to treat hazardous fuels but also to the fact that their treatments reduced owl habitat quality (from nesting to foraging) but did not reduce the amount of crown fire. Their model assumed vegetation dynamics (using FVS) and simulated fire using *FlamMap*. In a second paper Roloff et al. 2012 analyzed a different fuel management strategy for the same area. In that paper they found that active management "was more favorable to spotted owl conservation…than no management"

Although they used *FlamMap*, they did not actually burn up owl habitat with a landscape model. Instead they assumed that if 50% of the owl territory had crown fire *potential* then all of the territory would be lost to a fire. This assumption appears to overestimate loss of habitat to fire.

VII. Future Work Needed

- Conduct finer-scale analysis to evaluate responses to treatment within smaller landscape units (5^{th} or 6^{th} code hucs) and compare habitat trends across smaller landscape units that had different total proportions of area treated.

- Analysis of additional treatment scenarios that are not constrained by assumptions regarding access, ownership, and land use allocation to determine the area and spatial optimization of area that would be needed to affect habitat and NSO population outcomes. The fuel treatment scenarios that we analyzed in this project were constrained to a limited portion of the analysis landscape (the area presently available for treatment) and units were prioritized for treatment based on fire risk and other factors, not a true spatial optimization for limiting fire flow. Fewer limitations on treatment locations and using a formal spatial optimization approach to allocate treatments could produce different NSO population outcomes.

- We need more information on barred owl habitat associations and interactions with spotted owls on the Deschutes. Barred owls have been historically uncommon in this area, but detections have increased since 2010. Barred owl-specific surveys throughout the Deschutes (not just within NSO habitat) would provide important information on landscape-scale habitat associations of BDOW and overlap with NSO in this area.

VIII. Deliverables and Science Delivery

The team will deliver a full range of science and technology transfer products. We anticipate publishing 4-5 papers in peer-reviewed journals and presenting results at scientific and management conferences. A web page will describe the research progress and results. Workshops targeted at particular management and policy users will be held in OR and WA.

Deliverable Type	**Description**	**Delivery Dates**
Datasets and models	Integrated spatial (GIS) and modeling datasets on vegetation, fire, and Northern Spotted Owl habitat, in the eastern Cascade Mountains study area, for Forest Planning	in prep.

Deliverable Type	Description	Delivery Dates
	LADS model of landscape dynamics	in prep.
	HexSim model Northern Spotted Owl population dynamics	in prep.
Refereed publications	*Several refereed publications prepared on compatibility of fuel treatments and conservation of owl habitats and populations, and integrating fuel reduction with maintaining NSO prey, including papers on:*	
	Landscape scenario analysis. R. Scheller et al. Potential target journals: Ecological Applications, Landscape Ecology	in prep.
	Future northern spotted owl habitat dynamics and population responses in the Eastern Cascade Range. Singleton, P.H., B.G. Marcot, M. Raphael, J. Lehmkuhl., R. Scheller, P. Hessburg. For: Conservation Biology.	in prep.
	Landscape-scale habitat associations for barred owls and spotted owls in the Eastern Cascade Range, Washington. Singleton, P.H., (and others). For: Biological Conservation.	in prep.
	Overlap of barred owl and spotted owl habitat influences spotted owl pair site occupancy dynamics. Singleton, P.H., (and others). For: Journal of Wildlife Management.	in prep.
	Simulated population-level impacts of territorial interactions with barred owls on northern spotted owls in the Eastern Cascade Range, Washington. Singleton, P.H. (and others). For: Conservation Biology.	in prep.
	Spotted Owls, Barred Owls, and Fire Risk. P. Singleton, P. Hessburg, B. Salter, T. Flowe. Potential target journals: Forest Ecology and Management	in prep.
	Fire risk and owl habitat. P. Hessburg et al. Potential target journal: International Journal of Wildl. Fire	in prep.
	Analysis of sensitivity and uncertainty in an individual-based movement model of a threatened wildlife species. B. Marcot et al. Target journal: Environmental Modelling & Software	in initial review
	Other reports or journal manuscripts to be determined.	in prep.
Dissertation	Barred Owls and Northern Spotted Owls in the Eastern Cascade Range, Washington. Singleton, P.H. 2013. Ph.D. Dissertation. University of Washington. Seattle WA.	2013

Deliverable Type	Description	Delivery Dates
Agency report	US Forest Service General Technical Report submitted to JFSP with details of results by draining, etc.; or, as used in supplemental material for journal papers	in prep.
Workshops	A public workshop on dry forest restoration/fuels reduction and spotted owl management was held in Redmond, Oregon, during 2009. There were 225 attendees. A full report and recommendations can be found at: http://www.fws.gov/oregonfwo/ExternalAffairs/Topics/DryForestWorkshop/2009DryForestWorkshop.asp	2009
	Two one-day workshops were held with staff of the Okanogan-Wenatchee and the Deschutes National Forests during 2010 to discuss management strategies they use and felt necessary for us to model.	2010
	Development of stand silvicultural prescriptions that integrate fuel reduction and forest restoration, and NSO prey and nesting/roosting/foraging structural habitat. This workshop of 25 select managers and scientists was held during 2012 in Hood River, Oregon. A GTR listed below is in progress with expected publication at the end of 2013.	2012
Website	Summarize progress and display interim maps and other products: https://sites.google.com/a/pdx.edu/vegetation-fire-owl/	ongoing
Non-refereed publications	Silviculture and Monitoring Guidelines for Integrating Restoration of Dry Mixed-Conifer Forest and Spotted Owl Habitat Management in the Eastern Cascade Range. PNW GTR in prep for publication in late 2013. The results of the Workshop listed above.	2013
	US Forest Service, Pacific Northwest Research Station *Science Update* article	to be developed
	US Forest Service, Pacific Northwest Research Station *Science Findings* article	to be developed
Presentations	2009:	
	Kennedy, R. S. H., A. A. Ager, P. F. Hessburg, J. F. Lehmkuhl, B. G. Marcot, M. G. Raphael, N. H. Schumaker, P. H. Singleton, and T. A. Spies. 2009. Assessing the compatibility of fuel treatments, wildfire risk, and conservation of Northern Spotted Owl habitats and populations in the eastern Cascades. Invited poster presented at: 4th International Fire Ecology & Management Congress: Fire as a Global Process. 30 November - 4 December 2009, Savannah, Georgia.	presented

Deliverable Type	Description	Delivery Dates
	2010:	
	Lehmkuhl, J. F. and P. F. Hessburg. 2010. A Whole-Landscape Strategy to Restore Inland Northwest Dry Forests and Recover the Northern Spotted Owl. 24th International Congress for Conservation Biology: Conservation for a Changing Planet. 3-7 July 2010, Edmonton, Alberta, Canada.	presented
	2011:	
	Kennedy, R., P. Hessburg, B. Marcot, P. Singleton, M. Raphael, J. Lehmkuhl, A. Ager, and T. Spies. 2011. Conserving Northern Spotted Owl habitat and populations while mitigating wildfire risk and increasing resiliency of forest structure and function: balancing among conflicting ecosystem services in landscapes characterized by disturbance. Presented at: 2011 US-IALE (U.S. Regional Association of the International Association for Landscape Ecology) Annual Symposium, Portland, Oregon.	presented
	Singleton, P.H. 2011. Habitat overlap for northern spotted owls and barred owls in the eastern Cascades, Washington. Presented at: 2011 US-IALE (U.S. Regional Association of the International Association for Landscape Ecology) Annual Symposium. April 5, 2011. Portland, Oregon.	presented
	Singleton, P.H. 2011. Barred owls and northern spotted owls in the eastern Cascades, Washington. Presented at: The Washington State Chapter, Society of American Foresters Annual Meeting. May 12, 2011. Portland, Oregon.	presented
	Lehmkuhl, J. 2011. A foundation for integrating wildlife and restoration objectives in Cascadian dry forests. The Society of American Foresters, Northwest Chapter, Conference: Forest Restoration Beyond Fuel Reduction: What is the Vision? October 12-14, 2011, Bend, OR	presented
	2012:	
	Lehmkuhl, J. 2012. Overview: Creating Stand-Level Silvicultural Prescriptions & Monitoring Templates for Restoration & the Northern Spotted Owl in the Eastern Cascades. PNW Station & U.S. Fish and Wildlife Workshop on Creating Stand-level Silvicultural Prescriptions that Integrate Restoration and Ecological Objectives in the Eastern Cascade Range. Hood River, Oregon, Sept. 5-7, 2012	presented
	Lehmkuhl, J. 2012. An overview of alternatives for dry forest restoration and Northern Spotted Owl conservation in the eastern Cascade Range and their	presented

Deliverable Type	Description	Delivery Dates
	analysis by the Veg-Fire-Owl Project. The Wildlife Society 19th Annual Conference. Oct. 17, 2012, Portland, Oregon. Lehmkuhl, J. and others. 2012. Strategies for integrating dry forest restoration and Northern Spotted Owl conservation in the eastern Cascade Range. 5th International Fire Congress. Dec. 5, 2012, Portland, Oregon. Singleton, P. H., B. G. Marcot, J. Lehmkuhl, M. Raphael, R. Kennedy, and N. H. Schumaker. 2012. Modeling interactions between Spotted Owl and Barred Owl populations in fire-prone forests. Presentation at: 97th Annual Meeting of the Ecological Society of America, 5-10 August 2012, Portland, Oregon. Scheller, R.M., E. Haunreiter, R. Kennedy, P. Singleton. 2012. Projected dry forest landscape dynamics and the implications for Northern Spotted Owl habitat under alternative management scenarios. Invited Speaker at Symposium of The Wildlife Society 75th Annual Meeting. October, 2012. Portland, OR. Singleton, P. H., B. G. Marcot, M. Raphael, J. Lehmkuhl, N. Schumaker. 2012. Distribution and abundance of Northern Spotted Owls under alternative dry forest management scenarios. Presentation at: The Wildlife Society 19th Annual Conference, October 12-18, 2012, Portland, Oregon. Spies, T., P. Hessburg, and J. Lehmkuhl. 2012. Strategies for integrating dry forest restoration and conservation of the Northern Spotted Owl in the eastern Cascade Range. The Wildlife Society 19th Annual Conference. Oct. 17, 2012, Portland, Oregon. (Spies gave the presentation). 2013: Raphael, M.G. 2013. The Vegetation, Fire, Owl project: applications to Region 6 restoration initiatives. Presentation to Regional biologists and planners, POortland, OR.	 presented presented presented presented presented

Citations

Ager, A.A, N.M. Vaillant, M.A. Finney, H.K. Preisler. 2012. Analyzing wildfire exposure and source sink relationships on a fire prone forest landscape. Forest Ecology and Management. 267:271 – 283.

Anderson, H.E. 1982. Aids to determining fuel models for estimating fire behavior. USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden UT. INT-GTR-122.

Anthony, R.G., E.D. Forsman, A.B. Franklin, D.R. Anderson, and others. 2006. Status and Trends in Demography of Northern Spotted Owls, 1985-2003. Wildlife Monographs 163:1-48.

Dugger, K.M., R.G. Anthony, L.S. Andrews. 2011. Transient dynamics of invasive competition: Barred Owls, Spotted Owls, habitat, and the demons of competition present. Ecological Applications. 21:2459-2468.

Forsman, E.D., R.G. Anthony, K.M. Dugger, E.M. Glenn, and others. 2011. Population Demography of Northern Spotted Owls. Studies in Avian Biology No. 40.

Gutierrez, R., M. Cody, S. Courtney, D. Kennedy. 2004. Assessment of the potential threat of the Northern Barred Owl. In: Courtney, S.P. et al. (Eds.) Scientific evaluation of the status of the Northern Spotted Owl. Sustainable Ecosystems Institute. Portland, Oregon, p. 508.

Finney, M.A. 2002. Fire growth using minimum travel time methods. Canadian Journal Forest Research. 32(8): 1420 – 1424.

Finney, M.A., R.C. Seli, C.W. McHugh, A.A. Ager, B. Bahro, J.K. Agee. 2007. Simulation of long-term landscape-level fuel treatment effects on large wildfires. Int. Journal of Wildland Fire. 16(6): 712–727.

Hessburg, P.F., Agee, J.K., Franklin, J.F. 2005. Dry mixed conifer forests and wildland fires of the Inland Northwest: Contrasting the landscape ecology of the pre-settlement and modern eras. Forest Ecology and Management 211(1): 117-139.

Livezey, K. 2007. Barred Owl habitat and prey: A review and synthesis of the literature. Journal of Raptor Research 41:177-201.

Ohmann, J.L., M.J. Gregory. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest neighbor imputation in coastal Oregon, U.S.A. Canadian Journal of Forest Research. 32:725 – 741.

Phillips, S.J., R.P. Anderson, R.E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190:231-259.

Roloff, G.J., S.P. Mealey, C. Clay, J. Barry, C. Yanish, L. Neuenschwander. 2005. A process for modeling short- and long-term risk in the southern Oregon Cascades. Forest Ecology and Management 211:166-190.

Roloff, G.J, S.P. Mealey, J.D. Bailey. 2012. Comparitive hazard assessment for protected species in a fire-prone landscape. Forest Ecology and Management 277:1-10.

Schumaker, N.H. 2012. HexSim (Version 2.4). U.S. Environmental Protection Agency, Environmental Research Laboratory, Corvallis Or. (http://www.epa.gov/hexsim)

Scott, J.H., R.E. Burgan. 2005. Standard fire behavior fuel models: a comprehensive set of fuel models for use with Rothermel's surface fire spread model. USDA Forest Service, Rocky Mountain Research Station, Missoula MT. RMRS-GTR-153.

Singleton, P.H. 2013. Barred owls and northern spotted owls in the eastern Cascade Range, Washington. Ph.D. Dissertation. University of Washington, Seattle WA.

Society for Conservation Biology and American Ornithologists Union. 2008. Comments on the Final Recovery Plan for the Northern Spotted Owl. Available at. http://www.conbio.org/Activities/Policy/docs/SCB-AOU%20Review%20-%20Northen%20Spotted%20Owl%20Final%20Recovery%20Plan.pdf

Spies, T. A., M. A. Hemstrom, A. Youngblood, and S. Hummel. 2006. Conserving old-growth forest diversity in disturbance-prone landscapes. Conservation Biology 20(2): 351-362.

The Wildlife Society. 2008. Comments on the Final Recovery Plan for the Northern Spotted Owl. Available at http://joomla.wildlife.org/documents/NSO_final_plan.pdf

U.S. Fish and Wildlife Service. 2011. Revised Recovery Plan for the Northern Spotted Owl (Strix occidentalis caurina). U.S. Fish and Wildlife Service, Portland, OR. 258 p.
http://www.fws.gov/arcata/es/birds/nso/documents/USFWS2011RevisedRecoveryPlanNorthernSpottedOwl.pdf

Wimberly, M.C., and R.S.H. Kennedy. 2008. Spatially explicit modeling of mixed-severity fire regimes and landscape dynamics. Forest Ecology and Management 254:511-523.

Wimberly, M. C. 2002. Spatial simulation of historical landscape patterns in coastal forests of the Pacific Northwest. Canadian Journal of Forest Research-Revue Canadienne De Recherche Forestiere 32:1316-1328.

Acronyms and abbreviations used in this report:

BDOW = barred owl, *Strix varia*
DES = Deschutes landscape analysis area
GNN = gradient nearest neighbor vegetation inventory
LSOF = late-successional and old forest
LSR = late-successional [forest] reserve
NSO = northern spotted owl, *Strix occidentalis caurina*
RAWS = Remote Automatic Weather Stations
RRP = Revised Recovery Plan
USFS = U.S. Forest Service
USDA = U.S. Department of Agriculture
USFWS = U.S. Fish and Wildlife Service
WEN = Wenatchee landscape analysis area

Model names used in this report:

FBFM = fire behavior fuel model
FlamMap = fire simulation model
FVS = Forest Vegetation Simulator
HexSim = spatially explicit individual-based population simulation model
LADS = forest state-and-transition simulation model