Project Title: 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.

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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 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 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 two whole-landscape scenarios representing alternatives to current reserve allocations. All of our simulations assumed a wildfire regime going forward that reflects the regime variability experienced over the most recent 15 years of fire history, including the potential for large, rare fire events. We conducted our analysis in two study areas that encompassed the range of the northern spotted owl within the Okanogan-Wenatchee National Forest, Washington, and Deschutes National Forest, Oregon.

At the start of the simulation (reflecting current conditions), the primary landscape pattern that emerged for both analysis areas was that a substantial portion of the area capable of supporting NSO habitat was small- to medium-tree size, closed canopy forest. Changes in the area of NSO habitat through our 100-year simulation were realized as these areas grew into medium- and large-tree sizes, thereby increasing their value as spotted owl habitat. The development of NSO habitat through forest growth was counter-balanced by the loss of habitat to disturbances, including wildfires and intentional treatments, particularly during the second half of our simulation period.

NSO population changes through time generally tracked changes in total area of good and moderate NSO habitat. For most of the simulations in the Wenatchee analysis area, populations declined during the first 30 years in response to habitat loss from wildfires and fuel treatments, then increased slightly from years 30 to 50 as owl habitat values increased due to forest growth. NSO population declines were more sustained in simulations for the Deschutes analysis area, with notable population declines over the first 50 years and little or no population growth later in the simulation. Rates of population change during the entire simulation (simulation-duration lambda, or the mean number of territorial female spotted owls during the first decade of the simulation compared to the last decade of the simulation) for simulations in the

Wenatchee study area were close to 1 for No Treatment scenarios (indicating relatively stable populations) and ranged from 0.75 to 0.50 for active management scenarios (indicating declining populations). Simulation-duration lambda for simulations in the Deschutes study area without barred owl interactions were approximately 0.65 for No Treatment scenarios and 0.54 to 0.27 for active management scenarios (indicating substantial population declines under all scenarios). The spotted owl population declined to extinction in the Deschutes study area within the first 50 years for nearly all of the simulations when barred owl interactions were included.

No active management scenarios produced substantive landscape-level changes in area burned in our simulations, and all resulted in less habitat and fewer owls than the No Treatment scenarios, in both study areas. The naïve spatial allocation approach, focused exclusively on treating areas of highest fire risk regardless of NSO habitat values, produced the greatest reduction in NSO population compared to the No Treatment scenario. Population outcomes for structured allocation (treating areas of highest fire risk, but avoiding existing NSO habitat and recent activity centers) and the reserve-based allocation had similar population outcomes. We hypothesize that the lack of effect of active management scenarios on fire was the consequence of three factors; 1) treatments were implemented with highly limited spatial distribution and area treated due to current land allocation, 2) treatments could not be spatially optimized due to land allocation and access limitations, and 3) treatment units had limited effects as fire breaks in our LADS modeling scenarios, and only reduced high-severity fire frequency within 200 m of the treated units. Fire size distributions and return intervals were pre-determined based on initial parameter settings in LADS. This is an important limitation of LADS and may have minimized our ability to evaluate the effect of changed fuel patterns on fire, and consequently the development of 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.

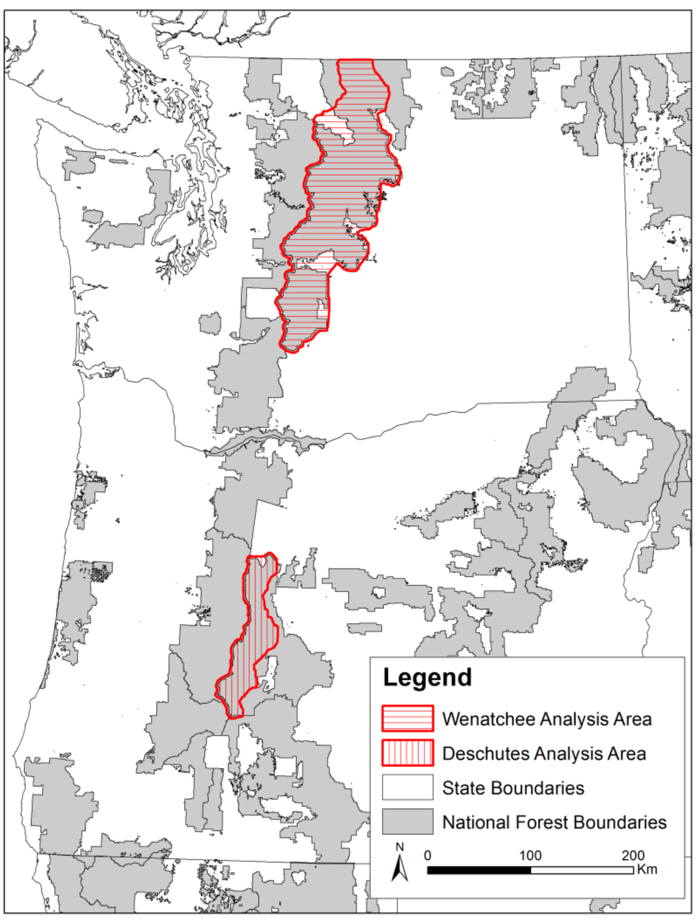

Figure 1. Analysis area locations within Washington and Oregon.

Our objectives were to develop and evaluate 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 two whole-landscape spatial allocation scenarios. 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.

Vegetation simulations

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-severity fire 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 spread rates. Fuel treatments are transitory and after a predefined duration transition to an appropriate post-treatment 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).

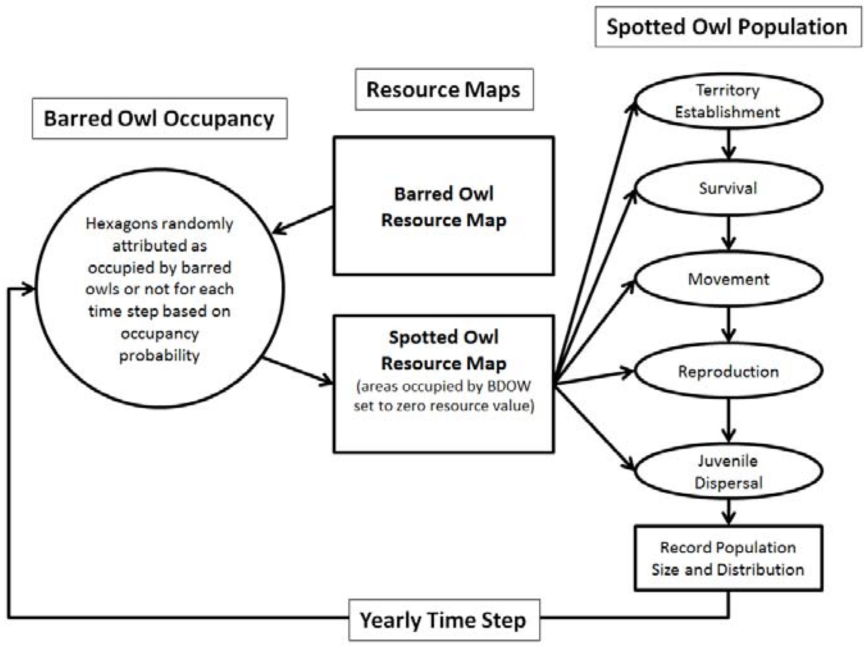

Figure 2. The NSO population model event sequence.

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).

Model Experiments

We evaluated 4 landscape management scenarios and 4 NSO population scenarios. The landscape management scenarios included a No Treatment scenario, and 3 strategies for spatial allocation of treatment (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). Treatments resulted in stands moving from a closed canopy (>60%) to an open (<40%) canopy condition, representing typical forest restoration thinning treatments. Treated areas functioned as fire breaks (fire spread set to zero) for 20 years following treatment. Depending on vegetation community type, treated areas became eligible for re-treatment in approximately 30 years, when they transitioned from open to moderate canopy conditions.

Table 2. Treatment scenario codes and descriptions.

Code	Strategy	Wen Treated ha	Des Treated ha	Intensity
NoTrt	No Treatment	None	None	None
N40H	Naïve	161311	64616	High
S40H	Structured	127017	64530	High
NWFP	Reserve	130320	59020	High

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. Approximately 40% of the available area was treated under each spatial allocatation 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

Vegetation

The transition from small/medium to large/very large sized trees varied 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 treatments altered forest transitions for select dominant cover types. By reducing fire severity, fuel treatments enabled individual cells to transition to larger and more fire resilient size and cover classes before the next high severity wildfire occurred. Because of the stochastic and variable nature of wildfire and the relatively low probabilities of a fire at a treatment unit, the effect of treatments could be 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 2) was primarily limited by the small area treated in total; for example, about a quarter of the total area was available for treatment in the Wenatchee study area. 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) and treatments were essentially as effective as randomly assigned treatments. This suggests that current restrictions on the fuel treatment placement may be impeding manager's ability to modify fire behavior across large landscapes. Faster transitions to more fire resilience conditions could be achieved and across more forest types if the fire treatable area was larger. We hypothesize that treatments across a larger landscape would also reduce 'treatment pressure' on the NSO habitat subset of the landscape, and the landscape would more broadly respond to the treatment 'shadow' effect (Finney et al. 2007, Schmidt et al. 2008).

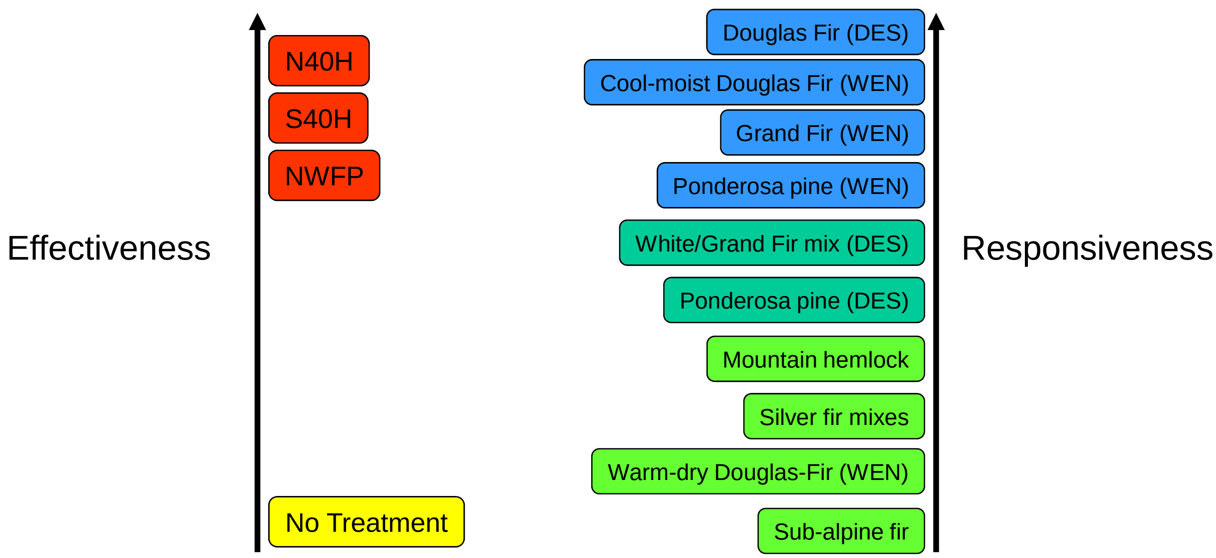

Figure 2. Relative treatment effectiveness and dominant cover type responsiveness for two study landscapes: Deschutes (DES) and Wenatchee (WEN). If location is not listed, the dominant cover type behaved similarly across both landscape

Treatment trajectories appeared to be a function of both the fixed target level and intensity of treatment and the initial vegetation size 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, with subsequent peaks in area treated occurring at approximately 30-year intervals as areas recovered into treatable forest structure conditions.

Our treatment scenarios could not be designed to spatially optimize fuel conditions to significantly interrupt fire flow on the Wenatchee landscape; approximately three-quarters of the landscape was wilderness or roadless area and therefore exempt from treatment due to land allocation. Our fuel treatment scenario treated approximately 40% of the 25% available area, net 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: growth of large areas of younger and relatively small diameter forest into larger, closed-canopy conditions and wildfires that will reset succession over large areas. 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, but that increase will be dependent on the rate at which disturbance processes move areas from late- to early-successional conditions. Fuel treatments can directly influence these transitions through active management and indirectly influence these transitions by protecting against the highest severity fires, although we hypothesize that their effectiveness is currently limited by the relatively scant area available for treatment.

Spotted Owl Habitat and Populations

The total area of NSO habitat (including both good and moderate habitat) was not substantially different at the end of the simulation compared to the beginning for either study area under the No Treatment landscape scenarios (95% of starting area for the Wenatchee and 112% for the Deschutes, averaged across 20 landscape simulation replicates), but relative amounts of good and moderate NSO habitat did change. For the Wenatchee analysis area under the No Treatment scenario, the amount of good NSO habitat increased to 189,600 ha, or 159% of the starting area (averaged across 20 landscape simulation replicates), while the amount of moderate habitat declined to 229,700 ha, or 76% of starting. For the Deschutes analysis area under the No Treatment scenario, the amount of good NSO habitat declined to 26,320 ha, or 88% of starting area, while the amount of moderate habitat increased to 65,250 ha, or 125% of starting.

Active management scenarios produced less good and moderate NSO habitat at the end of the simulations than the No Treatment scenarios in in both analysis areas. The ending amount of good habitat under the active management scenarios in the Wenatchee analysis area ranged from 154,100 ha (treatment scenario N40H: 131% of starting) to 168,600 ha (S40H: 143% of starting), and the ending amount of moderate habitat ranged from 246,900 ha (N40H: 62% of starting) to 279,000 ha (S40H: 66% of starting). For the Deschutes analysis area, the ending amount of good habitat under the treatment scenarios ranged from 17,720 ha (N40H: 59% of starting) to 24,470 ha (NWFP: 82% of starting). The amount of moderate habitat decreased up to year 90 in both study areas. Between years 90 and 100 a substantial area of the ponderosa pine type transitioned into closed canopy conditions and became moderate habitat at the end of the simulation period in both landscapes.

NSO population changes through time generally tracked changes in total area of good and moderate NSO habitat. For most of the simulations in the Wenatchee analysis area, populations declined during the first 30 years in response to habitat loss from fire and implementation of treatments, then increased slightly from years 30 to 50 as owl habitat values increased due to forest growth (Figure 3). NSO population declines were more sustained in simulations for the Deschutes analysis area, with notable population declines over the first 50 years and little or no population growth later in the simulation (Figure 4). Rates of population change during the entire simulation (simulation-duration lambda, or the mean number of territorial female spotted owls during the first decade of the simulation compared to the last decade of the simulation) for simulations in the Wenatchee study area were close to 1 for No Treatment scenarios (indicating relatively stable populations) and ranged from 0.75 to 0.50 for active management scenarios (indicating declining populations). Simulation-duration lambda for simulations in the Deschutes study area without barred owl interactions were approximately 0.65 for No Treatment scenarios and 0.54 to 0.27 for active management scenarios (indicating substantial population declines under all scenarios). The spotted owl population declined to extinction within the first 50 years for nearly all of the simulations including barred owl interactions in the Deschutes study area (Figure 4).

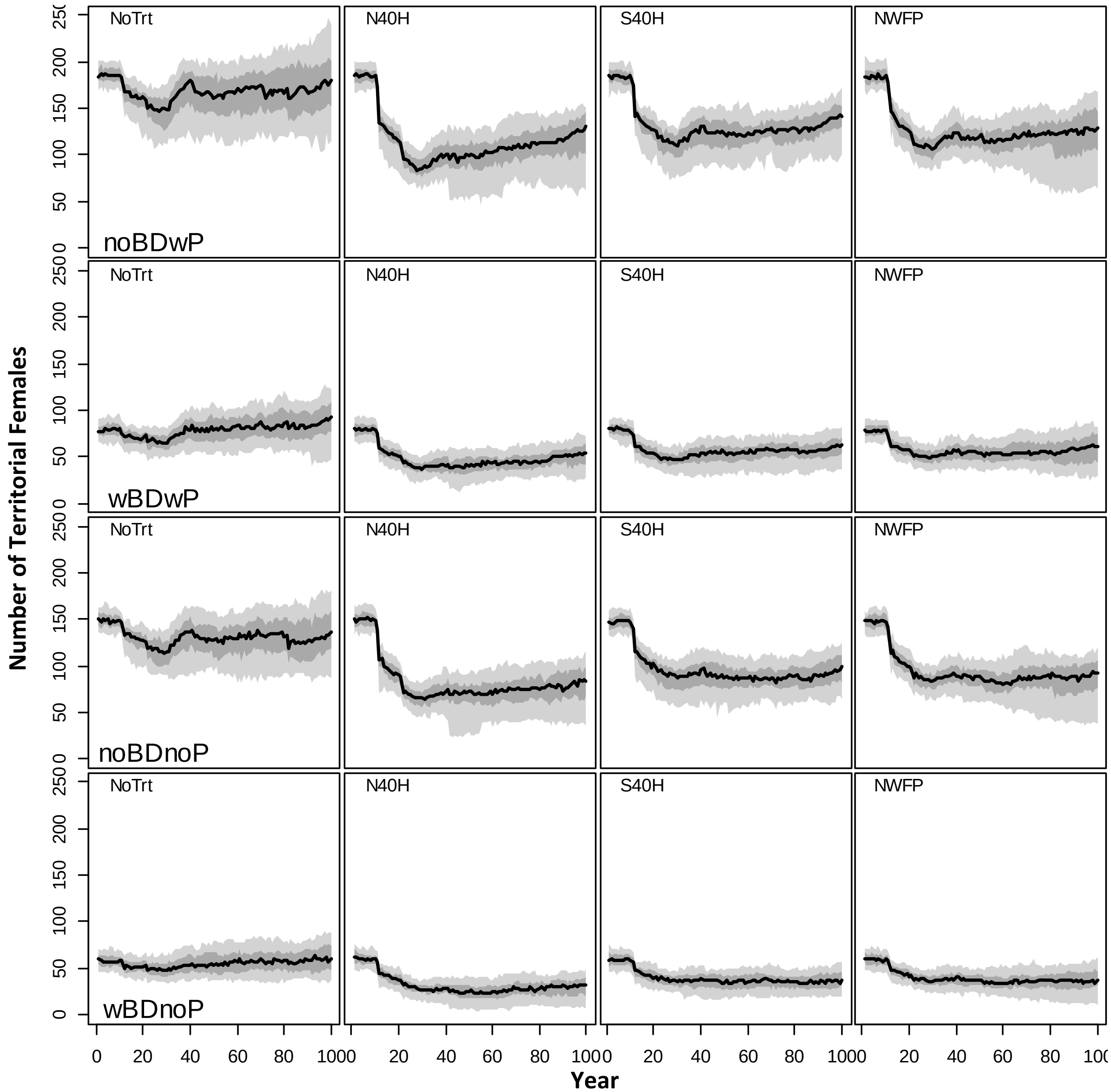

Figure 3. Simulated northern spotted owl population trajectories in the Wenatchee analysis area under 4 landscape management scenarios (columns) and 4 spotted owl population scenarios (rows). Lines depict median (black line), 50% quantile range (dark grey shade), and 90% quantile range (light grey shade) of the estimated number of owls through the simulation for 60 HexSim replicates for each scenario (see Table 2).

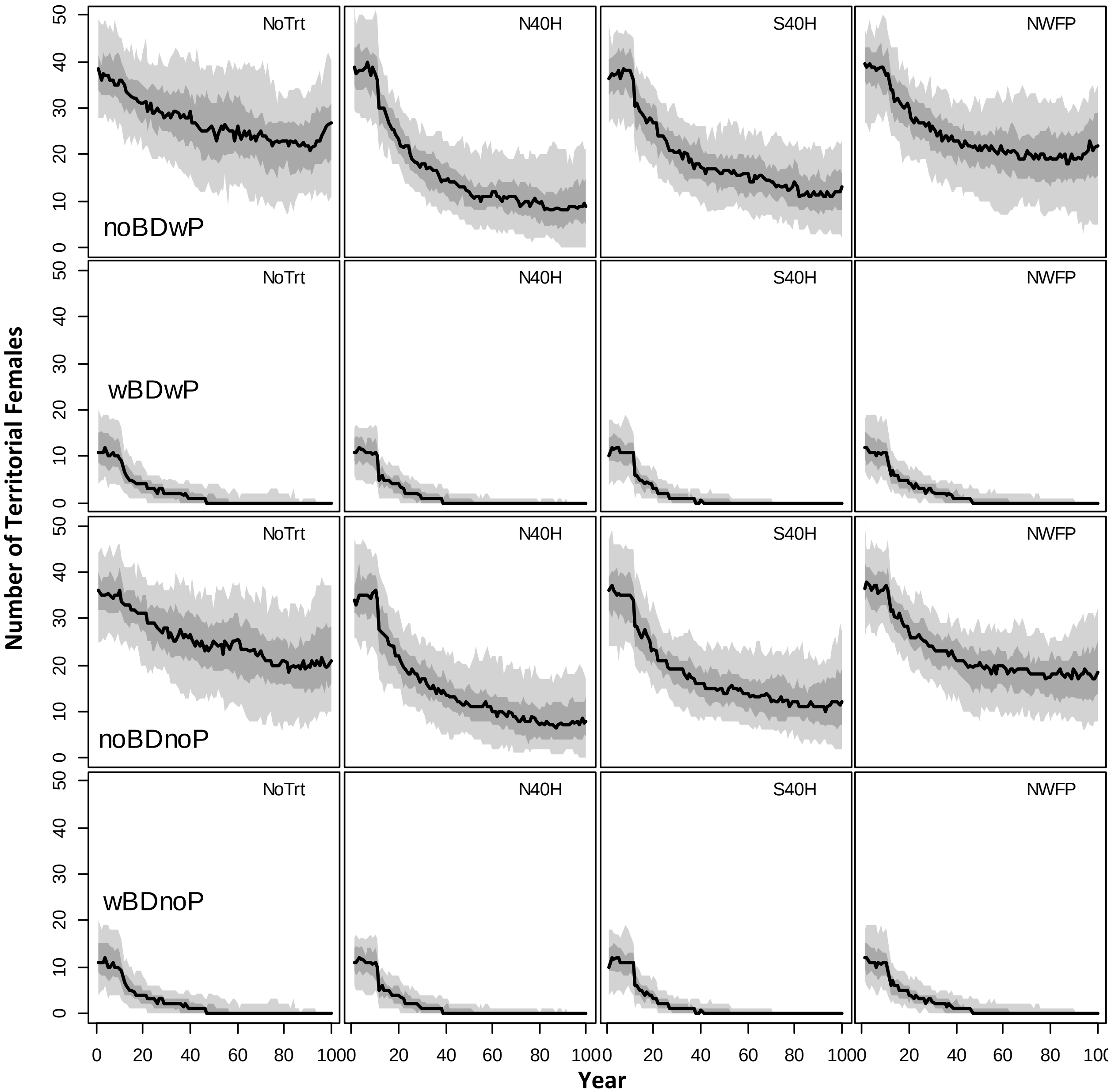

Figure 4. Simulated northern spotted owl population trajectories in the Deschutes analysis area under 4 landscape management scenarios (columns) and 4 spotted owl population scenarios (rows). Lines depict median (black line), 50% quantile range (dark grey shade), and 90% quantile range (light grey shade) of the estimated number of owls through the simulation for 60 HexSim replicates for each scenario (see Table 2).

Linear model tests confirmed that the active management scenarios produced significantly smaller ending population sizes and smaller minimum population sizes than the No Treatment scenario in the Wenatchee analysis area. The with barred owls, no habitats on private lands (wBDnoP) population scenario run on the N40H landscapes produced the biggest decline, with ending number of territorial females 52% smaller and minimum population size 56% smaller compared to the same owl population scenario run on the No Treatment landscapes. The no barred owls, with habitats on private lands population scenario run on the S40H landscapes produced the smallest decline, with ending number of territorial females 20% smaller and minimum population size 22% smaller compared to the same owl population scenario run on the No Treatment landscapes. Based on the linear model analysis, the N40H scenario produced the most substantial declines in ending and minimum spotted owl population size, and the S40H scenario produced the least substantial declines for the Wenatchee analysis area.

Ending and minimum spotted owl population sizes in the Deschutes analysis area were also smaller for population scenarios, without barred owl interactions, using the actively managed compared to No Treatment landscapes. Linear model tests of active management effects on minimum population sizes showed that the N40H, S40H, and NWFP landscapes produced minimum population sizes 60%, 50%, and 16% smaller than the No Treatment landscapes for the population scenarios including habitat values on private lands, and 60%, 43%, and 16% smaller than the No Treatment landscapes for the population scenarios without habitat values on private lands. Linear model tests of active management effects on mean last decade number of females (also without barred owl interactions) showed that the N40H, S40H, and NWFP landscapes produced ending population sizes 57%, 42%, and 17% smaller than the No Treatment landscapes for the population scenarios including habitat values on private lands, and 64%, 47%, and 16% smaller than the No Treatment landscapes for the population scenarios without habitat values on private lands.

V. Management Implications

The total area treated never exceeded 10% of each landscape analysis area in any scenario, so the effects of fuel treatments on the landscape in our simulations were limited by land allocation constraints. When we compared high-severity fire frequency in areas around treatment units to high-severity fire frequency under the No Treatment scenario, we found 0.12 fewer high-severity fires per 100-year simulation (a 24% decrease relative to the No Treatment scenarios), but only for areas within 200 m of treated units. That means that the treatments, which prevented fire within the treated area also had the effect of reducing surrounding fire frequency, but only in a limited area near the treatments. This outcome makes sense, given the way the *LADS* cellular automata seeks to meet a fire area and size objective, and in which fuel treatments become a barrier to fire spread, but it limited *LADS* ability to represent 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. In reality, fuel treatments that slow the spread of fire or reduce its flame length and intensity would give managers more opportunity to suppress wildfires. 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. The limited area of treatment in our scenarios and the limited effectiveness of treated areas for producing “fire shadow” effects in the LADS simulations both contributed to the limited effectiveness of our treatment scenarios for protecting NSO habitat from high-severity fire impacts.

Initial landscape conditions strongly defined the forest structural conditions that developed 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 small-sized trees. These areas of poor NSO habitat in the Wenatchee analysis area became moderate, then good NSO habitat over the course of our simulations. This pattern also occurred in the Deschutes analysis area, but did not produce as pronounced an increase in overall NSO habitat values because much of the Deschutes was already in the medium-sized tree class at the start of the simulations and therefore already moderate NSO habitat, and because of the abundance of forest cover types capable of growing into moderate but not good NSO habitat classes by virtue of their cover type or environmental setting (e.g., ponderosa pine and mountain hemlock forests).

The active management scenarios created long-term NSO habitat and population declines. 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 management activities in moderate habitat contributed to substantial short-term (simulation years 0 to 30) population declines and did not contribute to accelerated development of NSO habitat values later in the simulations. Under our scenarios, treated areas became eligible for re-treatment in approximately 30 years when the stands moved into moderate canopy conditions. Because LADS applies treatments based on a target area to be treated each year, and because all areas eligible for treatment were treated in the first two decades of the simulations, areas that became eligible for treatment later in the simulations were quickly treated again and never allowed to develop NSO habitat values. This was an important limitation of our vegetation modeling approach and also a caution for management plans that seek to reduce high severity fire while promoting owl habitat.

The combination of BDOW interactions and active management contributed to the most substantial NSO declines. 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

Only three other modeling studies have explored questions related to owl habitat, management and fire. 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). His findings might be consistent with our results if we could have optimally treated more of the landscape and avoided areas that were current or potential future NSO habitat.

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.

These studies along with ours suggest that the question of how to dynamically sustain owl habitat in fire prone landscapes is complex and needs much further evaluation. It's clear that low levels of treatment on a landscape scale, will not be sufficient to affect high-severity fire behavior. It's also clear that some fuel treatments designs intended to reduce loss of owl habitat to high severity fire will result in reduced owl habitat compared to a no-treatment option. However, several key questions remain unanswered including: 1) How does the rate and pattern of fuel treatment affect high severity fire in landscapes with different initial conditions of forest structure?; 2) How does the amount and landscape pattern of fuel treatments *inside and outside* existing and potential owl habitat affect dynamics of owl habitat and owl populations; and 3) how do different landscape management strategies affect owl habitat outcomes under different future fire scenarios?

VII. Future Work Needed

- Conduct additional sensitivity analysis with LADS to address two major limitations of our vegetation modeling approach; 1) fuel reduction treatments did not produce substantial fire shadow effects, and 2) thinning treatments did not contribute to accelerated development of NSO habitat values. The two primary arguments for active management within NSO habitat are reduction of fire risk by creating fuel breaks, and accelerating the development of structural diversity associated with NSO habitat. Our LADS modeling did not capture either of these processes effectively. Adjusting parameter settings related to the directionality and shape of fire events in LADS could produce different fire shadow effects relative to treatment units. Other approaches for representing treatments could include pre-treating the landscape (to explore differences in successional trajectories and disturbance patterns that emerge from a "fully restored" landscape), or applying treatments only in units with medium-sized or smaller trees (to allow areas with larger trees to develop closed canopies and contribute to NSO habitat values). Other vegetation modeling platforms should be considered if additional sensitivity analysis shows that LADS cannot adequately represent these processes.

- 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 treatments 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 quite 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.
	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.

Deliverable Type	Description	Delivery Dates
	Falke J.A., Flitcroft R.L., Dunham J.B., McNyset K.M., Hessburg P.F., Reeves G.H. 2014. Climate change and vulnerability of bull trout (Salvelinus confluentus) in a fire-prone landscape. Canadian Journal of Fisheries and Aquatic Sciences. In press.	In press
	Flitcroft R.L., Reeves G.H., Falke J.A., McNyset K.M., Benda L.E., Hessburg P.F. 2015. Response of spring Chinook salmon habitat to wildfires in the Wenatchee River subbasin, WA, USA. PLosOne	in review
	Hessburg, P.F.; Reynolds, K.M.; Salter, R.B.; Dickinson, J.D.; Gaines, W.L.; Harrod, R.J. 2013. Landscape Evaluation for Restoration Planning on the Okanogan-Wenatchee National Forest, USA. Sustainability 5(3): 805-840.	2013
	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 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
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 Review
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	2012

Deliverable Type	Description	Delivery Dates
	publication at the end of 2013.	
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
	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. Habitat overlap for northern spotted owls and barred owls in the eastern Cascades, Washington. Presented at: 2011 US-IALE (U.S. Regional	presented

Deliverable Type	Description	Delivery Dates
	Association of the International Association for Landscape Ecology) Annual Symposium. April 5, 2011. Portland, Oregon.	
	Singleton, P.H. 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 analysis by the Veg-Fire-Owl Project. The Wildlife Society 19th Annual Conference. Oct. 17, 2012, Portland, Oregon.	presented
	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.	presented
	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.	presented
	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	presented

Deliverable Type	Description	Delivery Dates
	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

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