Climate Change, Land Management, and Potential Northern Spotted Owl Habitat in Coastal Washington

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Introduction

Climate change and land management will interact to influence future vegetation structure and composition. Land managers need information on the potential effects of climate change to plan future management that balances the diversity of values that are linked to vegetation. Dynamic global vegetation models (DGVMs) are cutting edge tools to assess climate change effects on ecosystems (Fischlin et al. 2007). DGVMs link knowledge of plant physiology, biogeography, biogeochemistry, and biophysics, and integrate information from climate models to simulate changes in vegetation structure and composition and ecosystem function through time (Prentice et al. 1989, 2007; Foley et al. 1998; Cramer et al. 2001). MC1 is a DGVM that has been used for regional- to global-scale assessments of potential climate change effects on ecosystems (Daly et al. 2000; Bachelet et al. 2001). However, because MC1 generates simulations on relatively coarse-scale data grids, and simulates changes in broad plant functional types (e.g., evergreen needle-leaved forest), output is too coarse for use in many management and planning efforts. Moreover, MC1 does not account for effects of management.

Vegetation state-and-transition models (STMs), in contrast, simulate detailed community-level vegetation dynamics and effects of land management and natural disturbances on vegetation composition and structure over time. Output from STMs is community-specific and appropriately scaled for management and planning efforts, and STMs have been used for many different regional to sub-regional assessments (e.g., Hemstrom et al. 2001, 2002, 2007; Forbis et al. 2006; Weisz et al. 2009). However, until recently, STMs did not incorporate the potential effects of climate change. A recent project funded by the American Recovery and Reinvestment Act, called the Integrated Landscape Assessment Project (ILAP; http://oregonstate.edu/inr/ilap), developed techniques to make STMs "climate-smart" by using MC1 to inform the nature and rates of potential vegetation changes and probability of fire under different climate change scenarios (Halofsky et al. 2013). We refined and applied these techniques to the coastal region of Washington. Our objectives were to:

1. Explore how climate and land management might interact to shape future vegetation
2. Determine how management will affect habitat for the federally-protected Northern Spotted Owl (NSO) in coastal Washington

Methods

The study area encompasses approximately 5.8 million acres along the coast of Washington State, from the Canadian border to the Oregon border (Figure 1). Ownership in the study area is a mix of state, federal, and private (Figure 1). Elevation ranges from sea level to over 6,900 feet at Mount Olympus, the highest peak of the Olympic Mountains. A wet and humid maritime climate characterizes the western, coastal side of the study area, which receives 100 to 200 inches of precipitation per year depending on location, while the crest of the Olympic Mountains receives >230 inches of precipitation per year, making it the wettest location in the coterminous United States (Peterson et al. 1997). In contrast, the northeastern portion of the Olympic Peninsula is characterized by a drier, more continental climate owing to the rainshadow effect of the Olympic Mountains (and prevailing winds from the southwest during the winter). Rainfall in the northeastern portion of the peninsula is as low as 20 inches per year at lower elevations (Henderson et al. 1989). Most precipitation falls between October and March, and winter precipitation falls mainly as rain below 1,000 feet, as rain and snow between 1,000 and 2,500 feet, and as snow above 2,500 feet. Snow at higher elevations persists through the early part of summer.

Varied climatic conditions on the peninsula result in diverse ecological communities. Vegetation assemblages in the study area include temperate rain forests, mixed conifer forests, prairies, alpine tundra, subalpine parklands, wetlands, and riparian communities. There are 1,480 native vascular plant species on the Olympic Peninsula alone, including eight endemic species (Buckingham et al. 1995).

Developing climate-smart STMs to characterize the interacting effects of management and climate change on vegetation and NSO habitat in coastal Washington involved seven main steps:

1. Downscale global and regional climate model data for input to MC1 version 2.0 (MC2 hereafter)
2. Calibrate MC2 for the study area and run simulations using downscaled climate data
3. Develop climate-smart STMs (cSTMs) by integrating projections of vegetation and fire regime shifts from MC2 into previously-developed local STMs
4. Develop future land management scenarios (e.g., no management and current management) in stakeholder meetings
5. Run cSTMs under different climate and management scenarios
6. Refine vegetation-habitat relationships for NSO in coastal Washington
7. Summarize and interpret vegetation and NSO habitat results

Each of these steps is described in further detail below.

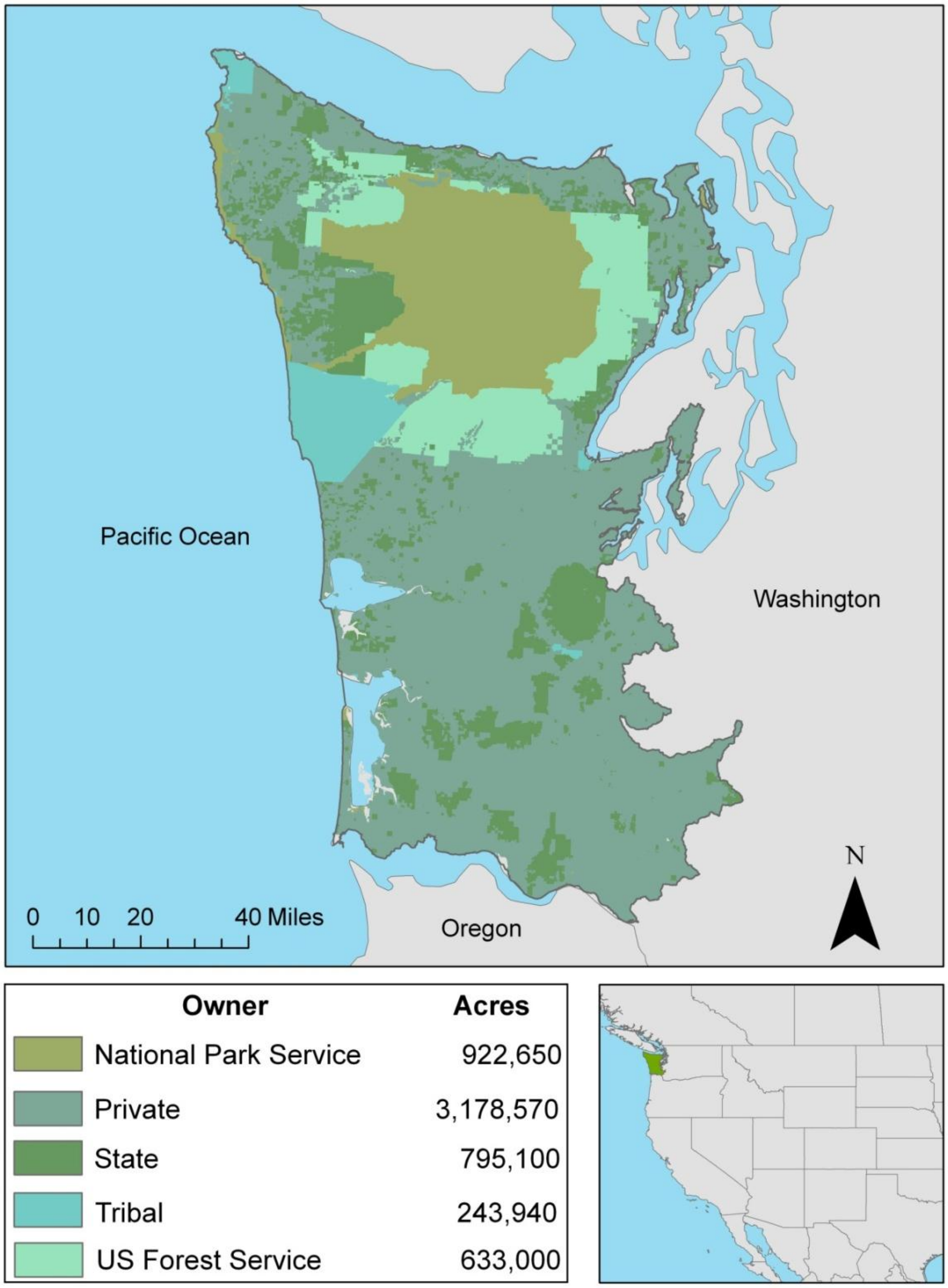

Figure 1. Land ownership in the coastal Washington study area.

1. Climate data

To run MC2, monthly values of four climate variables are required. These include precipitation, the monthly means of diurnal extreme temperatures, and a measure of atmospheric water content (usually vapor pressure deficit). For historical climate, the Parameter–elevation Relationships on Independent Slopes Model (PRISM) climate data set on a 30-arcsec grid (~2600 ft grain; Daly et al. 1997, 2008) was used. For future climate, we used output from one global climate model (GCM), the Hadley CM3 model (Gordon et al. 2000; Johns et al. 2003), which was included in the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 (CMIP3) multimodel dataset and subsequently in the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (IPCC 2007). We also used output from one regional climate model (RCM), RegCM3 (Hostetler et al. 2011). The RCM was constrained by ECHAM5 (Roeckner et al. 2003) GCM output. Both models were run under the IPCC Special Report on Emissions Scenarios A2 carbon dioxide emissions scenario (Nakićenović and Swart 2000). For the 2070-2099 period, Hadley CM3 (Hadley hereafter) projects a relatively hot and dry Olympic Peninsula (+6.8°F in maximum annual temperature, +5.8°F in minimum annual temperature, and −5.4 inches annual precipitation compared to the 1951-1980 means from PRISM data), and the RegCM3 ECHAM5 model (RegCM3 hereafter) projects a relatively hot and wet Olympic Peninsula (+5.9°F in maximum annual temperature, +6.7°F in minimum annual temperature, and +5.7 inches mean annual precipitation compared to the 1951-1980 means from PRISM data).

Climate data was downscaled to a 30-arcsec grid using a "delta" or "anomaly" method (Fowler et al., 2007) by Dominique Bachelet and Ken Ferschweiler at the Conservation Biology Institute (http://consbio.org/). The data covered the 2010 to 2099 time period.

2. MC2 calibration and simulations

The MC2 model was calibrated and run under the Hadley and RegCM3 climate scenarios for the coastal Washington region by David Conklin at Common Futures (see David Conklin's report to Washington Department of Natural Resources for full details). To calibrate MC2 for the study area, MC2 output for the historic period (1895-2009) was compared with other vegetation maps, one derived from Henderson et al. (2011) and two potential vegetation type maps from ILAP. The model was newly calibrated for this project to distinguish among distinct climatic/ecological zones (e.g., the Sitka spruce zone, western hemlock zone, and Pacific silver fir zone) using biogeography rules from Henderson et al. (2011) and auxiliary data layers for fog effect, topographic moisture, elevation, and wind specific to the Olympic ecoregion. Wildfire frequency was calibrated by comparing model output to historic fire records reported in Henderson et al. (1989). Since the auxiliary data layers and associated model coefficients from Henderson et al. (2011) were not available for the entire study area, MC2 simulations were restricted to the Olympic Peninsula (Olympic potential natural vegetation province sensu Henderson et al. 2011). MC2 simulated eight vegetation types for the historical period and an additional six types under future climate scenarios. One historical type and four future types were simulated on less than 1 percent of the landscape in most years, and these types were combined with vegetation types occurring under similar climatic conditions for purposes of linking MC2 with STMs.

3. Development of climate-smart state-and-transition models

We used a set of STMs that were developed in ILAP using the Vegetation Development Dynamics Tool framework, version 6.0.25, (ESSA Technologies Ltd. 2007). STMs were characterized by states, or unique combinations of vegetation cover and structure (Hemstrom et al. 2007). States were defined by overstory cover type and structural conditions. Cover types were defined by the dominant tree species in the upper-most canopy layer. Within cover types, structural classes were defined by combinations of tree diameter class (quadratic mean diameter of the largest 20% of the trees; 0 cm Diameter at Breast Height (DBH) = Grass/forb; <5 inches DBH = seedling/sapling; 5-10 inches DBH = pole; 10-15 inches DBH = small; 15-20 inches DBH = medium; 20-30 inches DBH = large; >30 inches DBH = giant), overstory canopy cover (<10% = grass/forb, 10-40% = low, 40-60% = medium, >60% = high), and canopy layering (single or multiple). A grass-forb state represented early-successional conditions before establishment of a significant tree canopy. Post-disturbance states in various tree diameter ranges were also included, representing conditions consisting of scattered live trees, standing snags, and down wood.

States were linked together by transitions, or drivers of change among states, representing vegetation growth and development, natural disturbances, and management. The vegetation growth and development transitions in seven of the nine models were largely determined using the Forest Vegetation Simulator (Crookston and Dixon 2005), but some were modified using expert opinion. Growth and development transitions in two of the models developed for the Oregon Coast Range (noted below) were derived using only expert opinion. Natural disturbance transitions included wildfire (of low, mixed and high severity), insect and disease outbreaks, and wind. Wildfire probabilities were derived from reported wildfire return intervals in Henderson et al. (1989). Low and high severity windstorm probabilities were derived from Harcombe (1986) and Henderson et al. (1989). Insect and disease outbreak probabilities were determined from expert opinion.

One STM was chosen to represent each of nine simulated MC2 vegetation types (Table 1), though MC2 vegetation types often encompassed more than one STM. It was determined there was no STM within the Washington Coast Range study region that could adequately represent two vegetation types simulated by MC2 to occur in the future under changing climate (temperate warm mixed forest and cool mixed forest). Both of the future types were "mixed" forests, meaning they had both conifer and hardwood components. Thus, we chose models developed in ILAP for the Oregon Coast Range that represented vegetation types dominated by conifers but with a significant hardwood component. For temperate warm mixed forest, we selected a model representing a type that is western hemlock-dominated but includes red alder-dominated states. For cool mixed forest, we chose a drier (temperate) type dominated by grand fir and Douglas-fir but also includes bigleaf maple-dominated states.

STMs developed in ILAP for the study area were independent, meaning that once a given area of land was classified into a certain potential vegetation type (PVT), represented by a single STM, it could not be reclassified into another PVT over time in the model simulations. Thus, while a given area could move among different states within an individual STM over time due to management, natural disturbances, and vegetation development, that area could not change PVTs. We altered the model structure, developing one large interconnected STM, and allowing shifts among PVTs with climate change and disturbance.

Table 1. Descriptions of vegetation types modeled by MC2 and state-and-transition models.

MC2 simulated vegetation type	State-and-transition model potential vegetation type	State-and-transition model description
Sitka spruce zone	Sitka spruce	This model applies to coastal forests of the Washington coast. Although dominant on the most coastal sites, Sitka spruce rarely dominates more inland stands; western hemlock generally dominates, with western redcedar, and Sitka spruce as sub- or co-dominants. Dense alder stands may occur in some locations after severe disturbance. Fire is extremely rare (the fire return interval is 588 years), but high and low severity wind disturbances have return intervals of 384 and 120 years, respectively. Hemlock looper outbreaks may also occur.
Western hemlock zone	Western hemlock - intermediate	This model represents stands composed of a mix of western hemlock and Douglas-fir. The fire return interval is 222 years. Wind disturbances occur, but only at low severity (low severity wind return interval is 120 years). Hemlock looper outbreaks may occur every 12-17 years and last from 1-5 years.
Temperate needleleaf forest	Douglas-fir/grand fir - dry	This model applies primarily to dry Douglas-fir and grand fir plant association groups. Fire is more common in this model than all others in coastal Washington, with a fire return interval of 200 years. Balsam wooly adelgid outbreaks may occur.
Pacific silver fir zone	Pacific silver fir - intermediate	This model represents mix stands of Pacific silver fir, Douglas-fir, western hemlock, and mountain hemlock at middle elevations. Growing seasons are short, dry, and cooler than in the western hemlock zone, and summer frosts are more common. Winter snow is common, and snow packs can be persistent. The fire return interval is longer than in western hemlock (625 years). Low severity wind and insect disturbances, including hemlock looper and balsam wooly adelgid, may occur.
Mountain hemlock zone	Mountain hemlock - wet	This model represents stands of mountain hemlock and lodgepole pine occurring at high elevations on the Olympic Peninsula. The fire return interval is very long (833 years).
Subalpine fir zone	Subalpine fir	This model represents stands of subalpine fir occurring at high elevation in the rain shadow in the northeast portion of the Olympic Peninsula. This model has a greater probability of wildfire than the other high elevation models in the region, with a fire return interval of 208 years. Insect disturbance by mountain pine beetle and balsam wooly adelgid may occur.

Subalpine parkland zone	Subalpine parkland	This model applies to the highest elevation areas in the Olympic Mountains and represents subalpine parklands, where trees are patchy or dispersed rather than contiguous. Subalpine fir is the dominant tree species in this habitat. The fire return interval is 385 years.
Cool mixed forest	Grand fir – dry (Oregon coast)	This model represents relatively dry forests with grand fir as a late seral species, but Douglas-fir is abundant in most locations. Bigleaf maple often occurs, especially following wildfire or timber harvest. Oregon white oak and Pacific madrone are common on some sites. The fire return interval is 200 years.
Temperate warm mixed forest	Western hemlock – wet (Oregon Coast)	This model applies to wet Douglas-fir and western hemlock forests with western redcedar as a component. Douglas-fir and red alder dominate early seral stands. Fire is not common (the fire return interval is 400 years). High and low severity wind disturbances have return intervals of 384 and 120 years, respectively. Hemlock looper outbreaks may occur.

Annual probabilities of vegetation shifts and wildfire were calculated from MC2 output and used to inform shifts in vegetation and wildfire frequency in our STM (Halofsky et al. 2013). The average probability of shifts for each selected MC2 vegetation type was calculated by dividing the area in which the vegetation type change occurred each year by the total area of the study region, yielding a proportion of the study area in which that occurred annually. We averaged the annual proportional change across the entire MC2 simulation period to develop probabilities for climate –induced vegetation shifts. Average probabilities for vegetation type changes were incorporated in the STM as transitions that lead from post-disturbance and early-successional states of a source PVT to the same (or functionally similar) structural state in a different PVT. Trend multipliers were also used to scale annual PVT shifts to the annual vegetation type shifts simulated by MC2 (Halofsky et al. 2013).

We assumed shifts in PVTs within the STM occurred only following a stand-replacing disturbance, when conditions are most conducive to plant establishment on a site. Thus, when an area of vegetation was simulated to be in a grass/forb or post-stand-replacing disturbance state in a given PVT, there was a certain probability of that area shifting to each of the other PVTs based on MC2 output (in some cases that probability would be zero, depending on the PVT to PVT shift). Whether a shift actually occurred depended on the “roll of the dice” in Monte Carlo simulations.

To modify fire probabilities in our STMs under changing climate, we used MC2 output for annual fraction of grid cells burned for each climate scenario in the study area. We compared annual fraction of grid cells burned in the future to the mean value for the MC2 simulated historical period (1895-2009) to scale future fire probability on an annual basis. See Halofsky et al. (2013) for further details on model linkage methods.

4. Development of future land management scenarios

In January 2013, we held a project kick-off meeting with all interested stakeholders, and worked with individuals from stakeholders interested in actively participating, including the Washington Department of Natural Resources (DNR), Olympic National Forest, and The Nature Conservancy, to determine what management scenarios to use for cSTM runs. Based on interactions with stakeholders, we ran the cSTMs under 1) a no management scenario that was characterized by no active land management; 2) a current management scenario that was characterized by current levels of land management, as determined by stakeholder input; and 3) a resilience scenario that was characterized management actions likely to increase ecosystem resilience to changing climate. For comparison, we also ran the cSTMs under the no management and current management scenarios without climate change effects.

Management transitions in the cSTMs included pre-commercial thinning, thinning from below, salvage harvest, and commercial harvest. Rates of these activities on different land ownerships and management units were determined by stakeholders.

5. Climate-smart state-and-transition model simulations

Running the cSTM simulations required characterizing the PVT (Table 1) and state for each 98-ft pixel in the study landscape. To characterize the PVT for each 98-ft (30-m) pixel and determine which STM to use for that pixel, we acquired PVT maps from ILAP (http://oregonstate.edu/inr/ilap). The PVT map represented a collection of plant association groups. The plant association group map was developed by Jan Henderson and downloaded ecoshare (http://ecoshare.info/). To determine the state for each pixel within a PVT, existing vegetation maps were downloaded from the Landscape Ecology, Modeling, Mapping and Analysis website (LEMMA, http://www.fsl.orst.edu/lemma). Existing forest vegetation maps were derived from imputations of the measured vegetation in inventory plots to 98-ft pixels using gradient nearest neighbor (Ohmann and Gregory, 2002). The method essentially assigns inventory plots and associated data to 98-ft pixels as a statistical function of LANDSAT-TM imagery and a variety of topographic, land ownership, and other data. Each existing vegetation pixel within a PVT was first assigned a cover type based on the importance value of the dominant tree species, a combination of both tree density and basal area. Importance values, like other cover and structure attributes, are data associated with the maps acquired from the LEMMA website. Then the pixel was assigned to a structural stage based on tree size, percent canopy cover, and number of canopy layers (categories described above). Total existing land area in each PVT-cover-structure combination was then computed to reflect current conditions, and we used that information as the initial conditions for cSTM runs. Although initial conditions are at the 98-ft pixel scale, the model output is at the strata scale, where a stratum is a combination of PVT, watershed, and ownership and land management unit.

We ran the cSTMs under two climate and three management scenarios (six simulations). Model simulations were run using the Path modeling platform, version 3.0.4 (Apex and ESSA 2011). We ran 30 Monte Carlo simulations for each climate-management scenario in the STM. All simulations were run for 90 years, the duration of the MC2 projections.

6. Refinement of vegetation-potential habitat relationships for Northern Spotted Owl

We refined vegetation-potential NSO habitat relationships to analyze effects of different climate and management scenarios on potential NSO habitat quality and quantity in the study region. NSO was included among the focal species evaluated for ILAP, and products from ILAP include binary lookup tables that define each state class as habitat or non-habitat for a given species based on published ecological knowledge and expert review (Morzillo et al. in press). Anita Morzilla (Oregon State University) refined the vegetation-potential habitat relationships for the Washington Coast Range to incorporate habitat quality (high-quality and low-quality habitat). These relationships were further refined with feedback from DNR experts.

The first step in development of the vegetation-potential habitat relationships was to rate each PVT for habitat quality (0 = not habitat, 1 = low quality habitat, or 2 = high quality habitat). Then, for the PVTs rated as low and high quality habitat, habitat ratings were assigned to each structural stage in the state-and-transition model (0 = not habitat, or 1 = habitat). Resulting high-quality and low-quality habitat attributes are shown in Table 2.

Table 2. High and low quality Northern Spotted Owl habitat attributes in the Washington coast range.

	Potential vegetation type	Quadratic mean diameter (inches)	Canopy cover (percent)	Number of canopy layers	Dominant cover type(s)
High quality habitat	Douglas-fir/grand fir - dry	>20	>60	>1	Douglas-fir/grand fir
	Sitka spruce	>20	>60	>1	Western hemlock mix
	Western hemlock - intermediate	>20	>60	>1	Douglas-fir/western hemlock
	Western hemlock - wet	>20	>60	>1	Douglas-fir
Low quality habitat	Grand fir - dry	>20	>60	>1	Douglas-fir/grand fir

7. Interpretation of results

STM simulation results were summarized for each of the six simulations (two climate scenarios * three management scenarios). Vegetation results were then linked to NSO habitat ratings to enable assessment of NSO habitat quantity and quality over time.

Results and Discussion

MC2 simulation results

MC2 simulation results suggest that, under both climate scenarios, climatically suitable habitat for alpine, subalpine parkland, mountain hemlock and subalpine fir will decline by the end of the century (Figure 2). Climatically-suitable habitat for Sitka spruce also declined under both scenarios, particularly under the RegCM3 scenario. Under the hot and dry Hadley scenario, there was expansion of climatically-suitable habitat for cool mixed forest along the coast, and dramatic expansion of temperate needleleaf forest across the Peninsula, with decline in area of climatically-suitable habitat for all other vegetation types that were dominant historically

(Figure 2). The cool mixed forest vegetation type is characterized by both evergreen and deciduous species, suggesting that the deciduous hardwood component in coastal forests may increase in the future. Hardwood species that may increase in abundance include red alder, bigleaf maple, and vine maple (Halofsky et al. 2011). Fire frequency increased under the Hadley scenario, with a fire return interval of 54 years (compared to 208 years for the historical period), which along with drier summer conditions, led to the expansion of the temperate needleleaf forest type. The range expansion of this vegetation type suggests that fire- and drought-tolerant species, such as Douglas-fir, lodgepole pine, and western white pine, will become more abundant (Halofsky et al. 2011).

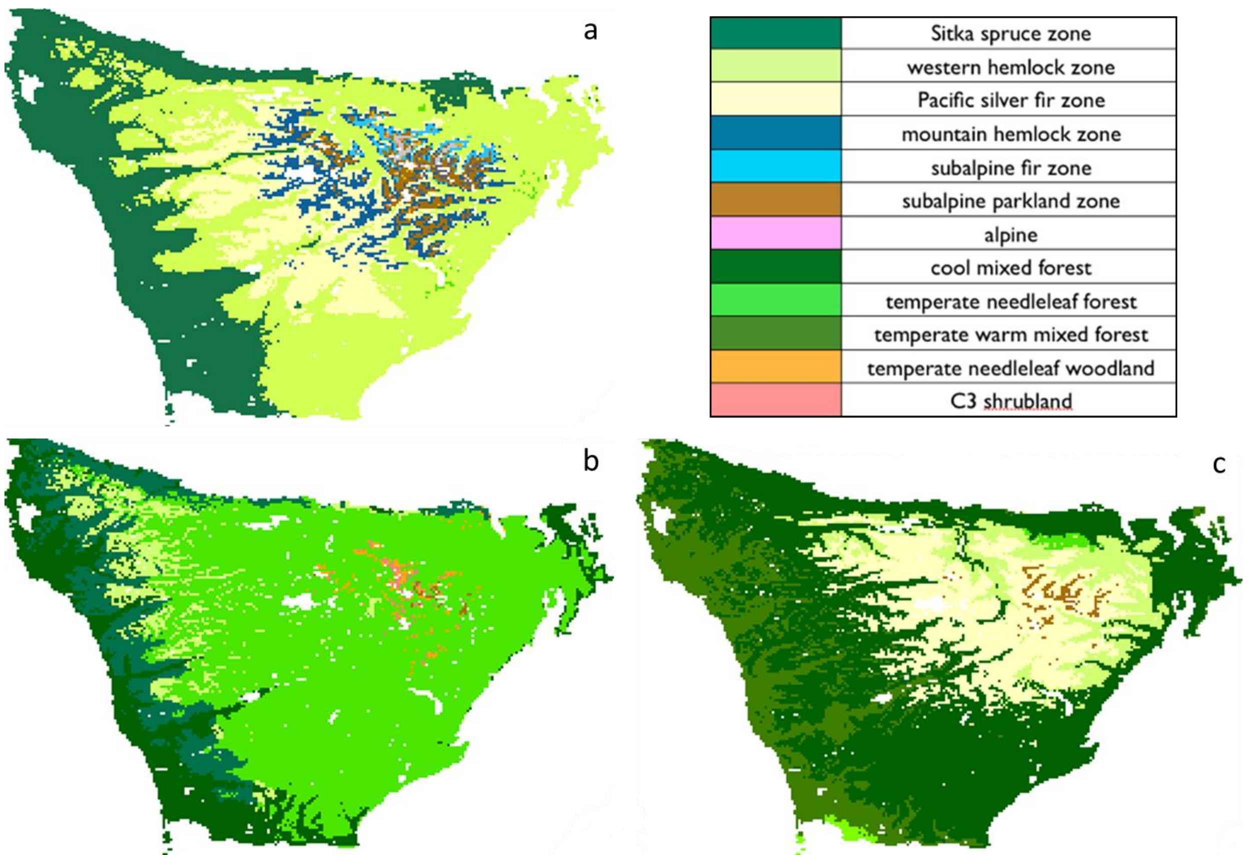

Figure 2. MC2 Dynamic Global Vegetation Model simulation output under a) historical conditions (1980-2009); b) the Hadley A2 global climate model scenario; and c) the RegCM3 A2 regional climate model scenario for the 2070-2099 period.

Under the hot and wet RegCM3 scenario, there was expansion of climatically-suitable habitat for temperate warm mixed forest along the coast, and expansion of climatically-suitable habitat for cool mixed forest inland (Figure 3). The mixed forest vegetation types are characterized by both evergreen and deciduous species, again suggesting that the deciduous hardwood component in forests of coastal Washington may increase in the future, particularly if precipitation increases, as it does under the RegCM3 scenario. Topographic patterns of vegetation were more distinct under the RegCM3 regional climate model simulations, with distinct Pacific silver fir and some western hemlock remaining in the future. The fire return interval under the RegCM3 model was 71 years, again suggesting increased fire frequency in the future.

State-and-transition model simulation results

The cSTM results suggest that, regardless of climate or management scenario in the Washington Coast Range, shifts in vegetation composition are likely (Figure 3). Specifically, a decline in the area of the western hemlock vegetation type is likely, with a more dramatic decline (approximately 50%) projected under the hot and dry Hadley scenario. The western hemlock vegetation type was replaced by Douglas-fir dominated vegetation types that are adapted to drier conditions, namely dry grand fir and dry Douglas-fir/grand fir types. Model results indicate western hemlock as a species will not likely disappear from the Washington Coast Range, but it will likely decrease in abundance and be replaced by more drought-tolerant conifer species.

Under both climate scenarios, vegetation shifts were slightly greater with management (Figure 3). This is likely because variable retention harvest and regeneration harvest on state and private industrial lands create the open, post-disturbance conditions that we modeled as being more susceptible to shifts in vegetation type under changing climate. Management also resulted in a decrease in the area of forest in larger size classes and an increase in the area in smaller size classes (e.g., Figure 4), since variable retention harvest and regeneration harvest remove large trees. Although thinning can facilitate development of late-successional forest habitat conditions by increasing species and structural diversity (Carey and Wilson 2001), this structural detail is not reflected in the cSTMs. For example, a multi-storied (>1 canopy layer), closed canopy condition (>60% canopy cover) within a given diameter range could represent a structurally diverse or homogenous condition. Thus, the resilience scenario, characterized by increased levels of thinning on National Forest lands, and current levels of management on DNR lands, did not mitigate impacts of climate change in the Washington Coast Range model simulations (results not shown). Rather, increased levels of current management on state lands resulted in increased vegetation change, rather than decreased vegetation change, under changing climate. Although not modeled, we believe planting could mitigate some of the change in vegetation we observed. Whether planting of currently climatically suitable species will result in the desired productivity of future forests is less certain.

The refined vegetation-NSO habitat relationships allowed us to determine the potential effects of climate change and management on potential NSO habitat (Figure 5). Without climate change or management, area of high-quality potential NSO habitat increased or remained approximately the same. However, under both climate change and management scenarios, area of high quality potential NSO habitat declined steadily through the century. These results suggest that climate change will result in vegetation shifts away from types that are typically associated with high-quality potential NSO habitat, and that current management will not mitigate those shifts, but rather expedite them. Results suggest that the probability of maintaining current levels of high-quality potential NSO habitat by 2100 are low (less than 20%) in many watersheds of the Washington Coast Range (Figure 6a). Reducing habitat goals to 75% of current levels increased the likelihood of maintaining this lower threshold into the future.

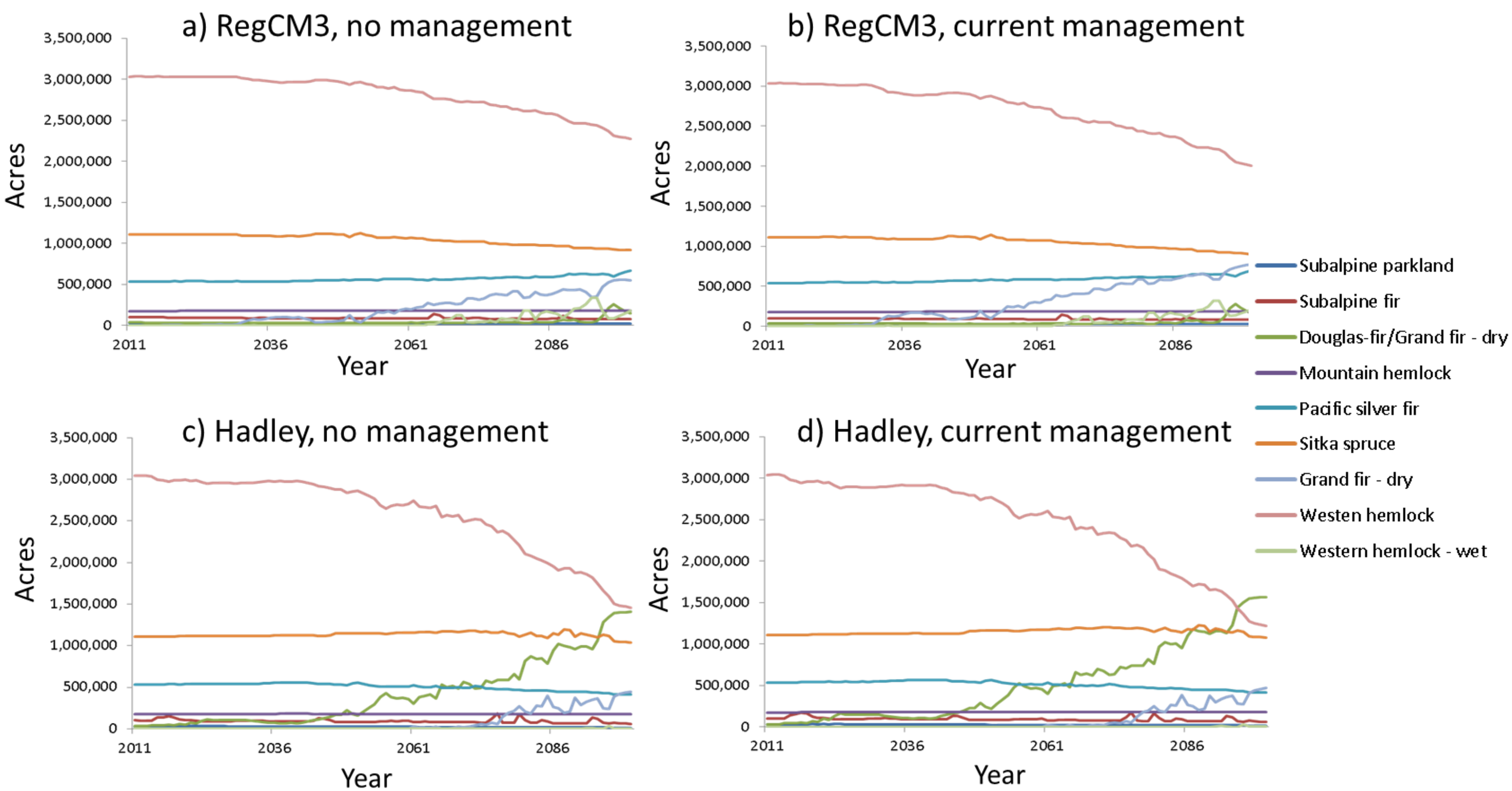

Figure 3. Future changes in area of potential vegetation types in the Washington coast range, as modeled by climate-informed state-and-transition models, under the a) RegCM3, no management; b) RegCM3, current management; c) Hadley, no management; and d) Hadley, current management scenarios.

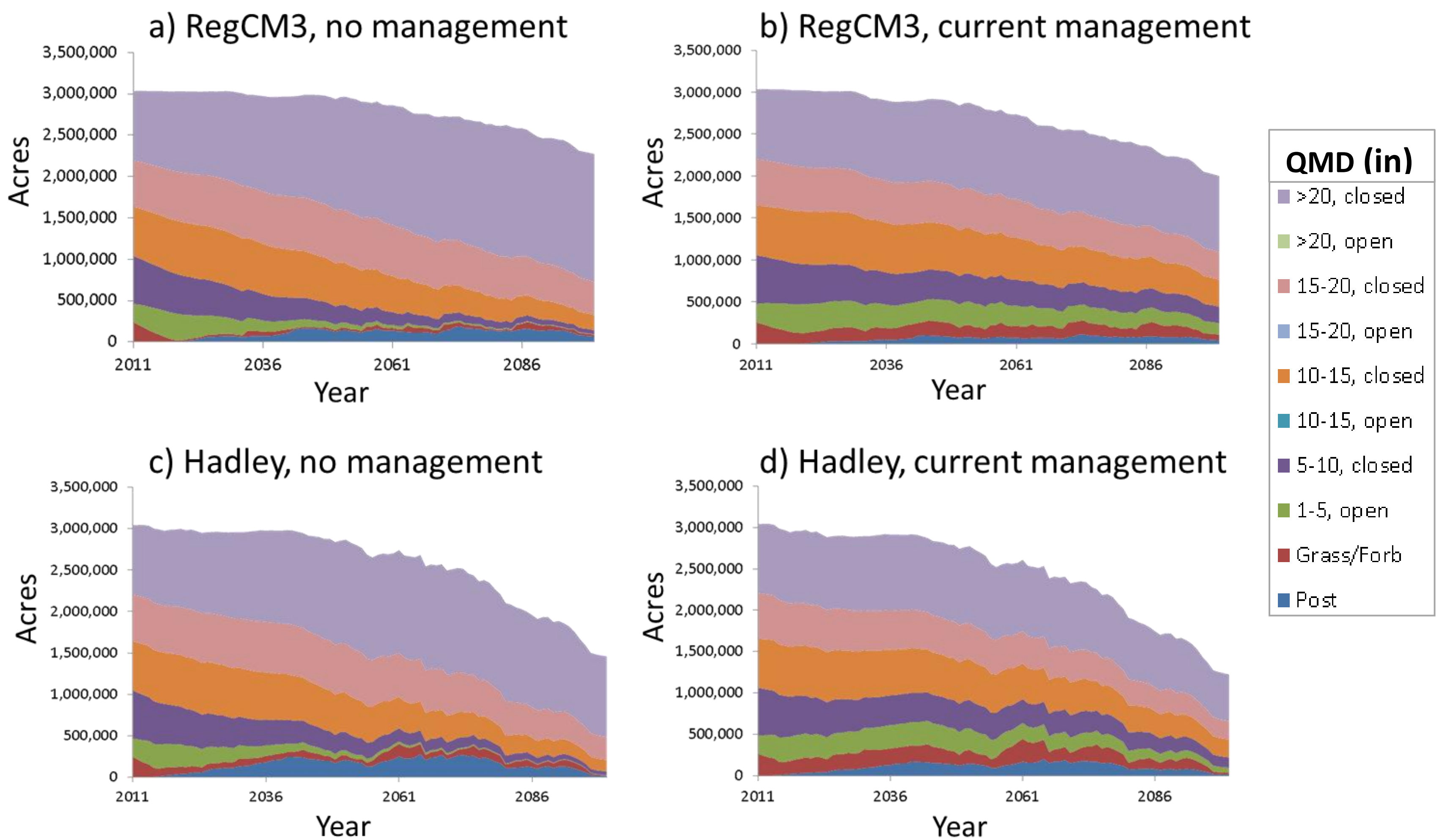

Figure 4. Future forest size class composition (classes determined by quadratic mean diameter (QMD) in inches) in the western hemlock vegetation type under the a) RegCM3, no management; b) RegCM3, current management; c) Hadley, no management; and d) Hadley, current management scenarios. Open and closed refer to forest canopy cover, where closed refers to canopy cover >40% and open refers to canopy cover <40%. The “Post” category represents areas that recently experienced stand-replacing disturbance.

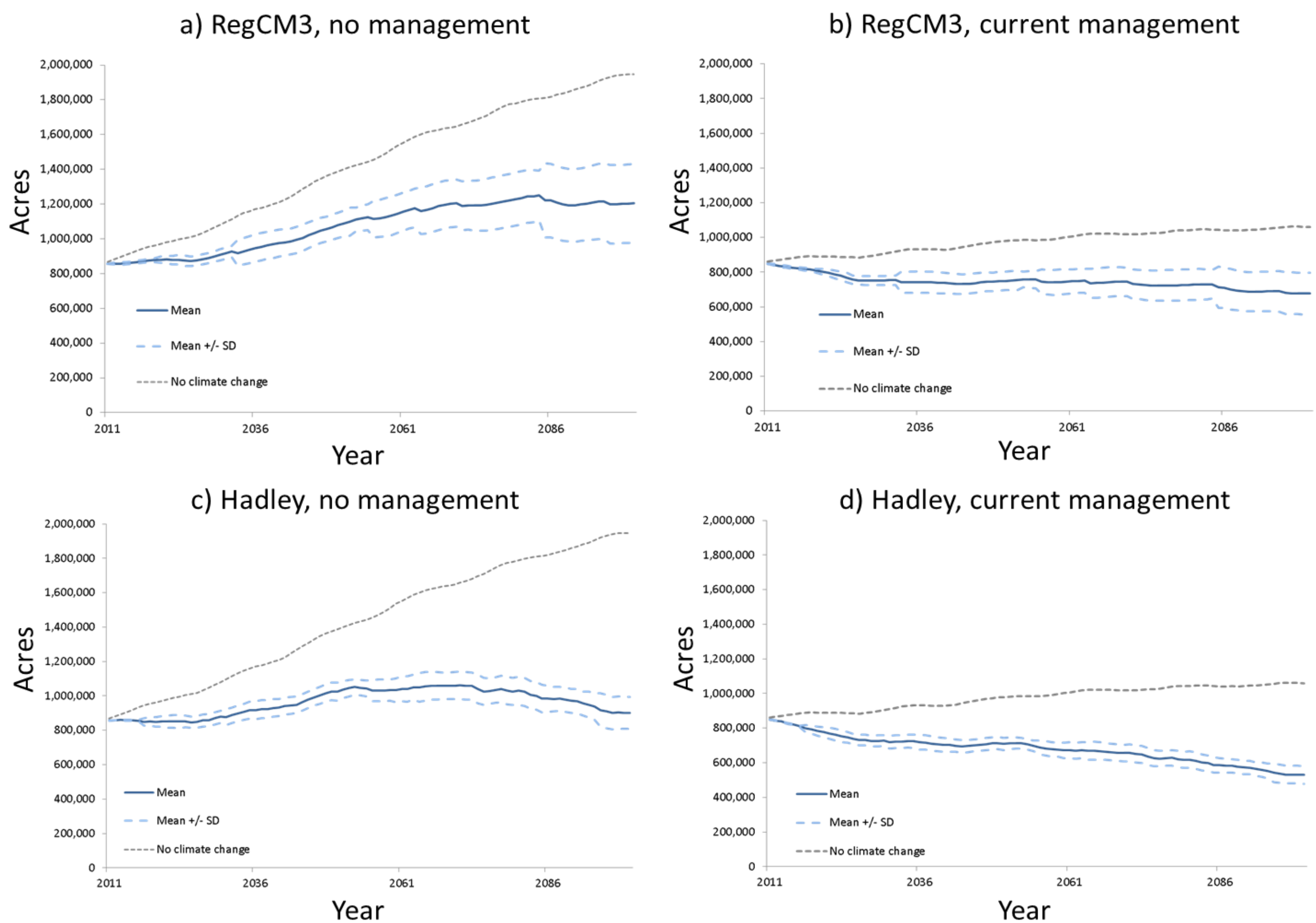

Figure 5. Area of high-quality potential Northern Spotted Owl habitat under the a) RegCM3, no management; b) RegCM3, current management; c) Hadley, no management; and d) Hadley, current management scenarios. Dark blue solid lines represent mean area of high-quality potential habitat across 60 Monte Carlo simulations, and light blue dotted lines represent the mean plus and minus one standard deviation. Gray dotted lines represent high-quality potential habitat trends when climate change is not considered in the model simulations.

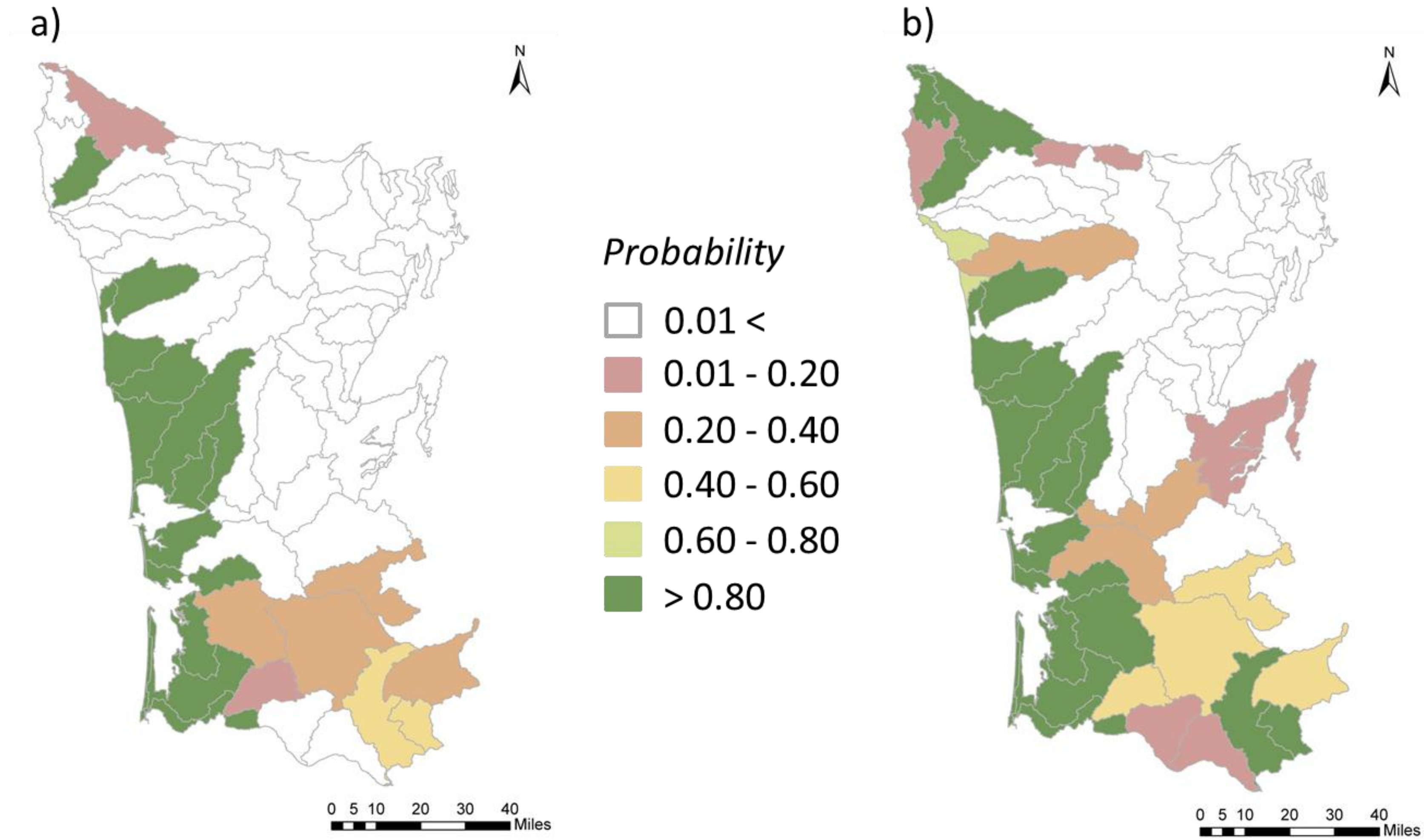

Figure 6. The probability of a watershed maintaining or exceeding current potential northern spotted owl habitat levels (a) and 75% of current habitat levels (b) in 2100. These probabilities were calculated using a metric called the Probability of Exceedance (Halofsky et al., in review) using all 60 total Monte Carlo simulations of the cSTMs combining output from both the RegCM3 and Hadley climate scenarios.

Model limitations

Our cSTM modeling approach has several limitations. As noted above, relatively minor variations in species composition and structure are not represented in the STMs; each state in the STMs encompasses a range of compositional and structural attributes. Thus, more nuanced effects of treatments, such as the effects of thinning on structural diversity, are not reflected in the models.

We did not incorporate planting after disturbance in the cSTMs. Planting typically occurs after stand-replacing disturbance, which is when climate-induced vegetation type changes can occur in the cSTMs. We were uncertain about what the effects of planting would be on rates of vegetation type shifts owing to climate change. For example, would planting of climate-adapted species prevent a vegetation type shift? Or would the type shift still occur owing to climatic changes that dictate which species inhabit a site? We plan to address these, and other planting issues, in future model development.

To link MC1 with our STMs, we in some cases represented several vegetation types with a single STM, thus resulting in loss of ecological detail. This loss of ecological detail may have resulted in us missing important vegetation type-specific responses to changes in climate and disturbance. We have also assumed that the known dynamics of plant communities and PVTs will be relevant in the future under different climatic conditions. However, vegetation growth rates, succession rates, and species interactions are likely to change in the future with climatic changes.

Climate scientists are still uncertain how wind patterns will change with climate. An increase or decrease in wind frequency and intensity would likely alter the rate of change in vegetation types with changing climate. Because future wind patterns are an area of uncertainty, we assumed future wind events would be similar to the past. Future model runs could double and halve wind to examine ranges in conditions under different wind scenarios.

Lastly, we assumed a 45-year harvest rotation on all private industrial lands, which does not likely represent the suite of management options applied on this land base. Furthermore, we were unable to ascertain management on tribal lands. We therefore assumed no management.

Conclusions

Despite the limitations to our approach, results from cSTMs can help to better understand the interacting effects of climate change and land management on future vegetation. For coastal Washington, cSTM results suggest that significant shifts in vegetation composition will likely occur with future climate change, and current management activities (without planting) will likely facilitate, rather than prevent, vegetation shifts. Both climate change and current land management activities may also contribute to a decline in high-quality potential NSO habitat in the future. These results can be used to develop adaptation options and guide future land management in coastal Washington.

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