

Species Status Assessment
Report Version 2.0
North Oregon Coast
Distinct Population Segment of the
Red Tree Vole (*Arborimus longicaudus*)



2023

U.S. Fish and Wildlife Service
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Pacific Region 1
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Acknowledgements

Cover page photo credits: Left - tree vole researcher and climber Eric Forsman in Oregon (Jim Swingle, USFS); Upper right - red tree vole (Northwest Ecosystem Survey Team); lower right - a red tree vole nest (Eric Forsman, USFS).

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Authors

This document was prepared by the U.S. Fish and Wildlife Service's (Service) red tree vole species status assessment team, Shauna Everett, Katherine Fitzgerald, and Gabrielle Robinson, with assistance from Zach Cravens and Gretchen Newberry.

Summary of Versions

Version 2.0

This report was prepared in 2022–2023 primarily by Shauna Everett and Katherine Fitzgerald of the Service's Oregon Fish and Wildlife Office, assisted by other office staff. It was updated to address new data and publications. Most notably, we revised our analytical units and framework to reflect new information.

Version 1.0

This report was prepared in 2019 by Sue Livingston of the Service's Oregon Fish and Wildlife Office and Rebecca Migala of the Service's Region 1 Regional Office, assisted by office staff, including the late Larry Reigel, to whom we dedicate this version. We appreciate the valuable assistance from Damon Lesmeister and Mark Linnell (USFS Pacific Northwest Research Station) in developing analytical units for our condition analysis. We appreciate valuable reviews by Mark Linnell, Jim Swingle, and Todd Wilson (USFS Pacific Northwest Research Station); Rob Huff (Bureau of Land Management, Oregon State Office); Lindsay Belonga (Confederated Tribes of Grand Ronde); Sarah Navarro, Nick Palazzotto, Jennifer Weikel, and Mike Wilson (Oregon Department of Forestry); Martin Nugent (Oregon Department of Fish and Wildlife); and Jake Verschuyt (National Council for Air and Stream Improvement).

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Executive Summary

This document presents the species status assessment (SSA) for the North Oregon Coast Distinct Population Segment (DPS) of red tree vole (*Arborimus longicaudus*), completed to assess the DPS' overall viability. The red tree vole is a conifer-obligate, arboreal rodent, found in western Oregon south to northwestern California (Figure ES-1). They are generally associated with old forests, either nesting within or in the vicinity of forests with sufficient structures to support nests. The SSA uses the conservation biology principles of resiliency, redundancy, and representation, collectively known as the “3Rs,” as a lens to evaluate the current and future condition of the species (USFWS 2016, p. 6). Resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions. Redundancy is the ability of a species to withstand catastrophes. Representation is the ability of a species to adapt to both near-term and long-term changes in its physical and biological environments.

Viability is the likelihood of the species to sustain populations in the wild within a biologically meaningful timeframe: in this case, the timeframe out to approximately 2080. We chose the 2080 future timeframe because we have data to reliably project the impact of future conservation and threats to the DPS, and its response, within the range of the red tree vole within this timeframe. Based on the red tree vole life history and habitat needs, we identified the potential stressors (negative influences), and the contributing sources of those stressors, that are likely to affect the species' current condition and viability. These stressors include habitat loss and modification through the effects of timber harvest, wildfire, large windstorms and other weather extremes, and tree disease; habitat fragmentation and population isolation; and predation. We evaluated how these stressors may be currently affecting the species and whether, and to what extent, they would affect the species in the future.

We used published habitat models completed for tree voles in our analysis area (the DPS) to derive population areas based on habitat patches large enough to accommodate approximately 100 or more individuals. We further grouped those 52 population areas into 17 geographic units which represent potential meta-populations. These population areas and geographic units represent tree vole assemblages that we evaluated for resiliency, redundancy, and representation (Figure ES-2).

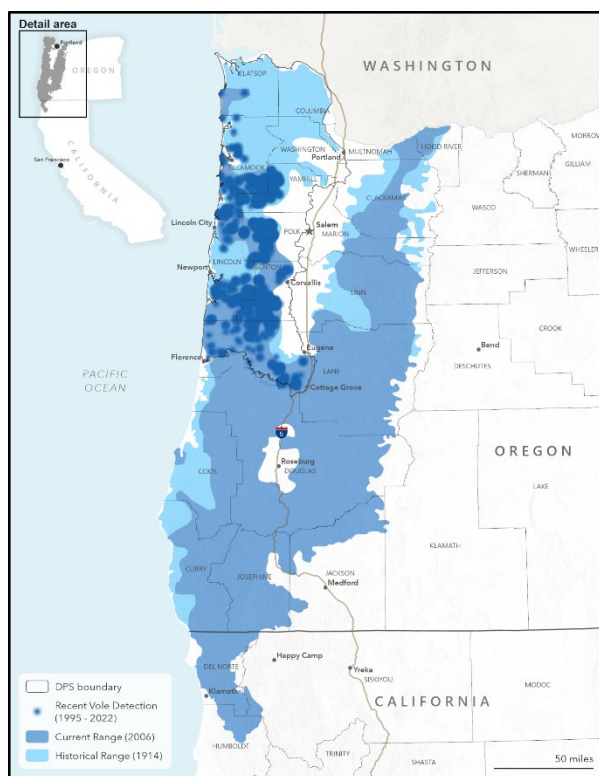


Figure ES–1. Historic and current red tree vole ranges.

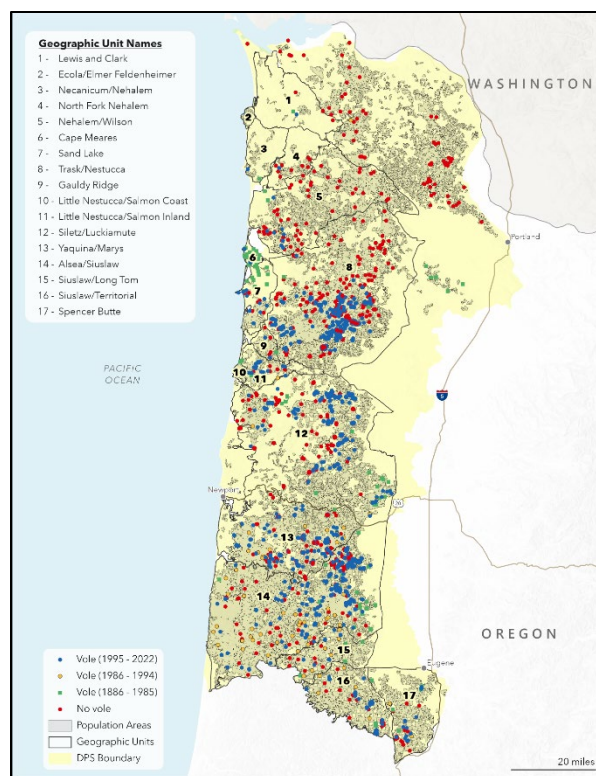


Figure ES–2. Red tree vole locations, population areas, and geographic units within the north Oregon coast DPS.

Modification of the area within the DPS through timber harvest over much of the 20th century, and habitat loss from episodic large wildfire events, played the greatest roles in removing habitat and contracting the range of the tree vole to its current size within the analysis area. Tree voles are restricted to existing habitat that mostly occurs on Federal and to a lesser extent State land. Tree voles are also found in young forests (< 80 years old) on private lands, particularly near old forests (> 80 years old) in public ownership. In the north coast subregion of the analysis area, tree voles are isolated in small patches, and most of the existing habitat is unoccupied. This fragmentation and isolation limit the resiliency of many of the vole population areas. Population isolation is further exacerbated by the limited home range size, natal dispersal, and low vagility of tree voles, as well as their low survival rates. Low numbers of tree voles moving very short distances significantly limit the capability of tree voles to expand across the landscape and connect with other population areas.

For current condition, an overall relative resiliency rating for each geographic unit was derived by combining population area resiliency ratings with measures of connectivity. We modeled resiliency of individual population areas based on the effective population size capacity. We developed a range of effective population size capacities based on an estimated habitat capacity and effective population size ratio of each population area. Connectivity had two components and considered distance to neighboring populations both within and between geographic units.

We categorized the overall resiliency condition for each unit as “high” and “moderate high” (generally secure), “moderate” and “moderate low “(marginally secure) or “low” (generally insecure). We based these categories primarily on our understanding of red tree vole habitat needs and the principles of conservation biology. We acknowledge that there is uncertainty associated with this model and some of the supporting data but consider the methodology as providing a reasonable and rational assessment of the status of the red tree vole across its range based on the best available information. Finally, we assessed representation and redundancy across the DPS. Of the six units currently rated in the high resiliency category, one is in the north coast subregion and the remaining five make up the southern half of the DPS (in the central coast subregion (Figure ES–3). The four largest of these, which occur in both subregions, also contain representation of both vegetation zones and therefore the behavioral capacity of tree voles to forage on different coniferous species (Figure ES–4).

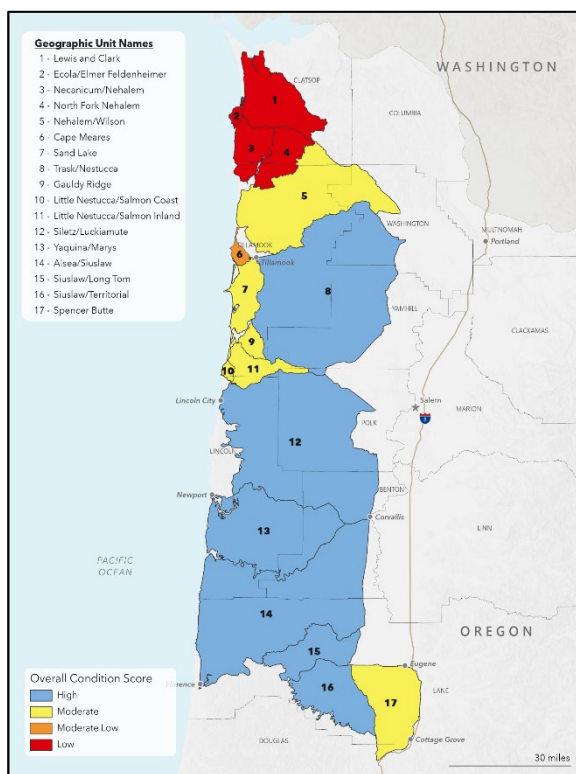


Figure ES–3. Current condition of red tree vole by their overall resiliency ratings

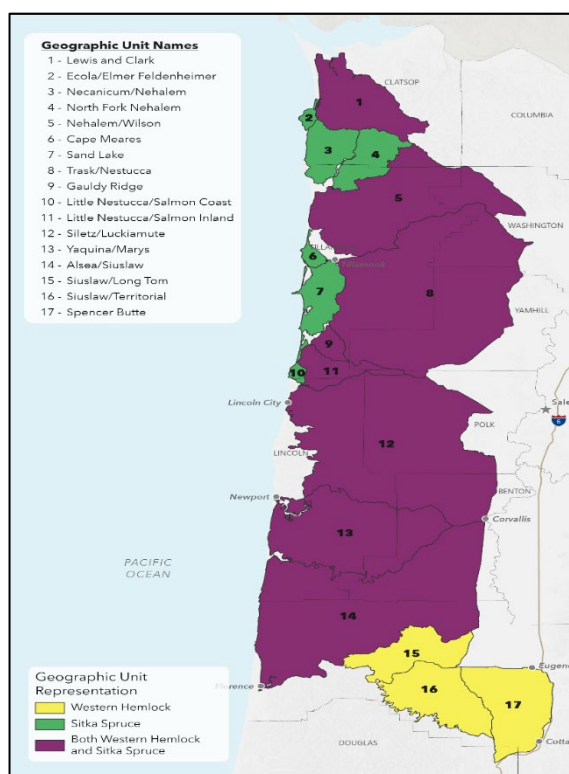


Figure ES–4. Current red tree vole representation across the DPS

In addition, these multiple units also provide for population redundancy, which also benefits from the large size of these units that makes them able to withstand most large-scale threats except perhaps for large catastrophic wildfires. The other units in the north subregion range in size from small to large and currently have either moderate or low resiliency.

We reassessed overall resiliency condition under two future scenarios, one representing a lower plausible future scenario and one representing an upper plausible future scenario of the status

quo plus habitat ingrowth. We added four future presumed occupied (due to future ingrowth) population areas to the analysis. In modeling future resiliency of individual units, we considered population area resiliency and connectivity (similar to the current condition), and also considered the effect of severity and scope of future Swiss needle cast disease and potential vegetation shifts, both influenced by climate change, to derive an overall future condition rating. We also assessed future representation and redundancy across the DPS.

Under the upper scenario, 10 units, representing most of the DPS, have high resiliency (Figure ES-5). Two units drop to low resiliency and the three northeastern-most units become extirpated. With high resiliency units occurring across both vegetation zones throughout the DPS, tree voles retain nearly their current levels of representation and redundancy.

Under a lower scenario, no units remain highly resilient, but six maintain moderate resiliency (Figure ES-6). Nine units, mostly small and in the north coast subregion, become extirpated. Both tree vole representation and redundancy decrease with the loss of extirpated units. However, the four largest units have moderate resiliency under the lower scenario due to their larger size, connectivity, and mix of vegetation zones. The four largest units also occur in both subregions, and contain both vegetation zones, providing representation across the DPS into the future even under this lower scenario. The six moderate resiliency units also provide for population redundancy, and the four largest would likely be able to withstand most large-scale threats except possibly for large catastrophic wildfires.

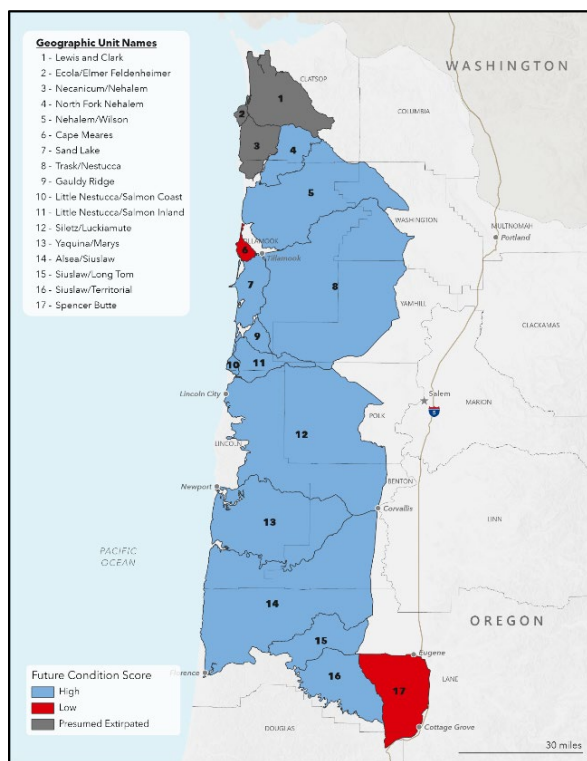


Figure ES-5. Future condition under a higher threats scenario

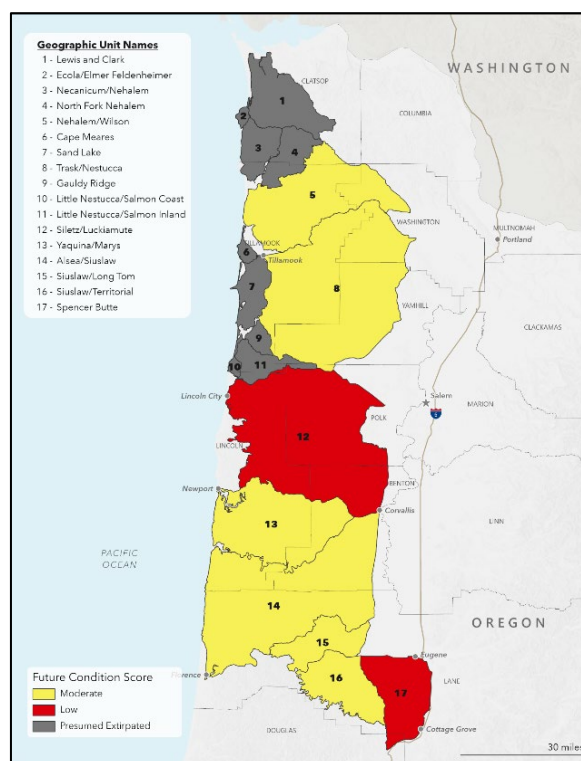


Figure ES-6. Future condition under a lower threats scenario

Land management has shaped the current distribution of tree vole populations in the analysis area. Tree voles are overwhelmingly restricted to State and Federal lands, where existing management plans and policy manage for tree voles or manage for habitat conditions suitable for the species. Federal land management practices of surveying and managing for tree voles, combined with large areas where programmed timber harvest does not occur, should allow for maintenance of tree vole populations into the future. Opportunities exist on State Forest land, especially in the northern portion of the DPS, to develop red tree vole habitat through their existing and future management plans and expand existing population areas on their ownership. Current management of private lands under the Oregon Forest Practices Act is expected to both provide habitat for, and contribute to habitat removal and isolation of, existing population areas of red tree voles.

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Acronyms

BLM	Bureau of Land Management
DPS	Distinct Population Segment
FPA	Forest Practices Act
GIS	Geographical Information Systems
HCP	Habitat Conservation Plan
LSR	Late-Successional Reserve
NCASI	National Council for Air and Stream Improvement
NGO	Non-Governmental Organization
NWFP	Northwest Forest Plan
OAR	Oregon Administrative Rules
ODF	Oregon Department of Forestry
ODFW	Oregon Department of Fish and Wildlife
OPRD	Oregon Parks and Recreation Department
ORS	Oregon Revised Statute
PA	Population Area
RCP	Representative Concentration Pathway
SNC	Swiss needle cast
SSA	Species Status Assessment
USDA	U.S. Department of Agriculture
USDI	U.S. Department of Interior
USFS	U.S. Forest Service (also, FS)
USFWS	U.S. Fish and Wildlife Service

Glossary

Analytical units - Geographic areas, also called geographic units, containing modeled blocks of habitat within which genetic and demographic connectivity is possible.

Connectivity - The ability of individuals from one local population to be able to access other local populations to help maintain genetic diversity and the ability to recolonize areas in the event of stochastic and catastrophic events. In this SSA, connectivity between and within

geographic units and/or the presence of impediments to such activity was assessed and was one of two factors, along with effective population size capacity, used to model current resiliency of individual population areas.

Connectivity factors - Used to rate the two types of connectivity in the current resiliency model - connectivity within and between geographic units. The factors have a two-category rating system (high, low) based on the presence and distance of nearby populations and forested land (connectivity within areas) and whether habitat blocks spanned the boundary of geographic units and both sides of the unit boundary were considered population areas (connectivity between areas).

Current condition analysis (model) - A systematic approach used to evaluate and describe the current condition of a species in terms of species' habitat and demographics, and the probable explanations for past and ongoing changes in abundance and distribution within the species' ecological settings.

Distinct Population Segment (DPS) - A listable entity under the Endangered Species Act that meets tests of discreteness and significance according to Service policy.

Effective population size - The size of an ideal population that would result in the same level of inbreeding or genetic drift as that of the population under study (Jamieson and Allendorf 2012, p. 578). It is usually substantially smaller than the actual number of individuals in the population, often 10 to 20 percent of the census population size (Frankham 1995, p. 100).

Effective population size capacity - The effective population size that could be supported by a given population area, based on estimates of the amount of habitat, population density (together, the habitat capacity), and effective population size ratio. Used to characterize the capability of the individual tree vole population areas to avoid inbreeding and to maintain evolutionary potential. In this SSA, this estimate provides the population component of the overall resiliency condition category for the unit.

Effective population size ratio – The ratio between the effective population size and the number of individuals in a population. The ratios used in this SSA range from 10 to 20 percent, which is an average range of ratios based on meta-analyses of different animal and plant populations (Frankham 1995; Frankham et al. 2014a, p. 56).

Extirpation - The elimination of a species from a particular local area.

Future Condition Analysis (Model) - A systematic approach used to evaluate and describe the species' response to probable future scenarios of environmental conditions and conservation efforts.

Geographic units - Geographic areas containing potential population areas derived by dividing the Distinct Population Segment of the red tree vole by features which are likely strong filters or obstacles to red tree vole movement (rivers and highways).

Habitat blocks - The building blocks of analytical units used in the current analysis consisting of patches of modeled habitat within close enough proximity that we expect red tree voles would be functionally connected. Habitat blocks are comprised of at least 52.5 ha of core habitat according to the most recent habitat model, at least 52.5 ha in old forest patches as identified in a 2017 habitat model updated in 2019, or a recent (since 1995) positive vole detection in or near the block.

Habitat capacity - The potential species carrying capacity based on the modeled suitability of vegetation cover. In this SSA, a range of estimates of habitat capacity was developed based on two different population density estimates, including a low-density and a high-density estimate, and two different habitat models. Habitat capacity estimates were used to generate a range of effective population size capacity estimates.

Habitat clusters - The building blocks of analytical units used in the 2019 SSA that were based on old forest patches of sufficient size and distance to potentially support a viable tree vole population.

2017 Habitat model - A model of predicted habitat (Linnell et al. 2017a, entire; Lesmeister and Linnell 2019, entire) used for the habitat cluster analysis in the 2019 SSA.

2023 Habitat model - A new habitat model (Linnell et al. 2023, entire) that includes information from recent vole nest surveys used for the current SSA.

Lower scenario - The lower plausible future condition scenario that incorporates lower values of the demographic features (habitat capacity, population density, and effective population size ratio), assumptions of less connectivity, and assumptions of higher potential impacts from Swiss needle cast and vegetation shifts.

Occupancy status - The three categories of occupancy: known occupied, presumed occupied, or presumed unoccupied. Known occupied population areas are those with the most recent detections, defined as positive survey results during or after the year 2010. Presumed occupied population areas have a positive survey detection from 1995 through 2009 or may be unsurveyed but are <2 km from a neighboring population area in the same unit with positive survey results during or after 1995. Presumed unoccupied population areas are those which have only negative detection surveys during or after 1995 or are unsurveyed and the nearest positive survey is in a population area >2 km distance away.

Old forest - forest or stand age class that is older than young forest and includes both mature forest (80 to 200 years) and old-growth (> 200 years) age classes. A wide variety of terms have been used to describe the older forest stands that tree voles tend to select (e.g., late-successional, old-growth, large conifer, mature, or structurally complex). In this SSA, we use these terms or specific stand ages when they appear in the cited literature. Otherwise, we use the term, “old forest,” when collectively referring to these stand conditions; based on recent habitat modeling, this generally means forest stands >80 years old (Linnell et al. 2017a, pp. 4–5).

Overall current resiliency condition - Evaluated for each geographic unit based on population area resiliency and connectivity (two types). The condition is assessed using five categories – high, moderate high, moderate, moderate low, or low.

Overall future resiliency condition - Evaluated for each geographic unit based on population area resiliency, connectivity (two types), vegetation shift and Swiss needle cast.

Population areas - Tree vole assemblages that were delineated by overlaying habitat blocks with geographic units. When a habitat block was contained within a single geographic area, that habitat block was carried forward as a population area. Habitat blocks crossing the boundaries of one or more geographic areas were divided into multiple population areas along those boundaries.

Population density estimates - The estimate of the number of individuals of a given species that occurs within a given area (i.e., amount) of habitat. In this SSA, two different population density estimates, a low-density and a high-density estimate, were used along with two different habitat models, to develop estimates of habitat capacity.

Relative suitability (ratings) - Ratings for the suitability for large fires assessed for each geographic unit. The ratings are low, moderate, or high suitability as follows: a high rating (HI) was given for geographic units with low average suitability where large wildfires are projected to occur less often than expected if wildfires were randomly distributed; a moderate rating (MOD) for geographic units with moderate average suitability (between 0.37 and 0.65) where large wildfires are projected to occur slightly more often than expected; and a low rating (LO) for geographic units with high average suitability (greater than 0.65), where large wildfires are projected to occur much more often than expected.

Resiliency ratings - A rating system used to assess both the current and future conditions. See definitions for overall current resiliency condition and overall future resiliency condition.

Swiss needle cast - Swiss needle cast is a foliage disease caused by the fungus *Phaeocryptopus gaeumannii*. The disease is specific to Douglas-fir, affecting no other tree species.

Upper scenario - The upper plausible future condition scenario that incorporates the higher values of the demographic features, a higher connectivity assumption, and lower potential impacts from Swiss needle cast and vegetation shifts.

Vegetation shifts - A change in the distribution and range of plant species or vegetation communities in response to changing temperatures and precipitation and increased growing season duration.

Vegetation zones - The two different zones in the analysis area consisting primarily of either Sitka spruce (*Picea sitchensis*) and western hemlock (*Tsuga heterophylla*) (the Sitka spruce zone) or western hemlock and Douglas-fir (the western hemlock zone). The Sitka spruce zone occurs in a narrow band along the coast, sometimes only a few kilometers in width, with

extensions up some river valleys, particularly in the northern portion of the analysis area. The western hemlock zone occurs in the Oregon Coast Range east of the Sitka spruce zone.

Wildfire synthesis ratings - A rating used in the future condition assessment that incorporates ratings for resiliency, size, suitability and severity of wildfires for each geographic unit.

Young forest - A forest or stand age class that is older than early seral and younger than mature or old-growth, typically described as > 15 and < 80 years old. In this SSA, we define young forest or young stand as < 80 years old but include other age ranges as reported in the literature.

1. INTRODUCTION

On June 18, 2007, the U.S. Fish and Wildlife Service (USFWS or Service) received a petition to list the dusky tree vole (*Arborimus longicaudus silvicola*) in all its range as threatened or endangered under the Endangered Species Act of 1973, as amended (Act). The petitioners also gave the Service two other listing options to consider if we determined that the subspecies was not a valid listable entity: 1) the north Oregon coast population of the red tree vole (*A. longicaudus*) as a Distinct Population Segment (DPS); or 2) the red tree vole throughout all its range because it is threatened or endangered in a significant portion of its range. On October 28, 2008, we published a 90-day finding that determined the petition presented substantial information and we initiated a status review. During that review, the best available scientific and commercial data led us to conclude that the dusky tree vole is not a valid subspecies for the purpose of our analysis. We therefore focused our analysis on the northern Oregon Coast Range population of the red tree vole. We determined the DPS be a listable entity primarily because of genetic differences. On October 13, 2011, we published a 12-month finding determining that listing the north Oregon coast population of the red tree vole as a DPS was warranted but precluded by higher priority actions to amend the Lists of Endangered and Threatened Wildlife and Plants. We added this DPS of the red tree vole to our candidate species list.

On December 19, 2019, after completing a species status assessment (SSA), we published a 12-month finding determining that the north Oregon coast DPS of the red tree vole was not warranted for listing as endangered or threatened under the Act. In March 2021, petitioners filed a complaint challenging our not-warranted finding. We reached a settlement agreement with the petitioners, which was approved by the court on May 23, 2022, to reconsider our not-warranted finding and to develop a new 12-month finding as to whether the north Oregon coast DPS of the red tree vole warrants listing as an endangered or threatened species. In accordance with the settlement agreement, we withdrew our 2019 finding determining that the north Oregon coast DPS of the red tree vole is not warranted for listing as endangered or threatened under the Act. The withdrawal returned the DPS to our candidate list. We are initiating a new status review to determine whether or not this DPS meets the definition of an endangered or threatened species under the Act. Under the settlement agreement, we will submit to the Federal Register a new 12-month finding on the status of the DPS by January 31, 2024.

2. ANALYTIC FRAMEWORK

Within the SSA we consider what a species needs to maintain viability. Using the SSA framework (Figure 1), we consider what a species needs to maintain viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (U.S. Fish and Wildlife Service 2016, entire; Smith et al. 2018, entire).

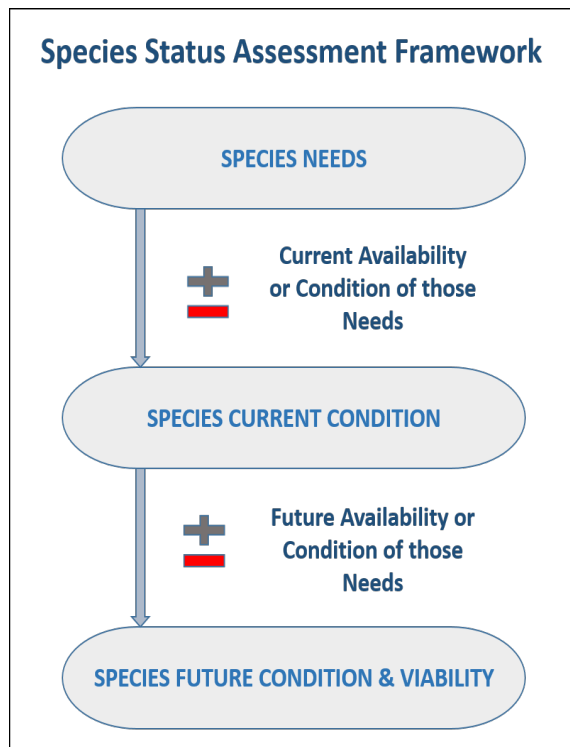


Figure 1: SSA Framework

Viability is the ability of a species to maintain populations in the wild over time. To assess viability, we use the conservation biology principles of resiliency, redundancy, and representation (Shaffer and Stein 2000, pp. 308–311). To sustain populations over time, a species must have the capacity to withstand the following circumstances:

- (1) environmental and demographic stochasticity and disturbances (Resiliency),
- (2) catastrophes (Redundancy), and
- (3) novel changes in its biological and physical environment (Representation).

A species with a high degree of resiliency, representation, and redundancy (the 3Rs) is better able to adapt to novel changes and to tolerate environmental stochasticity and catastrophes. In general, species viability will increase with increases in resiliency, redundancy, and representation (Smith et al. 2018, p. 306).

Resiliency is the ability of a species to withstand environmental stochasticity (normal, year-to-year variations in environmental conditions such as temperature, rainfall), periodic disturbances within the normal range of variation (fire, floods, storms), and demographic stochasticity (normal variation in demographic rates such as mortality and fecundity) (Redford et al. 2011, p. 40). Simply stated, resiliency is the ability to sustain populations through the natural range of favorable and unfavorable conditions.

We can best gauge resiliency by evaluating population level characteristics such as: demography (abundance and the components of population growth rate—survival, reproduction, and migration), genetic health (effective population size and heterozygosity), connectivity (gene flow and population rescue), and habitat quantity, quality, configuration, and heterogeneity. Also, for species prone to spatial synchrony (regionally correlated fluctuations among populations), distance between populations and degree of spatial heterogeneity (diversity of habitat types or microclimates) are also important considerations.

Redundancy is the ability of a species to withstand catastrophes. Catastrophes are stochastic events that are expected to lead to population collapse regardless of population health and for which adaptation is unlikely (Mangel and Tier 1993, p. 1083).

We can best gauge redundancy by analyzing the number and distribution of populations relative to the scale of anticipated species-relevant catastrophic events. The analysis entails assessing the cumulative risk of catastrophes occurring over time. Redundancy can be analyzed at a population or regional scale, or for narrow-ranged species, at the species level.

Representation is the ability of a species to adapt to both near-term and long-term changes in its physical (climate conditions, habitat conditions, habitat structure, etc.) and biological (pathogens, competitors, predators, etc.) environments. This ability to adapt to new environments—referred to as adaptive capacity—is essential for viability, as species need to continually adapt to their continuously changing environments (Nicotra et al. 2015, p. 1269). Species adapt to novel changes in their environment by either (1) moving to new, suitable environments or (2) by altering their physical or behavioral traits (phenotypes) to match the new environmental conditions through either plasticity or genetic change (Nicotra et al. 2015, p. 1270; Beever et al. 2016, p. 132). The latter (evolution) occurs via the evolutionary processes of natural selection, gene flow, mutations, and genetic drift (Crandall et al. 2000, pp. 290–291; Sgrò et al. 2011, p. 327).

We can best gauge representation by examining the breadth of genetic, phenotypic, and ecological diversity found within a species and its ability to disperse and colonize new areas. In assessing the breadth of variation, it is important to consider both larger-scale variation (such as morphological, behavioral, or life history differences which might exist across the range and environmental or ecological variation across the range), and smaller-scale variation (which might include measures of interpopulation genetic diversity). In assessing the dispersal ability, it is important to evaluate the ability and likelihood of the species to track suitable habitat and climate over time. Lastly, to evaluate the evolutionary processes that contribute to and maintain adaptive capacity, it is important to assess (1) natural levels and patterns of gene flow, (2) degree of ecological diversity occupied, and (3) effective population size. In our SSAs, we assess all three facets to the best of our ability based on available data.

The decision whether to list, down-list, or delist a species is based not on a prediction of the most likely future for the species, but rather on an assessment of the species' risk of extinction. Therefore, to inform this assessment of extinction risk, we describe the species' current biological status and assess how this status may change in the future to account for the uncertainty of the species' future. We evaluate the future biological status of the species by describing future scenarios representing the plausible conditions for the primary factors affecting the species and forecasting the projected future condition for the species in those scenarios, in terms of the 3Rs. As a matter of practicality, the full range of potential future scenarios and the potential future condition for each scenario is too large to individually describe and analyze, therefore our analysis does not include all possible futures, but those that we consider most reasonably plausible.

For the purpose of this assessment, we generally define viability as the ability of the species to sustain populations in the wild over the course of a biologically meaningful timeframe, in this

case, out to approximately 2080. We chose 2080 as the extent of our future analysis because it is the time at which most of the area that is in reserved land use allocations under Federal management would reach 80 years old, barring intervening disturbances. Reserved land use allocations are those Federal lands not managed for regulated timber harvest (USDA FS and USDI BLM 1994a, pp. A4–A5; 55–59) (see section 3.7 Ownership Patterns and Associated Regulatory Mechanisms). Habitat models indicate a strong association between red tree voles and forests where structural features associated with old-growth forest, such as complex branch and bole structures, generally begin to develop (Dunk and Hawley 2009, pp. 632–633; Forsman et al. 2016a, p. 74; Linnell et al. 2017a, pp. 2, 4). The threshold of 80 years has been used as both a management and ecological threshold to identify old forests, which includes late-successional (80-200 years old) and old-growth (>200 years old) forests (Spies and Franklin 1991, p. 92; USDA FS and USDI BLM 1994b, p. B-2; Molina et al. 2006, p. 308). Northwest Forest Plan land use allocations are already 80 years old or older, and by 2080, even those areas that were harvested immediately prior to the implementation of the Plan in 1994, and planted or naturally regenerated shortly afterwards, would reach 80 years old. By 2080 we would expect these areas to start to develop old-growth forest characteristics for red tree voles in terms of available habitat under the current forest management. However, habitat characteristics may not consistently occur in 80-year-old stands as much older forests provide the most stable habitat where tree voles are able to reach maximum capacity. Tree voles are regularly found in young forests (>15-20 to 80 years old), but population parameters in managed and young forests are not as well understood (Forsman et al. 2016a, pp. 19, 44–45; Piasecki et al. 2022, p. 5; NCASI 2022b, p. 4). The available data does not allow us to project with reasonable certainty the severity of threats and their impact to the tree vole within the range of the DPS beyond the timeframe of approximately 2080. Many of our threats are climate change based, and most analyses of climate change-related influence factors extend only through the end of the 21st century. Additionally, projections of some aspects of threats (wildfire, vegetation change, and Swiss needle cast) are available for the 2080 timeframe. In some cases, projections are also available for intermediate timeframes (see Appendix B); we discuss this information where it is available and provide qualitative evaluation of potential changes in threats and conservation benefits during the timeframe between now and 2080.

3. SPECIES INFORMATION

Published literature on the red tree vole also includes work conducted on the closely related Sonoma tree vole (*A. pomo*). Prior to 1991, both of these taxa were considered one (the red tree vole) (Johnson and George 1991, entire). Where pertinent information is lacking or limited for the red tree vole, we present information on the Sonoma tree vole because there have been no ecological or life-history differences noted for the two species (Smith et al. 2003, p. 187).

3.1 Taxonomy and Description

This section summarizes more thorough accounts of red tree vole taxonomy, including the putative dusky tree vole subspecies (Miller et al. 2006, pp. 64–65; U.S. Fish and Wildlife Service 2011, pp. 63720–63721). The red tree vole was first described from a specimen collected in Coos County, Oregon (True 1890, pp. 303–304). It was originally placed in the genus *Phenacomys* then the genus was proposed to be reclassified to *Arborimus* (Johnson 1973, p. 243). There is no universal arbiter of mammalian taxonomy, but the majority of the scientific publications over the past two decades have adopted *Arborimus* for the generic name, and we have as well.

NOTES ON TWO SPECIES OF PHENACOMYS IN OREGON

BY STANLEY G. JEWETT

In the dense forests of the Pacific Northwest, where the sun seldom penetrates the heavy growth of firs and spruces to mother earth, live two species of the most interesting of our small mammals, *Phenacomys longicaudus* in the tree tops, and *Phenacomys albipes* on the moss-covered floor of the forest.

Excerpt from a 1920 article in the Journal of Mammalogy.

The dusky tree vole was originally classified as a distinct species, *P. silvicolus* (Howell 1921 entire), later renamed *P. silvicola* (Miller 1923, p. 400), then changed to a subspecies (*A. l. silvicola*) Hall 1981, p. 788). Subsequent research put doubt on whether distinctions between the dusky and red tree vole warranted any separate taxonomic designation.

Neither discernable differences in morphological characteristics (Johnson and George 1991, p. 5) nor measurable genetic differences (Bellinger et al. 2005, p. 201) were detected among dusky and red tree voles found in Oregon. Genetic differences were found that clustered among three geographic regions in Oregon, one of which includes the northern Oregon Coast Range and approximates one of the range descriptions described for the dusky tree vole (Miller et al. 2006, p. 145). Genetic differences among these groups were sufficient to support subspecies recognition if there were congruent differentiations in other characteristics (Miller et al. 2009, in litt.). While statistical differences in some morphological features were measured in red tree voles and putative dusky tree voles, these features were considered to be of little diagnostic utility in classifying tree voles because the differences were subtle and exhibited a clinal pattern that correlated with latitude. Consequently, based on the best available scientific and commercial data, the Service concluded that the dusky tree vole was not a valid subspecies and analysis has been focused instead on the northern Oregon Coast Range population of the red tree vole. Genetic structure among the tree voles in the North Oregon Coast population is unknown. Voles in this area are genetically different from voles to the south or in the Cascade Range (Miller et al. 2006, entire), but there has not been any work on genetic structure within the DPS.

Tree voles are small, mouse-sized rodents that live in coniferous forests. Tree voles are less than 20.9 centimeters (cm) (8.2 inches (in)) long and weigh up to 49 grams (g) (1.7 ounces (oz)), averaging 24.7 g (0.87 oz) and 29.9 g (1.01 oz) for males and females, respectively ((Hayes

1996, p. 1; Verts and Carraway 1998, p. 301; Forsman 2010, in litt.). Pelage (fur) color ranges from brownish red to bright brownish-red or orange-red (Maser et al. 1981, p. 201). Though rare, cream-colored and melanistic (all black) forms of the red tree vole have been found (Swingle 2005, pp. 46, 82). Tree voles are arboreal, meaning they spend almost all of their time in the tree canopy; if they do come to the ground it is typically only to move quickly between trees. Though very rare, nests have been found on the ground, often occupied by males (Howell 1926a, pp. 55–56; Thompson and Diller 2002, p. 98). Their principal food is conifer needles, predominantly Douglas-fir (*Pseudotsuga menziesii*), and they are one of the few mammals to persist on this diet. They also feed on tender twig bark, the underlying cambium, or both (Maser 1966, pp. 143–145; 149–150; Forsman et al. 2009a, p. 264).

Red tree voles are solitary with a single adult with young occupying a nest. Nests are constructed of discarded resin ducts, conifer cuttings, vole fecal pellets, and sticks (Figure 2). Nest sizes range from small ephemeral structures about the size of a grapefruit, to nearly the size of a bushel basket that may completely encircle the trunk of the tree (Taylor 1915, p. 146; Howell 1926a, pp. 43–47; Verts and Carraway 1998, p. 310; Swingle 2005, p. 2). Nests of females tend to be larger than those of males (Swingle 2005, p. 41). Males and females live separate lives once leaving the nest, only coming together to breed. Further details of the life-history characteristics of tree voles are presented below (Section 3.4 Species Life History and Habitat).

3.2 Historical Range

Tree voles are endemic to the humid, coniferous forests of western Oregon and northwestern California (Maser 1966, p. 7). The historical range of the red tree vole encompasses western Oregon and extreme northwestern California, generally from the west slopes of the Cascade Range to the Pacific coast (Hayes 1996, p. 2; Verts and Carraway 1998, pp. 309–310; Forsman et al. 2016a, pp. 80–83), covering approximately 66,000 square kilometers (km²) (25,500 square miles (mi²)) across multiple ownerships (USDA and USDI 2007, pp. 287, 294–296) (Figure 3).

The species has not been found north of the Columbia River (Verts and Carraway 1998, p. 309). Originally, the red tree vole range was considered to extend as far south as Sonoma County, California (Benson and Borell 1931, p. 227), but tree voles in the southern portion of their range were later classified as a separate species, the Sonoma tree vole (Johnson and George 1991, p. 12). The Klamath River in northwestern California is considered the approximate boundary between the red tree vole and Sonoma tree vole (Murray 1995, p. 26) based on mitochondrial DNA analyses (Blois and Arbogast 2006, pp. 956, 958).

Within the Oregon Coast Range, the northern limit of the red tree vole's historical distribution was likely the Columbia River. The northernmost tree vole collection site is in the vicinity of Saddle Mountain in central Clatsop County (Verts and Carraway 1998, pp. 310, 546; Forsman et al. 2016a, pp. 28, 30, 32, 37). No tree voles have been detected during surveys in Clatsop and Columbia Counties (Forsman et al. 2016a, pp. 28, 30, 32, 37), although individual sites may be overlooked if voles are sparsely distributed or few in number (Price et al. 2015, p. 45).

Historically, the northern Oregon Coast Range had highly variable age distribution of forests, but close to half were likely in old growth at any given time (Teensma et al. 1991, entire; Wimberly et al. 2000, p. 176), and tree vole habitat modeling indicates as much as 60 percent of the forested area was tree vole habitat in 1914 (Forsman et al. 2016a, pp. 80–82). The forests along the Columbia River were considered Oregon’s most productive logging center in the late 1800s (Robbins 1997, p. 220), and much of the forest land in Clatsop and Columbia Counties was either harvested, burned, or both before early naturalists began faunal surveys in the area (Forsman et al. 2016a, pp. 19–20; 36–37). In addition, there is also a gap in the current and historical distribution of tree vole specimens and nests south of Saddle Mountain State Park in south-central Clatsop County, through the eastern two-thirds of Tillamook County south to the town of Tillamook (Forsman and Swingle 2009, in litt.; Forsman et al. 2016a, p. 229). There are no historical records of voles collected in this area, but there are also no records of early naturalists searching this area for tree voles (see section 3.2.3 Assessing Changes Between Historical and Current Red Tree Vole Distribution). Given that tree voles still occur in localized areas in the northern portion of the DPS, it is reasonable to conclude that tree voles occurred throughout much of the northern Oregon Coast Range prior to European settlement and the loss of forest habitat to logging and wildfires (Price et al. 2015, pp. 43, 45; Forsman et al. 2016a, p. 36).



Figure 2. A large red tree vole nest occupied by a female raising young. Note fresh Douglas-fir cuttings at three entrances (arrows), indicating recent activity at the nest. Discarded resin ducts and debarked twigs cover the top of the nest. Photo by Eric Forsman, from (Lesmeister and Swingle 2017, pp. 18–19).

3.3 Current Range and Distribution

Red tree voles continue to occur throughout much of their historical range, except for the northern Oregon Coast Range and the northern Oregon Cascade Range (Figure 3). They are considered uncommon or rare in these regions, being sparsely distributed with large areas devoid of tree voles (Forsman et al. 2004, pp. 297–298, 2016a, p. 36; USDA FS 2007, pp. 289, 294–296; Price et al. 2015, p. 43; Gaines et al. 2023, p. 16). On the northern end of the Oregon Coast Range, surveys on the Tillamook and Clatsop State Forests yielded tree vole nests on the Tillamook State Forest in 4 (5 percent) of the 86 plots surveyed. At the time of the survey, old forests (80 to 250 years old) on these two State Forests were present in less than 4 percent of the study area (Price et al. 2015, p. 38). For 82 of the plots, stands were randomly sampled regardless of their age, which ranged from 0–110 years. A second random sample was added to target older (>80 years) stands, and 3 of the 4 plots containing vole nests were in this old-forest sample. Of the nests found, 27 (82 percent) were unoccupied, and all were within or near (~ 492 ft (150 m)) older (90–125 years) forest stands (Price et al. 2015, pp. 38, 43, 48–49). The Bureau of Land Management (BLM) surveys targeting older forest stands within the Nestucca River basin in southern Tillamook County also found red tree voles, indicating that local populations persist in some patches of habitat (Forsman et al. 2016a, p. 21). These surveys suggest that tree voles are largely absent from most of the Clatsop and Tillamook State Forests except for small isolated populations in relict forests that were not burned or harvested in the early to mid-1900s (Price et al. 2015, pp. 43, 45, Figure 5). While tree vole habitat occurs in several large patches across the State Forests, it has, until perhaps recently, been largely absent in the area of the Tillamook Burn. The Tillamook Burn was a stand-replacing wildfire that burned over 1,200 km² (460 mi²) in 1933, then reburned in three successive fires over the next 18 years, for a combined total burn area of 1,400 km² (540 mi²) (Pyne 1982, pp. 330–331). The fire were followed by extensive salvage logging and clear-cutting of the remaining forests in 1934–1960 (Price et al. 2015, p. 38). It is reasonable to conclude that voles were present in this area prior to the fire, considering that much of the burned area contained older forest similar to forests occupied by tree voles in areas adjacent to the burn (Price et al. 2015, pp. 43, 45) (see section 3.2.1 Historical Range and section 3.4 Assessing Changes Between Historical and Current Red Tree Vole Distribution).

East of the DPS, red tree voles occur in the Columbia River Gorge almost as far east as the town of Hood River (Forsman et al. 2009b, p. 230). They also are found southwest of town, in the headwaters of the Lake Branch of Hood River (Forsman et al. 2009b, p. 229). This is the only known population on the east slope of the Cascade Range. The distribution of red tree voles continues south through the Cascade and Coast Ranges, joining at the southern limit of the Willamette Valley. In southwestern Oregon, the eastern distribution limit appears to include forested areas in Josephine County and along the western and northern border of Jackson County (Forsman et al. 2004, pp. 297–298, 2016a, p. 83; USDA FS 2007, pp. 289, 294–296). In California, red tree vole distribution is primarily limited to Del Norte and Humboldt Counties north of the Klamath River (Forsman et al. 2016a, p. 40).

Red tree voles are generally restricted to lower elevation coniferous forests, although there are a few records of this species above 1,300 meters (m) (4,265 feet (ft)) (Manning and Maguire 1999; Forsman et al. 2004, p. 300, 2016a, p. 36). Red tree voles may be limited to lower elevations because their nests do not provide adequate insulation to withstand higher-elevation winters (Hamilton 1962, p. 503). Because tree voles are active throughout the year, it is also possible they are absent from high-elevation areas because they find it difficult to forage on limbs covered with snow and ice during winter (Forsman et al. 2004, p. 300). Finally, their primary food source, Douglas-fir, is restricted from higher elevations, which may limit their distribution as well. Although tree voles are known to feed on other conifer species (Section 3.4.2 Diet), they are not known to feed on montane species such as mountain hemlock (*Tsuga mertensiana*) or Pacific silver fir (*Abies amabilis*).

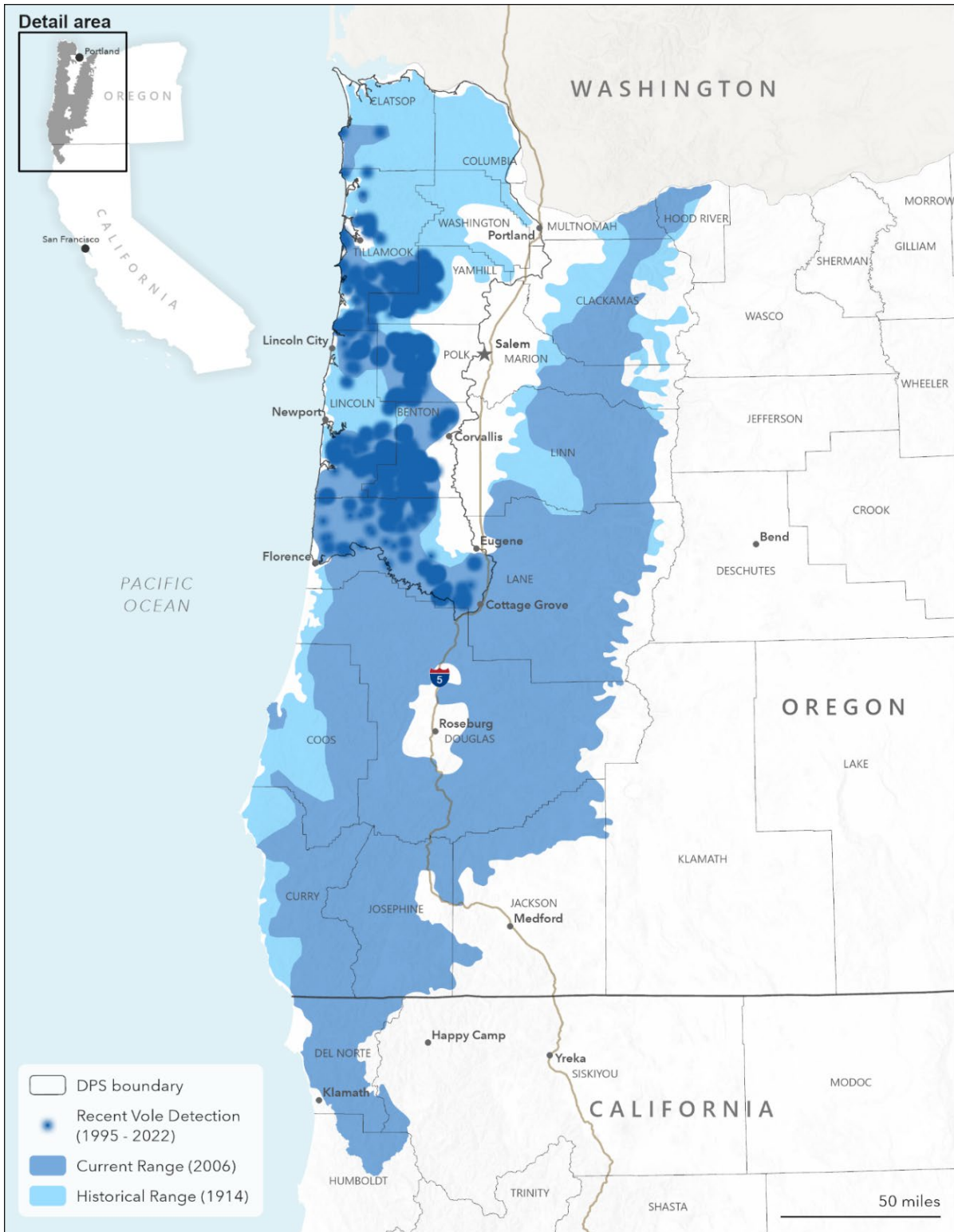


Figure 3. The north Oregon coast distinct population segment of the red tree vole (U.S. Fish and Wildlife Service 2019, pp. 3–4) with historical (1914) range, range as of 2006 based on species locations and modeled habitat (Forsman et al. 2016a, p. 83), and recent detections of voles from 1995-2022.

3.4 Assessing Changes Between Historical and Current Red Tree Vole Distribution

Although historical observations of tree voles are useful for assessing the species' range, they can be misleading because collectors did not search systematically or sample randomly. Also, tree voles may be naturally maintained at low densities due to a combination of life history traits, predation rates, and habitat availability (Forsman et al. 2016a, p. 47). Historical locations of tree voles tend to occur in clusters where a few collectors did intensive searches. Until extensive surveys were conducted beginning in the early 1990s, much of the range of the red tree vole had never been searched (Forsman et al. 2016a, pp. 6–10). The lack of historical documentation of tree vole presence thus cannot be interpreted as meaning that tree voles had limited populations or were historically absent from an area, especially if that area formerly provided suitable forest habitat for tree voles and was contiguous with known occupied areas. Searches by naturalists in the late 1800s and early 1900s were more of an inventory to find new species and to determine species presence as opposed to determining abundance of a particular species (Jobanek 1988, p. 370). Only portions of Oregon were searched, and coverage was cursory and localized. Given the arboreal existence of the red tree vole and difficulty of finding and observing them, few specimens were collected or observed until more was understood about their life history (Bailey 1936, p. 195; Jobanek 1988, pp. 380–381). Many nests were simply inaccessible to early naturalists. Nests were often high up in large trees, many of which were too big to climb without the benefit of climbing equipment, or the trees lacked enough branches on the lower bole to readily free-climb (Jobanek 1988, p. 391). One author noted that there was little hope for finding tree voles in virgin timber because large trees and the abundant moss often concealed hidden nests (Howell 1921, p. 99). Vernon Bailey, Chief Naturalist of the U.S. Bureau of Biological Survey, considered the red tree vole to be abundant in the wild yet rare in museum collections because of the difficulty in collecting them (Jobanek 1988, p. 382). Murray Johnson was the most prolific collector of tree voles (1957–1985) and spent most of his time searching in young forests (> 15 to 80 years) because he could not climb big trees (Forsman 2010, in litt.; Forsman et al. 2016a, p. 19; Swingle and Forsman 2016, p. 72). Historically, tree voles found in old forest were often from logging, such as those collected around Tillamook, Oregon, by Doug Bake in the 1960s-1970s (Forsman and Swingle 2010, pp. 103–105). Nest detectability was higher in young forest (20–60 years) with ground based surveys (84 percent), even when compared to climbing-based techniques in old forests (160-350 years) (5.5 percent) (McCoy et al. 2023, entire, n = 56 plots, 35 nests).

Descriptions of historical search efforts for red and Sonoma tree voles indicate that once the arboreal nature of the species was understood, searchers were more successful in finding tree vole nests and voles, often with little difficulty. Observers typically noted the patchy distribution of voles, and once they found voles, they tended to readily find multiple nests and voles in the same area (Taylor 1915, pp. 140–141; Howell 1926a, pp. 42–43; Clifton 1960, pp. 24–30; Maser 1966, p. 170, 2009, in litt.; Forsman and Swingle 2010, p. 104). For example, one researcher averaged one day of searching for every red tree vole cluster found in the Chehalem Mountains, Yamhill County, Oregon (Clifton 1960, p. 25), and another early researcher described more than 50 Sonoma tree voles being collected over 2 days near Carlotta, California, in 1913 (Howell 1926a, p. 43). In contrast, between 2002 and 2006, Forsman and Swingle (Forsman and Swingle

2006, unpublished data) spent 1,143 person-hours searching potential vole habitat in or near areas where voles historically occurred in or immediately adjacent to the DPS and captured or observed only 27 voles, equating to 42 hours of search effort per occupied nest found.

In considering survey efforts in recent decades for tree vole nests, between 19 (Piasecki 2022a, in litt.) and 21 person-hours have been spent surveying for each nest found in the north coast portion of the DPS, and 3.8 person-hours in the central coast portion (Forsman et al. 2016, p. 29, Table 1–9, combined search effort of retrospective and targeted surveys). Included in these data are searches within the Clatsop and Tillamook State Forests, where (Price et al. 2015, p. 43) spent 50 person-hours per nest found. The effort is higher, over 59 person hours per nest, when looking at only recently occupied nests, noting this is across a range of forest ages (20 to 320 years), with expectations that greater person hours per nest would occur in older forests (Piasecki 2022a, in litt.) because detectability is lower in old forest (McCoy et al. 2023, pp. 15, 18). Across the red tree vole range in Oregon and California, evidence of tree voles was found at 66 percent of historical (occupied prior to 1984) sites (Forsman et al. 2016a, pp. 9–10, 28); within or near the DPS, 50 percent of historical sites continued to be occupied in the northern part of the DPS and 75 percent in the southern portion of the DPS (Forsman et al. 2016a, p. 29). Although a rigorous quantitative comparison cannot be made between recent and historical observation data, the above anecdotal information suggests that tree vole numbers are greatly reduced in the DPS and red tree voles are now scarce in areas where they were once found with relative ease. Similarly, decreases in Sonoma tree vole numbers have been observed, with evidence of Sonoma tree voles at 44 percent of the historical sites that were revisited (Forsman et al. 2016a, p. 28). A recent model looking at ecosystem conditions known to influence tree vole populations showed current habitat capability reduced in the Coast Range, Cascades, and Klamath Mountains ecoregions at 26 percent, 42 percent, and 52 percent of their respective historical capacities (Gaines et al. 2023, p. 1).

Although we have no population estimates, the evidence suggests that distribution of red tree voles is smaller or more restricted within the DPS than historically. Within the northern Oregon Coast Range, Forsman et al. (2016, pp. 36–37) consider them uncommon or rare, having been eliminated from many areas. Within the DPS, red tree voles are now mostly restricted to isolated populations in or near old forest on Federal and State lands. Historical observations were by naturalists who primarily collected voles from younger forests where nests were more easily observable and accessible by free-climbing (Howell 1926a, p. 42; Clifton 1960; Maser 2009, in litt.; Forsman 2010, in litt.). These early naturalists were limited in their sampling by the size and form of trees (presence of low-lying limbs that allowed for free-climbing) they could climb, yet found many voles with relatively little effort. As evidence that tree voles are currently less abundant, researchers in recent years surveying many of these same areas have found comparatively few vole nests per unit effort, using climbing gear to access every potential nest observed, regardless of tree form or size (Forsman and Swingle 2006, in litt.; 2009, in litt.; Forsman 2009, in litt.; Piasecki et al. 2022, entire; McCoy et al. 2023, entire). Furthermore, retrospective surveys may overestimate the proportion of historical sites still occupied by tree voles (Forsman et al. 2016a, p. 41). The authors base this on not limiting their surveys to

historical nest groves, but instead also including large areas around the historical site (a 1- to 20-km radius, Forsman et al. 2016a, p. 9); if voles or nests were found, the site was still considered occupied, regardless of the distance from the historical location, and regardless of whether nests were occupied.

3.5 North Oregon Coast Distinct Population Segment and Analysis Area Description

This SSA looks at red tree voles in the northern Oregon Coast Range, in response to our finding that the northern Oregon Coast Range DPS of red tree voles warranted listing under the Act. That finding provided a map with a defined DPS boundary (U.S. Fish and Wildlife Service 2011, p. 63730). However, since that 2011 finding, we learned of substantive tree vole nest observations outside of that DPS boundary and developed a new boundary for assessment in the 2019 SSA. In our 2019 finding, we revised the description to include all known red tree vole occupied habitat clusters encompassing conifer-forested areas starting in Lane County north of the Siuslaw River to the Columbia River and west of the Willamette River and Coast Fork of the Willamette River to the Oregon coast (U.S. Fish and Wildlife Service 2019, pp. 3–4). In this assessment, occupied population areas refer to occupied geographic units which contain one or more known or presumed occupied population area.

Throughout this analysis we also refer to other regions in the vicinity of the analysis area, which is analogous to the DPS, on a regular basis (Figure 4). The Oregon Coast Range physiographic province is one such region and includes all of the DPS plus an area of similar vegetation and physiography to the south. We also refer to two different subregions of the analysis area, the north coast and central coast, as adopted by Forsman et al. (2016, p. 3).



Figure 4. Geographic regions referred to in this analysis. The DPS lies within the Oregon Coast Physiographic Province. “North Coast” and “Central Coast” are subregions used by Forsman et al. (2016, p. 3) and referenced in this document.

3.6 Vegetation

Except for the Willamette Valley, the analysis area is almost all forested land. The temperate rainforest that occurs in the analysis area is the most densely forested region in the United States and represents the greatest extent and size of temperate coniferous forests in the world (Franklin and Dyrness 1988, p. 53). Coniferous forests almost completely dominate the region, with hardwood dominants often limited to riparian areas or recently disturbed sites.

Dominant coniferous tree species are large and long-lived, occurring throughout the landscape rather than being isolated as scattered individuals or in localized pockets of favorable conditions. High amounts of precipitation occur, mostly as rainfall in the winter, and winters are generally mild. Large-scale natural disturbances are limited to infrequent but large, high-severity wildfires, and occasional windstorms (Franklin and Dyrness 1988, pp. 53–54; Agee 1993, pp. 189–191, 206–212; Wimberly et al. 2004b, pp. 151–152). The mild climate and uniform distribution of conifers make the area particularly suitable for tree voles.

There are two vegetation zones in the analysis area (Figure 5). The Sitka spruce (*Picea sitchensis*) zone consists primarily of Sitka spruce and western hemlock (*Tsuga heterophylla*), and occurs in a narrow band along the coast, sometimes only a few kilometers in width, with extensions up some river valleys, particularly in the northern portion of the analysis area. The western hemlock zone consists primarily of western hemlock and Douglas-fir and occurs in the Coast Range east of the Sitka spruce zone (Franklin and Dyrness 1988, pp. 44–46, 58–59, 70–73).

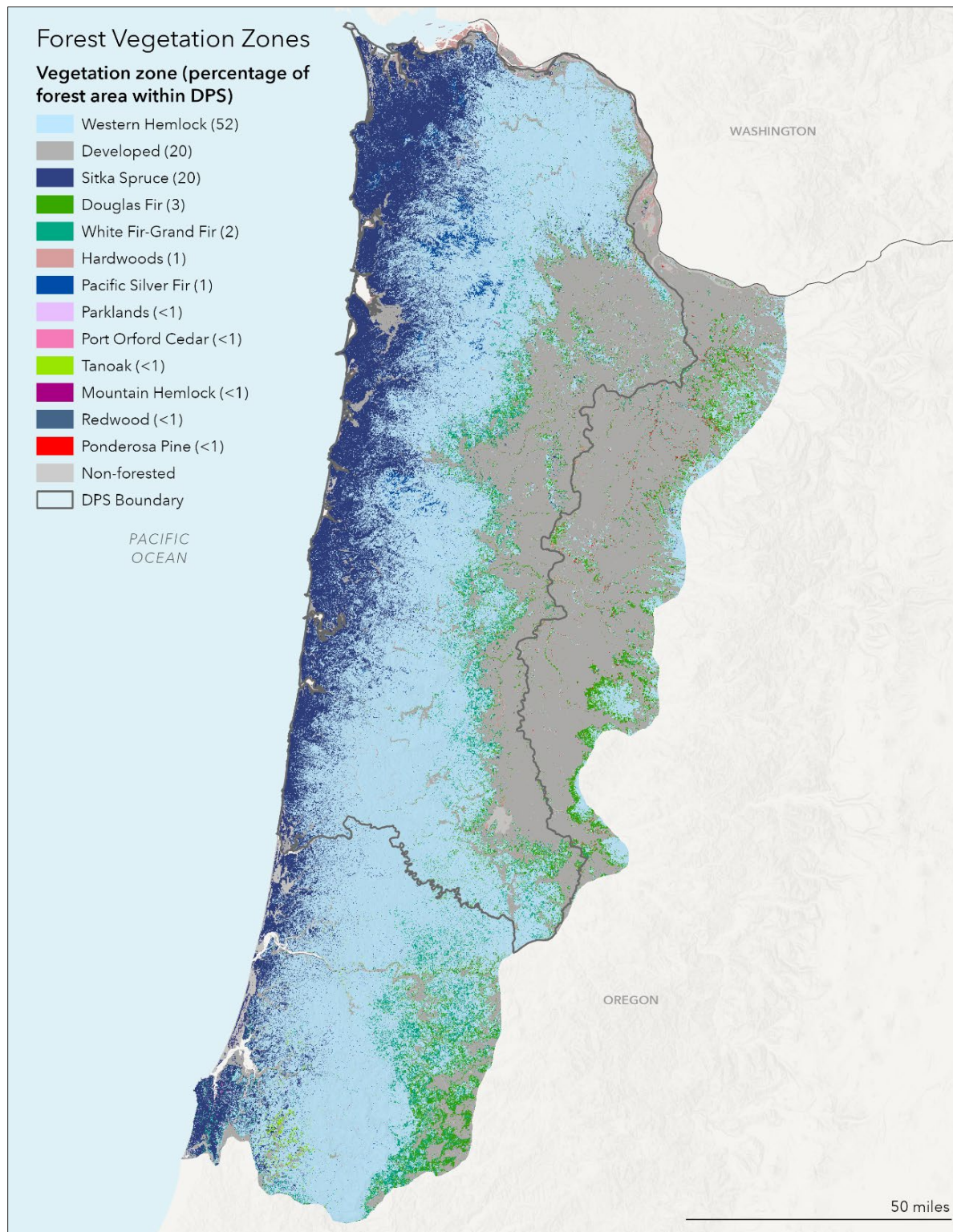


Figure 5. Potential Natural Vegetation (USDA FS 2021, in litt. GIS data) vegetation zones of the Pacific Northwest in the Oregon Coast Physiographic Province and Willamette valley. Most of the DPS is in the western hemlock zone, with a band of the Sitka spruce zone along the coast and small pockets of other vegetation zones sprinkled across the western hemlock zone or along the Willamette valley margin.

3.7 Ownership Patterns and Associated Regulatory Mechanisms

Private lands make up 69 percent of the ownership in the DPS (Table 1), with a mix of individual and industrial forest owners (Figure 6 and Figure 7).

Federal lands make up 17 percent of the DPS (Table 1, Figure 6). The USFS Siuslaw National Forest comprises over half (about 57 percent) of the Federal land within the DPS, and the Northwest Oregon District of the BLM makes up most of the remainder, along with a small portion of the Roseburg BLM District. The U.S. Fish and Wildlife Service, National Park Service, and Department of Defense make up less than 2 percent of the remaining Federal ownership in the DPS.

State lands comprise 12 percent of the DPS (Table 1, Figure 6). Most of the State ownership (11 percent of the DPS) is land managed by the Oregon Department of Forestry (ODF), primarily in the Tillamook and Clatsop State Forests, with other scattered parcels of State Forest land in the southern half of the DPS. Oregon Parks and Recreation Department (OPRD) State parks and other State-owned lands make up the rest of the State ownership, less than 1 percent of the DPS.

Tribal lands make up less than 1 percent of the DPS. Another 1 percent of the DPS is comprised of county and other local government lands and 0.13 percent is owned by non-governmental organizations (NGO) (Table 1).

Table 1. Ownership within the north Oregon coast DPS of red tree vole by agency and by land use category (USFS = U.S. Forest Service; BLM = Bureau of Land Management; ODF = Oregon Department of Forestry; NGO = Non-governmental organization). Area is in km² (mi²).

Ownership (Percent Area)	Ownership Area km ² (mi ²)	Land Use Category ^a	Category Area
Federal (17.1)	3,469 (1,339)		
USFS	1,988 (767)	Reserved	1,241 (479)
		Non-Reserved	747 (288)
BLM	1,422 (549)	Reserved	1,050 (406)
		Non-Reserved	371 (143)
Other Federal Agencies	60 (23)		
State (12.0)	2,443 (943)		
ODF	2,266 (875)	Constrained	1,011 (390)
		Non-Constrained	1,254 (484)
Other State Agencies	178 (69)	Constrained	49 (19)
		Non-Constrained	129 (50)
Tribal (0.4)	87 (34)		
Private (69.4)	14,090 (5,440)		
Local Government (1.0)	209 (81)		
NGO (0.1)	26 (10)		
Total	20,325 (7,848)		

^a “Reserved” and “Non-reserved” are categories of Northwest Forest Plan land use allocations designated in the Federal agency’s land use management plan. “Constrained” and “Non-constrained”, for ODF, are categories of management that generally restrict (Constrained) or allows (Non-constrained) timber harvest; they may include Northwest Forest Plan land use allocations, as well as other areas removed from the timber harvest land base (see section 7.2.2). We also applied the “constrained” category to Oregon Department of Fish and Wildlife (ODFW) wildlife areas and Oregon Parks and Recreation Department (OPRD) lands as these lands are managed for recreation (State Parks) or other resource retention that would likely retain tree vole habitat (see Section 7.2.2). Finally, when referring to landscapes which contain reserved and constrained lands, we use “constrained” as a general term.

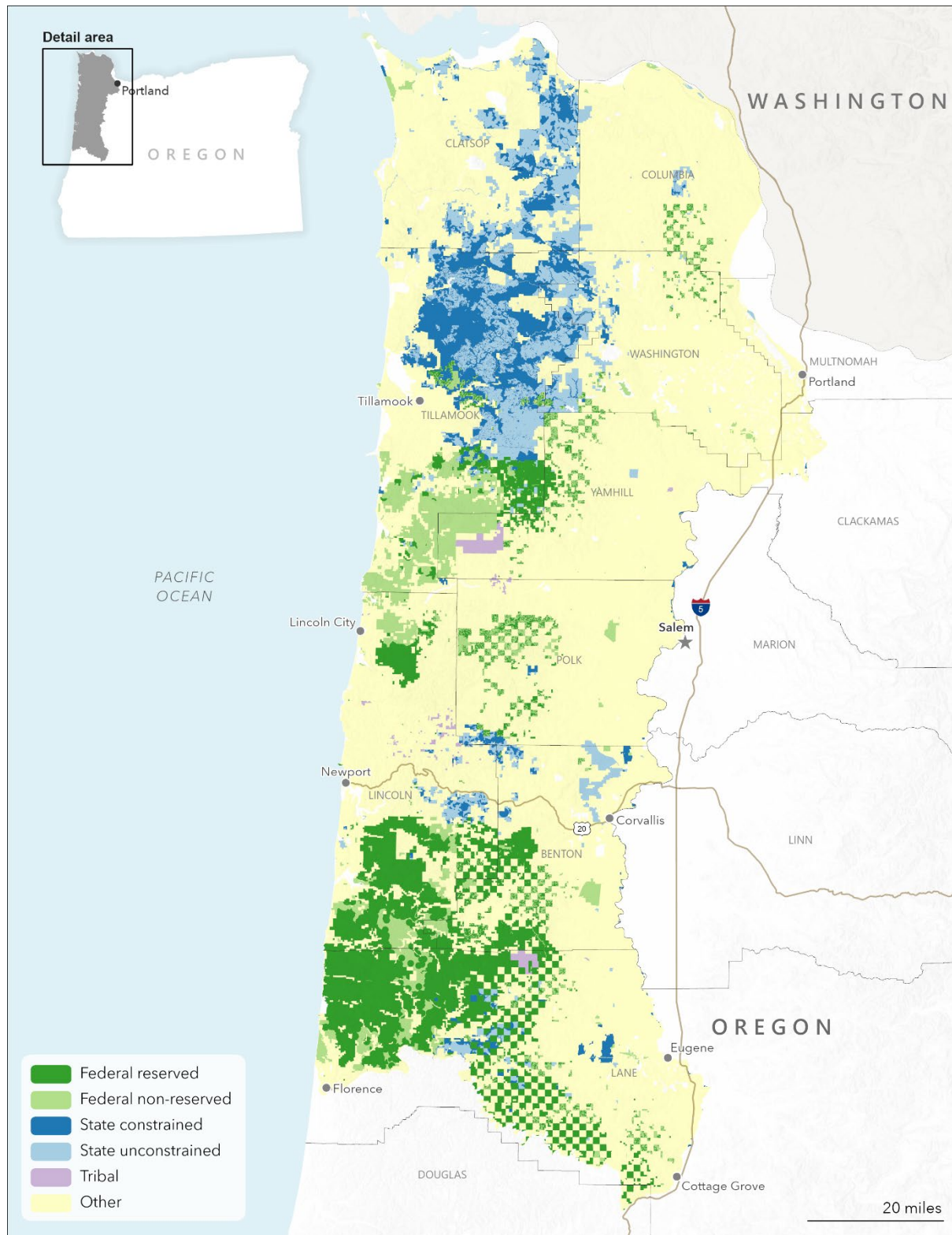


Figure 6. Ownership patterns within the north Oregon coast red tree vole DPS.

Ownership plays a strong influence in how the analysis area is managed for red tree voles. For Federal lands, we focus our analysis on the BLM and Forest Service because they make up almost all the Federal management in the analysis area and are the only Federal agencies with lands allocated to regulated timber harvest. The BLM and Forest Service lands are each managed under separate forest management plans. Both agencies have land use allocations where programmed timber harvest is excluded and which are likely to retain or develop red tree vole habitat (These include late-successional reserves (LSRs), riparian reserves, and congressionally reserved areas such as wilderness areas or wild and scenic river corridors. Forest Service and BLM land use allocation categories are tallied in Table 1.

The Forest Service manages their land under the Northwest Forest Plan (NWFP) (USDA and USDI 1994, entire). The red tree vole is considered a Survey and Manage species under the NWFP, requiring pre-project surveys for red tree voles prior to most habitat disturbing activities (except for thinning in stands less than 80 years old, as well as some other smaller footprint activities relating to fuels reduction and stream/riparian enhancement) (USDA and USDI 2011, p. 3, Attachments 1 and 2). Sites considered occupied (presence of voles or of nests with signs of recent occupancy) are protected with a minimum 4-hectare (ha) (10-acre (ac)) buffer where found (USDA FS and USDI BLM 2000, pp. 13–14). This approximates a 113 m (372 ft) radius circle around the nest, although the actual buffer is not necessarily centered on the nest or shaped as a circle. Standards and guidelines only require managing for “high-priority” sites because not all sites were believed to be required for reasonable assurance of species persistence (USDA and USDI 2000c, p. 10). The agency has developed a process for identifying high-priority sites to conserve the red tree vole (Huff 2016, entire; USDA FS 2022, p. 6). In addition, non-high-priority sites may not require surveys if the agency determines the site is not necessary to provide species’ persistence (USDA and USDI 2003, entire; 2006, entire). Although the BLM now manages their lands under Resource Management Plans (RMPs) finalized in 2016, rather than the NWFP, it manages for red tree voles similarly for its lands north of U.S. Highway 20, that is, requiring tree vole surveys in forests greater than 80 years old or with 60 percent or more canopy cover and to two or more “superdominant” conifer trees per acre on average across the stand, and establishing “habitat areas” at least 4.05 ha (10 acres) in size. South of Highway 20, there are no survey requirements, and only known tree vole sites within reserved land use allocations receive protective measures (USDI 2016, p. 101).

State Forest lands in the analysis area are managed under the Northwest Oregon Forest Management Plan (Oregon Department of Forestry 2003, entire, 2009, entire, 2010, entire, 2011a, entire, b, entire, 2012, entire). There is no specific direction to survey for red tree voles or protect sites where they are found. Red tree voles are, however, one of several species of concern identified by ODF, and some management is provided in the form of anchor habitats; these areas are intended to provide locales where populations will receive a higher level of protection in the short-term until additional tree vole habitat is created across the landscape (Oregon Department of Forestry 2010, p. 4.82-4.83, E.42), although thinning may occur. Management areas (non-

permanent reserves) for northern spotted owls (*Strix occidentalis caurina*) and marbled murrelets (*Brachyramphus marmoratus*) may also provide for conservation of red tree voles, assuming the voles occupy the those areas (Oregon Department of Forestry 2013a, entire, b, entire). State Forests are also managed for specific amounts of forest structural stages. The objective is to develop 15 to 25 percent of the State Forest landscape into each of two structure classes, older forest and layered (Oregon Department of Forestry 2010, pp. 4–48), each representing stands with larger trees and more complex structural conditions. Attaining these objectives would benefit the red tree vole.

Private forests must meet the standards under the Oregon Administrative Rules (OARs) and Oregon Revised Statutes (ORS), including ORS 527 and OAR 629, the Oregon Forest Practices Act (FPA) (Oregon Department of Forestry 2023b, entire) which provides no protections for red tree voles or their habitat unless voles are opportunistically located in some riparian areas or buffers set aside to protect other species, such as northern spotted owls, marbled murrelets, bald eagles (*Haliaeetus leucocephalus*), osprey (*Pandion haliaetus*), and great blue herons (*Ardea herodias*) (OAR 629–665–0110 through 0210). The predominant management on industrial forest ownerships is for high levels of wood production using clearcuts (with leave tree retention of 2 trees/ac (ORS 527.676)) with harvest rotations typically ranging from 30 to 60 years (Wimberly et al. 2004a, p. 148; Adams et al. 2002, pp. 13, 26; Spies et al. 2007a, p. 8).

Conversely, non-industrial private timber management is harder to characterize. While timber production is often the primary goal, priority objectives such as biodiversity or passive management are also common. Nonindustrial lands also tend towards being managed using partial harvest methods more than industrial lands and have longer harvest rotations (Adams et al. 2002, pp. 13, 26; Wimberly et al. 2004a, p. 148; Spies et al. 2007a, pp. 8–9). Finally, industrial timberlands tend to be distributed in large ownership tracts, whereas nonindustrial timberlands are patchily distributed in smaller tracts throughout the area (Figure 7).

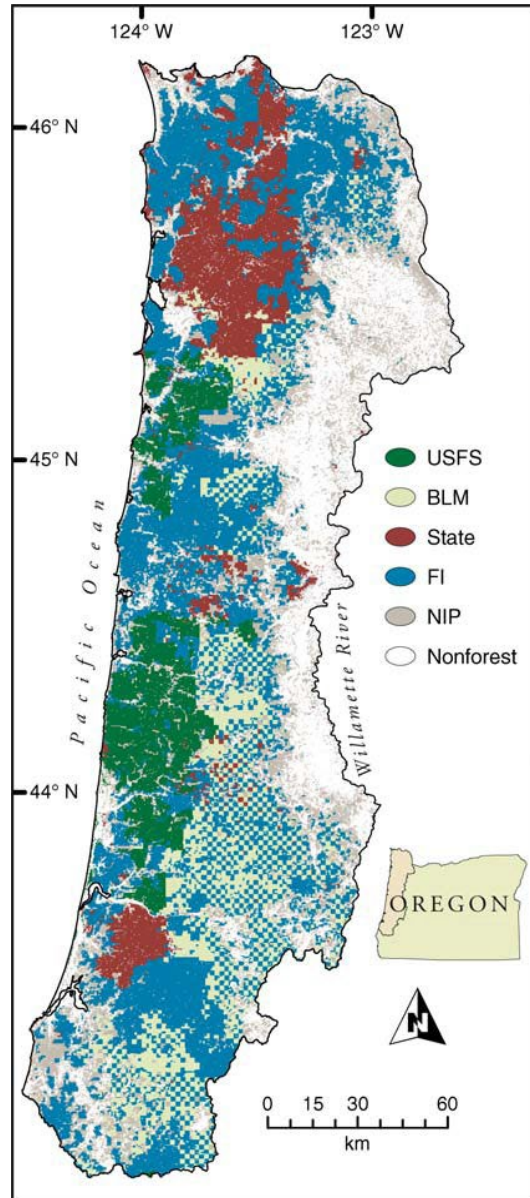


Figure 7. Ownership classes for forested land in the Coast Range physiographic province in Oregon. Abbreviations in legend are: USFS, U.S. Forest Service; BLM, Bureau of Land Management; State, State of Oregon; FI, forest industry; NIP, nonindustrial private forest and other miscellaneous ownership; nonforest, other land uses. Figure is from Spies et al. (2007, Figure 1, p. 7).

Four federally recognized Native American Tribes have lands within the analysis area and two tribes actively manage forest lands. The Confederated Tribes of the Grand Ronde manage 40 km² (15 mi²), and the Confederated Tribes of Siletz Indians manage 16 km² (6 mi²) of commercial timberland. These lands are generally managed to generate revenue and minimize or mitigate negative effects, while also protecting and enhancing those resources that are spiritually and culturally important to the Tribes (Confederated Tribes of Siletz Indians of Oregon 2010, entire; Confederated Tribes of the Grand Ronde 2013, entire). There are no specific protection measures for red tree voles or their habitat in either of the Tribal management plans. Though not

included in the Tribal ownership acreages in Table 1, the Confederated Tribes of Siletz Indians also manages an additional 16 km² (6 mi²) to conserve and develop marbled murrelet habitat over time (Confederated Tribes of Siletz Indians 2010, pp. 1–2). Retention and development of suitable murrelet habitat would be beneficial to red tree voles.

3.8 Analytical Units— Red Tree Vole Geographic Units

Although we have designated a DPS of the red tree vole, specific data on red tree vole abundance and extent or sizes of populations or subpopulations within the DPS are lacking. However, recent published habitat models reference, combined with data from surveys since 1995 done for red tree voles across the analysis area, allowed for a habitat-based approach to identify analytical units which we can evaluate under the species status assessment 3R framework.

Analytical units are geographic areas, called geographic units, containing potential population areas derived from modeled blocks of habitat with potential vole occupancy (see Appendix A, Section 2 for details). The building blocks of our analytical units are habitat blocks, which consist of patches of modeled habitat within close enough proximity that we expect red tree voles would be functionally connected. Habitat blocks met one or more of the following criteria: at least 52.5 ha of core habitat according to the most recent habitat model (Linnell et al. 2023, entire); at least 52.5 ha in old forest patches as identified in a 2017 habitat model updated in 2019 (Linnell et al. 2017a, entire; Linnell 2022, in litt.), or a recent (since 1995) positive vole detection in or near the block. Positive detections are most commonly from surveys where voles or recent sign of voles (active nests) are observed but may include incidental sightings, carcasses, tree vole remains found in owl pellets, or other observations. Potential population areas were delineated by overlaying these habitat blocks with geographic units. Geographic units were derived by dividing the DPS by features which are likely strong filters or obstacles to red tree vole movement (rivers and highways). Several areas of the DPS did not contain habitat and were not used in the analysis (see Appendix A, Section 4.2).

In total, 25 geographic units and 83 population areas were identified. Of the 83 population areas, 37 were considered to have known tree vole occupancy (positive survey detection since 2010); 15 were presumed occupied (positive survey detection from 1995 through 2009 or in an unsurveyed area near an occupied population area); and 31 were presumed unoccupied based on survey data since 1995. If a geographic unit did not contain any occupied (known or presumed) population areas, those units were not moved forward in the condition analysis. Out of 25 geographic units, 17 moved forward in the condition analysis. Out of 83 original population areas, 52 occupied population areas moved forward for current condition analysis. An additional four currently presumed unoccupied population areas were added to the future condition analysis due to potential future connectivity with occupied population areas.

Geographic units are shown in Figure 8 with units presented generally from north to south. Land management designation percentages per unit and the percent of the geographic unit containing

presumed occupied population areas are listed in Table 2. Occupied population areas and tree vole detections are shown in Figure 9.



Figure 8. Red tree vole geographic units and associated ownership.

Table 2. Ownership by geographic unit. Unit area is in km² (mi²). Private/Other includes private, local government, and non-governmental organization lands (see Table 1). PA = population area.

Geographic Unit	Area km ² (mi ²)	Percent unit in PA(s)	Ownership Percentage by Geographic Unit					
			Federal		State		Tribal	Private/ Other
			Reserved	Non- Reserved	Constrained	Non- constrained		
1. Lewis and Clark	582 (225)	0.2	0	1	1	4	0	94
2. Ecola/ Elmer Feldenheimer	30 (12)	8	0	0	0	2	0	98
3. Necanicum/ Nehalem	256 (99)	2	0	0	2	3	0	95
4. North Fork Nehalem	282 (109)	2	0	0	27	27	0	46
5. Nehalem/ Wilson	1292 (499)	6	1	1	38	25	0	35
6. Cape Meares	46 (18)	2	0	1	0	0	0	99
7. Sand Lake	261 (101)	22	2	22	1	1	0	74
8. Trask/ Nestucca	2661 (1027)	48	9	13	7	14	2	55
9. Gauldy Ridge	85 (33)	60	6	57	0	1	0	36
10. Little Nestucca/ Salmon Coast	36 (14)	61	0	68	0	0	0	32
11. Little Nestucca/ Salmon Inland	225 (87)	38	3	33	1	0	1	61
12. Siletz/ Luckiamute	2571 (993)	36	6	6	1	4	1	82
13. Yaquina/Marys	1246 (481)	58	33	5	2	4	0	56
14. Alsea/Siuslaw	2415 (932)	69	47	10	0	0	1	42
15. Siuslaw/Long Tom	411 (159)	66	22	3	5	8	0	62
16. Siuslaw/ Territorial	561 (217)	67	31	5	1	2	0	62
17. Spencer Butte	641 (247)	46	5	3	1	0	0	91

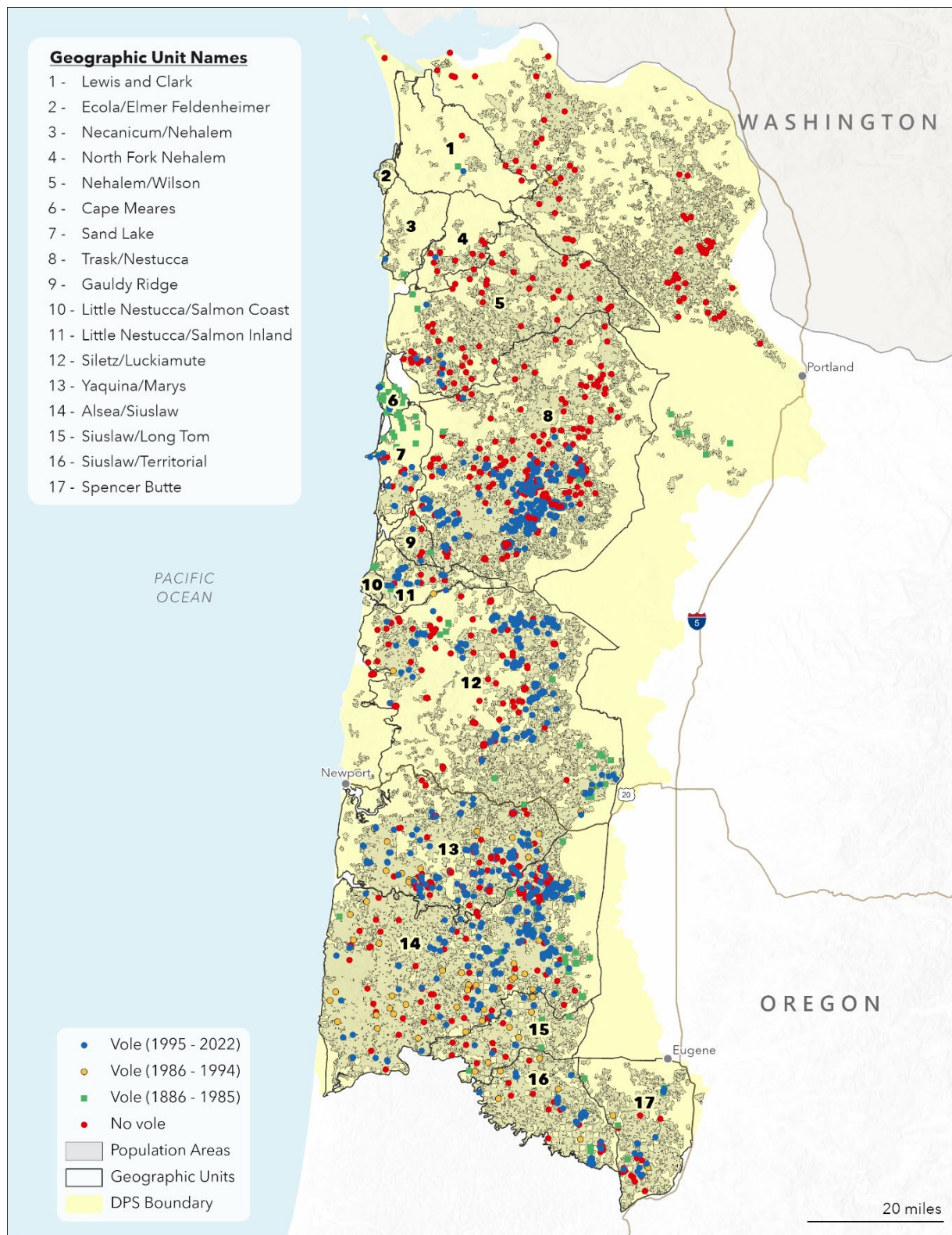


Figure 9. Red tree vole geographic units, occupied population areas, and survey results.

Below we describe each geographic unit in terms of its location, land ownership, population areas, vegetation zone(s), and unique features.

1. Lewis and Clark (582 km² (225 mi²); 0% population area)

This unit is the northern extent of presumed occupied units in the DPS. It is 5% State lands (1% of which is constrained), 1% Federal lands, and 94% private lands. A small population area makes up 0.2% of the unit and straddles a road on the Saddle Mountain State Natural area. The last survey with positive detection was in 2011. The population area and unit are isolated. The unit is bounded by the Necanicum River and Highway 26 to the south, the coast to the west, Highway 202 to the north and the Nehalem River to the east. The unit contains both vegetation zones.

2. Ecola/Elmer Feldenheimer (30 km² (12 mi²); 8% population area)

This is the smallest of the potentially occupied units in the DPS. It is 2% (unconstrained) State land and 98% private/other land. One small population area, making up 8% of the unit, is anchored on the Elmer Feldenheimer State Natural Area. The unit is bounded by the coast and by Highway 101, isolating it from other units. The unit is wholly within the Sitka spruce vegetation zone

3. Necanicum/Nehalem (256 km² (99 mi²); 2% population area)

This unit is 5% State land in scattered parcels of ODF managed forest land and 95% private/other land. A population area makes up 2% of the unit and about 2% of the unit is constrained, with only a small amount of overlap. This unit is isolated, bounded by Highway 101 and Nehalem Bay to the west and south, North Fork Nehalem River and Highway 53 to the east, and Highway 26 to the north. The population area and a majority of the unit is in the Sitka spruce vegetation zone.

4. North Fork Nehalem (282 km² (109 mi²); 2% population area)

This unit is 54% State lands and 46% private/other lands and contains one presumed occupied population area which makes up 2% of the unit. The State Forest lands are managed by ODF and about half of them, including the population area location, are in constrained status. The occupied population area is isolated, but connected via constrained lands to a large, presumed unoccupied population area in the unit; otherwise, the unit itself is also isolated. It is bounded by the Nehalem River to the south and east, the North Fork Nehalem River and Highway 53 to the west and Highway 26 to the north. The unit is primarily in the Sitka spruce zone and the occupied population area is fully in that zone, however the western hemlock zone is prevalent on the unit's eastern edge.

5. Nehalem/Wilson (1292 km² (499 mi²); 6% population area)

This is a large unit with about two-thirds State lands, one-third private lands, and 2% Federal land. The constrained State lands are divided into several large blocks and make up 39% of the unit. Only 6% of the unit is in four small, occupied population areas, all in the western portion of the unit. The unit is bounded on the west by the coast, the south by the Wilson River and Highway 6, the east and northeast by Highway 26, and the northwest by the Nehalem River. The population areas are isolated from other units, lacking connecting habitat blocks. Population areas contain both vegetation zones, though are primarily in the Sitka spruce zone. A very large unoccupied population area comprises the eastern half of the unit and is notable as the location of part of the historical Tillamook burns.

6. Cape Meares (46 km² (18 mi²); 2% population area)

This unit is small, isolated, and almost completely in private ownership (99%). Four small population areas comprise 2% of the unit, the largest of which is centered on Cape Meares National Wildlife Refuge. The population areas are connected by unconstrained forest but are isolated from neighboring units. The unit is bounded on three sides by the ocean and to the south by Highway 131. The unit is in the Sitka spruce vegetation zone.

7. Sand Lake (261 km² (101 mi²); 22% population area)

This unit is three-quarters private ownership, almost a quarter Federal lands, and 2% State lands. Only 3% is in a constrained status. The unit is comprised of one larger population area and five smaller population areas, all in the southern portion of the unit and associated primarily with USFS land, though one population area is on Cape Lookout State Park. Population areas make up 22% of the unit. It is isolated, not connected to other units by habitat blocks, and it is bounded on the west by the coast, the east by Highway 101, the east and south by the Nestucca River, and the north by Highway 131. The unit is nearly all within the Sitka spruce zone.

8. Trask/Nestucca (2661 km² (1027 mi²); 48% population area)

This unit is the largest in area of any unit with just over half in private ownership, a fifth in State ownership, a fifth in Federal ownership, and 2% in Tribal ownership. State ownership is primarily managed by ODF, about half of which is under constrained management. For the Federal lands, about half is managed by USFS as non-reserved lands and half is managed by BLM, mostly in reserved land use allocations. The Tribal lands include a block of commercial timberland managed by the Confederated Tribes of the Grand Ronde. The unit is comprised of one large, occupied population area and four small population areas, which collectively cover 48% of the unit. Tree vole surveys and positive detections have been focused in the center of the unit, on BLM land. The unit is connected by habitat block to units to the north and south. The unit is bounded by the Wilson River and Highway 6 to the north, Highway 101 to the west, Three Rivers and Highway 22 to the southwest, the Little

Nestucca and Salmon Rivers and associated highways to the south, and highways and the edge of the Willamette Valley to the east. The large population area is in the western hemlock zone, and two of the small population areas contain both vegetation zones, though this unit does not touch the Pacific coast.

9. Gaudy Ridge (85 km² (33 mi²); 60% population area)

This unit is small, just off the coast and is about one-third private and two-thirds Federal land managed by USFS. One percent is State land. About 6% of the land is in Federal reserved land use allocation. It is connected by habitat block to two units in the east and south with rivers separating them. It is bounded by the Little Nestucca River and Highway 130 to the southwest, the Three Rivers and Highway 22 to the east, and Highway 101 to the west and north. This unit is 60% population area comprised of one large population area with known occupancy. The unit is mostly in the Sitka spruce zone but contains western hemlock vegetation zone.

10. Little Nestucca/Salmon Coast (36 km² (14 mi²); 61% population area)

This unit is one of the smallest occupied units and 68% is in Federal ownership, most of that managed by USFS. The other third of the unit is private/other land. A single large, contiguous population area encompasses over 60% of the unit. The unit is fairly contiguously forested but isolated. It is connected by habitat block to the Little Nestucca/Salmon Inland unit to the north and east, though U.S. Highway 101 separates them. To the west is the Pacific coast and to the south is the Salmon River. The unit is fully within the Sitka spruce vegetation zone.

11. Little Nestucca/Salmon Inland (225 km² (87 mi²); 38% population area)

This is a smaller, inland coastal unit with more than half in private/other ownership, 36% managed by Siuslaw National Forest in a non-reserved status, and about one percent each in State (scenic corridor) and Tribal forest lands managed by the Confederated Tribes of Grand Ronde. Tribal managed lands do not contain tree vole habitat. Only 4% of the unit is in constrained status. About 38% of the unit is comprised of six occupied population areas. Habitat connects most population areas to three of the four surrounding units, separated by the Salmon River and Highway 18 to the south, Highway 101 to the west, and Highway 22 and the Little Nestucca River to the north. Half of the population areas are in the Sitka spruce zone and half contain both Sitka spruce and western hemlock vegetation zones.

12. Siletz/Luckiamute (2571 km² (993 mi²); 36% population area)

This unit is the second largest in the DPS, comprised of three large and 11 smaller occupied population areas, which collectively make up over a third of the unit area. Some of the population areas have known occupancy. The unit is primarily private land (82%), but also

contains Federal (12%), State (5%), and Tribal lands (1%), with 10% in constrained status. The largest population area is mostly private land but includes the 55 km² Oregon State University McDonald Dunn Forest, which we consider to be managed like State unconstrained lands. Highway 20 separates the unit from Yaquina/Marys unit to the south, the Salmon River and Highway 18 separate it from other units in the north, and the eastern edge is the Willamette Valley. The unit borders a portion of the coast and three of the population areas are completely within the Sitka spruce vegetation zone. Another three population areas contain both vegetation zones. The two largest population areas are in the western hemlock zone.

13. Yaquina/Marys (1246 km² (481 mi²); 58% population area)

This unit is comprised primarily of one large, known occupied population area encompassing over half of the unit. There are two small population area “inclusions” that are surrounded by the larger population area. The unit is 38% Federal land and 56% private land. From west to east, the population area itself is just over half Siuslaw National Forest, less than a third in BLM “checkerboard¹” ownership, and about a third private/other lands. Just over one-third is in constrained lands. The Federal ownership connects to habitat in the neighboring Alsea/Siuslaw unit to the south across the Alsea River and Highway 34. While the unit is bounded on the west by the coast, habitat does not extend into the Sitka spruce zone and so the entire unit is in the western hemlock vegetation zone.

14. Alsea/Siuslaw (2,415 km² (932 mi²); 69% population area)

This is one of the larger occupied units in the DPS and has the highest percent population area at 69%. This unit is over half Federal lands, 47% of which are on reserved land use allocations. Private/other lands make up 42%. The western half of the unit is contiguous forest managed by the Siuslaw National Forest, starting at the Pacific coastline. The eastern half of the unit is contiguous BLM, transitions to BLM checkerboard, and moves towards private/other lands into the edge of the Willamette Valley. While the western and eastern boundaries of the unit are hard edges, the Siuslaw River creates the southern boundary and Highway 34 and Alsea River the northern boundary of the unit, which provide a strong filter or obstacle, but not barrier, to tree vole movement. The Sitka spruce zone lies along the western edge of this unit, but the vast majority is in the western hemlock zone. The population area encompasses both Sitka spruce and western hemlock vegetation zones.

15. Siuslaw/Long Tom (411 km² (159 mi²); 66% population area)

This unit is comprised of one large, known occupied population area (66%). It is primarily in private/other ownership (62%) with 13% in contiguous blocks of State Forest land and 25%

¹ The “checkerboard” pattern of ownership refers to alternating 2.59 km² sections in public or private ownership. In the DPS, this is typically alternating block of BLM and private ownership, though some State lands are within checkerboard.

Federal ownership in BLM checkerboard. Constrained lands make up over a quarter of the unit, nearly all in BLM checkerboard with a small amount in State constrained. The public lands connect via the same habitat block to the unit to the south, separated by Highway 126, and to the unit to the north, separated by Highway 36. The unit is within the western hemlock zone.

16. Siuslaw/Territorial (561 km² (217 mi²); 67% population area)

This unit is primarily in checkerboard ownership with 62% private/other lands, 36% Federal land, and a small amount of State Forest lands. About one-third of the unit is in constrained status. One large known occupied population area comprises about 67% of the unit. The unit is bounded by the Siuslaw river, the southern limit of the DPS; and the Highways 126 and 200 separate it from neighboring units to the north and east, respectively. The unit is within the western hemlock zone.

17. Spencer Butte (641km² (247mi²); 46% population area)

This geographic unit represents the southeastern extent of the DPS and includes a forest butte on the edge of the Willamette Valley. Vegetation is influenced by the drier and warmer valley climate. It is over 90% in private ownership, with 6% in Federal reserved land use allocation managed by BLM in checkerboard ownership. Approximately 1.5 km² (0.6 mi²) is managed by the city of Eugene as a park, most of which is tree vole habitat. The unit is comprised of one large known occupied population area and one small, presumed unoccupied population area with habitat that connects to the Siuslaw/Territorial unit, separated by Highway 200. The majority of the unit is in the western hemlock zone.

3.9 Species Life History and Habitat

3.9.1. Reproduction

Red tree voles have low reproductive potential compared to other vole species within the Arvicolinae subfamily (see Table 3 for comparison with closely related heather vole (*Phenacomys intermedius*). Red tree vole litter sizes are among the smallest in this subfamily, averaging 2.9 young per litter (Maser et al. 1981, p. 205; Verts and Carraway 1998, p. 310). Clifton (1960, pp. 119–120) reported that captive tree voles became sexually mature at 2.5 to 3.0 months of age. Females breed throughout the year, with most reproduction occurring between February and September (Swingle 2005, p. 71). Red tree voles are capable of breeding and becoming pregnant immediately after a litter is born (Clifton 1960, p. 130; Hamilton 1962, pp. 492–495; Brown 1964, pp. 647–648), resulting in the potential for females to have two litters of differently aged young in their nests (Swingle 2005, p. 71; Forsman et al. 2009a, p. 270). Captive tree voles may have litters just over a month apart (Clifton 1960, p. 130). Two female voles in the wild produced litters at 30 to 35 day intervals (Forsman et al. 2009a, p. 270). In captivity, shorter gestation periods of 27–29 days may be typical (Clifton 1960, p. 92), but gestation

periods of 40 and 41 days were reported for females who bred immediately after giving birth (Hamilton 1962, pp. 486, 492–494). Young tree voles develop more slowly than similar-sized rodents of the same subfamily (Howell 1926a, pp. 49–50; Maser et al. 1981, p. 205), first exiting the nest at 30 to 35 days old and not dispersing until they are 47 to 57 days old (Forsman et al. 2009a, pp. 269–270).

Table 3. A comparison of reproductive potential between red tree voles and heather voles. Sources for red tree vole cited in text and include both in the wild and in captivity observations. Source for heather vole is Verts and Carraway (1998, pp. 308) unless otherwise noted.

Reproductive Variable	Red Tree Vole	Heather Vole
Sexual maturity	10–12 weeks	4–6 weeks
Gestation period	27–41 days	19–24 days
Mean litter size (range)	2.9 (1–4)	5.3 (2–9)
Age when juveniles first leave the nest	30–35 days	13–19 days ^a
Age when juveniles disperse	47–57 days	

^a McAllister and Hoffmann (1988, p. 3)

3.9.2. Diet

Tree voles are unique in that they are one of the few mammals that can persist on a diet of conifer needles (Forsman et al. 2016a, p. 1). They also harvest conifer twigs and consume the tender bark, underlying cambium, or both (Maser 1966, p. 143; Forsman et al. 2016a, pp. 49, 53). In most of their range, they feed primarily on Douglas-fir, although foraging on western hemlock, Sitka spruce, and grand fir (*Abies grandis*) has been recorded (Jewett 1920, p. 1266; Howell 1926a, pp. 52–53; Walker 1930, p. 234; Benson and Borell 1931, p. 230; Maser et al. 1981, p. 205; Forsman et al. 2016a, pp. 49–51). However, within the Sitka spruce vegetation zone, tree voles primarily consume needles from western hemlock and Sitka spruce, even when Douglas-fir trees are present (Forsman et al. 2016a, pp. 49–51). There is also a latitudinal difference in this food preference within the Sitka spruce zone for the north coast subregion (Forsman et al. 2016a, pp. 49–50) or northern half of the DPS. There may be tree voles south of the DPS along the Oregon coast that exhibit this feeding behavior, though the area has not been fully investigated (Swingle 2023, in litt.). Sonoma tree voles also feed on pines, specifically bishop pine (*Pinus muricata*) and introduced Monterrey pine (*P. radiata*) (Wooster and Town 2002, pp. 182–183; Forsman et al. 2016a, p. 50).

Conifer needles contain filamentous resin ducts that are filled with terpenoids, chemicals that serve as defensive mechanisms for trees by making the leaves unpalatable. Tree voles have adapted to their diet of conifer needles by stripping away these resin ducts and eating the more palatable portion of the needle (Benson and Borell 1931, pp. 228–230; Maser 1998, pp. 220–221; Kelsey et al. 2009, entire; Forsman et al. 2016a, pp. 51–52). Resin ducts may be located in different portions of the needle, depending on the tree species; this forces the tree vole to engage in different eating behaviors, depending on the tree species on which they forage. Paired resin ducts in Douglas-fir needles are located along the outer edges of the needle, so tree voles remove

the outside edge and consume the remaining middle portion of the needle. Conversely, western hemlock has a single resin duct located along the midline of the needle. Thus, voles foraging on hemlock needles will consume the outer edge of the needle and discard the center (Clifton 1960, pp. 35–45; Forsman and Swingle 2009, in litt.; Kelsey et al. 2009, entire; Forsman et al. 2016a, pp. 51–52). The location of resin ducts in Sitka spruce is midway between the edge of the needle and the midrib but can be absent or discontinuous and voles may only be eating portions of needles to avoid them (Kelsey et al. 2009, p. 13; Forsman et al. 2016a, p. 52). Douglas-fir has the lowest terpene resin concentration of the three species (Kelsey et al. 2009, p. 17) Sitka spruce contain a higher concentration of terpenoids and also alkaloids not present in the other two species, which may explain why tree voles are found in Western hemlock over Sitka spruce in the Sitka spruce vegetation zone (Kelsey et al. 2009, p. 17).

Tree vole preference for Sitka spruce and western hemlock needles within the Sitka spruce vegetation zone may be a requirement rather than a preference. Voles in the Sitka spruce vegetation zone rarely forage on Douglas-fir, even where it is available; foraging on Douglas-fir only becomes more evident where the Sitka spruce zone transitions into the adjacent western hemlock zone (Forsman and Swingle 2009, in litt.; Forsman et al. 2016a, pp. 49–54). Many have observed that tree voles adapted to a diet of one species of conifer would not eat another species when offered and some starved to death in captivity (Walker 1930, p. 235; Kelsey et al. 2009, p. 16; Maser 2009, in litt.). Because the resin ducts of western hemlock, Sitka spruce, and Douglas-fir needles are in different locations on the needle, their removal requires a different behavior depending on which species is being eaten (Clifton 1960, pp. 35–49; Kelsey et al. 2009, entire). Maser (Maser 2009, in litt.) suspected that voles raised in stands of western hemlock never learned the required behavior for eating Douglas-fir, although Walker (Walker 1930, p. 234) observed a single captive vole raised on hemlock needles that preferred hemlock but would eat fir or spruce in the absence of hemlock. Conversely, voles taken from Douglas-fir stands have been observed to eat both Douglas-fir and western hemlock in captivity (Clifton 1960, p. 44; Maser 2009, in litt.), although voles appear to be reluctant to switch between tree species (Walker 1930, p. 234; Forsman 2010, in litt. Forsman et al. 2016a, p. 52). Theories for this reluctance or inability to switch diets range from lack of appropriate intestinal flora for digestion to the feeding technique being a learned behavior passed from mother to young (Kelsey et al. 2009, p. 16; Forsman et al. 2016a, p. 52)

Tree voles consume much less free water than reported for most other vole species. Early researchers suspected that voles obtained water from their food and by licking it from tree foliage (Clifton 1960, p. 49; Maser 1966, p. 41; Maser et al. 1981, p. 205; Carey 1996, p. 75). This led to the conclusion by some that the availability of free water in the form of rain or dew may limit the distribution of tree voles to relatively humid forests in western Oregon and California (Howell 1926a, p. 40; Hamilton 1962, p. 503). More recent empirical evidence indicates that tree voles obtain almost all of their water from conifer needles, which are low in caloric value but high in water content (Forsman and Price 2011, p. 116).

3.9.3. Home Range Size and Dispersal

The only published data on home range sizes and natal dispersal come from red tree voles radio-collared outside of the analysis area, in the central Oregon Coast Range and Cascade Range of Douglas County (Swingle and Forsman 2009, entire). Tree vole home ranges are small and encompass their nest tree and a few adjacent trees. Eighteen of 45 radio-collared tree voles occupied only a single nest; however, the remainder occupied 2 to 6 different nests, ranging from 4 to 162 m (13 to 532 ft) apart, and averaging 45 m (148 ft) (Swingle and Forsman 2009, p. 277). The authors (Swingle and Forsman 2009, p. 282) suspect that using multiple nests is typical for males and non-breeding females. Mean and median home ranges were 0.17 ha (0.43 ac) and 0.08 ha (0.19 ac), respectively (Swingle and Forsman 2009, p. 278). Home range sizes did not differ among gender, age, or among voles occurring in young forests (22 to 55 years old) versus old forests (110 to 260 years old) (Swingle and Forsman 2009, pp. 277–279).

An unpublished study found mean male home ranges of 0.35 ha (0.86 ac) and mean female home ranges of 0.15 ha (0.37 ac) (Biswell unpublished data referenced in USDA FS and USDI BLM 2000, p. 8). Further, mean distance moved between consecutive nest trees for adult females and males was 31.4 m (103 ft), the greatest straight-line distance between consecutively occupied nest trees was 75.8 meters (249 ft), and when moving to a new tree, adult voles reoccupied previously constructed nest structures at least 68 percent of the time (Biswell 1996, p. 13). Additionally, red tree voles freely moved between nest trees with isolated canopies and crossed small forest roads, streams and large canopy gaps 30 m (98 ft) wide between those sites, necessitating ground movement (Biswell 1996, p. 13; Biswell 2005, p. entire). In another study, two radio-collared voles occasionally moved between nests on opposite sides of a 22-m-wide gravel road (Swingle 2005, p. 79).

Natal dispersal distances of tree voles are also short, and not substantially different from distances between nests within individual home ranges. The dispersal distance of six subadults monitored in Douglas County ranged from 3 to 75 m (10 to 246 ft), averaging 56 m (183 ft) (Swingle 2005, p. 63). The longest documented straight-line dispersal distance was for a subadult male who traveled 340 m (1,115 ft) over the course of 40 days (Biswell unpublished data referenced in USDA FS and USDI BLM 2000, p. 8).

The small home ranges and limited natal dispersal distances suggest that tree voles have limited ability to move into new areas. That is, juveniles do not venture far from their natal area to set up home ranges. This greatly restricts the ability of tree voles to expand and to establish new assemblages across the landscape. Because of this limited expansion capability, colonization is likely to occur at a slow rate as multiple generations expand incrementally over time (Linnell et al. 2018, p. 1179). This may also explain why tree voles tend to be found in clustered pockets across the landscape.

Given the limited natal dispersal capabilities of tree voles, forest fragmentation may be particularly problematic in terms of the ability for populations to persist or increase. Recent

modeling reveals that habitat suitability increases in areas with reduced fragmentation, as measured by amounts of nearby habitat, distance to such habitat, or distance to edges (Martin and McComb 2002; Rosenberg et al. 2016, p. 16; Johnston and Moskal 2017, p. 69; Linnell et al. 2017a, pp. 5–6, 2023, pp. 7–8)).

The point at which forest gaps become large enough to impede individual or population movements is not known. Howell (1926, p. 40) suggested that considerable expanses of land without suitable trees are a barrier to tree vole movements. Because tree voles do not move far (see earlier in this section), forest fragmentation can substantially restrict movements. Modeling of red tree vole habitat indicated that old forest cover (>80 years old)—especially within 200 m (656 ft) of red tree vole nests—is important to tree vole persistence (Johnston and Moskal 2017, p. 71). Combined with known natal dispersal distances, relatively small distances between forest habitat patches may serve as effective barriers to movements and thus colonization of new sites for red tree voles. This does not imply that tree voles, individually, cannot cross small canopy gaps. Radio-collared tree voles crossed logging roads, first-order streams, and canopy gaps up to 25 m (82 ft) wide (Biswell unpublished data referenced in USDA FS and USDI BLM 2000, p. 8; Swingle and Forsman 2009, p. 283). Some of these crossings occurred on multiple occasions by a single vole. This suggests that small forest gaps (Swingle 2005, p. 79) may not completely impair tree vole movement, but increasing gap size may be expected to limit tree vole movement and subsequent population expansion. There are three records of red tree voles captured in clearcuts (Borrecco 1972, p. 34; Corn and Bury 1986, pp. 404–405; Verts and Carraway 1998, p. 310), in one case over 200 m (656 ft) from the forest edge (Corn and Bury 1986, p. 404). In two of these instances, the authors suggested the individuals were most likely in the act of dispersing. Although tree voles may be capable of these movements, Swingle (2005, p. 79) suggested that the necessity of descending to the ground to cross openings may reduce survival.

3.9.4. Habitat

As mentioned above, red tree voles are found exclusively in coniferous forests or in mixed conifer/hardwood forests dominated by conifers (Hayes 1996, p. 3). Hardwoods are generally not recognized as an important habitat component (Biswell et al. 2002, p. 1) and have been found to have a negative relationship with habitat suitability (Forsman et al. 2016a, p. 66). Tree vole habitat is composed of coniferous trees suitable for foraging and nestbuilding, plus connected forest landscapes containing many suitable trees that support a population (Linnell et al. 2023, p. 4).

3.9.4.1. Nests

Tree vole nests are located in the forest canopy in the live crown on suitable foundations consisting of complex branch and bole structure, such as, palmate branch whorls, broken tops, forked trunks, cavities, dwarf mistletoe (*Arceuthobium* spp.) brooms, and abandoned nests of other species (Maser 1966, pp. 73–77; Swingle 2005, pp. 31–38; Forsman et al. 2008, pp. 1–2; Piasecki et al. 2022, pp. 30–31). Single large branches, dwarf mistletoe (*Arceuthobium* spp.)

brooms, cavities, and re-sprouted branch clusters serve as stable foundations for vole nests in larger trees, while whorls of branches, forked tops, split trunks, and broken tops can provide secure sites for nesting in smaller trees (USDA FS and USDI BLM 2000, p. 7; Piasecki et al. 2022, pp. 30–31). They use nests built by other species, or construct their own from twigs and resin ducts discarded from feeding, as well as fecal pellets, lichens, dead twigs, and conifer needles (Howell 1926a, p. 46; Clifton 1960, pp. 53–60; Maser 1966, pp. 94–96; Gillesberg and Carey 1991, p. 785; Swingle 2005, p. 39; Piasecki et al. 2022, p. 18).

With the exception of the Sitka spruce vegetation zone (see section 3.6 Vegetation), red tree voles throughout their range overwhelmingly use Douglas-fir for foraging and nesting (Jewett 1920, p. 165; Bailey 1936, p. 195; Swingle 2005, p. 31; Forsman et al. 2016, pp. 49–51). However, their nests have also been documented in Sitka spruce (Jewett 1920, p. 165), grand fir, western hemlock, Pacific yew (*Taxus brevifolia*), and non-conifers such as bigleaf maple (*Acer macrophyllum*) and golden chinquapin (*Castanopsis chrysophylla*) (Swingle 2005, p. 31). Within the Sitka spruce vegetation zone, tree vole diet and nest tree species selection favors western hemlock and Sitka spruce (Walker 1930, pp. 233–234; Forsman et al. 2008, p. 2, 2016a, pp. 49–50; Forsman and Swingle 2009, in litt.; Maser 2009, in litt. Price et al. 2015, p. 43), although some vole nests have been found in Douglas-fir in this vegetation zone (Howell 1921, p. 99; Jewett 1930, pp. 81–83; Forsman and Swingle 2009, in litt. Price et al. 2015, p. 43). When tree voles nest in a tree species that does not provide their preferred forage, (nesting in a Douglas-fir when western hemlock or Sitka spruce is the preferred forage species), there is almost always an interconnected limb to an adjacent tree of the preferred forage species, allowing ready access to food (Swingle 2005, p. 31; Forsman et al. 2016a, p. 50).

3.9.4.2. Old Forest

Tree voles (red and Sonoma) are more common and regularly occur in mature or old (> 80 years) or old growth (> 200 years) forests compared to young (>15 to 80 years) forests (Corn and Bury 1986, pp. 404–405, 1991, p. 245; Ruggiero et al. 1991, p. 460; Meiselman and Doyle 1996, p. 38; Gomez and Anthony 1998, p. 296; Martin and McComb 2002, p. 261; Jones 2003, p. 29; Dunk and Hawley 2009, entire; Forsman et al. 2016a, pp. 42–45; Rosenberg et al. 2016, p. 19; Rosenberg 2019, p. 168; McCoy et al. 2023, pp. 19–22). There is a consistent pattern of increasing density of trees with vole nests with increasing size class of forest (Forsman et al. 2016a, p. 25, Table 1-8). Habitat modeling and other empirical evidence across the range of the species shows that tree voles are associated primarily with old-forest characteristics such as older trees or stand ages, extent of old forest, larger trees (both in height and diameter), increased density of large trees, increased diversity in tree diameters, high levels of canopy cover, and diverse and complex canopy layering (Gillesberg and Carey 1991, p. 785; Meiselman and Doyle 1996, p. 36; Martin and McComb 2002, p. 259; Swingle 2005, p. 39; Dunk and Hawley 2009, p. 632; Forsman et al. 2016a, pp. 66–67, 74; Rosenberg et al. 2016, pp. 13–169; Johnston and Moskal 2017, p. 65; Linnell et al. 2017a, p. 5).

A wide variety of terms have been used to describe the older forest stands that tree voles tend to select (e.g., late-successional, old-growth, large conifer, mature, or structurally complex). In this analysis, we use these terms or specific stand ages when they appear in the cited literature. Otherwise, we use the term, “old forest,” when collectively referring to these stand conditions; based on recent habitat modeling, this generally means forest stands >80 years old (Linnell et al. 2017a, pp. 4–5). However, we also acknowledge that this is a general proxy and that stand age alone is not an indicator of tree vole habitat. Linnell et al. (2017a, p. 4) used an 80 year threshold to indicate tree vole habitat because it is an age where trees generally begin to develop structures on which tree voles can build nests. However, they also cautioned that such a threshold may mask the contribution of old-growth forests (>200 years) in providing higher densities of structural features that can support nests of tree voles and other arboreal rodents (Linnell et al. 2017a, p. 9). For example, the variables strongly associated with tree vole habitat modeled by Forsman et al. (Forsman et al. 2016a, pp. 66–67), higher densities of large (> 30 in (75 cm)) conifers and increased tree diameter diversity, are also typical characteristics of old-growth Douglas-fir forests in the Pacific Northwest (Spies and Franklin 1991, pp. 95–98). Hence, while we refer to stand age in our analysis, we realize that it is not an automatic indicator of habitat, and that suitable conditions may occur in some young stands and not in some old stands.

There are several hypotheses as to why red tree voles are associated with old forests or the structural characteristics typically found in old forests. These include the following:

1. High levels of primary production occurs in old-growth forests, with leaves concentrated in fewer trees, providing abundant forage opportunities and maximizing food availability for tree voles (Carey 1991, p. 8). Given that tree voles are arboreal, older forests simply have more volume of habitat available in any given area as a result of the increased tree crown heights as compared to younger forests (Rosenberg et al. 2016, p. 19). Tree canopy not only buffers weather changes but also has a high water-holding capacity, providing fresh foliage and a water source (Gillesberg and Carey 1991, pp. 786–787).
2. Old forest trees, especially old-growth trees, have complex branch and bole structures that tree voles and other arboreal rodents can build their nests on (cavities, broken tops, large limbs, dwarf mistletoe brooms, palmate branch whorls) compared to young forest trees that have less complex structures (Maser 1966, pp. 73–77; Thompson and Diller 2002, pp. 98–99; Swingle 2005, pp. 31, 36, 38; Forsman and Swingle 2009 in litt.; Forsman et al. 2016a, p. 44; McCoy et al. 2023, entire). In a four-year study looking at red tree vole nesting substrates and nest survival in the Oregon Coast Range, larger nests were more likely to survive year to year (Piasecki et al. 2022, p. 26). The largest nests were found in cavities and dwarf mistletoe brooms followed by broken top and split trees, features found in older forests (Piasecki et al. 2022, p. 31). Whether tree voles use pre-existing nests constructed by other species or not varies by stand age as well, with between 40-50 percent of tree vole nests in young forest and less than 5 percent in old forest constructed by other species, such as Humboldt’s flying squirrel (Piasecki et al. 2022, p. 18). In older forests, tree voles use live trees for nesting, where Humboldt’s flying squirrels often nest in snags (Carey 1991, pp. 11–12). In younger forests where these features aren’t available, both species tend to use the same features (McCoy et al.

2022) and tree voles more often used nests constructed by other species (Piasecki et al. 2022, p. 18). Settlement of tree voles may be positively influenced by the presence of conspecifics by providing cues about habitat quality (Linnell et al. 2018, p. 1179). Therefore, competition and opportunity for nest sites may vary across stand ages. Nests in old forest, which are more cryptic and higher in the canopy, may decrease tree vole predation (Durham et al. 2019, entire; Piasecki et al. 2022, p. 35; McCoy et al. 2023, entire).

3. Finally, old-growth Douglas-fir forests (multi-layered stands over 200 years old) may provide environmentally and structurally stable conditions compared to younger forests where trees are continuously growing and tree canopy architectures are changing (Carey 1991, p. 8).

3.9.4.3. *Young Forest*

Tree vole nests can be found in young forest (< 80 years) at relatively high densities (Jewett 1920, p. 165; Howell 1926a, pp. 41–45; Brown 1964, p. 647; Maser 1966, p. 40; Corn and Bury 1986, p. 404; Thompson and Diller 2002, p. 95; Swingle and Forsman 2009, p. 277; Forsman et al. 2011, p. 4; Price et al. 2015, p. 43). However, while voles were found in some young stands in coastal Oregon, the majority of younger stands examined were not occupied by tree voles (Forsman et al. 2011, pp. 4–5; Price et al. 2015, pp. 45–46). In one case, the young stands occupied by voles were adjacent to older forest stands (Price et al. 2015, pp. 45–46). Similarly, tree voles were found in young stands (20–40 years) within 1.3 km of old forests ($n = 54$ over three years) but not in stands > 1.3 km from old forest ($n = 13$ over two years) (NCASI 2022b, p. 11). Detection of tree vole nests in older stands is likely biased low because of greater difficulty in detecting nests in old forests (Swingle and Forsman 2009, p. 284; Marks-Fife 2016, p. 78; McCoy et al. 2023, pp. 20–23).

Persistence of red tree vole nests in young stands could be ephemeral. Surveys in formerly occupied young stands yielded no detections 3–7 years later (Forsman et al. 2016a, p. 32). However, a combination of stand age and distance from old forest influences occupancy. In a more recent study, which included portions of the DPS, tree vole nests were found in a variety of stand ages from 20 to 320 years old and the proportional density of likely occupied and recently occupied nests was correlated to stand age following a bimodal curve with peaks at around 30 year and beyond 100 year stand ages (Scoresby et al. 2022, entire; NCASI 2022b, pp. 9–15). The proportional density decreased across all stand ages as distance from old (> 80 years) forest increased, especially after 1.3 km (Scoresby et al. 2022, entire).

The suitability of young forests as red tree vole habitat, and their role in the abundance, persistence, or dispersal of red tree voles, is unclear. Based on surveys in young forests (22 to 55 years old) and observations of radio-collared tree voles, Swingle (2005, p. 78) and Swingle and Forsman (2009, pp. 283–284) concluded that some young forests may be important habitat for tree voles, particularly in landscapes where old forests have largely been eliminated or currently exist in isolated patches. However, Swingle (2005, p. 78) cautioned against using the occasional

presence of tree voles in young forests to refute the importance of old-forest habitats to tree voles. Available anecdotal evidence suggests that where tree voles occupy young forest stands, occupancy may be relatively short-lived (Diller 2010, in litt.) or intermittent (Hopkins 2010, in litt.; Scoresby et al. 2022, entire). As an example, Forsman et al. (2016a, p. 32) found several locations where occupied tree vole nests occurred in a 35-year-old plantation in Benton County, only to return to those stands three to seven years later and not find any occupied nests. (Hopkins 2010, in litt.) made similar observations; he also observed that likely occupied nests in old-growth stands (350-400 years) or stands with old-growth structural characteristics tended to remain occupied on follow-up visits. In some cases, tree voles persisted for at least ten years in small older stands fragmented by harvest 40 years prior to the surveys (Hopkins 2023, in litt.).

Habitat modeling reveals a higher probability that red tree voles will occupy young stands the closer the stands are to old forest or tree vole habitat (Rosenberg et al. 2016, p. 19; Johnston and Moskal 2017, p. 66; Linnell et al. 2017b, p. 5,6,9). Given the limited natal dispersal capability of red tree voles, it follows that the distance from vole habitat could affect occupancy of new sites. The distance between old forest habitat patches should be less than 2 km (1.2 mi) to support persistent tree vole populations (Lesmeister et al. 2016, pp. 14-15) and preliminary information suggests 1.3 km may be more appropriate (NCASI 2022b, pp. 10–11). This suggests that young forests may complement overall habitat suitability, but only when in close proximity to old forests. The occurrence of active nests in remnant older trees in young stands also indicates the importance of legacy structural characteristics (Biswell et al. 2002, p. 1). Young forest stands may serve as interim habitat for tree voles and may provide connectivity between remnant patches of old forest, perhaps up to some unknown threshold distance. However, it is unknown whether or not young forests are capable of supporting viable populations of tree voles over the long term; most sites in young forests are ephemeral or the habitat is removed because stands are harvested or commercially thinned (Forsman et al. 2016a, pp. 32–34).

Habitat Patch Size

We lack specific data on the minimum patch size of habitat required to sustain populations of the red tree voles over the long term. Johnston and Moskal (2017, pp. 65–66) suggest that habitat quality within 200 m (656 ft) of a nest site is important to red tree voles (this equates to 12.5 ha (31 ac) around a nest site). The authors concluded that, given the limited dispersal capabilities of the species and the tendency for nests to be clustered in stands, sufficiently large habitat patches were needed to support multiple individuals that could sustain a local population. A 20 ha (49 ac) minimum old-forest patch size has been suggested as necessary to support a breeding population of tree voles (Lesmeister et al. 2016, p. 14; Linnell et al. 2017a, p. 2,9). This was based on a population study documenting 1 vole/ha (0.4/ac) (Maser 1966, pp. 216–217) and assuming a minimum population size of 20 tree voles necessary for local persistence. Lesmeister et al. (2016, p. 14) did caution that the 20-ha (49-ac) patch size was somewhat arbitrary given the lack of information on patch sizes necessary for the long-term persistence of tree voles. Vole nests with signs of occupancy have been found in forest patches as small as 2 to 4 ha (5 to 10 ac), but they were in the oldest (350 to 400 years), most structurally complex stands available (Hopkins

2010). Compiled data on actual tree vole presence in primarily old-growth stands (> 200 years) in the Oregon Coast Range showed a minimum stand size of 30 ha (75 ac), with mean and median stand sizes of 192 and 129 ha (475 and 318 ac), respectively (Huff et al. 1992, pp. 6–7). Minimum patch sizes are influenced by such things as habitat quality within and surrounding the patch, the position of the patch within the landscape, and the ability of individuals to move among patches (Huff et al. 1992, p. 7; Martin and McComb 2003, pp. 571–579).

3.9.5. Survival

Estimates of red tree vole survival is limited to a single study wherein the annual survival of radio-collared tree voles was estimated at 15 percent (95-percent confidence interval = 6–31 percent), which may be greater than most terrestrial rodents (Swingle et al. 2010, p. 259). Predation was the greatest mortality source, accounting for 50 percent of all mortalities of radio-collared animals (Swingle et al. 2010, p. 257). Other mortality sources include disease, old age, storms, wildfires, and timber harvest (Maser et al. 1981, p. 206). Carey (1991, p. 8) suggested that wildfires and logging are far more important mortality factors than predation in limiting vole abundance. We discuss habitat loss due to wildfire and timber harvest elsewhere in this document (see section 5.1. Habitat Loss, Modification, and Fragmentation). We discuss predation below and we have no or limited data on the remaining mortality sources.

Red tree voles are prey for a wide variety of mammals and birds (see section 5.2 Predation), though there is little data on what affects the vulnerability of red tree voles to predators. Predators can have strong lethal and nonlethal effects, including nest abandonment, on tree voles (Linnell and Lesmeister 2020, p. 8618). Of 25 documented cases of predation on radio-collared voles, most occurred in young (22 to 55 years old) forests (Swingle 2005, p. 64; Forsman and Swingle 2009, in litt.). Predation by weasels (*Mustela sp.*), which accounted for 60 percent (15 of 25) of the predation events, occurred only in young forests, and 80 percent of the weasel predation was on female voles; however, the majority of the tree voles radio-collared in the study were females in young forests, so forest age and vole gender explained little of the variation in the data (Forsman 2010, in litt.; Swingle 2010, in litt.). Weasels accounted for seven of 12 observed mortalities of tree voles at artificial nest platforms in young (22–44 years old) forest (Linnell and Lesmeister 2020, p. 8617), and was followed by reduction of tree vole activity at the nests for several weeks (Linnell and Lesmeister 2020, p. 8619). Examination of paired plots of tree vole nests in the Oregon Coast Range on artificial nest platforms in young (33–44 years) versus old (> 150 years) forests showed that predator visitation rates to nests were higher in young forests, though no difference in apparent tree vole survival was detected ($n = 12$) (Durham 2019, pp. 27, 33, 35). This could suggest that predation risk may be higher in young forests than in old forests, although no data was provided on actual predation events and the degree to which the artificial platform may have influenced visitation rates was not discussed. Additionally, this study was on predation at the nest, and we do not know if there is a different predation rate away from the nest which could be affecting tree vole populations at the local level. Weasel predation on tree voles may be inversely proportional to nest height (Swingle et al. 2010, p. 260). Tree vole nests tend to be found in the lower portion of the tree crown (Gillesberg and Carey 1991, pp.

785–786; Swingle 2005, pp. 29–30; Marks-Fife 2016, p. 76) and tend to be higher above the ground in older stands or larger trees than in younger stands or smaller trees (Vrieze 1980, p. 18; Meiselman and Doyle 1996, p. 38; Swingle 2005, pp. 29–30). This is logical given that larger, older trees are taller, with the base of the tree crowns often higher above the ground, compared to smaller trees in younger stands. This allows for nesting at increased heights in old stands compared to young stands. Thus, tree voles could be more prone to predation in shorter trees or young stands where nests are typically closer to the ground. Female tree voles may be more susceptible to predation than males because they occupy larger, more conspicuous nests and they spend more time outside the nest collecting food for their young (Swingle et al. 2010, p. 261). Estimated annual apparent survival was higher for females (0.14; 95% CI: –0.04, 0.32) than males (0.01; 95% CI: –0.02, 0.02) in a predation study of tree voles using artificial nest platforms in young forest (22–44 years) (Linnell and Lesmeister 2020, p. 8617). In summary, there are few studies looking at the factors influencing survival though predation and habitat modification appear to be key factors. Tree voles likely depend on several forest characteristics to reduce predation risk and improve survival. A connected forest canopy or a large enough tree provides sufficient foraging and dispersal capability and minimizes the need to travel to the ground, which may increase predation risk. Nesting in old forests may reduce predation risk because the complexity of older stands may make tree vole nests, especially the larger nests of females, less conspicuous to predators. In addition, nesting at increased heights in trees in old forests, compared to young forests, may also reduce exposure to terrestrial predators.

4. RED TREE VOLE ECOLOGICAL NEEDS

In this section, we take what we know about the red tree vole life history and frame it in terms of what the species needs to maintain viability through time. We assess these needs at the scale of the individual, the population, and finally, the species, characterizing the biological status of the species in terms of its resiliency, redundancy, and representation.

4.1 Individual Needs

Red tree vole life stages can be broken down into juvenile, subadult, and adult stages (Table 4). We define the juvenile stage starting at birth and continuing until the individual leaves its natal nest. Young are born naked and blind and depend on the female to survive until they leave their natal nest (Howell 1926a, p. 48; Maser et al. 1981, p. 205). Early on the female provides food (through lactation) and a thermal source for the young. They are also dependent on the nest shelter that the female has built to hide from predators and to maintain body temperature. As the young get older, they learn how to forage, as well as how to navigate the forest canopy (Maser et al. 1981, pp. 205–206; Forsman et al. 2009a, pp. 268–269). At about 7–9 weeks of age, the young leave their natal nest to establish their own nest and home range (Swingle 2005, p. 63; Forsman et al. 2009a, pp. 268–269).

The subadult stage occurs between the time the tree vole leaves its natal nest until it establishes an individual home range and becomes sexually mature. There doesn't appear to be any difference in habitat use between dispersing subadults and adults, and the period between leaving

the natal nest and establishing a new nest can be very brief (as short as 4 days), with the new nest often less than 100 m from the natal nest (Swingle 2005, p. 63). Subadults occasionally venture further from their natal nests, but they are weak dispersers (Swingle 2005, p. 88).

We consider the adult stage beginning at sexual maturity, which is at around 2.5 to 3 months of age (Clifton 1960, pp. 119–120). The nest tree or surrounding trees provides the vole’s food (conifer needles and cambium or bark of small twigs) and their nesting material (primarily conifer cuttings, twigs, and resin ducts). While voles can travel on the ground, it is uncommon (Swingle 2005, pp. 62–63), and they may be at greater risk to other mortality sources. A structural platform or cavity is needed to support a nest, and old forests tend to provide the structural complexity that increases the abundance of these features. Finally, tree voles are prey to numerous predator species, ranging from terrestrial-based mustelids such as weasels, to diurnal and nocturnal raptors, to other arboreal rodents such as Humboldt’s flying squirrels (*Glaucomys oregonensis*) (see section 5.2 Predation). Consequently, reducing their predation risk is important. Old forests seem more conducive to protecting red tree voles from predators (see Section 3.9.5 Survival).

Table 4. Red tree vole life stage table summarizing the species needs.

Life Stage or Biological Process	Resource Needs	Function
Juvenile (birth to dispersal at ~47-60 days old)	Female: Source of food and, early on, thermal protection. Maintain and develop nest. Survival education.	Shelter and Feeding
All life stages	Food: Conifer boughs for food. Primarily Douglas-fir, Sitka spruce and western hemlock, depending on vegetation zone.	Feeding
Juvenile		
Subadult (dispersal period from leaving nest to establishing a new home range)	Nest material: Conifer twigs, lichens, and resin ducts discarded from feeding.	Shelter
Adult (onset of sexual maturity at ~2.5- 3 months of age)	Nest support structure: Solid structure to support a nest that can get rather large. Structures include abandoned nests of other species, large branches, dwarf mistletoe brooms, epicormic palmate branches, branch whorls, forked trunks, forked or broken tops, and cavities.	
	Protection from Predators: Connected conifer tree canopies to reduce foraging time outside of the nest and limit the need to travel to the ground to get to the next tree, which increases exposure risk.	Shelter

Subadult	Opportunity to populate new habitat: Connection to coniferous forest with sufficient structure for nests, or proximity to patches of old forest. Occupied patches of old forest may be important in providing emigrants to young forests post-disturbance.	Dispersal
Adult	Opportunity for breeding: Sufficiently large patches of habitat where both genders can persist separately yet come together to breed.	Breeding

In summary, the needs of individual tree voles are met in coniferous forest stands with 1) nest trees large enough to supply a vole's food, or, for smaller trees, connected to adjacent trees by adjoining branches; 2) connected tree canopies to facilitate breeding and dispersal and minimize time on the ground that may increase predation risk; 3) available structures to support nests; and 4) structural complexity and taller trees that likely reduce visibility and vulnerability to predators. Most of these features, the exception being connected canopies, are more common in older forests.

4.2 Population Needs—Resiliency

As described above (see Section 2 ANALYTIC FRAMEWORK), resilient populations are sufficiently large and well-connected that they can withstand and rebound from random environmental, genetic, and demographic events that may temporarily reduce their overall population health. Connectivity among red tree vole populations can be assessed by the permeability of the intervening matrix between populations including the similarity of the intervening landscape to occupied areas, and degree to which it facilitates movement among populations (Prugh et al. 2008, pp. 20773–20774). Applying this concept to red tree voles, the permeability of the intervening landscape between populations is assumed to be dependent on forest age and structure, with barriers to movement occurring when there is extensive recently disturbed forest (Linnell et al. 2017a, p. 7). Proximity to old forest was a primary contributor to relative habitat suitability of a young forest matrix in the (Linnell et al. 2017a, p. 6) model. Connections may exist long-term on the landscape, or may occur as a shifting mosaic, developing in some locales as other areas are removed through natural or human-caused disturbances. However, because of the limited vagility (ability to disperse or make extensive movements across the landscape) and low reproductive potential and life expectancy of tree voles, connectivity among populations most likely occurs not at the scale of individuals dispersing to new areas, but at the scale of generations as reproducing voles move across the landscape through time (Linnell et al. 2018, p. 1179). While young forests can support reproducing voles (NCASI 2022b, p. 17), the more stable that landscape is, as seen in old forest stands, the greater is the likelihood that connectivity among populations is possible.

Hence, resilient tree vole populations, summarized in Table 5, would need to be sufficiently large to persist following stochastic events. They would also need to be connected to other

populations through an intervening landscape that maintains permeability through time in the same or in different spatial locations.

Table 5. Summary of red tree vole population needs to maintain resiliency.

Population Fitness	Importance	Element
Healthy demography	Maintain a self-sustaining group of red tree voles with adaptive capacity and capable of withstanding stochastic events	Sufficiently large effective population size (N_e) (see 6.3.1. Red Tree Vole Habitat Capacity and Effective Population Size Capacity)
Habitat to support healthy demography	Provides needs for enough individuals to persist as a self-sustaining group of red tree voles	Coniferous trees suitable for foraging and nestbuilding and large enough connected patches of suitable trees to support a population
Connection to other populations	Ability to maintain gene flow and provide demographic support to adjoining tree vole assemblages	Intervening matrix between occupied tree vole population areas that can facilitate movement or will grow into habitat in sufficient time to facilitate demographic support

4.3 Species Needs—Representation and Redundancy

4.3.1. Representation

Representation is about having the breadth of genetic makeup at the species level to adapt to changing environmental conditions, and can be measured through diversity in genetics, ecological conditions, behavior, or morphology (see section 2 ANALYTIC FRAMEWORK). Increased representation or diversity may provide greater capacity to adapt to environmental changes.

Specific to red tree voles, representation includes the behavioral diversity in foraging capability in response to the availability of different coniferous species (see section 3.49.2 Diet). This tends to be associated with the vegetation zone, which reflects the predominant tree species, so vegetation is used a proxy for this behavioral diversity. Hence, an adequate distribution of tree voles within these vegetation zones will improve representation of the species. Maintaining a diversity of genetic, behavioral, and morphological traits will also benefit tree voles with ongoing and future environmental changes such as novel predators and their effects on the existing predator community (see section 3.49.5 Survival, as well as climate change and its effect on forest species composition in the future (see section 7.1.2 Climate Change).

4.3.2. Redundancy

Redundancy reflects the capacity of the species to withstand catastrophic events (a rare, destructive natural event that involves multiple populations) by having multiple populations adequately distributed across the landscape (see section 2 ANALYTIC FRAMEWORK). Generally, the greater the number of populations and the broader the distribution of the populations across the landscape, the better the species can withstand a catastrophic event.

Catastrophic events associated with the Oregon Coast Range discussed in this analysis are wildfires and windstorms. Large-scale high severity wildfires in the Oregon Coast Range are infrequent events (on the order of hundreds of years) and are most often stand replacing. The large wildfires over the past 150 years have ranged from 1,200 km² (460 mi²) to 3,240 km² (1,250 mi²) (see section 5.1.2 Wildfire). Smaller and less severe wildfires also occur in the area and could collectively contribute to habitat modification at landscape scales. Wildfires are the greatest catastrophic event that may affect tree voles in terms of size and severity, resulting in an immediate loss of habitat that isolates remaining populations.

Some windstorms may also fit in this category. On average, storms with winds or gusts reaching at least 119 km/hr (74 mi/hr) occur every 25 years for any given location in the central and northern Oregon coastal area (Harmon and Pabst 2019, pp. 2–3). While these events can be wide-spread with hurricane-force winds spanning multiple states, the actual stand-replacement habitat removal that typically occurs is scattered in patches across this area, unlike high severity wildfires that can often be mapped within a single footprint or a complex of adjacent footprints. This type of disturbance on a small scale can create structures in trees, such as broken tops, which can facilitate nest building. However, these disturbance events may be roughly equivalent in their resulting loss of standing trees. As an example, the 1962 Columbus Day storm from California to British Columbia killed a similar volume of timber across the area as did the 1933 Tillamook Burn (Harmon and Pabst 2019, p. 2). Patches of severe blowdown are usually less than 2 ha (5 ac) in area (Harmon and Pabst 2019, p. 13), although Harcombe et al. (2004, p. 76) found blowdown areas from the initial wind event growing in size to roughly 50 ha (120 ac) because exposed stand edges become vulnerable to less severe wind events, expanding the size of the openings.

Tree voles may recover from a catastrophic events if the area they occupy is larger than the footprint of the stand-replacing disturbance event or if patches of refugia within the footprint exist, and the red tree vole population areas remaining after the event are sufficiently large to remain resilient until the time that the disturbed area is returned to suitable habitat (Table 6). Alternatively, red tree vole population areas may be smaller and well-distributed across the analysis area such that when a large event, or multiple smaller events, occurs the remaining population areas continue to function and are connected to other remaining population areas. This would allow the vole population areas to maintain their resiliency through time until the intervening disturbed area returns to habitat that is suitable for population area connectivity or occupancy.

Table 6. Summary table of red tree vole species needs.

3Rs	Needs for long-term-viability	Description
Resiliency	Interconnected healthy tree vole population areas with habitat to provide for feeding, sheltering and protection from predators	Population areas of red tree voles with (1) sufficiently large effective population size; (2) sufficient amount of habitat; and (3) intervening matrix of forest between that allows for occasional demographic and genetic exchange
Representation	Maintain diversity	Resilient tree vole population areas distributed across the two vegetation zones (Sitka spruce and western hemlock)
Redundancy	Sufficient distribution of healthy tree vole population areas	Sufficient distribution to guard against catastrophic events
	Sufficient number of healthy tree vole population areas	Adequate number of healthy tree vole population areas to buffer against catastrophic losses
	Sufficient size (area) of healthy tree vole population areas	Adequate size of tree vole population areas corresponding to the scale of the catastrophic event such that sufficient individuals remain to persist in an area post-disturbance.

5. FACTORS INFLUENCING THE SPECIES

5.1 Habitat Loss, Modification, and Fragmentation

There has been an estimated 23 percent Oregon-wide reduction in the tree vole range between 1914 and 2006; for the North coast subregion of the analysis area (Figure 4) that range reduction is 80 percent (Forsman et al. 2016a, p. 82). Contraction of old forest has substantially shaped and constrained the current distribution of red tree voles in the northern half of the Oregon Coast Range (Linnell et al. 2017a, p. 6). Old-forest cover in the DPS contracted by more than 80 percent in extent from 56 percent in 1911 to 11 percent by 2015 (Linnell et al. 2017a, p. 6). Multiple areas of the north coast subregion where tree voles were historically found in the 1940s through 1970s had few or no voles when revisited over the past two decades. In the time since the voles were originally found, virtually all of these locations had been harvested, burned, or both, and subsequently converted to either nonforest use or to intensively managed stands of young forest (Forsman et al. 2016a, p. 37). Landscapes throughout the Coast Range have become increasingly fragmented and dominated by younger patches of forest, as old and mature forests

have been converted to young stands through timber harvest and wildfire (Wimberly et al. 2000, p. 175, 2004, p. 152; Wimberly 2002, p. 1322; Martin and McComb 2002, p. 255; Wimberly and Ohmann 2004, p. 631). More recently, gains in old forest (> 80 years) on some federally managed lands have occurred in the Oregon Coast physiographic province (1994-2017), especially in areas where there were large, stand-replacing wildfires from the mid-19th and early-20th centuries (Davis et al. 2022, pp. 39–40). Tree vole modeled habitat trends in the DPS showed increases on Federal lands but up to 50 percent decreases on non-Federal lands from 2006 to 2022 (Linnell et al. 2023, p. 8).

Habitat loss and modification can be attributed to multiple sources. Wildfires were the primary source of large patches of stand-replacing disturbance prior to European settlement, with fires as large as 3,237 km² (1,250 mi²) occurring in the Coast Range in the mid-1800s (Teensma et al. 1991, p. 2). Beginning in the mid- 1900s, the primary disturbance was timber harvest, with wildfires accounting for a small portion of the loss. Where development occurs, it is primarily associated with urban areas and along the edges of the Willamette Valley (Johnson et al. 2007, p. 41; Spies et al. 2007a, p. 11). Another potential source of habitat loss and modification for red tree voles is Swiss needle cast, a foliage disease specific to Douglas-fir caused by the fungus *Phaeocryptopus gaeumannii*.

5.1.1. Timber Harvest and Management

The historical losses of old forest and ongoing management of most non-Federal forests on a short-rotation schedule have resulted in the loss and fragmentation of tree vole habitat. Land ownership had the greatest influence on changes in forest structure during the 20th century, with State and Federal ownership retaining more large-conifer structure than private lands in the Oregon Coast Range (Wimberly and Ohmann 2004, p. 63). Between 1972 and 1995, timber clearcut harvest rates in all stand types were nearly three times higher on private land (1.7 percent of private land per year) than public land (0.6 percent of public land per year), with the Oregon Coast Range dominated by private industrial ownership and having the greatest amount of timber harvest as compared to the adjacent Klamath Mountain and Western Cascades Provinces (Cohen et al. 2002, p. 122). Within the Oregon Coast Range, there has been a substantial shift in timber harvest from Federal to State and private lands since the 1980s, with an 80 to 90 percent reduction in timber harvest rates on Federal lands (Azuma et al. 2004, p. 1; Spies et al. 2007b, p. 50). Much of the decline in timber harvest on Federal lands is a result of implementation of the NWFP in 1994 (Spies et al. 2007a, p. 7). Area of old forest (> 80 years) has actually increased on Federal lands in the Oregon Coast Range by 38.8 percent from 1993 to 2017. This has occurred in spite of approximately 19,000 acres in losses to timber harvest (Davis et al. 2022, p. 55).

Timber harvest not only removes tree vole habitat, but short rotations that manage for young stands may maintain these areas as unsuitable or shorter term tree vole habitat as compared to old forest (Forsman et al. 2016a, p. 32; Scoresby et al. 2022, entire). Tree voles may be excluded from young stands because suitable nesting structures may be absent. Where artificial nesting platforms were installed in young (20-80 years) forests adjacent to old forests, a 5.8-fold increase

in plots containing tree vole nests was observed (Linnell et al. 2018, p. 1177). Though other unknown factors may be limiting populations, this suggests that increasing available nesting substrates may increase red tree vole abundance in young forests where such substrates are limiting (Linnell et al. 2018, p. 1174).

Where stands are subject to thinning, persistence of tree voles is not well understood. Anecdotal evidence indicates that thinning young stands occupied by tree voles can reduce or eliminate voles from these stands (Swingle 2010, in litt.; Biswell 2010, in litt.; Wilson and Forsman 2012, p. 185). Conversely, when vole nests classified as occupied (based on indication of activity such as presence of fresh green resin ducts) were protected with a 10-ac (4-ha) buffer zone during thinning treatments, signs of occupancy at these nests post-treatment were found, although signs of occupancy were intermittent through time (Hopkins 2010, in litt.). Red tree voles may ultimately come back to a treated stand, but how long it will be after the treatment before the stand is reoccupied is unknown. If and when tree voles return likely depends on a multitude of factors including magnitude, intensity, and frequency of the treatment within the stand; type and amount of structure left after treatment (available nesting platforms); and, whether or not there is a refugium or source population nearby that is available to supply voles for recruitment when the treated stand becomes suitable again (Forsman 2010, in litt.; Swingle 2010, in litt.; Biswell 2010, in litt.; Hopkins 2010, in litt.).

Young stands are likely to provide linkages and complement existing old forests the closer they are and the more similar they are in structure to old forests (Linnell et al. 2017a, p. 6; Linnell and Lesmeister 2019b, p. 572). However, thinning treatments in these stands have the potential to further reduce vole numbers in the short term, especially if thinning does not account for structural features and the connectivity of those features that are important to red tree voles (Swingle and Forsman 2009; Wilson and Forsman 2013, pp. 84–86). In the long run, thinning that accelerates the development of large trees and structure for nests could favor tree voles, assuming the stands could be colonized.

5.1.2. Wildfire

Wildfires are infrequent in the Oregon Coast Range but can be large, stand-replacing events that kill most of the overstory (Agee 1991, pp. 28–30, 1993, pp. 187–191, 205–212; Teensma et al. 1991, p. 3; Forsman et al. 2016a, p. 20, Fig. 1-6), although low- and moderate-severity fires also occur (Teensma et al. 1991, p. 3; Impara 1997, p. 92; Gedalof et al. 2005, p. 170; Meyn et al. 2007, pp. 294, 301–303). Warm, dry climate conditions, combined with Euro-American settlement, may have influenced the onset of large-scale wildfires (Weisberg and Swanson 2003, p. 25). Occurrence of fire in the low frequency, high severity fire regime of the Oregon Coast Range is limited primarily by climate and weather, ignition, and regional wind patterns (Reilly et al. 2021, p. 410). Although wildfire return intervals are estimated at 150–300 years (Teensma et al. 1991, pp. 2–3; Long et al. 1998, p. 786; Long and Whitlock 2002, p. 223), it is difficult to infer a cycle because the historical fire record in these forests is not long enough to establish a pattern. Wildfires in Coast Range forests probably do not exhibit a regular frequency, but instead

occur at irregular intervals (Agee 1991, p. 29; Teensma et al. 1991, pp. 2–3). The temperate rainforest of the Oregon Coast Range rarely burns because fuels are rarely dry enough. Consequently, wildfires in the Oregon Coast Range are typically associated with infrequent weather or climate events, such as drought or east winds, that dry the fuels sufficiently to allow fires to start and spread (Teensma et al. 1991, p. 3; Gedalof et al. 2005, p. 170; Meyn et al. 2007, p. 294). Dry east winds are infrequent on the Oregon Coast Range but exceptionally strong (Reilly et al. 2022, p. 6).

In the mid-1800s, a 3,240 km² (1,250 mi²) fire or fire complex burned over the southern portion of the analysis area, and within a few years, the 1,200 km² (460 mi²) Nestucca fire burned to the north (Figure 10). The Tillamook fires in the northern part of the DPS burned a combined area of 1,420 km² (550 mi²) from 1933-1951, but 2 other wildfires burned concurrently with the 1933 Tillamook fire, adding an additional 400 km² (150 mi²) (Teensma et al. 1991, p. 2). The wildfires of the 20th century seem to have eliminated tree voles from much of their footprint, based on the absence of tree vole detections during surveys of the Tillamook Burn area in the Oregon Coast Range, as well as surveys of two fire areas in the Cascade Range that burned in the mid-19th and early 20th centuries (Forsman et al. 2016a, p. 43). Tree voles have not recolonized the Tillamook Burn, possibly because it is too far from a population source or because subsequent management of the burned area has maintained unsuitable habitat conditions, or both. For example, the Tillamook Burn area was salvage-logged, replanted with Douglas-fir, and intensively managed with occasional thinning to promote growth rates and timber volume production. Moderate to severe Swiss needle cast infections over large portions of the burn area has also restricted crown closure, tree growth, and tree vole habitat development (Wilson 2019, in litt). Tree vole surveyors found that these stands typically had low crown closure and were mostly lacking the canopy structures needed to support nests (Forsman et al. 2016, p. 43–44). Conversely, other old fire areas in the Oregon Coast Range from the mid-1800s have shown an improvement in old-forest abundance and diversity (Davis et al. 2015, p. 38). These areas overlap substantially with the large blocks of tree vole habitat on Federal lands, managed primarily by USFS, within the analysis area (Units 3,5,7,9, and 10, Figure 8).

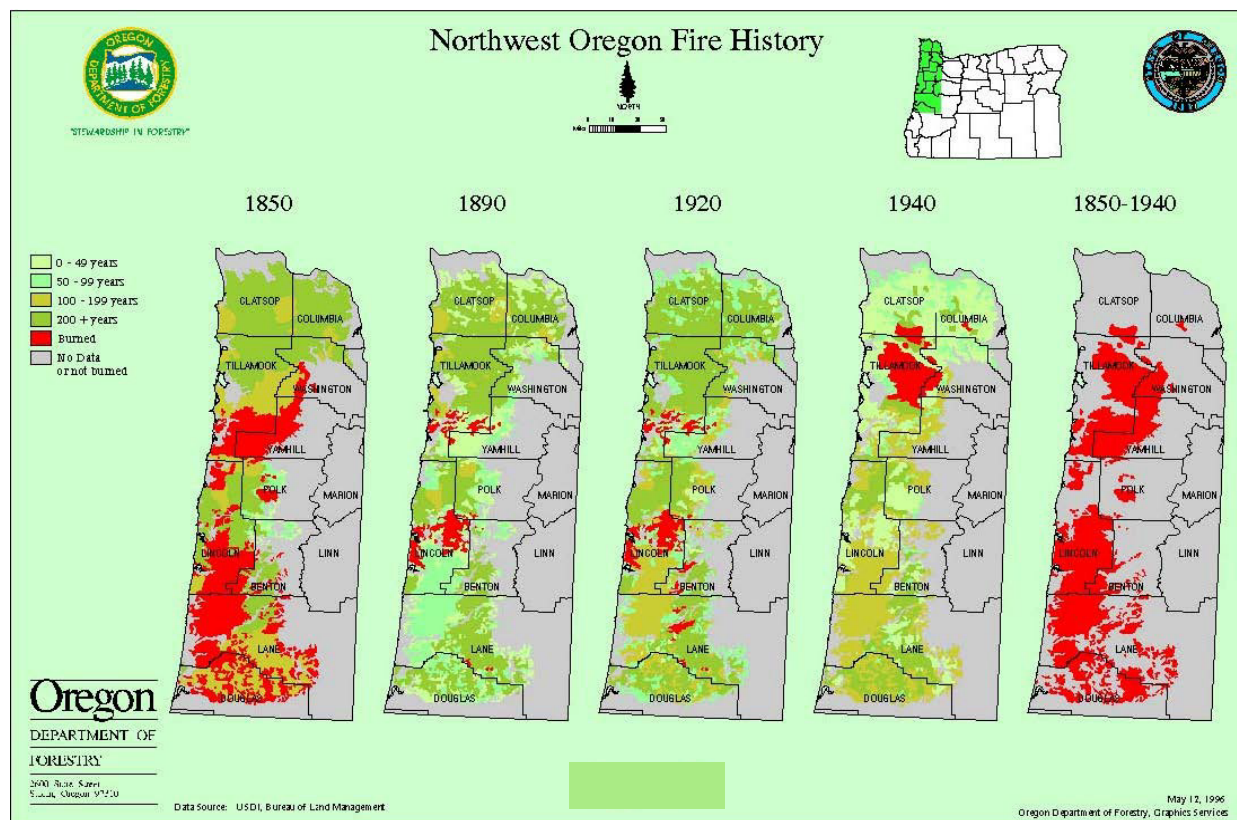


Figure 10. Pattern of large-scale wildfire history and vegetation change in the Oregon Coast Range from 1850 to 1940. Figure is from an anonymous, undated source (Anonymous, undated, p. 11), but the individual fire and vegetation maps correspond with Teensma et al. (1991, unnumbered map section).

Wildfires have historically influenced the Coast Range landscape, typically removing tree vole habitat across extensive areas (Morris 1934, pp. 317–322; Pyne 1982, pp. 336–337; Agee 1993, p. 212; Wimberly 2002, p. 172). Another complication in these wetter forests has been a pattern of multiple reburns that occurred, such as the Tillamook Burns of 1933, 1939, 1945, and 1951. Reburns may or may not add large amounts of additional area to the original burn, but they have the potential to impede the development of the stand for decades, delaying the ultimate return to forest habitat suitable for red tree voles (Agee 1993, p. 213). Yet despite the large wildfires, large patches of old forest continued to remain across the historical landscape as red tree vole refugia, sustaining tree voles until the burned areas recovered to suitable habitat and became available for recolonization (Wimberly et al. 2000, p. 177; Forsman et al. 2016a, p. 84). However, much of the analysis area no longer retains the historical amount and distribution of old-forest patches as a result of timber harvest over the past 60 to 80 years. The degree to which burned areas are managed will determine their ability to develop conditions suitable for tree voles, as well as the speed with which habitat will develop.

5.1.3. Swiss Needle Cast

Although there are numerous forest insects and pathogens that occur in the Oregon Coast Range and may affect red tree vole habitat, their outbreaks are generally sporadic and asynchronous. We focus our discussion on Swiss needle cast disease, which could affect tree voles by reducing habitat quality and quantity. Swiss needle cast is already present throughout most of the DPS (Ritóková et al. 2021, p. 18) and appears to be undergoing an intensifying epidemic in the Oregon Coast Range (Ritóková et al. 2016, p. 7).

Swiss needle cast is a foliage disease specific to Douglas-fir caused by the fungus *Phaeocryptopus gaeumannii*. Although the fungus is found throughout the range of Douglas-fir in Oregon it is primarily found, and is more consistently severe, along the western slope of the central and northern Oregon Coast Range, primarily in sites with higher levels of spring or summer rainfall and where mild winters favor pathogen growth and reproduction; this area primarily overlaps the Sitka spruce vegetation zone, but is also found in the western hemlock zone (Hansen et al. 2000, p. 777; Stone et al. 2008, p. 171; Shaw 2008, p. 1). Dendrochronological reconstruction of Swiss needle cast outbreaks in western Oregon from 1895–2011 show they are widespread and synchronous, with primary periodicities of 20–40 years in response to annual changes in climate, specifically, winter and summer temperatures and summer precipitation (Lee et al. 2017, pp. 1179, 1182). Outbreaks tend to be more severe with warm winter and cool, wet summer periods (Lee et al. 2013, p. 683).

Douglas-fir accounted for less than 20 percent of the forest composition prior to the 1940s in this portion of the Oregon Coast Range, but timber harvest and large-scale planting of Douglas-fir on cutover areas make it a more dominant species today in managed areas (Hansen et al. 2000, p. 777). The wetter, milder weather, combined with a uniform distribution of the host species, favors the fungus and helps increase the disease severity (Hansen et al. 2000, p. 777; Shaw 2008, p. 1). The affected area has increased from 530 km² (205 mi²) in 1996 to 2,387 km² (922 mi²) in 2015, mainly on the coastal side of the Oregon Coast Range (Ritóková et al. 2016, pp. 5–6, Figure 5, 2021, p. 4, Figure 2). The latest aerial surveys in Oregon indicate over 2,660 km² (1027 mi²) of forest, over 17 percent of the Oregon Coast Range, show symptoms of the disease (Ritóková and Stevens 2022, p. 1). Disease severity is higher in young plantation trees than in mature forest trees (Lan et al. 2019, p. 10).

Swiss needle cast has been identified as the most likely cause of historic annual growth suppressions of coastal Douglas-fir in Oregon (Lee et al. 2013, p. 685). The disease causes premature needle loss which, although rarely lethal, reduces tree growth rates by 20 to 55 percent (Shaw 2008, pp. 1–2; Maguire et al. 2011, p. 2074). Effects also include reduction in tree height, diameter growth, and total tree volume (Hansen et al. 2000, pp. 773, 777; Maguire et al. 2002, p. 86). Young Douglas-fir infected with the pathogen are not expected to outgrow the disease (Black et al. 2010, p. 1680). Most of the research on this disease has occurred in managed plantations less than 40 years old (Shaw 2009, in litt.), although the fungus is known to limit growth in established overstory trees greater than 100 years old, even within mixed-species

stands (Black et al. 2010, p. 1680). During drought conditions in 2015 through 2018, mortality was observed in trees greater than 90 years old that had lived with the disease for more than 20 years (Shaw et al. 2021, pp. 414–415). Disease expression increases and foliar retention decreases in trees in younger plantations compared to trees in mature and older forests (Lan et al. 2019, p. 79), and symptom expression is greater on private lands than on public lands (Mildrexler et al. 2019, pp. 25–27). Future steps needed to manage Swiss needle cast are unclear. For example, conflicting information exists as to whether fertilizing afflicted plantations alleviates or exacerbates disease severity (Shaw et al. 2011, p. 116; Mulvey et al. 2013, p. 156). Thinning treatments to improve tree vigor in infected stands do not appear to significantly affect the disease severity (Mainwaring et al. 2005, p. 2402; Shaw et al. 2011, p. 116).

Swiss needle cast can also affect competition between tree species (Lee et al. 2017, p. 11184). Given our current knowledge, a possible scenario in coastal stands dominated by Douglas-fir infected with Swiss needle cast is a transition to the non-host Sitka spruce and western hemlock as the dominant cover, moving these sites closer to the historical species composition present before forest management converted them to Douglas-fir (Filip 2009, in litt.). This could benefit tree voles in the Sitka spruce zone. Where these non-host species are deficient or absent in infected stands, reestablishing them in the stand is the only known treatment certain to reduce the spread and extent of Swiss needle cast. There is still too much uncertainty in our understanding of this pathogen to accurately project future trends in vegetation. While it could result in a return of western hemlock and Sitka spruce that were removed as a result of conversion to Douglas-fir plantations, it will be decades before these stands develop into the old forest conditions most suitable as red tree vole habitat. Furthermore, the commercial value of Douglas-fir timber is a major incentive to continue research to develop pathogen treatments that would allow continued existence of productive Douglas-fir stands. In addition, breeding programs focusing on Douglas-fir with genetic tolerances to the SNC pathogen are also a priority (Johnson 2002, p. 81; Jayawickrama et al. 2012, p. 256). Thus, any return to a vegetative composition of predominantly non-host species in managed forest plantations within the Sitka spruce vegetation zone as a result of Swiss needle cast is speculative.

Given reduced growth rates of Douglas-fir trees infected with Swiss needle cast, they may never develop the structures needed for red tree vole nests as they may lose their competitive advantage to surrounding tree species (Shaw 2008, p. 2). In addition, the disease reduces the production of conifer needles, which would affect forage availability and cover for red tree voles and could affect connectivity among tree canopies. For example, moderate to severe Swiss needle cast infections over large portions of the historic Tillamook burn are thought to have a large effect on crown closure, tree growth and forage availability for tree voles compared to other historic fire areas due to intensive management of the forest (Wilson 2019, in litt.). Hence, Swiss needle cast may or may not result in loss of existing habitat but based on the reasoning above, we infer that it is likely to reduce overall habitat quality and reduce the ingrowth of tree vole habitat, which can affect tree voles at the population level.

5.1.4. Fragmentation and Isolation

The loss of much of the old forest within the analysis area has reduced habitat for tree voles to relatively isolated patches, contracting to Federal lands from 1986-2022 (Linnell et al. 2023, pp. 6–7); tree voles are especially vulnerable to the effects of isolation and fragmentation due to their small home ranges and limited dispersal capabilities. Tree voles in the Oregon Coast Range evolved in vast, well-distributed expanses of primarily late-successional forest with highly variable age distribution (Wimberly et al. 2000, p. 176). It is estimated that old forest covered 52 to 85 percent of the Oregon Coast Range at any point in time over the past 1,000 years (Wimberly et al. 2000, p. 175; Wimberly and Ohmann 2004, p. 642). In 1936, extensive patches of large-conifer Douglas-fir forest connected much of the central and southern portions of the Oregon Coast Range Province. However, in the northern quarter of the province, patches of large Douglas-fir were combined with large spruce-hemlock forest, intermingling with large patches of open and very young stands (Wimberly and Ohmann 2004, p. 635). Most of those open and young stands encompassed the 1,210 km² (467 mi²) that had recently burned in the 1933 Tillamook fire. Red tree vole habitat also showed a corresponding trend from 1914 to 1936, with a substantial habitat decline in the north coast subregion. The decline from 60 to 28 percent of the subregion was a result of timber harvest, as well as the 1933 Tillamook Burn, which was responsible for the loss of 10 percent of the forest area in this subregion (Forsman et al. 2016a, pp. 80–82).

By 1996, large blocks of the remaining large-conifer forest were restricted to Federal and State lands in the central portion of the Oregon Coast physiographic province, having been eliminated from most private lands (Wimberly and Ohmann 2004, p. 635). Elsewhere, large-conifer forests were primarily isolated in scattered fragments on public land. The 1936 area of the Oregon Coast Range Province covered by large Douglas-fir (5,315 km² (2,052 mi²)) and large spruce-hemlock (891 km² (344 mi²)) cover types declined 58 percent by 1996, primarily as a result of timber harvest. Conversely, the combined area of small Douglas-fir and spruce-hemlock forests increased by 87 percent (Wimberly and Ohmann 2004, pp. 639–641). Red tree vole habitat changed accordingly from 1936 to 2006, with substantial declines in the north coast and central coast subregions. Tree vole habitat declined from 28 to 12 percent of the forested area in the north coast subregion, and from 54 to 16 percent of forested area in the central coast subregion (Forsman et al. 2016a, p. 82). Not only have amounts of old forest decreased, but the spatial distribution of those forests has changed. Prior to European settlement, vegetation simulations indicate that mature (80 to 200 years) and old-growth forest (> 200 years) patches had the highest densities of patches of all successional stages within the Oregon Coast Range Province (Wimberly 2002, p. 1322). In addition, old-growth patch sizes were large, ranging from 2,100 to 8,500 km² (810 to 3,280 mi²), with a median of 4,300 km² (1,660 mi²), while patches of less than 80-year-old forests were generally less than 2,000 km² (770 mi²) (Wimberly 2002, p. 1322). As of 1995 in the Oregon Coast Range Province, the largest old-growth patch is 6.5 km² (2.5 mi²), while the largest patch of early-seral forest (less than 30 years old) is larger than 5,000 km² (1,900 mi²), and the largest patch of 30-to 80-year-old forest is larger than 3,000 km² (1,150 mi²) (Wimberly et al. 2004, p. 152). Correspondingly, over the last century, the mean patch size of

predicted red tree vole habitat range-wide in Oregon declined by 98 percent, from 129 km² (50 mi²) to 2.4 km² (1 mi²) (Forsman et al. 2016a, pp. 80–81). In summary tree vole habitat in the DPS has changed from old forest being the dominant forest type in the early 1900s to a fragmented network of smaller patches scattered through a matrix of predominantly young forest (Forsman et al. 2016a, p. 80).

This increasing isolation of old-forest patches due to maintenance of young stands in the intervening areas is a stressor for red tree voles because of their limited vagility. As noted earlier, the greatest known dispersal distance for an individual red tree vole is 340 m (1,115 ft) (Biswell unpublished data referenced in USDA FS and USDI BLM 2000, p. 8), but shorter distances from 3 to 75 m (10 to 246 ft) appear to be more the norm for dispersing subadults, based on limited studies (Swingle 2005, p. 63). The average distance between patches of old forest in the analysis area (3.1 km $\pm$ 4.7 km (1.9 mi)) far exceeds the known maximum dispersal distances of individual red tree voles (Linnell et al. 2017a, p. 8). A matrix of surrounding young forest is not entirely inhospitable for dispersing red tree voles, but long-term persistence in these stands is unknown and likely limited to specific conditions. The ability of red tree voles to successfully move among remaining patches of fragmented habitat depends on their vagility, as well as tolerance for and permeability of the intervening matrix habitat (Pardini 2004, p. 2581; Prugh et al. 2008, pp. 20773–20774). An intervening matrix of extensive areas of commercially thinned young forests or forests <20 years old likely impede the movement of tree voles between old-forest patches (Linnell et al. 2017a, p. 7).

Under conditions of fragmentation, the ability of individuals to disperse between patches of remaining habitat is restricted. The fragmented nature of existing tree vole habitat amplifies the effects of future habitat removal, because even small (<1.4 percent) reductions in amounts of old forest can dramatically increase the mean distance between patches of old-forest cover, thus affecting the habitat availability for red tree voles (Linnell et al. 2017a, p. 6). A recent model simulating red tree vole occupancy and movements across the landscape, which incorporated changes in the amount and location of red tree vole habitat between 1986 and 2020, showed increasingly patchy distributions of red tree voles, and relatively low numbers of red tree voles per area of habitat within the analysis area (Heinrichs et al. 2023, pp. 15–16). Another recent model documented reductions in tree vole dispersal suitability in the entire Oregon Coast Range ecoregion, which the authors attributed to timber harvest, human development and wildfires (Gaines et al. 2023, p. 20). Thus, there is potential for the loss of local tree vole population areas as remnant habitat patches formerly occupied by tree voles may not be recolonized due to the distance between habitat fragments and the short-distance dispersal of the species, leading to further isolation of the remaining population areas, and likely local extirpations.

In addition to affecting habitat availability and distribution at the landscape-scale, fragmentation also has implications at the stand-scale by altering habitat suitability along habitat edges. Such edge effects include altered microclimates and potentially increased vulnerability to generalist predators (Yahner 1988, p. 337; Saunders et al. 1991, pp. 20–22; Chen et al. 1993, p. 220). In old-growth Douglas-fir forests, altered environmental conditions may extend up to 137 m (450

ft) from the forest edge, to the extent that patches less than 10 ha (25 ac) in size provide essentially no forest interior habitat (Chen et al. 1992, p. 395). One red tree vole habitat model found that red tree voles tended to avoid edges when building their nests, suggesting that habitat fragmentation and associated edge effects influence habitat suitability (Johnston and Moskal 2017, p. 36). However, tree vole researchers have found vole nests along forest edges, and suggested these edge habitats may provide enhanced nesting opportunities in the form of more complex bole and limb structures and deeper live crowns as a result of increased sunlight exposure along edges (Swingle 2019, in litt).

5.1.5. Effects of Habitat Loss, Modification, and Fragmentation on Red Tree Voles

Red tree vole population isolation and small population size are a consequence of several of the stressors listed above which cause habitat loss and fragmentation. Current tree vole distribution patterns across the species range corresponded to patterns of wildfire and timber harvest and the capacity of the landscape to support populations declined from 1986–2020 in a recent dynamic habitat-population model (Heinrichs et al. 2023, pp. 13–14, 17). Simulated population rates of decline over this time period ranged from 0.7 percent per year in the DPS to 1.2 percent per year in the Cascades region, an area more impacted by wildfires since 1986 (Heinrichs et al. 2023, pp. 13–14).

Isolated populations are more likely to decline than those that are not isolated (Davies et al. 2000, p. 1456). In addition to isolation, population size also plays an important role in extinction risk. Small, isolated populations place species at greater risk of local extirpation or extinction due to a variety of factors, including loss of genetic variability, inbreeding depression, demographic stochasticity, environmental stochasticity, and natural catastrophes (Franklin 1980; Shaffer 1981, p. 131; Gilpin and Soule 1986, pp. 25–33; Soule and Simberloff 1986, pp. 28–32; Lehmkuhl and Ruggiero 1991, p. 37; Lande 1994). Stochastic events that put small populations at risk of extinction include, but are not limited to the following: variation in birth and death rates, fluctuations in gender ratio, inbreeding depression, and random environmental disturbances such as wildfire, wind, and climatic shifts (Shaffer 1981, p. 131; Gilpin and Soule 1986, p. 27; Blomqvist et al. 2010).

The isolation of populations and consequent loss of genetic interchange may lead to genetic deterioration, for example, that has negative impacts on the population at different timescales. In the short term, populations may suffer the deleterious consequences of inbreeding; over the long term, the loss of genetic variability diminishes the capacity of the species to evolve by adapting to changes in the environment (Franklin 1980, pp. 140–144; Soule and Simberloff 1986, pp. 28–29; Nunney and Campbell 1993, pp. 236–237; Reed and Frankham 2003, pp. 233–234; Blomqvist et al. 2010). Although we do not have information on relative levels of genetic variability in red tree vole populations, one researcher suggested that genetic inbreeding may be maintaining cream-colored and melanistic tree vole pelage polymorphisms at a few populations within the red tree voles range (Swingle 2005, p. 82).

Species in which populations have recently become isolated through habitat fragmentation do not necessarily function as a metapopulation and, especially in the case of species with poor dispersal abilities such as the red tree vole, local populations run a high risk of extinction when extirpations outpace dispersal and immigration (Brown and Kodric-Brown 1977, p. 445; Gilpin 1987, p. 136; Hanski and Gilpin 1991, p. 13; Hanski et al. 1996, p. 539; Harrison 1991, pp. 82–83). Some conservation biologists suggest that for species with poor dispersal abilities, habitat fragmentation is likely more important than habitat area as a determinant of extinction probability (Shaffer and Samson 1985, p. 146).

There are multiple features of red tree vole biology and life history that limit their ability to respond to habitat loss and fragmentation, as well as to stochastic environmental events. Their current restricted distribution within the analysis area makes them vulnerable to stochastic events that could further isolate tree vole population areas and limit their recolonization capability. Small home ranges and limited dispersal distances of tree voles, as well as their apparent reluctance to cross large openings, impedes their ability to readily recolonize isolated habitat patches. Their limited vagility, combined with their low survival rate, restricts the ability of vole population areas to expand and connect with other population areas. Their low reproductive rate and the lengthy development period of young, relative to other vole species, are life-history characteristics that slow the time it takes for populations to grow or rebound from stochastic or catastrophic events; insularization (isolated into islands of habitat) of tree voles in the analysis area further exacerbates these inherent vulnerabilities (Bolger et al. 1997, p. 562). Red tree voles are considered highly vulnerable to local extirpations due to habitat fragmentation or loss (Huff et al. 1992, p. 1).

5.2 Predation

In the only quantitative study of red tree vole mortality in naturally occurring nests conducted to date, Swingle et al. (2010, p. 258) found that weasels (*Mustela* spp.) are the primary predators of red tree voles. However, weasels (*M. erminea* and *M. frenata*) were also the primary predator of voles on artificial nest platforms (n = 8 mortalities, 10 percent of detections, 168 nest platforms) (Linnell and Lesmeister 2020, p. 8620). Northern spotted owl is known as a major predator of red tree voles (Forsman et al. 1984, p. 40) and numerous studies collecting owl fecal pellets from 1970-2009 have documented remains of red tree voles (Forsman et al. 2016a, pp. 11–13). Percentage of owl territories with tree voles in their diet was higher in the Central Coast (66 percent) than the North Coast of Oregon (19 percent) and overall abundance in owl diets was 2.1 ± 1.1 percent in the North Coast and 12.3 ± 1.0 percent in the Central Coast (Forsman et al. 2016a, pp. 11–13). These two areas cover the DPS with the North and Central coasts separated roughly at Highway 18 (Forsman et al. 2016a, p. 12). Age distribution of red tree voles in these pellets was 35 percent post-dispersal subadults, 43 percent 1st-year adults, and 19 percent 2nd-year adults (Marks-Fife et al. 2020, p. 201). The authors suggested the high percentage of dispersal-age tree voles in northern spotted owl pellets meant that age class was either more abundant than adults, exhibited characteristics that made them more vulnerable to predation, or both (Marks-Fife et al. 2020, p. 203). One explanation for the higher abundance could be due to

seasonal weather patterns influencing tree vole productivity and thus abundance of dispersal-age individuals (Marks-Fife et al. 2020, p. 204)

Many other animals feed on tree voles, including ringtails (*Bassariscus astutus*) (Alexander et al. 1994, p. 97), fisher (Golightly et al. 2006, p. 17), Pacific marten (*Martes caurina*) (Eriksson et al. 2019, p. 8), barred owls (*Strix varia*) (Wiens 2012, p. 57), and a variety of other nocturnal and diurnal raptors (Miller 1933, entire; Maser 1965a, entire, b, entire; Forsman and Maser 1970, entire; Reynolds 1970, entire; Graham and Mires 2005, p. 39; Linnell and Lesmeister 2020, p. 8617). Other documented predators include the Steller's jay (*Cyanocitta stelleri*) (Howell 1926a, p. 60; Linnell and Lesmeister 2020, p. 8617), gopher snakes (*Pituophis catenifer*) (Swingle et al. 2010, p. 258), flying squirrels (Linnell and Lesmeister 2020, p. 8617), domestic dogs (*Canis familiaris*) (Swingle et al. 2010, p. 258), and house cats (*Felis catus*) (Swingle 2005, pp. 90–91). In addition, Maser (1966, p. 164) found tree vole nests that had been torn apart and inferred the destruction was likely caused by northern flying squirrels, raccoons (*Procyon lotor*), western gray squirrels (*Sciurus griseus*), or Douglas' squirrels (*Tamiasciurus douglasii*), apparently in search of young voles. Tree vole nests can be disturbed by birds in apparent pursuit of invertebrates and were positively correlated with the presence of flying squirrels (Linnell and Lesmeister 2020, p. 8618). Forsman (2010) recorded video footage of flying squirrels, western gray squirrels, and Douglas' squirrels chasing tree voles or tearing into tree vole nests in what appeared to be attempts to capture voles, and flying squirrels have recently been documented as predators on tree voles (Linnell and Lesmeister 2020, p. 8617).

Red tree voles persist in many areas despite the large numbers of predators (Forsman et al. 2004, p. 300). However, invasive barred owls have expanded into the Pacific Northwest and are a relatively new predator of red tree voles. Barred owls are known to displace northern spotted owls from their home ranges, and negative relationships between barred owl occurrence and spotted owl survival, fecundity, and population trends are evident (see Wiens 2012, p. 3, 4 for summary); but it is unknown whether or not barred owls reduce predation on red tree voles by spotted owls (Diller et al. 2016, p. 705). Red tree voles, among other mammal species, are an important prey item of barred owls, particularly during fall and winter (Wiens 2012, p. 39). While the varied diet of the barred owl, compared with the spotted owl, may potentially limit their pressure as predators on tree voles, the fact that their territories outnumber those of spotted owls in the southern portion of the analysis area by a greater than 4.5:1.0 ratio (Wiens 2012, p. 45) may increase that pressure. Prey species that typically comprise the majority of spotted owl diets (e.g., flying squirrels (*Glaucomys* spp.), woodrats (*Neotoma* spp.), and tree voles) comprised <3 percent of diets at two study sites in Oregon (Baumbusch 2023, p. 27), with tree voles constituting a mean of 0.7 percent (SD 6) of the dietary composition (percent of total prey numbers) in the Oregon Coast Range site (Baumbusch 2023, p. 23) where an estimated 26 red tree voles would be taken by a breeding barred owl pair; however, barred owl home ranges can be 2-4 times smaller than spotted owls in this area, thus over an area equivalent to a spotted owl home range, 4 barred owl pairs would take slightly more red tree voles, 104, than a spotted owl pair raising 2 young (Baumbusch 2023, p. 29). While this results in relatively similar to slightly increased amounts of tree voles taken by barred owls than spotted owls, it is still not clear how

the invasion of the barred owl may have changed predation pressure on the tree vole because barred owls also forage on other predators of red tree voles, such as weasels, Steller's jays, and other owl species (Wiens 2012, pp. 137–138), though a recent study in the Oregon Coast Range did not show these species in barred owl diets (Baumbusch 2023, pp. 23–25). However, barred owls consume other species that likely consume tree voles and have been known to disturb nests, such as other birds, flying squirrels, and Douglas' squirrels (Forsman 2010, in litt.; Linnell and Lesmeister 2020, p. 8617; Baumbusch 2023, pp. 23–25, 61). Therefore, while the invasion of barred owls remains a concern, the best available information does not indicate if predation by this species is having population-level impacts on red tree voles.

While predation is a stressor on individuals, the best available information does not indicate predation is a driver of population decline for red tree voles. As such, predation was not carried through as an influence factor that impacts the future condition of the DPS.

5.3 Existing Regulatory Mechanisms and Conservation Measures

There are existing State and Federal regulatory mechanisms and management plans that affect the impact of some of these stressors on red tree voles.

5.3.1. State Mechanisms

There are currently no State regulations protecting red tree voles or their habitat. However, the red tree vole is identified by the Oregon Department of Fish and Wildlife (ODFW) as a sensitive species in the Oregon Coast Range (Oregon Department of Fish and Wildlife 2016a, p. 11). Rather than serve a regulatory function, the sensitive species list identifies species for managers and the public to prioritize conservation actions and encourage voluntary actions to improve the species status. The red tree vole is also listed in the Oregon Conservation Strategy with specific actions believed necessary for conservation (Oregon Department of Fish and Wildlife 2016b).

The red tree vole is not a specific species targeted for protection under the Oregon Forest Practices Administrative Rules and Oregon FPA, which regulate timber harvest in Oregon. Many of the guidelines targeted to conserve other wildlife species are not expected to provide for long-term persistence of red tree vole population areas, given their isolated nature, the tree vole's relatively specialized habitat requirements and limited dispersal abilities, and the allowance for removal of some buffers if the target species is no longer present. In addition, short rotations and intensive management of the surrounding stands will not likely develop or retain the structural features advantageous to red tree voles, thus contributing to the threat of habitat modification and maintaining the isolation of any tree voles that may be present in these areas.

Riparian protection buffers (OAR 629–642–0000 through 629–642–0800) and other wetland protections (OAR 629–Division 645; OAR 629–Division 650) are often suggested as providing habitat and connectivity for red tree voles. However, small mammals may experience increased risk and local extirpation events due to predation in narrow corridors or isolated fragments of

habitat (Henderson et al. 1985, p. 103; Mahan and Yahner 1999, pp. 1995–1996). Soulé and Simberloff (1986, pp. 33–34) specifically suggest that forest interior species such as the red tree vole would likely avoid using such areas for movement between remaining patches of coniferous forest because of lack of interior habitat. Indeed, Johnston and Moskal (2017, p. 69) found a negative influence of forest edge with modeled tree vole habitat (see section 5.1.2 Fragmentation and Isolation). Poor-quality habitat conditions for red tree voles in riparian management areas, such as from reduced canopy cover or greater amounts of hardwoods, may reduce their probability of survival in moving through such a patch (Martin and McComb 2003, p. 577). Because red tree voles have relatively low reproductive rates and limited vagility, this reduced survival probability is not likely to be offset by large numbers of dispersers, as it might be for species with higher fecundity and vagility (Martin and McComb 2003, p. 577). Hence, there is little regulatory protection for red tree voles under the Oregon FPA.

State lands make up 12 percent of the DPS and a majority of that is managed by ODF. Personnel recorded tree vole nest locations as ancillary information collected during climbing inspections of marbled murrelet nests (Gostin 2009), though that practice has ceased. ODF identified the red tree vole as a species of concern and established “anchor habitat areas” for managing species of concern, such as the red tree vole, in portions of the analysis area. Anchor habitat areas are an ODF designation not intended to provide permanent reserves, but to provide locales where populations will receive a higher level of protection in the short term until additional species’ habitat is created across the landscape (Oregon Department of Forestry 2010, p. 4.82). Anchor habitats, along with layered and older-forest structure patches, may provide patches of red tree vole habitat across the State Forests now or in the future. Layered is defined as a stand type that occurs as the process of understory reinitiation progresses where openings in the canopy persist. Shrub and herb communities are more diverse and vigorous, and two or more distinct layers of tree canopy appear. Older forest structure is defined as occurring when forest stands attain structural characteristics such as numerous large trees, multi-layered canopy, substantial number of large, down logs, and large snags. It is not the same as old growth, although some of its structures are similar to old growth (Oregon Department of Forestry 2010, p. 4.11). The layered and older-forest structure patches may not be retained through time; rather, they can be designed as a shifting mosaic across the landscape, so that once patches reach a layered or older-forest structure condition, they may only be retained until other patches on the landscape reach a similar condition, at which time the original patches may be harvested (Oregon Department of Forestry 2010, p. 4.48-4.55). Given the limited dispersal capabilities of red tree voles, it is not clear how they will move from existing habitats to newly recruited habitat without a plan for improving permeability in the intervening lands.

In 2022, ODF submitted an application for an Endangered Species Act incidental take permit with a habitat conservation plan (HCP) for their State Forest lands in western Oregon, including those in the DPS. Red tree vole is a proposed covered species. HCPs are planning documents that describe the anticipated effects of the proposed taking, how those impacts will be minimized or mitigated to the maximum extent practicable, and how the HCP is to be funded. Implications of being included as a covered species vary depending on the plan, but in general assures that

habitat will be set aside and managed for the species as compensation for covered activities, such as timber harvest, and that measures will be implemented to avoid or minimize take of the covered species. ODF proposes to maintain, enhance, and increase red tree vole habitat in constrained habitat conservation areas. If the permit is issued and the plan implemented, this will potentially increase amount of habitat and connectivity of tree voles especially throughout the north coast subregion.

5.3.2. Federal Mechanisms

The Forest Service and BLM make up 17 percent of the DPS and are the only entities explicitly managing for red tree voles through required surveys and conservation of occupied sites. The Survey and Manage standards and guidelines on Forest Service lands throughout the analysis area, and similar guidelines on BLM lands north of Highway 20, provide some protection to the species, including pre-project surveys for voles and retaining buffers around active sites for many activities (USDA FS and USDI BLM 2000, entire, 2011, entire; Biswell et al. 2002, entire; Huff 2016, entire; USDI BLM 2016, p. 101). In addition, Federal lands implement a lower level of timber harvest compared to other ownerships; most of the Federal land base in the range of the DPS is not managed for timber extraction goals or managed for late-successional characteristics.

5.4 Summary of Influence Factors

Habitat loss, modification, and fragmentation have had the strongest influence in driving the current distribution of red tree voles in the analysis area. Loss of habitat has restricted their distribution and size of population areas, resulting in isolation. Sources of habitat loss and modification include timber harvest, wildfire, and, potentially, Swiss needle cast. The best available science indicates that these factors have had an impact to tree voles at the population level. Historically the agent of habitat loss has been wildfire, but over the last century, the primary agent has been timber harvest. Forest regulatory mechanisms relating to timber harvest have been in effect in the analysis area since the 1970's, when State and Federal regulations were first enacted (Oregon Forest Practices Act, National Forest Management Act of 1976, Federal Land Policy Management Act of 1976). The lack of regulatory mechanisms prior to the passage of these acts shaped the current distribution of red tree voles in the analysis area through the effects of forest management and habitat loss. Timber harvest on private lands must comply with the Oregon Forest Practices Act, while State, Federal, and Tribal lands have forest management regulations and plans they follow for their lands. Hence, the effects of regulatory mechanisms on tree voles correspond to the effects of habitat loss. These factors have had substantial population-level effects that are anticipated to continue, and to be the primary drivers of species viability.

Tree voles persist in areas despite the large number and variety of predators and are a predominant prey item for several species. Habitat condition may affect red tree vole vulnerability to predators, with old forests providing more structural complexity that may make nests more difficult to detect, and taller trees and consequently higher nest heights possibly reducing vulnerability to terrestrial predators. While predation is a stressor on individuals, the

best available information does not indicate whether predation is a driver of population decline for red tree voles. As such, predation was not carried through as an influence factor that impacts the future condition of the DPS.

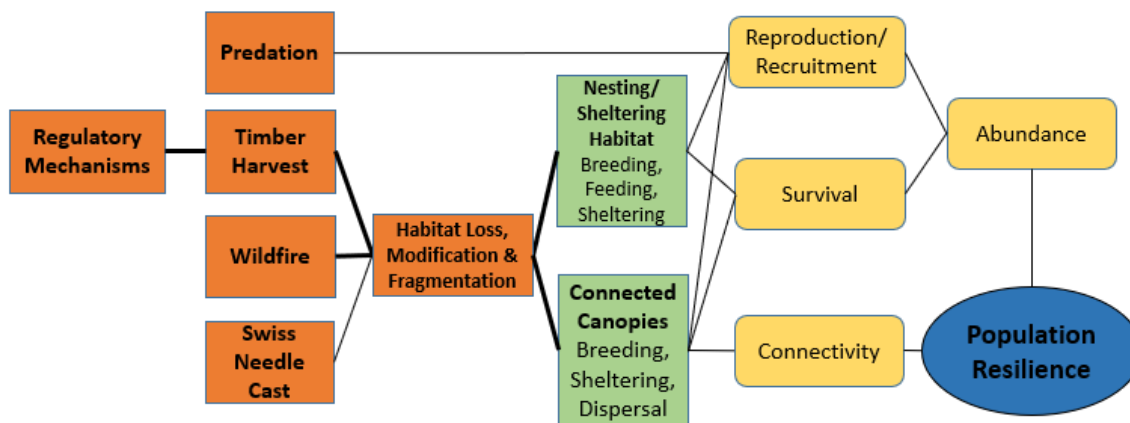


Figure 11. Conceptual diagram of the primary factors influencing resiliency of the red tree vole. Orange boxes are influence factors, green boxes are habitat needs, and yellow boxes are demographic/population needs that contribute to population resiliency. Thicker connecting lines indicate greater influence of that factor relative to other factors.

6. CURRENT CONDITION

6.1 Overview

To assess the biological status of the red tree vole in the north Oregon Coast Range analysis area, we used the best available information, including peer reviewed scientific literature and academic reports, unpublished reports, survey data provided by State and Federal agencies and private entities, and specimen data collected from museums. Additionally, we consulted with species experts who provided important information and comments on red tree vole life history, genetics, habitat, and distribution. Fundamental to our analysis of the red tree vole was the determination of scientifically sound analytical units at a scale useful for assessing the species. In this report, we defined red tree vole analytical units (geographic units) based primarily on known occurrence locations and modeled habitat (Lesmeister and Linnell 2019, entire; Linnell et al. 2023, entire) (see Appendix A, Section 2).

6.2 Difficulties in Estimating Tree Vole Abundance

Historical and contemporary surveys show that tree voles typically occur at low densities compared to other voles, with clusters of nests patchily distributed across the landscape. (Forsman et al. 2016a, p. 47) suggested that tree vole populations are naturally maintained at low densities because of adult territoriality, low reproductive potential, high rate of predation, and the

low density of trees with good nest support structures. Hence, obtaining a robust sample size of tree voles is labor intensive.

The ability to quantitatively estimate the population size of tree voles is further complicated because traditional population estimate methodologies require catching and marking individuals (mark-recapture methodologies), and tree voles are difficult to capture with traditional small mammal sampling methods given their arboreal nature and diet of conifer needles (Swingle et al. 2004; Swingle 2005, p. 5; Forsman et al. 2016a, p. 43). Hence, survey efforts focus on searching for nests as an indirect representation of tree vole occurrence. Three techniques are currently available to definitively determine if a tree vole nest is occupied: 1) dissect nest in search of tree voles, 2) gently probe a nest with a stiff piece of wire to force tree voles out (Swingle et al. 2004), or 3) set up remote cameras on potential nests to confirm vole presence (Linnell and Lesmeister 2020, p. 8612; Piasecki 2022b, entire). More often, surveyors make assumptions about nest occupancy based on signs of recent activity such as green fecal pellets or fresh conifer cuttings (Biswell et al. 2000, 2002). However, using the presence or absence of green resin ducts and cuttings to determine the occupancy status of nests can be misleading and unreliable for assessing actual nest occupancy by voles because the resin ducts can retain a fresh appearance for months, up to a year, if stored in the nest or out of sunlight, resulting in potential overestimates of active nest occupancy (USDA and USDI 2007, p. 290).

Furthermore, it is difficult to establish a relationship between nest abundance and density of tree voles (Forsman et al. 2019, pp. 2–3) because: 1) nests can be difficult to detect, especially without climbing trees (Howell 1926a, p. 45; Swingle 2005, p. 78; Swingle and Forsman 2009, p. 284; Forsman et al. 2016a, p. 42; Marks-Fife 2016, p. 111; McCoy et al. 2023, entire); 2) tree voles can use multiple nests (Swingle 2005, p. 59); and 3) the number of tree vole nests can accumulate over multiple generations. Tree vole nests may persist for years, and potentially for a decade or more in older stands or if built upon nests of other species (Jewett 1920, p. 165; Thompson and Diller 2002, p. 99). In a recent study surveying young (20–49 year old) stands, 457 nests trees were climbed, 23 percent had recent vole sign, and 8 percent had voles verified from captures (Moriarty 2023, in litt.). From a sample of tree vole nests in forest stands <100 years old, Thompson and Diller (2002, pp. 94–95) reported a median nest persistence time (length of time nests remained intact) of 28.6 months (95 percent confidence interval 25.8–34.8) with a <10 percent probability that a nest would persist beyond 5 years. Nest persistence is related to both the size of the nest and the stand age, with persistence higher in larger nests located in older forests (Piasecki et al. 2022, entire).

Very little is known about tree vole density, and available abundance estimates are often reported as relative abundance of trees with tree vole nests in different occupancy classes. There are only a two published sources that could be used to approximate tree vole density, each with uncertainties. Portions of each of these study areas occur in the southern end of the DPS and use visual observations of voles. Maser (1966, pp. 170–205) located a young forest (approximately 50 years) site with a high number of tree vole nests where the trees were easy to climb. Over a three-month period, he climbed to each nest and determined the number of juvenile, subadult,

and adult tree voles in each occupied nest, reporting 2.55 tree voles per ha (1.02/ac). Because this included tree voles of all ages, a post hoc calculation of Maser’s data (1966, pp. 202–203) indicates he located 0.97 adults per ha (0.39/ac) based on 12 adult tree voles he observed on the 12.4 ha (30.6 ac) study area. Data from this study area represented an unusual concentration of tree voles in an open population sampled over a long time period and are likely not representative of average conditions for tree voles (Forsman et al. 2019, p. 3). Further, assumption of perfect detection in this study likely results in underestimates of density. In a second study on tree vole nest detection using distance sampling methods, Marks-Fife (2016, p. 79) estimated a mean of 1.91 (SE $\pm$ 0.97) adult tree voles per ha (0.76 ± 0.38 voles/ac) in forest that ranged in age from 25 to over 200 years old. The author points out that the estimate only applies to occupied stands (in the non-random sample of stands surveyed), and while probably closer to true density of adult tree voles in occupied stands, the estimates exhibited high variability and are not appropriate to apply to the landscape level of all potentially suitable tree vole habitat (Marks-Fife 2016, p. 82). This estimate has been identified as one which likely overestimates abundance of tree voles, due to some unsupported assumptions (Forsman et al. 2019, p. 3). For this SSA, we were able to use new unpublished information on nest data from National Council for Stream and Air Improvement (NCASI 2022a, in litt.) to generate an additional estimate of red tree vole density of 0.56 voles per ha (0.23/ac) (see Appendix A, Section 3.1).

6.3 Condition Analysis Model

In the absence of tree vole population estimates, we developed a coarse model to produce a qualitative “condition category or rating” for each of the 17 geographic units with at least one population area with presumed occupancy, identified in section 3.8 Analytical Units—Red Tree Vole Geographic Units (see Appendix A, Section 5 for details). The model is based on the elements that red tree voles require to maintain population resiliency (Table 5, section 4.2 Population Needs—Resiliency). In short, those needs are: 1) sufficiently large population size; 2) conifer trees in large enough patches to maintain individual interaction within a population; and 3) an intervening matrix of habitat between populations to facilitate movement among populations. Our model incorporated the first two needs by developing population area resiliency ratings from an estimated effective population size capacity based on modeled existing habitat, a range of population density estimates, and a range of estimates of the ratio between population size and effective population size to assess evolutionary potential and vulnerability to inbreeding (see Section 6.3.1 below). We incorporate the last need using a rating factor for connectivity based on the possible permeability of the matrix between population areas and geographic units (see Section 6.3.2 below).

6.3.1. Red Tree Vole Habitat Capacity and Effective Population Size Capacity

Habitat capacity is the potential species carrying capacity based on the modeled suitability of vegetation cover. We developed a range with a minimum and maximum value, rather than point estimate, for this parameter using two recent habitat models (Linnell et al. 2017a, entire, 2023, entire; Linnell 2022, entire) and two population density estimates (Marks-Fife 2016, p. 79;

NCASI 2022a, entire). The range of estimates provides a measure of confidence or uncertainty with respect to the habitat capacity of each population area. We then use the range of habitat capacity estimates to generate a range (minimum and maximum) of effective population sizes (see Appendix A, Section 3 for details), that might be supported by the habitat in each population area. An effective population size is the size of an ideal population that would result in the same level of inbreeding or genetic drift as that of the population under study (Jamieson and Allendorf 2012, p. 578). It is usually substantially smaller than the actual number of individuals in the population, often 10 to 20 percent of the census population size (Frankham 1995, p. 100).

There has been robust discussion in the published literature about using effective population size estimates as thresholds for certain management decisions on animal and plant species as well as what those thresholds should be (Traill et al. 2010, entire; Brook et al. 2011, entire; Flather et al. 2011, entire; Jamieson and Allendorf 2013, entire; Frankham et al. 2013, entire; Frankham et al. 2014a and b, entire; Franklin et al. 2014, entire; Rosenfeld 2014, entire). Effective population sizes can be estimated from demographic information such as sex ratios, variance in family size, and population size fluctuations over generations (Frankham et al. 2007, p. 241). However, we lack that information for red tree voles. Instead, we estimated the range of effective population size as 10 to 20 percent of our minimum and maximum tree vole habitat capacity values, which is an average ratio based on meta-analyses of different animal and plant populations (Frankham 1995; Frankham et al. 2014a, p. 56). We use this estimated range for effective population size capacity to characterize the capability of the individual tree vole population areas to avoid inbreeding, to maintain evolutionary potential, and to ultimately provide the population component of the overall resiliency condition rating for the unit (see Appendix A, Table A-6 and Tables A-12–13 for intermediate tables with detailed numbers for current and future scenarios).

We used five categories for the population area resiliency rating factor. Population areas with an effective population size capacity of less than 100 (threshold for inbreeding depression) was classed as a low condition. A range between 100 and 1,000 was classed as moderate because it surpassed the inbreeding threshold but did not meet the threshold for evolutionary potential. A range above 1,000 met both criteria and was considered high. An effective population size threshold of 100 is considered a point that would minimize the chance of inbreeding depression over 5 generations in the wild, and an effective population size of 1,000 to maintain evolutionary potential in perpetuity (Frankham et al. 2014a, pp. 58–59). In general, an effective population size of greater than or equal to 50 was originally recommended to avoid inbreeding depression over the short term, and greater than or equal to 500 was recommended to retain genetic variation and evolutionary potential (Rosenfeld 2014, entire; Frankham et al. 2014a, entire, b, entire; Franklin et al. 2014, entire). More recently, some conservation geneticists have proposed to increase the 50/500 “rule” to 100/1000 based on evidence obtained since the original recommendation (Frankham et al. 2014b, entire). For our analysis, therefore, we use the 100 and 1,000 thresholds for reduced inbreeding and maintaining evolutionary potential, respectively. Such thresholds can vary by species, and there are no empirical estimates for red tree voles. Consequently, we use these thresholds as part of our analysis as a relative means of comparing estimated resiliency among tree vole population areas.

6.3.2. Red Tree Vole Connectivity

Populations are better able to withstand stochastic events if they are connected to each other and can rely on movement between them to overcome substantial losses in an individual subpopulation. Our analysis, by design, looked at distinct aggregations of occupied habitat that were spatially removed from each other (see Appendix A, Section 2); hence, by the nature of the analysis, tree vole population areas across the DPS are isolated. Consequently, our connectivity analysis looks at the potential for connectivity of these currently isolated population areas to their neighboring areas. We considered the intervening land types and ownership and its potential to provide current or future habitat, even if suboptimal.

In general, habitat specialists with limited dispersal capabilities, such as the red tree vole, have a lower critical threshold for responding to fragmented habitats; such species may experience the environment as functionally disconnected even when their preferred habitat still comprises nearly half of the landscape (With and Crist 1995, p. 2452; Pardini et al. 2010, p. 6). For example, poor-quality habitat conditions for red tree voles in riparian management areas, such as from reduced canopy cover or greater amounts of hardwoods, may reduce their probability of survival in moving through such a patch (Martin and McComb 2003, p. 577). Because red tree voles have relatively low reproductive rates and limited vagility, this reduced survival probability is not likely to be offset by large numbers of dispersers, as it might be for species with higher fecundity and vagility (Martin and McComb 2003, p. 577). There is some evidence that small mammals may experience increased risk and local extinction events of predation in narrow corridors or isolated fragments of habitat (Henderson et al. 1985, p. 103; Mahan and Yahner 1999, pp. 1995–1996). The successful use of corridors to maintain regional populations is highly species-specific (Debinski and Holt 2000, p. 351; Rosenberg et al. 2019, p. 683) and depends on the spatial configuration of the remaining habitat, the quality of the corridor habitat, and the habitat specificity and dispersal ability of the species in question (Henein and Merriam 1990, p. 157; Fahrig and Merriam 1994, p. 53; With and Crist 1995; Rosenberg et al. 1997).

In the case of the red tree vole, connectivity between patches of old forest tree vole habitat is most likely achieved over multiple generations, at the population level, as individuals move and settle iteratively through suboptimal habitats of young forest matrix (Linnell et al. 2018, p. 1179; Linnell and Lesmeister 2019b, p. 568). Young forest landscapes managed for industrial forests are highly dynamic and may best be described as a shifting mosaic of young stand ages up to 40–50 years. Patches of marginal habitat may develop in this landscape but are ephemeral as stands of marginal habitat are harvested while other stands grow towards harvest age. Hence, for tree voles to navigate such a landscape, they must take advantage of any retained habitat that might exist in buffers or reserves, as well as the transitory marginal habitat in young forests. While we know that tree voles occupy young forests, we know it is often closely associated with nearby old-forest habitat, and there has been no empirical investigation yet to determine whether gene flow is occurring across the matrix between contemporary population areas of tree voles (Linnell and Lesmeister 2019b, p. 574).

We assigned connectivity rating factors of either high or low for each population area based on conditions within geographic units and between geographic units. Within geographic units, connectivity is based on the potential for demographic and gene flow between population areas as measured by the presence of forested areas between population areas no further than 2 km apart. We used 2 km because tree vole nests have been observed in young forests (20–80 years old) where those forests are within 2 km of old forest (Forsman et al. 2016a, pp. 32, 45; Lesmeister et al. 2016, pp. 14–15; Linnell et al. 2017a, p. 5; Scoresby et al. 2022, entire) and young forest may function as connectivity habitat in those situations (Lesmeister et al. 2016, p. 15). The potential for connectivity between geographic units was assessed by whether habitat blocks spanned the boundary of geographic units and whether both sides of the unit boundary were considered population areas. We recognize that the highways and rivers that divide geographic units represent a strong filter, but if a habitat block was contiguous between those units, then connectivity could occur. For each population area, we assumed high connectivity if either another population area was within 2 km with forest between them or if population areas on either side of a geographic unit boundary were connected by the same original habitat block (see Appendix A, Section 5).

6.3.3. Summary of Current Condition Categories

An overall resiliency condition category for each geographic unit was assigned using metrics which incorporated population area resiliency ratings and rating for the two types of connectivity (Table 7). We categorized the final resiliency condition for each unit as “high” (generally secure) and “moderate high” (generally secure, with uncertainty as to if it is moderate or high), “moderate” (marginally secure) and “moderate low” (marginally secure, with uncertainty as to if it is moderate or low) or “low” (generally insecure). We based these categories primarily on our understanding of red tree vole habitat needs and the principles of conservation biology. We acknowledge that there is uncertainty associated with this model and some of the supporting data but consider the methodology as providing a reasonable and rational assessment of the status of the red tree vole across its range.

Table 7. Current condition rating key for assessing resiliency overall resiliency of geographic units. The estimated effective population size is described in section 6.3.1. Red Tree Vole Habitat Capacity and Effective Population Range. Connectivity is described in section 6.3.2. Red Tree Vole Connectivity.

Condition Category	Estimated Effective Population Size (N_e) Capacity (Population Area Resiliency)	Connectivity Potential Within Geographic Units	Connectivity Potential Between Geographic Units	Overall Resiliency Condition <i>At least one population area in the unit meets the following criteria:</i>
High	Range is > 1000	Another population area is within 2 km and separated by forested lands	Population areas on either side of a geographic unit boundary are connected by the same habitat block.	N_e range is high or N_e range is moderate high and at least one connectivity factor is high
Moderate High	Range is >100 to > 1,000			N_e range is moderate high and both connectivity factors are low or N_e range is moderate and at least one connectivity factor is high
Moderate	Range is >100 and < 1000 or Range is <100 to >1000 (high uncertainty)			N_e range is moderate and both connectivity factors are low or N_e range is moderate low and at least one connectivity factor is high
Moderate Low	Range is 0 to >100 but <1,000	Population area >2 km or <2 km but the area in between is not forested	Habitat block does not span unit boundary or spans unit boundary but either side is not a population area	N_e range is moderate low and both connectivity factors are low or N_e range is low and at least one connectivity factor is high
Low	Range is <100			N_e range is low and both connectivity factors are low

6.3.4. Current Condition Ratings

The results of the red tree vole condition model provide the basis for our analyses of the species' current status using the 3Rs. The current condition resiliency ratings allow us to directly assess

and compare the resiliency of each red tree vole geographic unit (Table 8, Figures 12 and 13), which then support our analyses of the species' redundancy (within and between the geographic units) and representation (across its environmental settings). We emphasize that this portion of the assessment is a "snapshot in time" of the red tree vole's current condition and does not consider future trends. Chapter 7 assesses the species' potential condition under several future scenarios.

Table 8. Current condition resiliency rating by geographic unit, showing the population area resiliency rating and connectivity components, from north to south. Population area resiliency ratings are color coded according to Table 7 as blue = high (HI), green = moderate high (MOD HI), yellow = moderate (MOD), purple = moderate with high uncertainty (MOD High Uncertainty), orange = moderate low (MOD LO), and red = low (LO). Results of population area analysis are shown in Figure 12. Geographic unit ratings are color-coded according to Table 7 as blue = high (HI) or generally secure, yellow = moderate or marginally secure (MOD), and red = low or generally insecure (LO). Results of geographic units analysis are shown in Figure 13.

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
1. Lewis and Clark	Saddle Mountain Road	LO	LO	LO	LO
2. Ecola/ Elmer Feldenheimer	Elmer Feldenheimer North	LO	LO	LO	LO
3. Necanicum/ Nehalem	Oswald West	LO	LO	LO	LO
4. North Fork Nehalem	Tillamook South Fork Nehalem North	LO	LO	LO	LO
5. Nehalem/ Wilson	Tillamook South Fork Kichlis Middle	MOD LO	HI	LO	MOD
	Tillamook South Fork Kichlis North	MOD LO	HI	LO	
	Tillamook South Fork Nehalem South	LO	HI	LO	
	Anderson Creek	LO	HI	LO	
6. Cape Meares	Cape Meares	LO	LO	LO	MOD LO
	Fall Short	LO	HI	LO	
	Hodgdon Creek	LO	HI	LO	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
	O'Hara Creek	LO	HI	LO	
7. Sand Lake	Tierra Del Mar	MOD LO	HI	LO	MOD
	Andy Creek	LO	HI	LO	
	South of Sandlake	LO	HI	LO	
	Cape Lookout West	LO	HI	LO	
	Cape Lookout North	LO	HI	LO	
	Cape Lookout South	LO	HI	LO	
8. Trask/Nestucca	Nestucca Block Trask	HI	HI	HI	HI
	Moon Creek Nestucca Block Inclusion	LO	HI	LO	
	East Beaver Creek	LO	HI	LO	
	Gopher	LO	HI	LO	
	Tillamook South Fork Kichlis South	LO	LO	LO	
9. Gauldy Ridge	Nestucca Block Gauldy	MOD LO	LO	HI	MOD
10. Little Nestucca/Salmon	Nestucca Block Salmon Coast	MOD LO	LO	HI	MOD
11. Little Nestucca/Salmon Inland	Bower Creek	LO	HI	LO	MOD
	Nestucca Block Salmon West	MOD LO	HI	HI	
	Nestucca Block Salmon East	MOD LO	HI	HI	
	"2006"	LO	HI	LO	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
	Neskowin Creek West	LO	HI	LO	
	Neskowin Creek East	LO	HI	LO	
12. Siletz/ Luckiamute	South Block Luckiamute	MOD HI	HI	HI	HI
	South Fork Teal Creek South Block Inclusion ²	LO	HI	LO	
	No-Name South Block Inclusion ¹²	LO	HI	LO	
	Middle Ridge South Block Inclusion ¹²	LO	HI	LO	
	McTimmonds Creek South Block	LO	HI	LO	
	Norton	LO	HI	LO	
	Potter Creek	LO	HI	LO	
	BLM Checkerboard	MOD (High Uncertainty)	HI	LO	
	Salt Creek	LO	HI	LO	
	Nestucca Block Luckiamute	LO	LO	HI	
	Treat River	LO	LO	LO	
	Deadwood Mountain	MOD HI	HI	LO	
	Dry Creek	LO	HI	LO	
	North Fork Siletz	LO	HI	LO	
13. Yaquina/ Marys	South Block Yaquina	HI	HI	HI	HI

² This population area is nearly or completely surrounded by South Block Luckiamute.

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
	Skunk Creek South Block Inclusion ³	LO	HI	LO	
	Bull Run Creek South Block Inclusion ¹¹	LO	HI	LO	
14. Alsea/ Siuslaw	South Block Alsea	HI	LO	HI	HI
15. Siuslaw/ Long Tom	South Block Long Tom	MOD HI	LO	HI	HI
16. Siuslaw/ Territorial	South Block Territorial	MOD HI	LO	HI	HI
17. Spencer Butte	Spencer Butte	MOD (High Uncertainty)	LO	LO	HI

³ This population area is surrounded by South Block Yaquina.

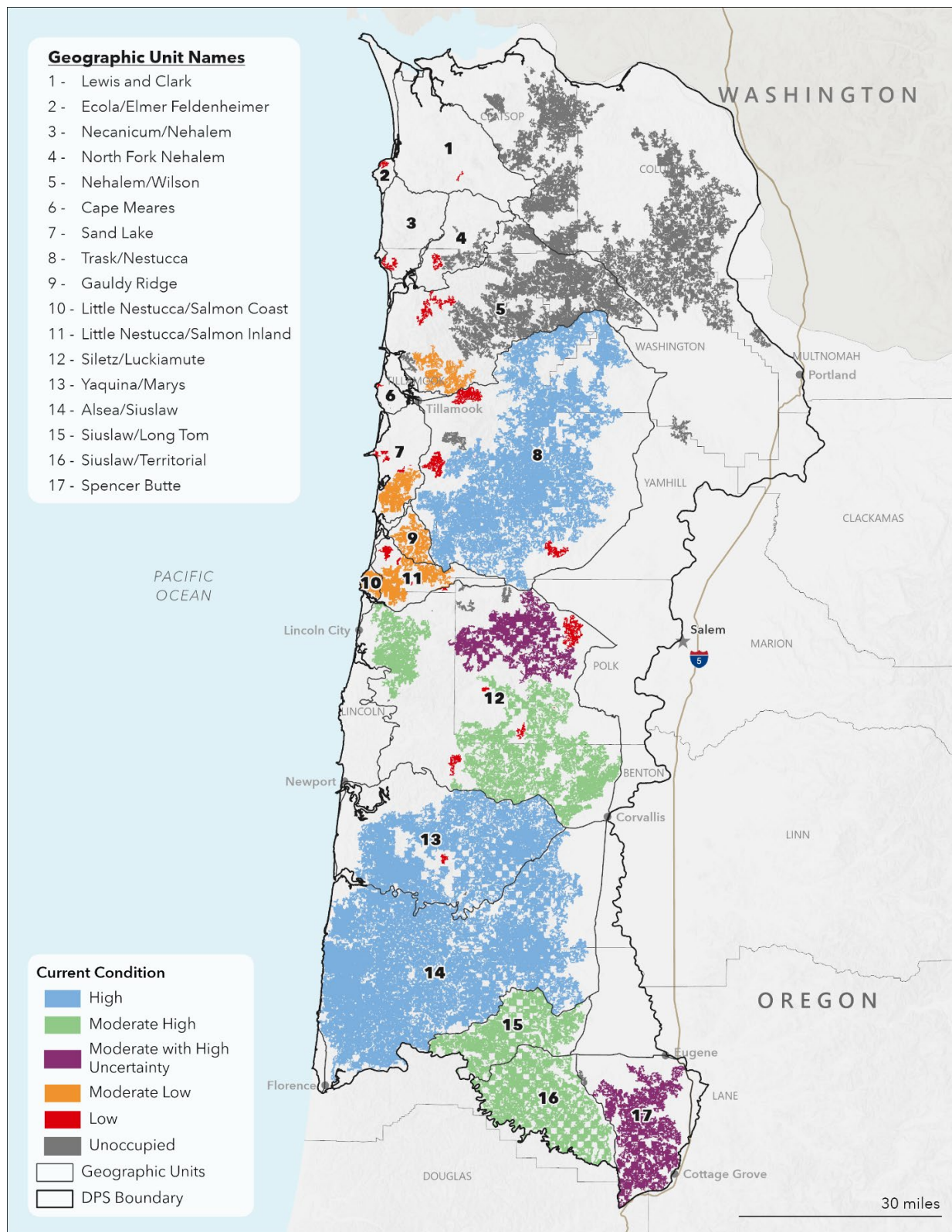


Figure 12. Population resiliency ratings of tree vole population areas for current condition.

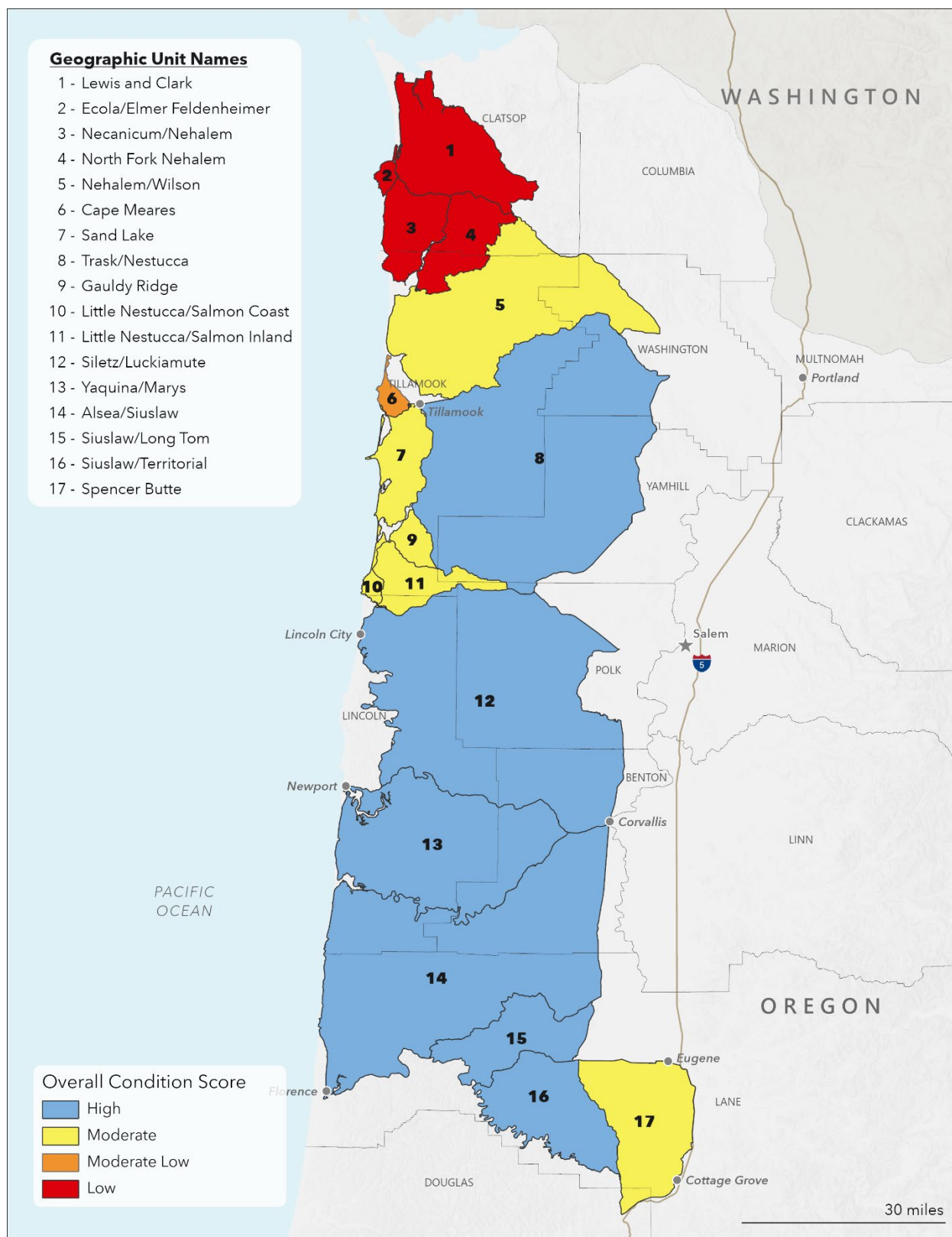


Figure 13. Current condition of red tree vole geographic units depicted by their overall resiliency condition ratings (see Table 8).

Compared to historical conditions, red tree vole habitat has been substantially reduced (Dunk and Hawley 2009, p. 632; Forsman et al. 2016a, pp. 80–81), is even more restricted within the DPS (Dunk 2009, pp. 4–5; Forsman et al. 2016a, pp. 80–82; Lesmeister et al. 2016, p. 28). Within the DPS habitat has continued to decrease the most on private lands, up to 50 percent since 2006, consistent with timber harvest (Linnell et al. 2023, pp. 7–8). Moreover, large blocks of older forest (greater than 400 ha (1,000 ac)) are restricted primarily to Federal lands, with contiguous blocks separated by great distances (Moeur et al. 2005, p. 77). Fragmentation complicates habitat availability for red tree voles, which select for patches of large tree structure where fragmentation is minimized (Martin and McComb 2002, p. 262). Having evolved in extensive areas of relatively more contiguous late-successional forest, tree voles are especially vulnerable to the negative effects of fragmentation and isolation due to their limited dispersal capability coupled with their low reproductive potential.

The most recent modeling efforts used light detecting and ranging (LiDAR) and satellite imagery (Lesmeister et al. 2016, entire; Linnell et al. 2017a, entire) and Landsat imagery with Forest Inventory and Analysis National Program plot data (Bell et al. 2021; Linnell et al. 2023, entire). These two models provide higher resolution and higher density sampling of the vegetation than the modeling used in previous DPS analyses (Dunk 2009, entire) wherein sampling was limited to 388 Forest Inventory Analysis plots, which are long-term vegetation sampling plots systematically placed across the landscape (see Dunk 2009, p. Fig. 1). All three models used an analysis area that was a subset of the DPS and which roughly captured the forested areas and a majority of the public lands in the DPS (see Linnell et al. 2017a, Fig. 5, 2023, Fig. 1c). Using data from the most recent model (Linnell et al. 2023, GIS data) and our calculations of land ownership (see Table 1), we calculated percent habitat by land ownership using all categories of tree vole habitat suitability identified in the model (low, moderate, and high) to define potential habitat (Table 9). The DPS is larger than the modeled area, but we assume the modeled area captures all the potential habitat in the DPS.

Table 9. Habitat by ownership within the north Oregon coast distinct population segment of red tree vole derived using the most recently published tree vole habitat model (Linnell et al. 2023, GIS data).

Ownership	Area km² (mi²) in Habitat	Percent of Land Ownership in Habitat	Percent Habitat of Total Habitat
Federal	1685 (651)	48.6	56.9
Private	758 (293)	5.4	25.6
State	465 (180)	19.0	15.7
Tribal	33 (13)	38.3	1.1
Local	19 (7)	9.2	0.7
NGO	1 (0.4)	4.1	0
Totals	2962 (1144)	14.6 (of DPS)	100

In the DPS, habitat change has been the highest (65 percent) than elsewhere across the species range, primarily due to timber harvest (Linnell et al. 2023, pp. 6–7). Furthermore, red tree vole habitat is disproportionately found on Federal lands in the DPS, which contain 63 percent of predicted suitable and highly suitable tree vole habitat according to one model (Linnell et al. 2017a, p. 5). Using a more recent model (Linnell et al. 2023, GIS data), we calculated that about 57 percent of all potential tree vole habitat in the DPS was on Federal lands (Table 9) but Federal lands comprise only 17 percent of the DPS (Table 1). Since 1987, habitat trends have generally increased on Federal lands (Linnell et al. 2023, pp. 6–7). One Oregon range-wide tree vole habitat model estimated that red tree vole habitat was restricted to 22 percent of the area capable of developing into potential tree vole habitat (Forsman et al. 2016a, p. 80). When broken down by subregions containing the DPS, this same model estimated that 12 and 16 percent of lands capable of producing habitat in the north coast and central coast subregions, respectively, were suitable for red tree voles as of 2006 (Forsman et al. 2016a, pp. 80–82).

A more optimistic model of red tree vole habitat within the Coast Range physiographic province of Oregon indicated that tree vole habitat currently makes up almost 50 percent of the province, with just under half of that habitat occurring on private lands (Spies et al. 2007a, p. 10, Figure 2). However, we believe the modeling efforts described in the previous paragraphs are more accurate descriptions of red tree vole habitat in the analysis area for the following reasons. First, the analyses provide results specific to the DPS or to subregions roughly equivalent to the DPS, whereas the Oregon Coast Range physiographic province, which includes the DPS and most of the analysis area, covers an additional 7,280 km² (2,810 mi²) extending south of the DPS and analysis area (Figure 4). Second, Spies et al. (2007b, p. 51, Appendix D) assessed tree vole habitat by developing habitat capability index models that reflect habitat characteristics important for survival and reproduction based on literature and expert opinion. The variables they used were restricted to existing geographic information system layers that could be projected into the future using forest dynamics models. They were not able to empirically verify their red tree vole habitat capability index model with independent data, although it was reviewed by two published experts. Conversely, models described in the previous paragraphs were empirically developed based on the presence or absence of red tree vole nests.

6.4 Current Condition 3 Rs

6.4.1. Resiliency

Resiliency describes the ability of a population to withstand environmental or demographic stochastic disturbance and is positively related to population size and growth rate, patch size, and connectivity to other populations. The demographic conditions from the red tree vole model, which incorporate estimates of abundance and connectivity, are primarily used to assess red tree vole resiliency for individual vole population areas. As noted previously, our evaluation of the 3Rs here does not consider future trends or conditions, just the current status of the populations.

Below we describe the resiliency outcomes for each geographic unit and conclude with an overall summary of resiliency.

1. Lewis and Clark (582 km² (225 mi²); 0.2% population area)

This unit has an overall low resiliency rating driven by one small population area of low resiliency and low connectivity. It is 94% private land with very little habitat (about 112 ha according to the 2023 model). The last survey and positive vole detection was in 2011.

2. Ecola/Elmer Feldenheimer (30 km² (12 mi²); 8% population area)

This is the smallest unit in the DPS and has an overall low resiliency rating driven by one small population area of low resiliency and low connectivity, anchored by a State natural area. The unit is 98% private land. The 2017 habitat model showed no habitat and the 2023 model only showed 3 hectares. The last survey and positive vole detection was in 2011.

3. Necanicum/Nehalem (256 km² (99 mi²); 2% population area)

This unit is 5% State land in scattered parcels of ODF managed forest land and 95% private/other land. A population area makes up 2% of the unit and about 2% of the unit is constrained, with only a small amount of overlap. This unit is isolated, bound by Highway 101 and Nehalem Bay to the west and south, North Fork Nehalem River and Highway 53 to the east, and Highway 26 to the north. The population area and a majority of the unit is in the Sitka spruce vegetation zone.

4. North Fork Nehalem (282 km² (109 mi²); 2% population area)

This unit has an overall low resiliency rating driven by one small population area of low resiliency and low connectivity. The 2017 habitat model showed significantly more potential habitat than the 2023 model (937 ha versus 97 ha). The unit is just over half State lands and the population area occurs on constrained ODF lands. The last survey and positive vole detection was in 2011.

5. Nehalem/Wilson (1292 km² (499 mi²); 6% population area)

The overall resiliency rating for this unit is moderate driven by two population areas with moderate low resiliency and high within unit connectivity of all four small population areas, located in the western portion of the unit. The other two population areas are low resiliency and the unit is not connected to neighbors via currently occupied habitat. This is a large unit with about two-thirds State lands. Constrained State lands, divided into several large blocks, make up 39% of the unit. Three of the population areas have recent positive vole detections (2011 or 2018) and one is unsurveyed but presumed occupied due to distance. Despite the small population areas, the unit contains a large amount of habitat (>4,000 ha) due to a very large unoccupied population area that comprises the eastern half of the unit. This area had some surveys in 2011 but had no vole detections. It is notable as the location of part of the historical Tillamook burns and is likely habitat that has developed more recently but had not had the connectivity or time to be colonized by voles.

6. Cape Meares (46 km² (18 mi²); 2% population area)

The overall resiliency rating for this unit is moderate low. It is comprised of four small population areas with low resiliency, three of which are potentially connected to each other and the largest of which is centered on Cape Meares National Wildlife Refuge with a last survey and positive detection date of 1996. Otherwise, the unit is nearly all in private ownership and isolated from other units. The other three population areas were surveyed with positive detections in either 2003 or 2011.

7. Sand Lake (261 km² (101 mi²); 22% population area)

This unit is overall moderate resiliency. The unit is comprised of one larger population area with moderate low resiliency and five smaller population areas of low resiliency, all in the southern portion of the unit and associated primarily with USFS land, though one population area is on State park land. The population areas are all potentially connected by forest lands within the unit but the unit itself is isolated from other units. All six population areas have had recent vole detections (since 2003), the most recent being in 2021.

8. Trask/Nestucca (2661 km² (1027 mi²); 48% population area)

This unit is the largest in area in the DPS with a mix of ownerships. It rated high for overall resiliency due to a very large population area with high effective population size capacity and connectivity both within and between units. There are also four other smaller population areas with low resiliency and some within unit connectivity. About half of the Federal and State lands, which underlies most of the large population area, are in reserved land use allocations. Tree vole surveys and positive detections have been focused on the center of the unit on BLM land and southwestern portion of the unit on USFS land. One population area is presume occupied by distance, one has an older (1996) positive detection, and three have had recent positive detections. The large population area had a positive vole detection in 2022.

9. Gauldy Ridge (85 km² (33 mi²); 60% population area)

This unit rated moderate for resiliency. It is made up of one large population area with moderate low resiliency and high between unit connectivity to two neighboring units. The unit is two-thirds USFS lands, though only about 6% of the unit is in Federal reserved land use allocation. The most recent positive vole detection in the unit was in 2018.

10. Little Nestucca/Salmon Coast (36 km² (14 mi²); 61% population area)

This is the second smallest unit and rated overall moderate resiliency due to a single large population area with a moderate low effective population size capacity and high sub rating for potential between unit connectivity. Most of the unit is USFS land but is not designated as reserved. The most recent positive vole detection in the unit was in 2018.

11. Little Nestucca/Salmon Inland (225 km² (87 mi²); 38% population area)

This unit is one of the smaller occupied units and rated overall moderate resiliency. While the six population areas rated low or moderate in effective population size capacity, the population areas are all connected by forest within the unit and the two largest are connected

to three neighboring units. One population area is unsurveyed but presumed occupied due to connectivity while population areas have recent occupancy. Over 36% of the unit is managed by Siuslaw National Forest but only 4% of the unit is a reserved land use allocation. The 2017 habitat model showed about 30% more habitat than the 2023 model. The most recent positive vole detection in the unit was in 2018.

12. Siletz/Luckiamute (2571 km² (993 mi²); 36% population area)

The overall resiliency rating for this unit was high. This unit is the second largest in the DPS, comprised of three large and 11 smaller population areas. Most of the smaller population areas rated low for effective population size capacity, but two large units had moderate high resiliency for that sub rating. These two areas are on opposite sides of the unit, and both contain reserved and non-reserved blocks of public land. The largest population area rated moderate for effective population resiliency due to the high uncertainty introduced by the significantly lower amount of habitat shown in the 2017 versus the 2023 model. There is high connectivity potential within the unit among the population areas due to forested lands between most areas. One of the larger population areas is connected to a neighboring unit, so between-unit connectivity ratings were high. The unit is primarily private land (82%), and the largest population area is mostly on private land. The three larger and two inclusion population areas have had recent (2018 or later) positive detections. Four of the population areas are unsurveyed but presumed occupied due to potential connectivity. The most recent positive vole detection in the unit was in 2022.

13. Yaquina/Marys (1246 km² (481 mi²); 58% population area)

This unit rated high for resiliency driven by the high effective population size capacity of the primary population area, comprising over half of the unit, and the between unit connectivity to the units to the south and north. There are also two small population area “inclusions” that are surrounded by the larger population area, and these were low resiliency. One inclusion had a positive vole detection in 2022 and the other is presumed occupied due to connectivity. The unit is over a third Federal land and most of that is a reserved land use allocation. The last known positive tree vole detection in the large population area was in 2022.

14. Alsea/Siuslaw (2,415 km² (932 mi²); 69% population area)

This unit had an overall high resiliency rating. This is one of the larger units in the DPS and consists of a single population area which is connected across the unit and makes up 69% of the unit area. The effective population size capacity rating was the highest of any unit (2,891 – 22,603 voles). The unit is connected to other units along its northern and southeastern boundary, so the connectivity rating was high. This unit is over half Federal lands, 47% of which are in reserved land use allocations. Most of the tree vole surveys have been on Federal land and concentrated in the eastern BLM checkerboard ownership. The last positive detection was in 2022.

15. Siuslaw/Long Tom (411 km² (159 mi²); 66% population area)

This unit had an overall high resiliency rating driven by a single large population area with a moderate high effective population size capacity and high between unit connectivity ratings. While primarily in private ownership (62%), constrained lands make up over a quarter of the unit, nearly all in BLM checkerboard. Most of the tree vole surveys have been conducted on BLM ownership and the last positive detection was in 2021.

16. Siuslaw/Territorial (561 km² (217 mi²); 67% population area)

This unit rated high due to its single, large population area with a moderate high effective population size capacity and high rating for connectivity to a neighboring unit. It is primarily in checkerboard ownership with about one-third of the unit in constrained status. The 2023 model showed nearly double the amount of habitat of the 2017 model, and both indicated that habitat was primarily on the BLM ownership. Most of the tree vole surveys have been on the BLM ownership, with occupancy detected as recent as 2022.

17. Spencer Butte (641km² (247mi²); 46% population area)

The unit is comprised of one large known occupied population area and rated moderate for overall resiliency. The effective population size capacity ranged from <100 to >1000, indicating high uncertainty in that estimate. This uncertainty was driven primarily by the underlying habitat models. The 2017 model showed 865 ha of habitat and the 2023 model indicated significantly more habitat at 7,598 ha. The population area takes up nearly half the unit and is not connected to the neighboring unit, so connectivity ratings were low. It is over 90% in private ownership and vole surveys have primarily been conducted on the public ownership parcels. The last positive detection was in 2011.

The primary factor influencing current condition of tree voles is loss or reduced development of habitat. This has resulted in fragmentation of habitat, which impedes the ability of red tree voles to disperse and connect with other population areas. A group of five large units making up most of the southern half of the DPS and a large unit in the central part of the DPS rate high for current condition and together form the foundation for the current tree vole habitat in the DPS (Figure 12). These units retain large, contiguous, or connected blocks of tree vole habitat. Five of these units contain primarily Federal land, a large portion in constrained status. The two most northern of those units contain a mixture of land ownerships with the Trask/Nestucca unit comprised of nearly equal amounts private, Federal, and State lands and the Siletz/Luckiamute unit containing a majority of private land anchored in places by State and Federal contiguous habitat areas. The four most southern units are also connected by a large underlying habitat block. Together, these six units make up about two-thirds of the DPS.

Most of the remaining units are smaller and located along the coast in the northern part of the DPS. The exception is the Spencer Butte unit in the very southeast part of the DPS, which had a moderate condition rating. Five units along the north central coast, nearly all bordering the larger Trask/Nestucca unit, had moderate condition ratings. Most of these units contain large amounts

of USFS land that, while not in reserved land use allocations, offer more contiguous habitat potential. Another coastal unit is fairly isolated and had a moderate low condition rating. The largest unit with a moderate rating, just to the north of the Trask/Nestucca unit, shows significant habitat but it is fragmented and does not contain many vole detections.

The remaining three units in the northernmost portion of the DPS contain very small population areas with low resiliency and are isolated, with limited ability for demographic or genetic support to or from nearby units. These units may be particularly vulnerable to extirpation by having a limited ability to persist and respond to stochastic events.

6.4.2. Redundancy

Redundancy describes the ability of a species to withstand catastrophic events by maintaining multiple, resilient populations distributed (and connected) within the species' ecological settings and across the species' range.

Species with adequate redundancy are able to withstand catastrophic events. While 52 population areas in 17 geographic units may sound like substantial redundancy, it must be considered within the context of the estimated resiliency of the individual units as well as the scale at which a catastrophic disturbance may occur and thus how many units, or how big a portion of individual units, are affected. Red tree voles are well distributed on most Federal lands throughout the analysis area, where most of the available habitat remains. The scale of catastrophic events in the Oregon Coast Range cause us to heavily weigh the largest units in their contribution to redundancy. Catastrophic events in the Oregon Coast Range that could affect red tree voles are wildfire, and to a lesser degree, large wind events.

Large storms with severe winds are regular occurrences in the Oregon Coast Range, creating localized patches of blowdown that are unlikely to severely affect an individual tree vole habitat unit (see section 4.3.2 Redundancy). However, occasionally severe weather events occur with winds severe enough to blow down large sections of forest to the degree that localized areas of windthrow may reduce existing vole population areas or further fragment or isolate population areas or units from neighbors. For the smallest units, such as Cape Meares, such an event may be enough to severely impede their resiliency and cause their extirpation.

Wildfires in the Oregon Coast Range are infrequent events (on the order of hundreds of years) and are most often stand replacing. Historic fire sizes have ranged from 1,200 km² (460 mi²) for the mid-1800s Nestucca fire, to as large as 3,240 km² (1,250 mi²) in the mid-1800s fire complex in the southern DPS (see section 5.1.2 Wildfire and Figure 21 in Appendix A). Unit sizes in the DPS range from 36 km² to 2,661 km² in size. Taking the smaller end of the large historic fires, 1,200 km², three units (Trask/Nestucca, Siletz/Luckiamute, and Alsea/Siuslaw) are about twice as large as a fire that size. We assume tree vole populations in those areas, while reduced, could survive if a fire were to occur in any one of those units, because large areas of habitat would remain unburned. Also, units could remain connected. Another two units (Yaquina/Marys and Nehalem/Wilson) are slightly larger than 1,200 km² so that some habitat would remain if a fire

were to occur on those units. These units also have connectivity to neighboring units and therefore a pathway to potential recolonization. The remaining 12 units would be consumed by such a large fire. For the larger size of historic fires (3,240 km²), any one unit or a complex of smaller units could be consumed (see Figure 21 in Appendix A). Fragmentation of habitat is likely to occur with any catastrophic fire, which may leave limited habitat in some areas which tree voles can persist until burned areas recover over the following eight or more decades. The degree to which this loss of habitat and fragmentation will happen will depend on the size and specific location.

There is broad distribution of large, connected population areas and units with high resiliency ratings across the southern portion of the DPS and in the central portion of the DPS. These units also contain representation of both vegetation zones. Any one of these units could be severely impacted by wildfire, depending on the fire's size and severity. While they may provide adequate redundancy, their ability to support or be supported by the overall population could be limited due to fragmentation of habitat. Most of the medium to smaller sized units with lower resiliency ratings could be extirpated in a single large wildfire event. Under the current condition, units with low or moderate ratings are less likely to contribute to redundancy to the overall population because of their limited size and inability to provide immigration support to adjoining units. In addition, the units in the northern portion of the DPS along the coast represent majority Sitka spruce zone, so any losses to those units from catastrophic events would also impact representation.

As with resiliency, redundancy of the species is best supported by the five units in the southern half of the DPS plus the Trask/Nestucca unit in the northern portion of the DPS. Large wind events may impact portions of some units, but there is likely adequate redundancy. However, in the event of a very large, catastrophic, and stand-replacing wildfire or wildfire complex, any one unit is vulnerable to complete loss or substantial degradation. If the fire(s) were large enough, several units could be impacted. Depending on the location, this would substantially reduce red tree voles in the DPS and could isolate, or further isolate existing population areas and units, limiting refugia from which to recover as the burned areas regrow.

6.4.3. Representation

Representation describes the ability of a species to adapt to changing environmental conditions over time and is characterized by the breadth of genetic and environmental diversity within and among populations. Because of the lack of comprehensive genetic data with which to characterize the red tree vole's representation range wide, we discuss the environmental diversity of red tree vole habitats to assess its current representation.

Genetic structure among tree voles in the analysis area is unknown. They are genetically different from voles to the south or in the Cascade Range (Miller et al. 2006, p. 145), but there has not been any work on genetic structure within the analysis area. Such work would be helpful to understand whether smaller population areas of tree voles might be isolated from the remaining population areas, particularly those in the northern portion of the analysis area.

Tree voles are also morphologically similar, although there does appear to be a clinal change in size, with voles tending to be smaller as one moves south in the taxon (Miller et al. 2010, p. 69). Tree voles do exhibit different foraging behaviors necessary for feeding on the leaves of these different coniferous species. The observed difference in foraging behavior may be learned (Forsman et al. 2016a, p. 52). The difference is necessary to remove the unpalatable resin ducts in the conifer needle, which are located in different portions of the needle, depending on which coniferous species is consumed (see section 3.9.2 Diet). Alternatively, the difference may be based on different intestinal flora necessary to digest specific tree species or counteract the specific species toxins (Forsman et al. 2016a, p. 52). Red tree voles found in the Sitka spruce vegetation zone generally feed on Sitka spruce, western hemlock, or both species, which are the dominant tree species found in this zone (see Section 3.9.2). The Sitka spruce zone is restricted to the coastal portion of the analysis area (Figure 5), and most of the red tree vole population occurs outside of this zone. Retaining red tree vole population areas within the Sitka spruce zone will be necessary to maintain representation of this behavioral trait. Tree voles occupying the western hemlock zone mainly feed on Douglas-fir, the predominant species found in this zone. Retaining this trait is also important, but the western hemlock zone occurs throughout most of the DPS, as well as the entire species range.

We used vegetation zones defined by Potential Natural Vegetation (USDA FS 2021, in litt.) as a proxy for this behavioral trait to determine which of the 52 population areas and 17 geographic units contained the behavioral diversity in foraging capability in response to the availability of different coniferous species. We considered a population area containing a vegetation zone if >10 percent of the area was in that zone. For population areas with >10 percent of both vegetation zones, we recorded it as both. To derive a unit rating we aggregated the population area ratings; in other words, if all population areas in a unit were in a single zone, we considered that unit to contain that vegetation zone, but if the unit included a unit with both zones, or at least one unit with each zone, we considered the unit to contain both zones.

Results are provided in Appendix A, Table A–16 and summarized in Figure 13 below. For population areas, 19 were in the Sitka spruce zone, 17 were in the western hemlock zone, and 16 were considered to have both zones. Eight units, including the five largest, occur in both vegetation zones and individually represent the spectrum of coniferous species and associated foraging behaviors. Six small units in the northern half of the DPS occur in the Sitka spruce zone and the three units in the southeastern edge of the range only occur in the western hemlock zone. The loss of the north coast subregion units, or the loss of the coastal portions of the large units in the southern part of the DPS would result in a decrease in ecological and behavioral representation of the red tree vole.

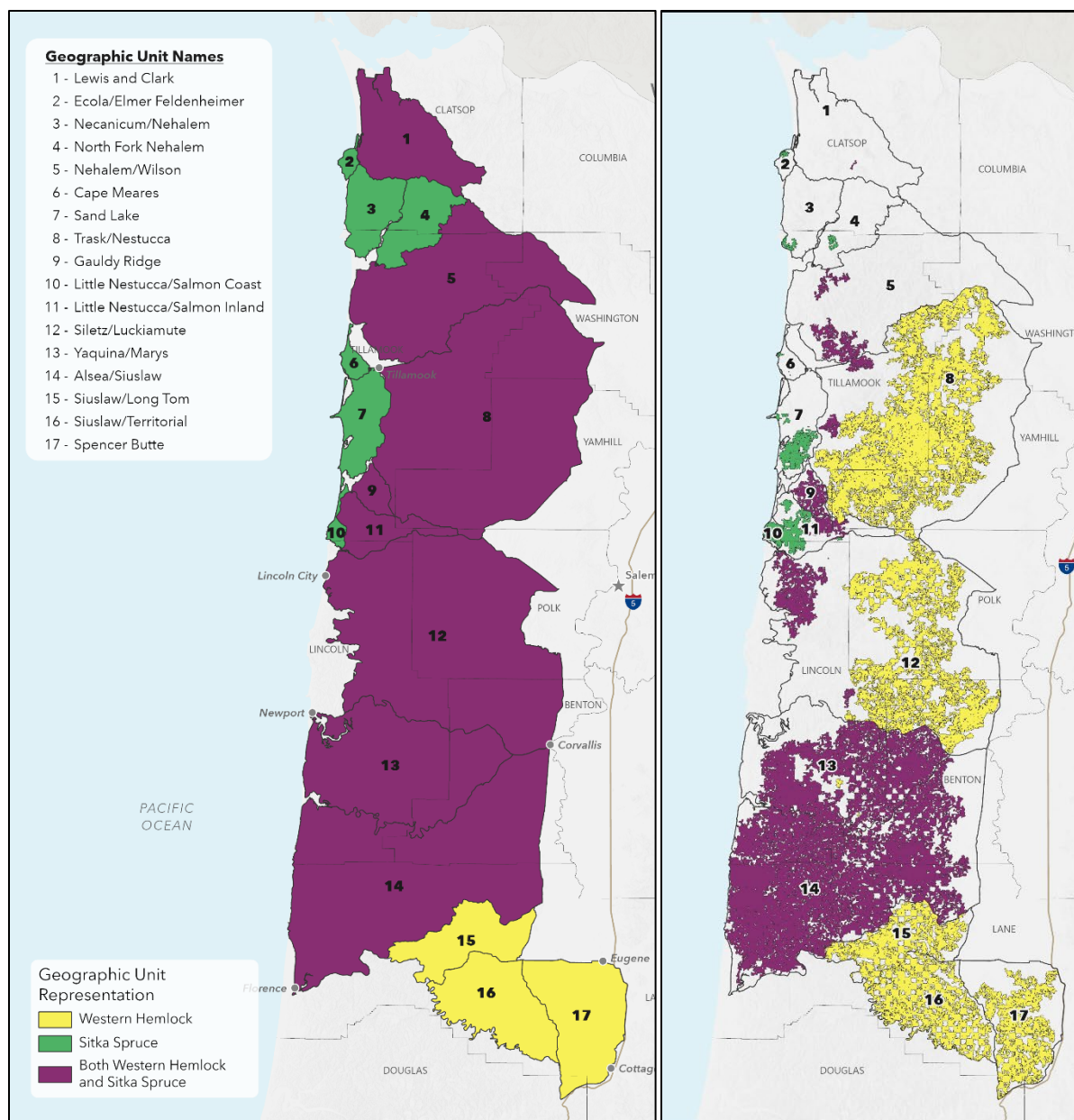


Figure 14. Representation by geographic units (left) and population areas (right).

6.5 Summary of Current Condition

We evaluated 17 tree vole geographic units comprised of 52 occupied population areas in the DPS. In modeling current resiliency of individual units, we derived an effective population size capacity and considered connectivity to derive an overall relative resiliency rating. We also assessed representation and redundancy across the DPS. Six units have high resiliency ratings under the current condition. One is in the north coast subregion and the remaining make up the southern half of the DPS (in the central coast subregion). The four largest of these, in both subregions, also contain representation of both vegetation zones and hence, the behavioral

capacity of tree voles to forage on different coniferous species. In addition, these units also strongly provide for population redundancy simply due to their size, being large enough to withstand most events except for large, catastrophic wildfires, which could limit their individual unit resiliency and redundancy, depending on the fire size and location. The other units in the north subregion range in size from small to large and are either moderate or low resiliency. The smallest coastal units are in the Sitka spruce vegetation zone where tree voles primarily feed on western hemlock, Sitka spruce, or both.

7. FUTURE CONDITION

We assessed trends in stressors and derived future scenarios that may occur within the analysis area. To aid in the comparison of vole units (with each other and under various future scenarios) and assess the species' viability under the 3Rs, we categorized the final condition ratings under each future scenario as "high" (unit generally secure), "moderate" (unit marginally secure), or "low" (unit generally insecure). We based these categories primarily on our understanding of red tree vole habitat needs, known stressors, and the principles of conservation biology. The main stressor for which we could make reasonable projections to carry into future scenarios was timber harvest and its consequential effects on habitat fragmentation and isolation. We also assess the effects of climate change, particularly in relation to the changes it will have on the prevalence of Swiss needle cast, potential vegetation shifts, and wildfire. We were not able to project probability of catastrophic events such as wildfire through time. However, we note that wildfire events are likely to occur at some point in time and the longer the time frame in which we analyze future scenarios, the more likely it is that catastrophic wildfire will occur.

7.1 Factors Influencing the Future Condition of the Species

Here we summarize information on trends of primary stressors and factors that may play into future trends (Figure 14). These factors have had or are expected to have substantial population-level effects and be the primary drivers of species viability. They encompass or relate to the other factors influencing viability discussed in Chapter 5. We use this information either to develop our future scenarios or to provide context for interpreting our scenarios and the effects on red tree voles in the analysis area.

We acknowledge the growth of barred owl populations in the DPS and how their relatively recent invasion may alter predator and prey communities and affect the red tree vole. However, as noted earlier (see section 5.2 Predation), the best available information does not indicate a population-level impact on the red tree vole by barred owl presence and does not indicate whether predation, is a driver of population decline for red tree voles. Therefore, predation is not considered in the future condition analysis.

Many of the key influence factors carried forward in this SSA are exacerbated by climate change. We did not identify climate change itself as an influence factor, but as a threat

multiplier. The ways climate change may impact the species at the population level is captured via other influence factors, however, we do describe the future context of climate change below.

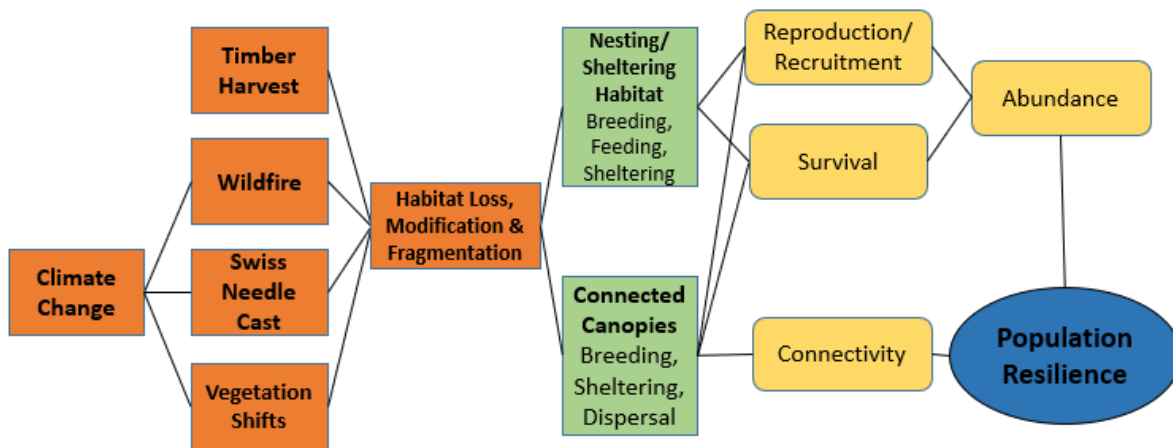


Figure 15. Conceptual diagram of the primary factors influencing future resiliency of the red tree vole. Orange boxes are stressors, green boxes are habitat needs, and yellow boxes are demographic/population needs that contribute to population resiliency.

7.1.1. Projected Trends in Timber Harvest and Red Tree Vole Habitat

Loss and modification of tree vole habitat by timber harvest will continue within the analysis area. In addition, timber management that precludes habitat development will also occur. More than 75 percent of the future timber harvest is expected to come from private timberlands (Johnson et al. 2007, entire; Spies et al. 2007b, p. 50) and modeling of future timber harvests to the year 2054 indicates that harvest levels on private lands in western Oregon will be maintained at the current rate (Adams and Latta 2007, p. 13). Harvest rates on Federal lands are projected to occur at a lower rate compared to private lands given existing management (see section 5.1.1.2 Timber Harvest and Management).

Implementing current land management policies in the Oregon Coast Range Physiographic Province is projected to provide an approximately 20 percent increase of red tree vole habitat by approximately 2100, primarily on Federal and State lands (Spies et al. 2007b, pp. 53, Figure 2). Vegetation simulations ran until approximately 2100 indicate that private industrial timber lands will generally be dominated by open, small-, and medium-sized coniferous forests (Johnson et al. 2007, p. 42; Spies et al. 2007b, p. 55). Old-forest structure and habitat will greatly increase on Federal and State lands, and large, continuous blocks of forest will increase primarily on USFS and State lands by 2100 (Johnson et al. 2007, pp. 41–42). The estimate of old forests on State lands, however, may be a substantial overestimate because the analysis was not able to fully

incorporate the complexity of the State Forest management plan (Johnson et al. 2007, p. 43; Spies et al. 2007a, p. 11).

Loss of forest land to development is projected to occur in 10 percent of the Oregon Coast Range Province by approximately 2100, and would most likely occur on non-industrial private lands, near large metropolitan areas, and along the Willamette Valley margin (Johnson et al. 2007, p. 41; Spies et al. 2007a, p. 11). Timber production in the Oregon Coast Range is declining on Federal lands and increasing on private lands, and overall production is projected to stay at recent harvest levels. Actual production may result in harvest levels higher than projected because harvest levels estimated for private industrial timberland were conservative (Johnson et al. 2007, pp. 42–43) and timber production on State lands may be underestimated by 20 to 50 percent (Johnson et al. 2007, p. 43). Johnson et al. (2007, pp. 45–46) described several key uncertainties that were not accounted for in their projections of future trends until approximately 2100 in the Oregon Coast Range that could potentially affect their results. These uncertainties include: effects of climate change; recently adopted initiatives that may result in an increased loss of forest land to cities, towns, and small developments; a possible decrease in global competitiveness of the Oregon Coast Range forest industry; sales of industrial forests to Timber Management Investment Organizations that may result in a shift of land use to other types of development; the effects of Swiss needle cast on the future of plantation forestry; and effects of wildfire. Most of these scenarios would result in a loss of existing or potential tree vole habitat, contributing further to the present loss, modification, fragmentation, and isolation of habitat for the red tree vole within the analysis area, although the magnitude of that loss is uncertain.

7.1.2. Climate Change

Changes in recent global climate are unprecedented over many centuries to many thousands of years (IPCC 2023, p. 11). Specifically, and due to human influence, the atmosphere and oceans have warmed, amounts of snow and ice have decreased, sea levels have risen, and weather and climate extremes are being observed (IPCC 2023, pp. 11–12).. There is a strong and consistent relationship between cumulative carbon dioxide emissions and projected global temperature change; in the near term, global warming continues to increase in nearly all considered scenarios and modelled pathways (IPCC 2023, p. 33)..

Many species are subject to an increased risk of extinction as a consequence of climate change, particularly as climate change interacts with other stressors. Many plant species are not expected to shift their geographical range fast enough to respond to projected rates of climate change. Animal species with low rates of dispersal, especially in landscapes with no elevation refugia (characteristics shared by the red tree vole) are especially at risk (IPCC 2014, p. 70). The future risk to plant and animal species is corroborated by observations of historical climate change impacts, which caused significant ecosystem shifts and species extinctions over the past several millennia (IPCC 2014, pp. 13, 67).

The most recent climate change projections for the Pacific Northwest are based on the Intergovernmental Panel on Climate Change (IPCC), fourth assessment report (May et al. 2018,

entire), with temperatures predicted to rise an average of 0.54 °F per decade over the next century, which is a larger increase per decade than was experienced over the last century. In the Northwest (Oregon, Washington, and Idaho) all seasons will experience warming with more extreme summer heat, drought events and higher summer moisture deficits, while extreme winter cold events will be less common (May et al. 2018, pp. 1038–1043). According to the latest Oregon climate assessment (Fleishman 2023, entire), if greenhouse gas emissions continue at current levels, representative concentration pathway (RCP) 8.5, annual temperature in Oregon is projected to increase by an average of 5°F by the 2050s (2040–2069) and 8.2°F by the 2080s (2070–2099) (Table 10) (Fleishman 2023, p. 11). Under RCP 4.5, which represents moderate reductions in global greenhouse gas emissions, annual temperature is projected to increase by an average of 3.6°F by the 2050s and 4.6°F by the 2080s (Fleishman 2023, p. 11). Summer temperatures are projected to increase more than winter temperatures (Mote and Salathé Jr 2010, pp. 41–42; Salathé et al. 2010b, pp. 65–66; Cayan et al. 2012, p. 8; Pierce et al. 2013, p. 845; Fleishman 2023, p. 11). In addition, heat waves are projected to increase in frequency, intensity and duration, especially under higher-emissions scenarios (Hayhoe et al. 2004, p. 12423; Tebaldi et al. 2006, pp. 191–200; Salathé et al. 2010a, p. 69; Cayan et al. 2012, p. 10; Pierce et al. 2013, p. 848; Dalton et al. 2017, p. 8; Fleishman 2023, p. 16). However, atmospheric high-pressure ridges over the Pacific Ocean are projected to weaken, which would result in reduced heat extremes for coastal Oregon compared to inland areas (Dalton et al. 2017, p. 8), diminishing though not completely abating the effects in the Oregon Coast Range.

Table 10. Projected future changes in mean annual and seasonal temperature (°F) in Oregon from historical baseline (1970–1999) for the 2050s (2040–2069) and 2080s (2070–2099) under RCT 4.5 and RCP 8.5. Values are the average changes from 35 global climate models and the 5th to 95th percentile range across the models. Table reproduced from (Fleishman 2023, p. 11)

	2050s		2080s	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
ANNUAL	3.6 (1.8, 5.4)	5.0 (2.9, 6.9)	4.6 (2.1, 6.7)	8.2 (4.8, 10.7)
Winter	3.3 (1.6, 5.1)	4.5 (2.4, 6.5)	4.2 (1.8, 6.5)	7.4 (4.2, 9.8)
Spring	3.1 (1.4, 5.0)	4.1 (2.0, 5.9)	3.8 (1.7, 6.0)	6.7 (3.8, 9.2)
Summer	4.5 (2.2, 6.8)	6.3 (3.6, 8.9)	5.5 (2.7, 8.3)	10.2 (6.5, 13.9)
Fall	3.7 (1.5, 5.4)	5.2 (2.6, 7.0)	4.7 (2.0, 6.9)	8.6 (4.6, 11.4)

Future precipitation trends vary considerably, but most simulations project slight increases for western Oregon (Hayhoe et al. 2004, p. 1242; Christensen and Hewitson 2007, p. 890; Littell et al. 2011, p. 74; Dalton et al. 2017, p. 9). Nearly all simulations show a decrease in summer precipitation and many show an increase in winter precipitation (Mote and Salathé Jr 2010, pp. 42–43; Halofsky et al. 2011, p. 15; Cayan et al. 2012, pp. 13–20; Pierce et al. 2013, p. 849; Dalton et al. 2017, p. 9; Fleishman 2023, p. 11). Annual precipitation is projected to increase in Oregon by mid- and late-century and under RCP 4.5 and RCP 8.5 scenarios (Table 11), however, we have less confidence in model projections for precipitation as they are more variable than those for temperature (Dalton et al. 2017, p. 9; Fleishman 2023, p. 11). Overall, extreme heat and extreme precipitation events are projected to be more frequent.

Table 11. Projected future relative changes in total annual and seasonal precipitation (%) in Oregon from the historical baseline (1970–1999) for the 2050s (2040–2069) and 2080s (2070–2099) under RCP 4.5 and RCP 8.5. Values are the average changes from 35 global climate models and the 5th to 95th percentile range across those models. Table reproduced from (Fleishman 2023, p. 11).

	2050s		2080s	
	RCP 4.5	RCP 8.5	RCP 4.5	RCP 8.5
ANNUAL	1.9 (-4.9, 9.0)	2.7 (-6.0, 11.4)	3.4 (-5.6, 15.3)	6.3 (-5.2, 19.9)
Winter	4.9 (-6.4, 16.5)	7.9 (-4.7, 24.3)	7.3 (-6.3, 19.9)	14.5 (-2.8, 37.1)
Spring	1.9 (-8.9, 12.1)	2.7 (-7.2, 17.4)	3.4 (-7.7, 14.9)	3.6 (-9.4, 15.6)
Summer	-6.3 (-28.5, 16.1)	-8.7 (-33.1, 22.5)	-4.6 (-24.2, 22.3)	-7.7 (-38.7, 33.5)
Fall	0.5 (-17.0, 14.4)	-0.8 (-17.1, 14.9)	1.5 (-15.0, 18.1)	1.9 (-17.2, 24.2)

In North America, and specifically in the Pacific Northwest, effects of forest pathogens, insects, and wildfire on forests are expected to increase, resulting in an extended period of high fire risk and large increases in area burned (Karl et al. 2009, pp. 136–137; Shafer et al. 2010, pp. 183–185; Mote et al. 2014, p. 495; OCCRI 2010, pp. 16–18; Romero-Lankao et al. in Barros et al. 2014, pp. 1459–1461). The pattern of higher summer temperatures and earlier spring snowmelt, leading to greater summer moisture deficits and consequent increased wildfire risk, has already been observed in the forests of the Pacific Northwest (Karl et al. 2009, p. 136).

These projections discussed above indicate further reduction and isolation of red tree vole habitat over the next century. Tree vole habitat will be affected by climate change mainly via changes in disturbances, including wildfire, tree diseases like Swiss needle cast, and potential vegetation shifts. Red tree voles in the analysis area cannot shift their range farther north due to the existing barrier of the Columbia River, which defines the northern boundary of their current and historical range. In addition, their range already occupies the summit of the Oregon Coast Range, so a shift to higher elevations is also not possible in the analysis area. Climate change may lead to extirpations of local populations if range shift in response to environmental change does not occur (Karl et al. 2009, p. 137).

7.1.3. Vegetation Shifts

Warmer and drier growing season conditions are expected to affect vegetation, and ultimately red tree vole habitat, in several ways. The distribution and range of vegetation communities are predicted to shift in response to changing temperatures and precipitation and increased growing season duration. In Oregon, the range and area of temperate coniferous forest (coastal western hemlock forests associated with the Coast Range) is projected to contract by 2080, and be replaced by mixed evergreen and deciduous forests (Shafer et al. 2010, pp. 180–181; Dalton et al. 2017, pp. 54–55).

While there is the potential for substantial vegetation shifts due to climate change, there is considerable variability in those projections. For instance, a review of existing literature on vegetation shifts finds that by the end of the 21st century in the Pacific Northwest, Douglas-fir

occurrence will range from “no change to total loss,” western hemlock as “increase to total loss” with “some shifts,” and Sitka spruce projected as, “some to total loss,” depending on the model used (Peterson et al. 2014, pp. 111–112). In addition, projections of vegetation distribution are usually based on modeling suitable climate for the tree species and mapping the projected species’ range accordingly. However, tree species are long-lived and mature forests can persist under suboptimal conditions, preventing better suited vegetation from gaining a foothold until disturbance removes the original forest (Sheehan et al. 2015, p. 27). Consequently, maritime forests such as the Sitka spruce and western hemlock vegetation zones found in the analysis area may remain relatively stable over the 21st century in the absence of a stand replacing disturbance (Halofsky et al. 2018, p. 13). Finally, global climate models don’t incorporate local climate patterns, and even with uncertainty the Pacific Ocean would likely ameliorate temperature extremes brought on by climate change, as well as continue to generate coastal fog and high levels of precipitation (Peterson et al. 2014, p. 112), thus maintaining habitat for Sitka spruce forests in the Pacific Northwest. However, a recent trend in reduced fog inland of the Oregon coast has been noted (Dye et al. 2020, p. 1). Consequently, in the absence of a stand-replacing disturbance, coastal temperate forests of the northern Oregon Coast Range may remain through the century.

On the other hand, it is possible that the coastal temperate forests of the northern Oregon Coast Range will change significantly over the next 60 years. Multiple models, based on a variety of climate models, emissions scenarios, and vegetation models, show a complete or nearly complete loss of climatically suitable habitat for western hemlock and Sitka spruce within the DPS by the end of the 21st century (Crookston et al. 2010, p. 1208, GIS data; Peterson et al. 2014, pp. 102, 111–112; Mathys et al. 2016, pp. 7–8; Natural Resources Canada 2022). See also Appendix A, Section 6.3 and Figures A-10, A-11, A-12, A-13, and Appendix B, Section 1.2).

Although established trees may persist in climatically unsuitable conditions, repeated seasons of unsuitable conditions, particularly hot drought, may cause widespread tree mortality after only a few years, due to hydraulic failure (permanent damage to the tree’s water transport mechanisms) and/or carbon starvation (in which trees use more carbon than they can make via photosynthesis, because they have slowed photosynthesis to conserve water) (Wang et al. 2012, entire; Allen et al. 2015, pp. 22–25; Hember et al. 2017, pp. 1698–1707). For example, widespread tree mortality occurred in California in response to drought between 2012 and 2016 (Brodrick and Asner 2017, entire; Pile et al. 2019, entire). Hot, dry conditions can kill trees directly, or cause enough stress that trees become susceptible to mortality from insects and diseases that would not otherwise cause mortality (USFS and ODF 2021, pp. 4–5). For example, western redcedar dieback is now occurring within the DPS and surrounding region, apparently due to drought (Seebacher 2007, pp. 36, 66–68; Goodrich et al. 2022, entire; USFS and ODF 2021, p. 10). Increasing western hemlock mortality has been observed in and around the DPS since 2015, apparently due to the combination of drought and a pathogen (LeBoldus et al. 2019, p. 33; Ramsey 2018, pp. 2–3; Zobrist 2018, pp. 2–3). Outside of the DPS, Douglas-fir mortality has spiked in southwestern Oregon, and true fir (*Abies* spp.) mortality has increased in eastern Oregon, and this mortality

event is now referred to as “firmageddon” (Gilles 2022, entire; Shaw 2023, entire; USFS et al. 2022, pp. 5–12).

Of the three tree species most important to tree voles, most models indicate the DPS will remain the most climatically suitable by the end of the century for Douglas-fir (Crookston et al. 2010, p. 1208; Peterson et al. 2014, pp. 102, 111–112; Mathys et al. 2016, pp. 6, 8), though productivity could decline (Peterson et al. 2014, p. 112) and climate-related stress may have an exacerbating effect on prevalence of diseases that affect Douglas-fir, such as Swiss needle cast (see Section 5.1.3). The commercial and ecological importance of Douglas-fir in Oregon means effects of climate change will be monitored closely.

It is plausible that either western hemlock, Sitka spruce or both, which are important to the coastal populations of tree vole, may be nearly or entirely lost from the DPS over a period of 60 years as the climate becomes increasingly unsuitable for those species (see Appendix A, Section 6.3 for end of century and Appendix B, Section 1.2 for mid-century).

7.1.4. Swiss Needle Cast

Swiss needle cast, which is influenced by climate, is expected to increase in intensity and expand its distribution in the Oregon Coast Range. Already, warmer winter temperatures and increasing spring precipitation have increased the distribution and severity of the disease (Stone et al. 2008, pp. 169, 174; Black et al. 2010, p. 1679; Littell et al. 2013, p. xxxi). In the Oregon Coast Range between 1996 and 2015, disease distribution increased from 530 km² (205 mi²) to 2,387 km² (922 mi²) (Ritóková et al. 2016, p. 5), although disease outbreaks have been widespread and synchronous since 1895 (Lee et al. 2017, p. 11179). Conditions that would most exacerbate the impacts of Swiss needle cast are likely those which provided for severe outbreaks in the past, i.e., warmer winters with cool, wet summer periods (Lee et al. 2013, p. 683) or, specifically, conditions in late spring to midsummer which result in periods of leaf wetness (Lee et al. 2017, p. 11168). Swiss needle cast impacts have been increasing in mature closed-canopy stands on the east slopes of the Oregon Coast Range with recent trends in warming winters (Lee et al. 2017, p. 11184). In the wet, western slope of the Oregon Coast Range, winter temperature was found to be a primary predictor of the spatial variation in abundance of the Swiss needle cast-causing fungus and thus the severity of the disease, presumably because of its effect on fungal growth (Stone et al. 2008, p. 175).

Future weather in Oregon is predicted to be warmer across all seasons under either RCP 4.5 or RCP 8.5 climate scenarios (Fleishman 2023, p. 11), but it is not clear whether it will be wetter, drier, more variable, or whether current precipitation patterns will continue (Tables 10 and 11). Summers in Oregon are expected to be warmer and drier, and extreme heat events are project to be more frequent (see Section 7.1.2 Climate Change). Swiss needle cast impacts to trees appear to be more severe during drought conditions (Shaw et al. 2021, pp. 414–415). Future warming during winter and summer seasons is predicted to increase Swiss needle cast frequency and intensity in the coastal fog zone where needle wetness is maintained (Lee et al. 2013, p. 688).

Disease severity is expected to increase at higher elevations and at more inland sites where fungal growth is currently limited by cold winter temperatures (Lee et al. 2013, p. 688, 2017, p. 11184). The extent of this expansion has not been estimated. Furthermore, the intensity and frequency of the disease in coastal Oregon will vary, likely increasing in the coastal fog zone, and decreasing in areas where warm and dry summers already limit fungal spore germination (Lee et al. 2013, p. 687). Overall, however, Swiss needle cast may become a significant issue beyond the coastal fog zone in the future (Lee et al. 2017, pp. 11167, 11184).

Given that Swiss needle cast disease mostly occurs in young Douglas-fir stands and substantially reduces their growth rate, the primary impact to red tree vole habitat is likely a reduction in overall habitat quality and ingrowth in infected areas. Forest development will be slower overall. Swiss needle cast would reduce Douglas-fir needles, which serve as food, nesting material, and cover, for the red tree vole. While Swiss needle cast has not historically resulted in mortality of trees, many trees greater than 90 years old that were chronically infected for over 20 years died during a 2015-2018 drought near Tillamook, Oregon, within the DPS (Shaw et al. 2021, p. 414). If summer droughts increase in the future, mortality of Swiss needle cast infected trees may increase. In that part of the tree vole range where their principal diet is Sitka spruce or western hemlock, one possible long-term beneficial effect of this pathogen is the potential restoration of these tree species into the forest canopy. However, it would take decades, and a management shift for private industrial timber lands who plant Douglas-fir trees, for western hemlock and Sitka spruce to return and become prevalent in fir-dominated stands and develop the older forest characteristics conducive to red tree vole habitat.

7.1.5. Wildfire

Projected impacts of climate change are expected to increase the risk of large-scale wildfires in Pacific Northwest forests. The predictions of how climate change will specifically affect wildfire activity in coastal rainforests, including frequency and magnitude, vary because there has been little area burned in these forests over the past several decades with which to base projections.

Studies summarized by Reilly et al. (2018, pp. 52–54), offer variable projections for wildfire in coastal rainforests in Oregon. All found some increase in wildfire risk and projected acres burned through this century, but estimates ranged from minor increases of <1 to 2 percent the area at high risk for large wildfire in the Oregon Coast Range (Davis et al. 2017, p. 179), to increases in an index of fire potential by 2.5 to 5 times in the Oregon Coast Range (Liu et al. 2013, pp. 132–133), and increases in area burned from 76 to 310 percent across western forests of Oregon and Washington inclusive of the Oregon Coast Range (Rogers et al. 2011, p. 11). This projected increase of 76 to 310 percent may seem high but really reflects a relatively small amount of predicted burn area because the recent area burned in moist forests is relatively low (Spies et al. 2018, p. 54). The historical data used by Rogers et al. (2011, p. 3) only captured wildfires from 1971 to 2000, and therefore missed the large fire events that occurred previously and are of concern in this assessment. Annual fire occurrence probabilities are expected to increase on average by 2100 in the Pacific Northwest coastal range under climate change, with a 50 to 70

percent increase from baseline (1971-2000) projected under RCP8.5 (Gao et al. 2021, p. 1). Though the extent, frequency, and severity of wildfires is expected to remain the greatest in drier forests of the Pacific Northwest, the greatest proportional increase of burned area in the future is expected to occur in moist forests (Powers and Kertis 2022, p. 1).

While specific predictions of how climate change may affect wildfires in the coastal Oregon forests are variable, what seems most clear is that climate regimes for the Oregon Coast Range are projected to include increased temperatures with increased drought conditions. While increased winter precipitation might restore fuel moistures in many fire regimes, this is not beneficial to coastal rainforests because soils are already saturated in the winter, so increased future precipitation will not add to the fuel moisture content. Instead, the region is predicted to be more affected by intense summer droughts that would incur a relative increase in wildfires in the climate-driven fire regime of the Oregon Coast Range (Rogers et al. 2011, p. 6).

Wildfire suppression organization, tactics, and technology (e.g., increased road access, air tankers, and incident command teams) have improved since the large fires of the last two centuries resulting in a reduction in forest fires (Wimberly et al. 2004, p. 153); although Weisberg and Swanson (2003, p. 25) note that suppression success may have been influenced by the reduction in fuel accumulations accomplished by previous extensive wildfires in the 1800s. Regardless, the intense, large, high-severity wildfires that can occur in the Oregon Coast Range are driven by severe weather events like droughts or east wind patterns (Teensma et al. 1991, p. 3; Agee 1997, p. 154; Gedalof et al. 2005, p. 170; Meyn et al. 2007, p. 294; Reilly et al. 2022, pp. 5–7), conditions under which wildfire suppression is greatly limited or even ineffectual (Impara 1997, pp. 262–263). Furthermore, current wildfire suppression efforts may become less effective against future wildfires associated with climate change (Rogers et al. 2011, p. 9).

Past and current forest management is connected to the wildfire regime, though there has been disagreement in the literature about how different forest management regimes affect fire severity (Thompson et al. 2007, p. 10746; Levine et al. 2022, p. 1). In a recent study of a large dataset of fires occurring from 1985 to 2019 in mixed conifer forests in Northern California (notably a different set of conditions from the Oregon Coast Range), the odds of high-severity fire were 1.8 times greater on private industrial land than on public land, and 1.9 times greater than on other land (Levine et al. 2022, p. 4). Also, high severity burns adjacent to and within 1 km of private industrial land were 1.4 and 1.3 times higher, respectively, than 3 km away (Levine et al. 2022, p. 4). The authors suggest that this could be due to the prevalence of continuous forest-fuel structures of younger, even-aged forests, but acknowledge the mechanisms underlying the association between private industrial land and high-severity fire are complex (Levine et al. 2022, p. 6). In a study focused in southwestern Oregon, land ownership was found to be an important predictor of fire severity after daily fire weather and stand age, and pre-forest biomass was not an important predictor of fire severity (Zald and Dunn 2018, p. 1075). While fire weather was important, local forest conditions that differed between land ownership types remained key even during extreme fire weather conditions (Zald and Dunn 2018, p. 1075). Young age, spatial homogenization, and continuous fuel arrangement, are the forest

characteristics (more often found on private, high-intensity forestry plantations) that drive wildfire severity more than absolute biomass or decades of fire exclusion (Zald and Dunn 2018, pp. 1075, 1077). Data from the more recent megafires on the western side of the Cascade mountains in the Pacific Northwest in 2020 indicates that even under extreme weather conditions, vegetation structure and topography significantly affect fire severity patterns. Specifically, early seral forests concentrated on private land experienced the highest proportion of high-severity fire and mature stands burned severely only under extreme winds and especially on steeper slopes (Evers et al. 2022, pp. 8, 11). However, results from modelling pre-fire forest structure showed the influence of forest management on fire severity was minimal (Reilly et al. 2022, p. 11). Finally, several studies on the role of stand structure and fire severity on westside Cascades forests suggest that older forests are more fire resistant than young plantations under moderate weather conditions due to higher biomass and moisture (Lesmeister et al. 2019, p. 14, 2021, p. 1).

Although mixed and high-severity wildfires occurred within the analysis area historically, in the past there were many additional areas of old forest that were less isolated from other old forest stands and could serve as a population source or as refugia for tree voles displaced from forests that burned; under current conditions, there are fewer such refugia available (Wimberly 2002, p. 1322; Wimberly et al. 2004, p. 152) (see section 5.1.2 Fragmentation and Isolation), however old forests can still provide refugia for associated species (Naficy et al. 2023, entire), especially for the moist Douglas-fir/western hemlock zone, where there is a high potential for fire refugia in old, high biomass forests across a fairly broad range of modeled fire weather conditions (Naficy et al. 2021, p. 10). Though infrequent, past wildfires in the Oregon Coast Range have burned areas as large as 3,250 km² (1,250 mi²), which is an area equivalent to all or substantive portions of the largest and most resilient red tree vole geographic units. Consequently, it is reasonably likely that a stand-replacing wildfire capable of impacting large areas of remaining tree vole habitat could occur within the analysis area.

7.2 Future Scenarios

We developed two scenarios which represent plausible sideboards of our demographic parameters and identified threats. The lower plausible future condition scenario (hereafter lower scenario) incorporates lower values of the demographic features (habitat capacity, population density, and effective population size ratio), assumptions of less connectivity, and assumptions of higher potential impacts from Swiss needle cast and vegetation shifts. The upper plausible future condition scenario (hereafter upper scenario) incorporates the higher values of the demographic features, a higher connectivity assumption, and lower potential impacts from Swiss needle cast and vegetation shifts.

Similar to our current condition analysis, our analysis of future condition was based on habitat, wherein we revised our estimates of effective population size capacity based on assumed changes in red tree vole habitat condition consistent with harvest patterns by land ownership and land use allocation (described below for each land ownership type; Appendix A, Section 6).

Because of the potential for habitat recruitment over the approximate 60-year analysis period (to approximately 2080), population areas with presumed unoccupied status were included in future condition analysis if they met the following conditions: 1) another population area in the same geographic unit is connected by constrained land, or 2) another population area in an adjacent geographic unit is connected by constrained land and a current habitat block. Here we use the term constrained to mean both State constrained and Federal reserved lands.

Just like the current condition analysis, we used both the 2023 and 2017 (updated in 2022) habitat models, two population densities, and two values of effective population size ratios. Instead of a range, however, we chose one of each for the scenarios. Because the 2023 model habitat capacity estimates were generally higher overall (164,718 ha versus 153,226 ha of habitat in the DPS) and higher in presumed occupied habitat (149,057 ha versus 135,728 ha) than the 2017 model, we chose the 2023 model for the upper scenario and the 2017 model for the lower scenario. We chose 1.91 voles/ha for an upper scenario and 0.56 voles/ha for a lower scenario for vole population density. We chose 20 percent of the minimum population capacity for the upper scenario and 10 percent of the minimum population capacity for a lower scenario for effective population size capacity.

Connectivity within geographic units is based on the potential for connectivity of population areas as measured by the presence of constrained or unconstrained forested lands between population areas. We assume under either upper or lower scenarios that constrained lands would remain forested and potential habitat. We did not apply a minimum distance between population areas separated by constrained lands. We assumed that unconstrained forests lands <2km would remain connected only under the upper scenario. We note that while unconstrained lands could provide young forest for potential habitat and natal dispersal (within a certain distance of old forest), we have greater certainty that constrained lands will expand and connect as habitat in the future.

We also included ratings for Swiss needle cast and vegetation shifts, two factors which, due to climate change, may influence resiliency. Under an upper future scenario, Swiss needle cast will be present at current or lower levels than today across the DPS, thus all ratings for this factor are high. Under a lower scenario, we assume Swiss needle cast will increase in severity and extent all areas of the DPS, primarily in response to the predicted warming winter temperatures under both RCP 4.5 and RCP 8.5 climate scenarios. We infer increase in severity and extent would reduce overall tree vole habitat quality and reduce the ingrowth of tree vole habitat, thus all ratings for this factor are low.

For vegetation shifts, under an upper future scenario these shifts would be unlikely to occur at a pace or scale that would affect the health or distribution of Douglas-fir, western hemlock, or Sitka spruce tree species. Population areas would retain the representation status they have currently (see Figure 13 and Appendix A, Table A–16) and there would be no effect to resiliency. Under a lower future scenario, the climatic suitability for western hemlock and Sitka

spruce would change such that both tree species would be lost from the area over the 60-year analysis time period (Crookston et al. 2010, GIS data; Mathys et al. 2016, pp. 7–8, Fig. 4c; Natural Resources Canada 2022). We would assume that red tree voles which have the behavior trait to feed on these species would not be able to adapt quickly enough and those voles would be lost. A high resiliency rating for this factor indicates a population area which is primarily in the western hemlock zone. A low resiliency rating indicates a population area which is primarily in the Sitka spruce vegetation zone. A moderate resiliency rating indicates population areas which contain both vegetation zones and thus are likely to contain both feeding behaviors. We assume, under the lower scenario, that some voles with the western hemlock and Sitka spruce feeding behavior may be lost, but voles with Douglas-fir feeding behavior would remain in those population areas.

Our rationale and evaluation of overall resiliency condition ratings were similar to current condition (see section 6.3 Condition Analysis Model, Table 7) and are described in detail in Appendix A, Section 6.

Future Condition Timeframe and Habitat Changes

We considered for our future condition analysis a timeframe out to approximately 2080. This timeframe was chosen because it approximates the time at which all the lands in the NWFP late-successional reserve (LSR) land use allocation would be nearly at or above 80 years old and barring any disturbances all of the conifer-forest-capable land in these allocations would be of an age that begins to provide conditions suitable for red tree voles. The NWFP went into effect in 1994, and young stands in LSR status at the time were meant to grow into late-successional forest. Hence, the youngest stands at the time of LSR designation would be over 80 years old by approximately 2080. Although BLM has since revised their forest management plans and no longer operate under the NWFP, we expect that much of their reserved land use allocations not already in a late-successional stage will also be at or near 80 years old by 2080 because many of them were designated as LSRs while they were under the NWFP. Our assumption that all 80-year old stands are suitable tree vole habitat likely overestimates projected habitat (or at least overestimates habitat that supports stable populations) to some degree because it uses a minimum forest age threshold to represent suitable red tree vole habitat, while most forests classified as tree vole habitat are much older than that minimum age (see section 3.9.4 Habitat). On the other hand, we could be underestimating habitat, as red tree voles do live and reproduce in young forests, though adjacency to old forests remains a key influencing factor (see section 3.9.4 Habitat).

We estimated that 90 percent of reserves will contain tree vole habitat by 2080. The NWFP presented no specific targets for the amount of old forest within LSRs. Instead, it was estimated that 50–100 years of NWFP implementation would result in restoring older forest conditions on Federal lands to within the estimated historical range of 40–60 percent of the area in old forest. This is a plan-wide estimate and includes drier physiographic provinces where losses of old-forest from wildfires is expected. It also includes all land use allocations, not just the reserved

land use allocations. As such, greater amounts of old-forest would be expected in wetter provinces such as the Oregon Coast Range, as well as in reserved land use allocations where old-forest habitat is expected to develop and be retained (Davis et al. 2015, pp. 7–8). However, we believe it is incorrect to assume that 100 percent of an allocation will ever become habitat for tree voles. The reasons for this include: (1) not all stands that are at least 80 years in age necessarily contain tree vole habitat, perhaps due to structural conditions or vegetation composition (large amounts of hardwoods); and (2) some portions of an allocation may undergo minor disturbance events (wind, landslides, forest insects, and pathogens) preventing that entire allocation from maturing at the same rate. Given these uncertainties, the estimated 90 percent of reserves that will contain red tree vole habitat by 2080 likely represents maximum red tree vole occupancy of these areas, based on the best available information we have about land management tendencies.

We discuss our future scenario assumptions for each of the four land ownership categories separately. We then describe the resultant changes for each analysis unit and how they affect red tree vole resiliency, redundancy, and representation. Results are shown in Tables 12–14 and Figures 17–18 below.

7.2.1. Federal lands

We divided Federal lands into those that had reserved land use allocations (where red tree vole habitat was likely to be retained over time) and non-reserved land use allocations (the timber harvest matrix and other areas where tree vole habitat was not likely to be maintained). For USFS lands, the non-reserved allocation actually includes riparian reserves that occur in the timber harvest matrix because we were not able to obtain mapped reserves to remove them from this allocation and add them to a reserved allocation. As a result, non-reserved land may be overestimated, but for the most part non-reserved land use allocations were comprised of land where programmed timber harvest is meant to occur. Similarly, allocations we classified as “reserved” may include some areas where tree vole habitat might be removed or altered; in addition, red tree vole surveys are not required in stands <80 years old where thinning is proposed (USDA and USDI 2011, entire), which is an activity that may occur in some reserved allocations where development of late-successional forest is an objective. As such, these factors may somewhat overestimate future habitat. There were also some Federal lands that were not managed under the NWFP (such as Service lands) and we considered those to be non-reserved for the purposes of the analysis. However, they were such a small portion of the overall Federal ownership (see Table 1) as to not substantively affect our results. For the reserved lands, we assumed tree vole habitat would remain through time and that unsuitable habitat would gradually grow into habitat. For non-reserved lands we assumed that unsuitable habitat would remain unsuitable and that current habitat would be removed through time.

7.2.2. State lands

State lands were divided into 3 categories, based on what State entity owned the lands. We assumed that lands owned by OPRD (State Parks) and wildlife areas owned by ODFW would all

maintain suitable habitat and that unsuitable habitat would grow into suitable tree vole habitat at the same rate as on Federal lands. As such, we considered these State-managed lands as “constrained” lands.

For State Forest lands, we obtained a map layer of “constrained” management areas (Oregon Department of Forestry 2023a, entire). These are areas where timber harvest is not planned within the foreseeable future for various reasons. Harvest may be precluded because of regulatory or management planning direction (e.g., no-take buffers around species listed under the Act, or areas designated in the management plan to develop old-forest structure). It may also include areas that are removed from the timber harvest base because of accessibility issues (e.g., overly steep terrain) or administrative reasons (e.g., along road rights-of-way). As such, some of these areas may not function in the long term as tree vole habitat given their configuration on the landscape (e.g., narrow corridors along road rights-of-way that may otherwise be amid unsuitable habitat), which may lead to an overestimation of red tree vole habitat on State lands compared to other ownerships. However, we did remove stream buffers outside of constrained areas from the constrained category to reduce some of this effect. Similar to what was done for Federal lands, we assumed that tree vole habitat within the management areas with timber harvest constraints would be retained, and unsuitable habitat would gradually grow into suitable tree vole habitat in time. Conversely, we assumed that outside of the constrained areas red tree vole habitat would be harvested, limiting the ability for habitat to develop in the long term.

7.2.3. Tribal lands

Two tribes manage forest lands within our analysis area. They are generally working forests managed to provide various natural, economical, and cultural resources, although the Reed Creek parcel managed by the Siletz Tribe is explicitly managed for the benefit of marbled murrelets, which may also benefit red tree voles. We expect tree vole habitat to be gained in some areas and lost in others but do not have the spatial information to assume where or how much habitat is gained/lost. We assume, for the purposes of our analysis, that current amount of tree vole habitat on Tribal lands will remain the same under an upper future scenario, and we treat these lands similar to unconstrained lands under a lower future scenario. We note that Tribal ownership within the analysis area is such a small proportion of the overall analysis area that its management will not be a driver of this analysis.

7.2.4. Private lands

We acknowledge that the private land category represents a diverse array of owners with equally diverse management objectives. This includes some county and municipal ownerships, where management may range from protecting areas for municipal watersheds, to managing for timber receipts. The vast array of land in this category, however, is that owned by private landowners. Land under private ownership may range from industrial timberlands generally managed on short harvest rotations to maximize economic return, to small family woodlots that may be managed for a variety of purposes from maximizing economic returns to retaining the area for aesthetic value, wildlife, recreation, or other reasons. We do not have the data to tease apart these

differences for our analysis. As such, we assume that suitable tree vole habitat will be harvested, and that unsuitable tree vole habitat will not grow into suitable habitat under the lower future scenario. However, in an upper future scenario, we assume that not all the remaining tree vole habitat will be harvested. We also acknowledge some habitat will continue to be protected, especially through riparian and wildlife site protection buffers under the Oregon Forest Practices Act. Furthermore, some private forest lands in young forest may provide habitat. Therefore, under the upper future scenario, we assumed that private lands would retain the same proportion of suitable habitat as they currently contain.

Table 12. Future condition rating key. Ratings are assigned to each population area, except for overall future resiliency condition, which is an aggregated rating for the geographic unit. Some ratings, denoted in *italic font*, are specific to upper or lower scenarios. WH = western hemlock; SS = Sitka spruce; PA = population area.

Condition Category	Effective Population Size (N_e) Capacity (PA Rating)	Connectivity Potential Within Geographic Units	Connectivity Potential Between Geographic Units	Vegetation Shift	Swiss Needle Cast (SNC)	Overall Future Resiliency Condition <i>At least one population area (PA) in the unit meets the following criteria:</i>
High	> 1000	Separated from another population area by constrained forested lands, or (<i>in upper scenario only</i>) by <2 km of currently forested land	Another population area in adjacent unit is separated by constrained forested lands	Currently WH zone; <i>All ratings high in upper scenario</i>	<i>All ratings high in upper scenario</i>	1. N_e is high, vegetation shift is high or moderate and SNC is high, or 2. N_e is moderate, at least one connectivity factor is high, vegetation shift is high, and SNC is high
Moderate	> 100 and < 1000			Currently both WH and SS zones		1. N_e is high, vegetation shift is high or moderate, and SNC is low, or 2. N_e is moderate, at least one connectivity factor is high, vegetation shift is moderate or high, and SNC is high or low
Low	< 100	Separated from another population area by unconstrained forested lands	Another population area in adjacent unit is separated by unconstrained forested lands	Currently SS zone	<i>All ratings low in lower scenario</i>	1. N_e is moderate, at least one connectivity factor is high, vegetation shift is moderate or high, and SNC is low, or 2. N_e is moderate, both connectivity factors are low, vegetation shift is moderate or high, and SNC is high or low, or 3. N_e is low, at least one connectivity factor is high, and vegetation shift is moderate or high, and SNC is high
Presumed Extirpated						1. All PAs in the unit presumed unoccupied, or 2. All PAs low N_e and both connectivity factors are low, regardless of vegetation shift or SNC rating, or 3. All PAs low N_e low and SNC is low, regardless of other ratings, or 4. All PAs low vegetation shift ratings, regardless of other factors

Table 13. Upper scenario future condition rating results. Population area names with gray fill indicate those which had unoccupied status in current condition but are considered as potentially occupied in future condition. Blue represents a high rating (HI), yellow a moderate rating (MOD), red a low rating (LO), and dark gray presumed extirpated (EXT).

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss needle cast	Overall Resiliency Rating for Unit
1. Lewis and Clark	Saddle Mountain Road	LO	LO	LO	HI	HI	EXT
2. Ecola/ Elmer Feldenheimer	Elmer Feldenheimer North	LO	LO	LO	HI	HI	EXT
3. Necanicum/ Nehalem	Oswald West	LO	LO	LO	HI	HI	EXT
4. North Fork Nehalem	Tillamook South Fork Nehalem North	LO	HI	LO	HI	HI	HI
	Rector Ridge	MOD	HI	LO	HI	HI	
5. Nehalem/Wilson	Tillamook South Fork Kichlis Middle	HI	HI	LO	HI	HI	HI
	Tillamook South Fork Kichlis North	MOD	HI	LO	HI	HI	
	Bay City Electric	LO	HI	LO	HI	HI	
	Tillamook South Fork Nehalem South	HI	HI	LO	HI	HI	
	Anderson Creek	MOD	HI	LO	HI	HI	
	Nestucca Block Wilson	HI	HI	HI		HI	
6. Cape Meares	Cape Meares	LO	LO	LO	HI	HI	LO

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss needle cast	Overall Resiliency Rating for Unit
	Fall Short	LO	HI	LO	HI	HI	
	Hodgdon Creek	LO	HI	LO	HI	HI	
	O'Hara Creek	LO	HI	LO	HI	HI	
7. Sand Lake	Tierra Del Mar	MOD	HI	LO	HI	HI	HI
	Andy Creek	LO	HI	LO	HI	HI	
	South of Sandlake	LO	HI	LO	HI	HI	
	Cape Lookout West	LO	HI	LO	HI	HI	
	Cape Lookout North	LO	HI	LO	HI	HI	
	Cape Lookout South	LO	HI	LO	HI	HI	
8. Trask/Nestucca	Nestucca Block Trask	HI	HI	HI	HI	HI	HI
	Moon Creek Nestucca Block Inclusion	LO	HI	LO	HI	HI	
	East Beaver Creek	LO	HI	LO	HI	HI	
	Gopher	LO	HI	LO	HI	HI	
	Fawcett Creek	MOD	HI	LO	HI	HI	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss needle cast	Overall Resiliency Rating for Unit
	Tillamook South Fork Kichlis South	MOD	LO	LO	HI	HI	
9. Gauldy Ridge	Nestucca Block Gauldy	MOD	LO	HI	HI	HI	HI
10. Little Nestucca/Salmon	Nestucca Block Salmon Coast	MOD	LO	HI	HI	HI	HI
11. Little Nestucca/Salmon Inland	Bower Creek	LO	HI	LO	HI	HI	HI
	Nestucca Block Salmon West	MOD	HI	HI	HI	HI	
	Nestucca Block Salmon East	MOD	HI	HI	HI	HI	
	“2006”	LO	HI	LO	HI	HI	
	Neskowin Creek West	LO	HI	LO	HI	HI	
	Neskowin Creek East	LO	HI	LO	HI	HI	
12. Siletz/ Luckiamute	South Block Luckiamute	MOD	HI	HI	HI	HI	HI
	South Fork Teal Creek South Block Inclusion	LO	HI	LO	HI	HI	
	No-Name South Block Inclusion	LO	HI	LO	HI	HI	
	Middle Ridge South Block Inclusion	LO	HI	LO	HI	HI	
	McTimmonds Creek South Block Inclusion	LO	HI	LO	HI	HI	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss needle cast	Overall Resiliency Rating for Unit
	Norton	LO	HI	LO	HI	HI	
	Potter Creek	LO	HI	LO	HI	HI	
	BLM Checkerboard	MOD	HI	LO	HI	HI	
	Salt Creek	LO	HI	LO	HI	HI	
	Nestucca Block Luckiamute	LO	LO	HI	HI	HI	
	Treat River	LO	LO	LO	HI	HI	
	Deadwood Mountain	MOD	HI	LO	HI	HI	
	Dry Creek	LO	HI	LO	HI	HI	
	North Fork Siletz	LO	HI	LO	HI	HI	
13. Yaquina/ Marys	South Block Yaquina	HI	HI	HI	HI	HI	HI
	Skunk Creek South Block Inclusion	LO	HI	LO	HI	HI	
	Bull Run Creek South Block Inclusion	LO	HI	LO	HI	HI	
14. Alsea/ Siuslaw	South Block Alsea	HI	LO	HI	HI	HI	HI
15. Siuslaw/ Long Tom	South Block Long Tom	MOD	LO	HI	HI	HI	HI

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss needle cast	Overall Resiliency Rating for Unit
16. Siuslaw/Territorial	South Block Territorial	MOD	LO	HI	HI	HI	HI
17. Spencer Butte	Spencer Butte	MOD	LO	LO	HI	HI	LO

Table 14. Lower scenario future condition rating results. Population area names with gray fill indicate those which had unoccupied status in current condition but are considered as potentially occupied in future condition. Blue represents a high rating (HI), yellow a moderate rating (MOD), red a low rating (LO), and dark gray presumed extirpated (EXT).

Geographic Unit	Population Area	Effective Population Size Capacity	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
1. Lewis and Clark	Saddle Mountain Road	LO	LO	LO	MOD	LO	EXT
2. Ecola/ Elmer Feldenheimer	Elmer Feldenheimer North	LO	LO	LO	LO	LO	EXT
3. Necanicum/ Nehalem	Oswald West	LO	LO	LO	LO	LO	EXT
4. North Fork Nehalem	Tillamook South Fork Nehalem North	LO	HI	LO	LO	LO	
	Rector Ridge	LO	HI	LO	MOD	LO	
5. Nehalem/Wilson	Tillamook South Fork Kichlis Middle	LO	HI	LO	MOD	LO	MOD
	Tillamook South Fork Kichlis North	LO	HI	LO	MOD	LO	

Geographic Unit	Population Area	Effective Population Size Capacity	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
	Bay City Electric	LO	HI	LO	LO	LO	
	Tillamook South Fork Nehalem South	LO	HI	LO	MOD	LO	
	Anderson Creek	LO	HI	LO	MOD	LO	
	Nestucca Block Wilson	MOD	HI	HI	HI	LO	
6. Cape Meares	Cape Meares	LO	LO	LO	LO	LO	EXT
	Fall Short	LO	LO	LO	LO	LO	
	Hodgdon Creek	LO	LO	LO	LO	LO	
	O'Hara Creek	LO	LO	LO	LO	LO	
7. Sand Lake	Tierra Del Mar	LO	LO	LO	LO	LO	EXT
	Andy Creek	LO	LO	LO	LO	LO	
	South of Sandlake	LO	LO	LO	LO	LO	
	Cape Lookout West	LO	LO	LO	LO	LO	
	Cape Lookout North	LO	LO	LO	LO	LO	
	Cape Lookout South	LO	LO	LO	LO	LO	

Geographic Unit	Population Area	Effective Population Size Capacity	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
8. Trask/Nestucca	Nestucca Block Trask	MOD	HI	HI	HI	LO	MOD
	Moon Creek Nestucca Block Inclusion	LO	HI	LO	HI	LO	
	East Beaver Creek	LO	LO	LO	MOD	LO	
	Gopher	LO	LO	LO	HI	LO	
	Fawcett Creek	LO	HI	LO	MOD	LO	
	Tillamook South Fork Kichlis South	LO	LO	LO	MOD	LO	
9. Gauldy Ridge	Nestucca Block Gauldy	LO	LO	LO	MOD	LO	EXT
10. Little Nestucca/Salmon Coast	Nestucca Block Salmon Coast	LO	LO	LO	LO	LO	EXT
11. Little Nestucca/Salmon Inland	Bower Creek	LO	LO	LO	LO	LO	EXT
	Nestucca Block Salmon West	LO	LO	LO	LO	LO	
	Nestucca Block Salmon East	LO	LO	LO	MOD	LO	
	“2006”	LO	LO	LO	LO	LO	
	Neskowin Creek West	LO	LO	LO	MOD	LO	
	Neskowin Creek East	LO	LO	LO	MOD	LO	

Geographic Unit	Population Area	Effective Population Size Capacity	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
12. Siletz/ Luckiamute	South Block Luckiamute	LO	LO	LO	HI	LO	
	South Fork Teal Creek South Block Inclusion	LO	LO	LO	HI	LO	
	No-Name South Block Inclusion	LO	LO	LO	HI	LO	
	Middle Ridge South Block Inclusion	LO	LO	LO	HI	LO	
	McTimmonds Creek South Block Inclusion	LO	LO	LO	HI	LO	
	Norton	LO	LO	LO	MOD	LO	
	Potter Creek	LO	LO	LO	HI	LO	
	BLM Checkerboard	LO	LO	LO	HI	LO	
	Salt Creek	LO	LO	LO	HI	LO	
	Nestucca Block Luckiamute	LO	LO	LO	LO	LO	
	Treat River	LO	LO	LO	MOD	LO	
	Deadwood Mountain	MOD	LO	LO	MOD	LO	
	Dry Creek	LO	LO	LO	LO	LO	
	North Fork Siletz	LO	LO	LO	HI	LO	

Geographic Unit	Population Area	Effective Population Size Capacity	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
13. Yaquina/ Marys	South Block Yaquina	MOD	LO	HI	HI	LO	MOD
	Skunk Creek South Block Inclusion	LO	LO	LO	HI	LO	
	Bull Run Creek South Block Inclusion	LO	LO	LO	HI	LO	
14. Alsea/ Siuslaw	South Block Alsea	HI	LO	HI	MOD	LO	MOD
15. Siuslaw/ Long Tom	South Block Long Tom	MOD	LO	HI	HI	LO	MOD
16. Siuslaw/ Territorial	South Block Territorial	MOD	LO	HI	HI	LO	MOD
17. Spencer Butte	Spencer Butte	LO	LO	LO	HI	LO	LO

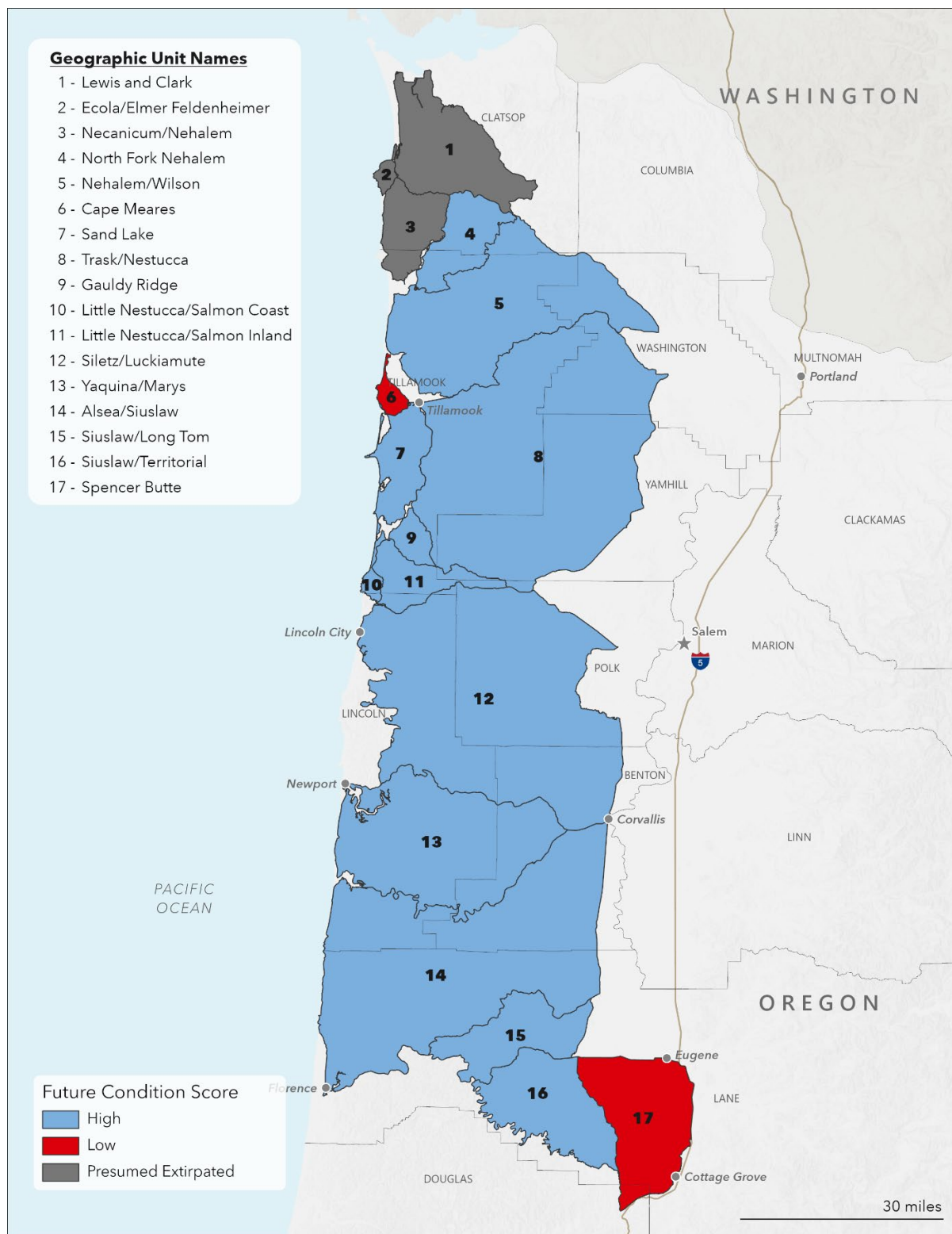


Figure 16. Future condition upper scenario ratings by geographic unit. The upper plausible future condition scenario incorporates the higher values of the demographic features, a higher connectivity assumption, and lower potential impacts from Swiss needle cast and vegetation shifts.

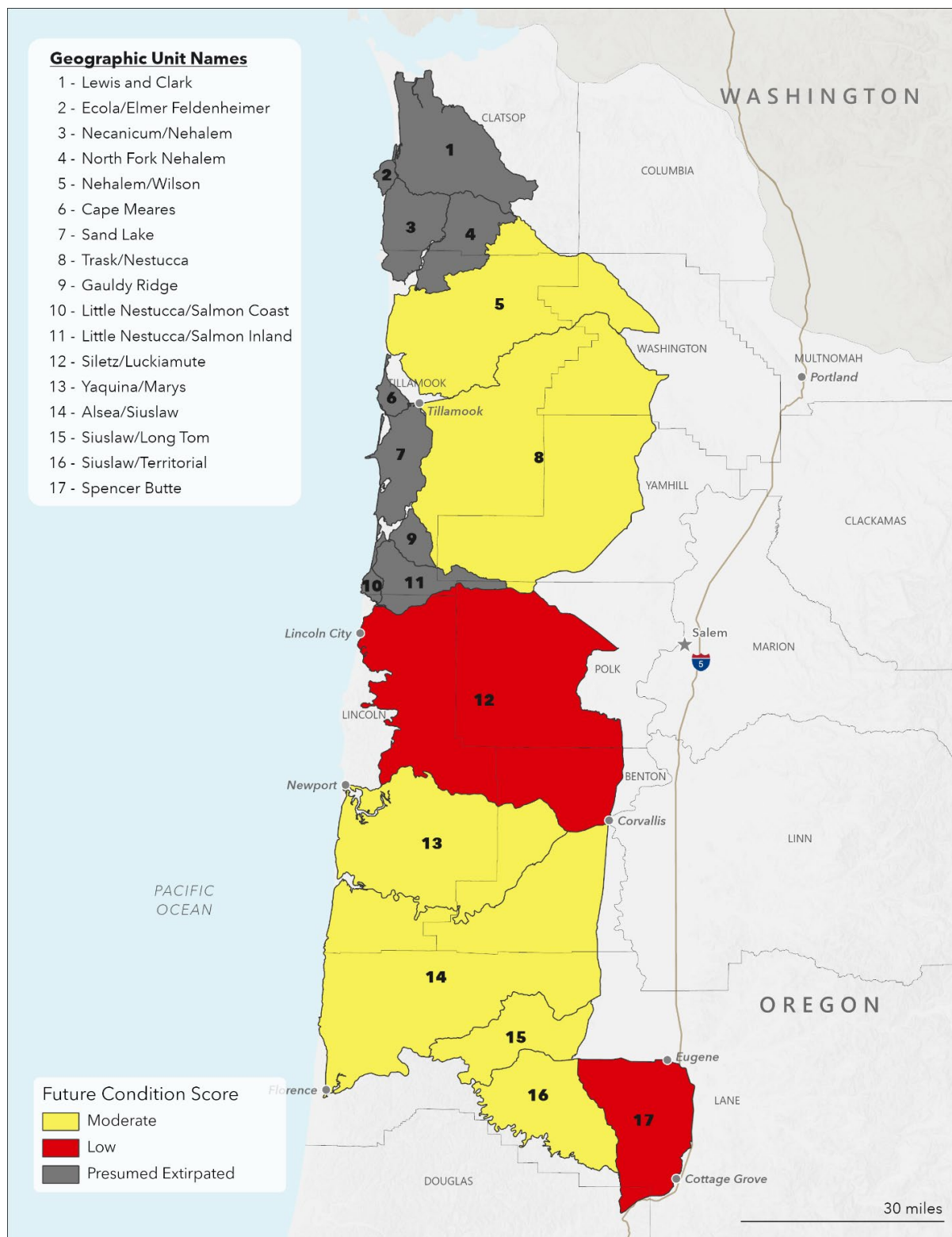


Figure 17. Future condition lower scenario ratings by geographic unit. The lower plausible future condition scenario incorporates lower values of the demographic features, assumptions of less connectivity, and assumptions of higher potential impacts from Swiss needle cast and vegetation shifts.

7.3 Resiliency

Below we describe the future resiliency outcomes for each geographic unit, listing the total area of each unit in km² and mi² and what percentage of the unit is comprised of one or more tree vole population areas and conclude with an overall summary of resiliency.

1. Lewis and Clark (582 km² (225 mi²); 0.2% population area)

This unit becomes extirpated under both future scenarios owing primarily to its small and isolated single population, lack of habitat, and majority private land ownership.

2. Ecola/Elmer Feldenheimer (30 km² (12 mi²); 8% population area)

This smallest unit in the DPS becomes extirpated under both future scenarios owing primarily to its small and isolated single population area, lack of habitat, and lack of reserved land.

3. Necanicum/Nehalem (256 km² (99 mi²); 2% population area)

This unit becomes extirpated under both future scenarios owing primarily to its small and isolated single population, lack of habitat, and majority private land ownership.

4. North Fork Nehalem (282 km² (109 mi²); 2% population area)

This unit adds an additional, larger potential population area in future scenarios owing to connection of habitat with an existing population area, underlaid with constrained ODF land. Under the upper scenario, this new population area has moderate effective population size capacity, and the two population areas are connected, which increases its overall resiliency rating from the current condition under the upper future scenario. Under the lower scenario, the unit becomes extirpated as both population areas would have low resiliency, and both would be affected by vegetation shifts as they contain Sitka spruce vegetation zone.

5. Nehalem/Wilson (1292 km² (499 mi²); 6% population area)

This unit adds two population areas in the future; and the Nestucca Block Wilson population area covers nearly half the unit and serves to connect multiple population areas within the unit and connects to the Trask/Nestucca unit. This raises the unit rating from moderate (currently) to high under the upper future scenario. Under a lower scenario, all but largest population area drop to low resiliency and most population areas are affected by vegetation shift, but connectivity within and between units remains high (owing to the Nestucca Block Wilson large population area) so the unit retains a moderate overall resiliency rating in the future compared to current condition. The underlying State constrained lands, which make up over a third of the unit, contribute to its potential future resiliency. Additionally, the Nestucca Block Wilson population area shows large amounts of future habitat, which is becoming or

showing as suitable now in some models since the Tillamook burns of the 1930s–1950s. This currently unoccupied population area is more likely to be recolonized by voles in the future as connectivity increases between the smaller occupied population areas.

6. Cape Meares (46 km² (18 mi²); 2% population area)

Despite potential connectivity within units and multiple population areas, this unit moves from a current condition rating of moderate-low to low under an upper future scenario and becomes extirpated under a lower future scenario. Its four population areas are small and located primarily on private land. The largest population area on constrained lands, Cape Meares National Wildlife Refuge, is likely too small and isolated to be resilient from future genetic and stochastic events. This unit is also totally within the Sitka spruce zone so could be lost under a lower future scenario in terms of vegetation shift.

7. Sand Lake (261 km² (101 mi²); 22% population area)

Under the upper future scenario, this unit is in high condition owing to one larger population area of moderate resiliency and potential connectivity via USFS lands between multiple low resiliency population areas. Under a lower future scenario, the unit would likely become extirpated. The population areas are not big enough or connected by reserved lands to maintain resiliency. This is also one of the coastal units mostly within the Sitka spruce vegetation zone, which would be lost under a lower future scenario.

8. Trask/Nestucca (2661 km² (1027 mi²); 48% population area)

This unit is the largest in size in the DPS with a mix of land ownership types and vegetation zones. It is projected to be in high condition for overall resiliency in the upper future scenario and is anchored by a very large population area (Nestucca Block Trask) which contains constrained lands and is rated high for effective population size capacity and connectivity within and between units. Two other population areas are projected to have moderate resiliency under the upper future scenario, and most of the population areas are connected within the unit. For lower future scenario, most of the population areas were rated in low condition and some connectivity was lost due to the underlying private or unconstrained lands, but the Nestucca Block Trask population area maintained within- and between-unit connectivity and a moderate effective population size capacity. Therefore, the overall unit rating was moderate under this lower future scenario. The addition of a new population area did not affect the overall condition in either future scenario. This unit is notable as a current anchor in the northern region of the DPS and is projected to remain so in the future under either scenario.

9. Gauldy Ridge (85 km² (33 mi²); 60% population area)

This unit rated high in the upper future scenario due to its moderate effective population size capacity combined with its connectivity to adjoining units and location in both vegetation zones. For the lower future scenario, the unit is presumed extirpated. Under the lower future scenario, the effective population size capacity is reduced to low, connectivity to adjoining units is low because there is little of the area in constrained status (though the unit is two-thirds USFS land), and vegetation shifts and Swiss needle cast could severely affect the entire unit.

10. Little Nestucca/Salmon Coast (36 km² (14 mi²); 61% population area)

In the upper future scenario, this unit increases into high condition due to the between-unit connectivity and potential for movement of voles over time between those units. Under a lower future scenario, all ratings drop to low, and the unit likely becomes extirpated. The effective population size capacity under the lower future scenario is low and the unit becomes isolated due to lack of constrained land between it and the adjoining Little Nestucca/Salmon Inland unit. While not in reserved land use status, most of the unit is USFS land managed by the Siuslaw National Forest, and it is likely the unit would continue to grow habitat and become connected to the neighboring unit in the future. However, the unit is the Sitka spruce zone, and a lower future vegetation shift scenario would mean the potential loss of this unit.

11. Little Nestucca/Salmon Inland (225 km² (87 mi²); 38% population area)

This unit is one of the smaller occupied units, made up of six population areas mostly connected by non-reserved USFS lands. It increases to high condition under the upper future scenario due to two population areas of moderate effective population size capacity with within- and between-unit connectivity and both vegetation zones present. Under the lower future scenario, it would likely become extirpated due to all population areas rating low for effective population size capacity, having low connectivity from lack of constrained lands, and having some population areas in the Sitka spruce vegetation zone.

12. Siletz/Luckiamute (2571 km² (993 mi²); 36% population area)

This unit retained a high overall resiliency condition under an upper future scenario. It is the second largest unit in the DPS, comprised of three large and 11 smaller occupied population areas. Under the upper future scenario, the three large population areas have moderate effective population size capacity and are spread out around the unit, most connecting to other population areas and the two largest population areas connecting to other units. In the lower future scenario, only one population area retains a moderate resiliency sub-rating, and connectivity drops to low given the underlying unconstrained lands, resulting in the overall resiliency rating dropping to low. The unit contains both vegetation zones, and those population areas in the Sitka spruce zone would be lost in a lower scenario. The unit is

comprised primarily of private land (82%), and the largest population area is mostly on private land, which could be reduced or lost in a lower future scenario.

13. Yaquina/Marys (1246 km² (481 mi²); 58% population area)

This unit has high resiliency in the upper future scenario, driven by the high effective population size capacity of its primary population area which comprises over half of the unit, and the between-unit connectivity to the units to its south and north. The two small population area “inclusions” that are surrounded by the larger population area have low resiliency but are likely to be subsumed by the large population area in an upper future scenario. Under a lower future scenario, the unit’s resiliency drops to moderate. The large population area has moderate effective population size capacity under the lower future scenario but remains potentially connected to neighboring units. This unit contains over one-third Federal land, and most of that land is in reserved land use allocations. This unit and the large population contain both vegetation zones but is comprised mostly of western hemlock meaning that it would be affected by Swiss needle cast, but not undergo vegetation shifts in the lower future scenario.

14. Alsea/Siuslaw (2,415 km² (932 mi²); 69% population area)

This unit is projected to have overall high resiliency under the upper future scenario and moderate resiliency under the lower future scenario. This is one of the larger units in the DPS and consists of a single population area which is connected across the unit and makes up 69% of the total unit area. This unit is connected to other units along its northern and southeastern boundary via reserved lands, so connectivity is high under both future scenarios. This unit is comprised of over 50 percent Federal land, of which 47 percent are in reserved land use allocations. The unit contains both vegetation zones, so the small part of the western edge of the unit/population area in the Sitka spruce zone would be undergo vegetation shifts under the lower future scenario, but the majority of the unit would remain resilient from vegetation shifts.

15. Siuslaw/Long Tom (411 km² (159 mi²); 66% population area)

This unit has overall high resiliency under the upper future scenario and moderate resiliency under the lower future scenario, driven by a single large population area with a moderate-high effective population size capacity and high between-unit connectivity. While the unit is primarily in private ownership (62 percent), constrained lands make up over a quarter of the unit, nearly all in BLM checkerboard, which means some connectivity could be maintained under a lower future scenario. The unit is wholly within the western hemlock vegetation zone and therefore is unlikely undergo vegetation shifts, but it is vulnerable to Swiss needle cast which lowers the overall resiliency rating under a lower future scenario.

16. Siuslaw/Territorial (561 km² (217 mi²); 67% population area)

This unit retains high resiliency under the upper future scenario and drops to moderate resiliency under the lower future scenario due to its single, large population area with a moderate-high effective population size capacity and high rating for connectivity with a neighboring unit. It is primarily in checkerboard ownership with about one-third of the unit in constrained status, so connectivity between units would likely be maintained in the future. The unit is wholly within the western hemlock vegetation and therefore unlikely to undergo vegetation shifts but is vulnerable to Swiss needle cast which lowers the overall resiliency rating under a lower future scenario.

17. Spencer Butte (641km² (247mi²); 46% population area)

The unit has low overall resiliency under both future scenarios, driven primarily by lack of connectivity. The single population area takes up nearly half the unit, which is over 90% in private ownership. That population area has moderate resiliency under the upper future scenario and low resiliency under the lower future scenario. The unit is wholly within the western hemlock vegetation zone, so vegetation shifts are unlikely, but it is vulnerable to Swiss needle cast in a lower future scenario.

Summary for Upper Future Scenario

Under an upper future scenario, all six high current condition units retain high overall resiliency ratings. In addition, four increase from moderate to high condition, and one increases from low to high condition (Table 15). The southernmost unit, Spencer Butte, drops into low condition, as does the small, isolated Cape Meares unit on the coast. The three northeastern-most units with the least habitat and fewest voles become extirpated under the upper future scenario. With the two largest units in the northern portion of the DPS joining most of the southern region with high resiliency, most of the range shows high resiliency under the upper future scenario. The DPS likely has the capacity to absorb loss of individuals because of the relatively large units with large, resilient, and well-connected population areas. Much of this additional future capacity is due to the role of reserved Federal and State lands continuing to grow suitable habitat and connect several new population areas. Two units (Trask/Nestucca and North Fork Nehalem) increase in resiliency based primarily on the likelihood of a currently unoccupied population area becoming occupied in the future.

Summary for Lower Future Scenario

Under a lower future scenario, there are no units with high resiliency (Table 15). The four largest units (Nehalem/Wilson and Trask/Nestucca in the north and Yaquina/Marys and Alsea/Siuslaw in the south) are projected to have moderate resiliency due to their larger size, connectivity, and mix of vegetation zones. The large, centrally located Siletz/Luckiamute unit drops from currently high resiliency to low resiliency in the future due to its lack of reserved lands, and for similar reasons Spencer Butte also drops from moderate current resiliency to low future resiliency. All

other units (9 total) become extirpated under the lower future scenario, including four which currently have moderate resiliency. Six of the nine units are located on the coast and have a high proportion of Sitka spruce vegetation zone which we project would be lost to vegetation shift under a lower future scenario. Additionally, the North Fork Nehalem unit would decrease from a low current condition to likely extirpated because the currently large, unoccupied population area would not have a chance to become occupied, and the unit contains Sitka spruce vegetation zone vulnerable to vegetation shift.

Table 15. Current and future condition summary by geographic unit. Blue represents a high rating (HI), yellow a moderate rating (MOD), orange a moderate low rating (MOD LO), red a low rating (LO), and dark gray represents presumed extirpated (EXT).

Geographic Unit	Current	Future Upper	Future Lower
1. Lewis and Clark	LO	EXT	EXT
2. Ecola/ Elmer Feldenheimer	LO	EXT	EXT
3. Necanicum/ Nehalem	LO	EXT	EXT
4. North Fork Nehalem	LO	HI	EXT
5. Nehalem/Wilson	MOD	HI	MOD
6. Cape Meares	MOD LO	LO	EXT
7. Sand Lake	MOD	HI	EXT
8. Trask/Nestucca	HI	HI	MOD
9. Gauldy Ridge	MOD	HI	EXT
10. Little Nestucca/Salmon Coast	MOD	HI	EXT
11. Little Nestucca/Salmon Inland	MOD	HI	EXT
12. Siletz/ Luckiamute	HI	HI	LO
13. Yaquina/ Marys	HI	HI	MOD
14. Alsea/ Siuslaw	HI	HI	MOD
15. Siuslaw/ Long Tom	HI	HI	MOD
16. Siuslaw/ Territorial	HI	HI	MOD
17. Spencer Butte	MOD	LO	LO

Overall Summary – Future Resiliency

Under existing Federal and State land management regimes, and barring large-scale catastrophic disturbances, red tree vole habitat is projected to be developed and maintained in the analysis area sufficient to support some of the units. Experts project that if old-forest harvest restrictions remain in effect on Federal lands, red tree voles will likely continue to occupy extensive areas of Federal lands (Forsman et al. 2016a, p. 85). They also expect that tree voles may eventually recolonize areas where ODF actively manages the land to produce tree vole habitat (Forsman et al. 2016a, p. 39). In our analysis, we assumed recolonization would occur within or via constrained (i.e. State constrained or Federal reserved) lands. The intervening State Forest land in three units in the north coast subregion (North Fork Nehalem, Nehalem/Wilson, and Trask/Nestucca units) could further develop into tree vole habitat under the existing management plan (and even more so under ODF's proposed Western Oregon HCP). As such, the units with the largest currently suitable habitat and Federal or State constrained land ownership (Nehalem/Wilson, Trask/Nestucca, Yaquina/Marys, Alsea/Siuslaw, Siuslaw/Long Tom, and Siuslaw/Territorial) are likely to retain at least moderate resiliency over time, as predicted in both our future scenarios. This is also consistent with modeling indicating that implementing current land management policies in the Oregon Coast Range is projected to provide a modest increase (approximately 20 percent) in red tree vole habitat over the modeled 100 year time span, primarily on public lands (Spies et al. 2007b, p. 53).

We project that the small, northern-most units with low effective population size capacities (Lewis and Clark, Ecola/Elmer Feldenheimer, and Necanicum/Nehalem) will ultimately become extirpated under either future scenario because they all have effective population size capacities that indicate a high probability for inbreeding, are isolated, have little current habitat, and low potential for connectivity due to private land ownership. The large units with primarily private or unconstrained lands, the medium-sized units, and the small coastal units, vary in future resiliency depending on the future scenario. Under a lower future scenario, most of the small coastal units would also become extirpated. Even though many of these units currently have sufficient habitat to retain the population areas, their small population size and location in the Sitka spruce vegetation zone makes them vulnerable under our future scenario modeling to other events unrelated to habitat, including loss of genetic diversity, inbreeding depression, demographic stochasticity, environmental stochasticity, and natural catastrophes (Franklin 1980, entire; Shaffer 1981, p. 131; Gilpin and Soule 1986, pp. 25–33; Soule and Simberloff 1986, pp. 28–32; Lehmkuhl and Ruggiero 1991, p. 37; Lande 1994, entire).

7.4 Redundancy

Generally, redundancy is likely to be reduced in the future by the extirpation of occupied units projected under either the upper (3 units extirpated) or lower (9 units extirpated, including all six that occur in the Sitka spruce zone) future scenario. The addition of the four population areas presumed to become occupied in the future would help bolster species redundancy, but the units with low effective population size capacities become more vulnerable to catastrophic events if their population numbers decline over time. Overall, tree voles under the upper future scenario are projected to maintain a greater number of populations in high condition as currently exist despite a few extirpated populations, contributing to similar redundancy in the future as exists

currently. Redundancy under a lower future scenario is characterized by six units in moderate condition, with distribution across much of the current range being maintained (with the exception of the farthest north area).

Because redundancy is a measure of a species ability to withstand catastrophic events, it is influenced both by the distribution of populations across the landscape (as described above) as well as the likelihood of a catastrophic event occurring. With any catastrophic disturbance event, individual population areas would likely be retained following the disturbance, but they could be fragmented and isolated, limiting the ability of individuals within those areas to persist long enough to recolonize recovered areas. The largest tree vole units are likely to withstand catastrophic windstorm events currently and will likely remain able to do so into the future, but even the largest units in the DPS are vulnerable to catastrophic, stand-replacing wildfires now, and will likely be more so in the future because of climate change.

Past wildfires in the Oregon Coast Range have burned areas as large as 3,250 km² (1,250 mi²), which is an area equivalent to all or substantive portions of the largest and most resilient red tree vole geographic units. We assume under a lower scenario a fire, fire complex, or multiple fires of that size would be plausible over our timeframe. Under the upper scenario, we assume a fire the size of the lower end of the past 200 years of the most catastrophic wildfires, the Nestucca fire of the mid-1800s (1,200 km² (460 mi²)), would be plausible.

The likelihood of large fires may vary across the DPS, given the relatively warmer and drier conditions in the southeastern portion of the DPS (Spencer Butte, Siuslaw/Territorial, and Siuslaw/Long Tom geographic units), compared with the wetter and cooler conditions along the coast and in the northern portion of the DPS (Davis et al. 2017, p. 180). Through most of the DPS, we expect that conditions will become more suitable for large fires than they are now. We used a model of suitability for large fires, projected to the climate period surrounding 2080 for the RCP 8.5 scenario (Davis et al. 2017 and associated GIS data) to look at an average of fire suitability for each tree vole geographic unit. We also looked at the current (2020) time period as a comparison. In every unit, suitability for large fires increased from the 2020 to the 2080 time period (Appendix A, Table A–18). For two units located in the southeastern portion of the DPS, this increase resulted in a rating change, but even in a high-emissions scenario (RCP 8.5) all units maintain moderate or low suitability for fires by the end of the century when compared with forested areas across Oregon and Washington (Davis et al. 2017, p. 180; and see Appendix A, Section 8).

Different forest management regimes affect fire severity. In recent studies in Oregon and California, ownership and management were found to have a great influence on fire severity (Zald and Dunn 2018, p. 1075; Evers et al. 2022, pp. 8, 11; Levine et al. 2022, pp. 1, 4). In general, and except under extreme fire weather conditions, fire is more severe on young or early seral forests on private land. While we don't have the data to predict fire severity under upper- or lower scenarios, we can look at the underlying land ownership. While we expect that large fires within the DPS will generally be severe, with stand replacement occurring in a large proportion

of the burned area, public lands may be more likely to include some fire refugia that provide pockets of reduced burn severity because public lands are more likely to have old forest (see section 7.1.5). Therefore, we assume units with primarily public land may have less severe wildfires than those with primarily private land, and that those units with a mixture of both land types would have an intermediate level of fire severity (see Appendix A, Section 8.3 and Table A–19).

We assumed that fire suppression would continue to occur and be effective in typical fire season conditions. However, under extreme fire conditions, which are the conditions most likely to lead to large, severe fires like those that have occurred before in the Oregon Coast Range (Abatzoglou et al. 2021, pp. 6–7; Reilly et al. 2022, pp. 5–7), firefighting is more dangerous and less effective, and firefighting resources may already be strained by fires occurring in more fire-prone areas, as occurred with the 2020 Labor Day fires in western Oregon (Abatzoglou et al. 2021, p. 1; Shuman et al. 2022, p. 3). Therefore, we did not assume that large fires would be effectively suppressed in the future.

We assume that a unit will have the greatest probability of withstanding catastrophic fires when it contains resilient tree vole populations, is large enough that substantial amounts of habitat will be outside of even very large fire perimeters, has low suitability for large fires, and is primarily made up of public lands that will provide some degree of fire refugia. We rated each unit according to how closely it approached this description for each of the factors listed above, and overall (see Appendix A, Section 8). Tables 16 and 17 summarize how we characterize the impact of fire risk (last column) on the projected resiliency ratings obtained from both our upper (Table 16) and lower (Table 17) future condition analysis (first column), using the factors described above (size larger than fire perimeter, i.e., “size;” suitability for large fires; and inclusion of public land, i.e., “severity”).

Table 16. Summary of fire rating under a higher plausible future scenario.

Unit Number and Name		Upper Resiliency Rating	Size Rating Modifier	Suitability Rating Modifier	Severity Rating Modifier	Resulting Resiliency with Fire Risk
1	Lewis and Clark	EXT	LO	HI	LO	EXT
2	Ecola/Elmer Feldenheimer	EXT	LO	HI	LO	EXT
3	Necanium/Nehalem	EXT	LO	HI	LO	EXT
4	North Fork Nehalem	HI	LO	HI	MOD	MOD
5	Nehalem/Wilson	HI	MOD	HI	HI	HI
6	Cape Meares	LO	LO	HI	LO	LO
7	Sand Lake	HI	LO	HI	LO	MOD LO
8	Trask/Nestucca	HI	HI	HI	MOD	HI
9	Gauldy Ridge	HI	LO	HI	MOD	MOD

10	Little Nestucca/Salmon Coast	HI	LO	HI	HI	MOD HI
11	Little Nestucca/Salmon Inland	HI	LO	HI	MOD	MOD
12	Siletz/Luckiamute	HI	HI	HI	LO	MOD HI
13	Yaquina/Marys	HI	MOD	HI	MOD	MOD HI
14	Alsea/Siuslaw	HI	HI	HI	MOD	HI
15	Siuslaw/Long Tom	HI	LO	MOD	MOD	MOD LO
16	Siuslaw/Territorial	HI	LO	MOD	MOD	MOD LO
17	Spencer Butte	LO	LO	HI	LO	LO

Table 17. Summary of fire ratings under a lower scenario.

Unit Number and Name		Lower Resiliency Rating	Size Rating Modifier	Suitability Rating Modifier	Severity Rating Modifier	Resulting resiliency with fire risk
1	Lewis and Clark	EXT	LO	HI	LO	EXT
2	Ecola/Elmer Feldenheimer	EXT	LO	HI	LO	EXT
3	Necanium/Nehalem	EXT	LO	HI	LO	EXT
4	North Fork Nehalem	EXT	LO	HI	MOD	EXT
5	Nehalem/Wilson	MOD	LO	HI	HI	MOD
6	Cape Meares	EXT	LO	HI	LO	EXT
7	Sand Lake	EXT	LO	HI	LO	EXT
8	Trask/Nestucca	MOD	LO	HI	MOD	MOD LO
9	Gauldy Ridge	EXT	LO	HI	MOD	EXT
10	Little Nestucca/Salmon Coast	EXT	LO	HI	HI	EXT
11	Little Nestucca/Salmon Inland	EXT	LO	HI	MOD	EXT
12	Siletz/Luckiamute	LO	LO	HI	LO	LO
13	Yaquina/Marys	MOD	LO	HI	MOD	MOD LO
14	Alsea/Siuslaw	MOD	LO	HI	MOD	MOD LO
15	Siuslaw/Long Tom	MOD	LO	MOD	MOD	MOD LO
16	Siuslaw/Territorial	MOD	LO	MOD	MOD	MOD LO
17	Spencer Butte	LO	LO	HI	LO	LO

Of 12 units with high resiliency ratings in the upper scenario, three maintain high resiliency even with fire risk considered, three drop to high-moderate resiliency, three drop to moderate resiliency, and three drop to moderate-low resiliency.

Of the six units with moderate resiliency under the lower future scenario, one maintained moderate resiliency even with fire risk considered, but the other five drop to moderate-low resiliency when we incorporated fire risk.

Although all units maintain moderate or low suitability for fires, by the end of the century as compared with forested areas across Oregon and Washington even in a high-emissions climate change scenario (RCP 8.5) (Davis et al. 2017, p. 180), large-scale, stand-replacing wildfire consistent with historical fire regimes in the Oregon Coast Range remains the greatest threat to red tree voles. There is no way to predict whether a catastrophic wildfire will or will not occur within the 60-year timeframe we used for this analysis. Nor can we predict where it will occur within the analysis area. However, the longer we project into the future, the greater the probability becomes that such an event, or multiple events, will occur because of climate change.

In summary, redundancy will be similar under an upper future threats scenario and reduced under a lower future threats scenario based on the distribution of occupied tree vole units across the current range. Catastrophic fire(s) may contribute to reduce redundancy in the future.

7.5 Representation

In our future scenarios, representation of red tree voles in the western hemlock vegetation zone is fairly secure, barring very large, stand-replacing wildfires. However, Swiss needle cast, in a lower future scenario, could reduce the resiliency of red tree vole populations in the western hemlock vegetation zone. Any reduction in resiliency could result in some loss of representation, with fewer individuals available to contribute to species diversity. The loss of some red tree vole representation in the Sitka spruce zone in the future may occur because much of the occupied habitat of that vegetation type occurs in smaller population areas along the north coast, which currently have only moderate or low resiliency red tree vole population areas. These units continue to remain small under future scenarios, and while many of them increase in resiliency in the upper future scenario, all are assumed to become extirpated under the lower future scenario. The loss of red tree vole population areas, particularly in the north coast subregion of the analysis area, would likely result in a loss of representation in the species.

7.6 Summary of Future Condition

We evaluated 17 tree vole geographic units comprised of 52 occupied population areas plus an additional four presumed future occupied population areas. In modeling future resiliency of individual units, we derived an effective population size capacity and considered connectivity and the effect of future Swiss needle cast disease and potential vegetation shifts to derive an overall relative resiliency rating. We also assessed representation and redundancy for each unit.

Under an upper future scenario, 10 units, representing most of the DPS, are projected to be highly resilient. Two other units decrease into low resiliency, and the three northeastern-most units are projected to become extirpated. With high resiliency across the DPS under the upper future scenario, tree voles retain representation across both vegetation zones and maintain redundancy to sustain catastrophic events. Under a lower future scenario, none of the units are projected to be highly resilient, but the four largest units are projected to be moderately resilient due to their larger size, connectivity, and mix of vegetation zones. Nine other units, mostly small and in the north coast subregion, are expected to become extirpated under the lower future

scenario. The extirpation of these nine units would result in a decrease in redundancy, and because most of these units are in the Sitka spruce vegetation zone, also a decrease in representation. However, as the four largest units are located in both subregions and represent both vegetation zones, these units are a valuable source of representation. The size of these four largest units also make it unlikely that a single catastrophic event could impact the entire DPS at once, indicating that they provide the DPS with a valuable source of redundancy. However, catastrophic wildfires, depending on the size and location, could greatly decrease the resiliency of population areas within these units, which would lead to a decrease overall in representation and redundancy for the DPS under a lower future scenario.

8. SYNTHESIS

The North Coast DPS of the red tree vole has undergone a decrease in viability over the past 100 years due to net loss of habitat, combined with an associated decline or extirpation of red tree vole populations in these areas. The loss of historical viability is primarily due to a combination of timber harvest and catastrophic wildfires that are characteristic of the Oregon Coast Range fire regime. Consequently, tree voles currently occur in fragmented and isolated population areas primarily restricted to Federal and State lands. Multiple features of tree vole biology, including low reproductive capacity and low vagility and natal dispersal capability, limit the ability of the population to rebound from the level of habitat loss and fragmentation that has occurred. Stressors that will continue to affect species viability include continued timber harvest that removes or precludes habitat development, and the contribution of climate change to the spread and severity of Swiss needle cast, shifts in vegetation, and the increased threat of catastrophic wildfires.

Smaller, isolated vole geographic units could become extirpated over time under existing management regimes. Additional small coastal units could become extirpated under a lower future scenario. In the upper future scenario, most of the DPS retains high resiliency, representation, and redundancy. The largest tree vole units that encompass the large blocks of Federal land in the analysis area are expected to maintain resiliency through time in either the upper or lower future scenarios we considered and remain the foundation of the red tree vole population in the analysis area; the assumption here is that current Federal management practices continue and that there is no major loss of habitat to catastrophic wildfires. Catastrophic wildfires in the Oregon Coast Range are difficult to impossible to predict or manage for and are the principal threat to most units even though the likelihood of occurrence is low in any given unit in any given year.

Opportunities exist to increase the resiliency of existing vole population areas through habitat development, particularly on State lands and in the northern portion of the DPS. Young forests, if managed to retain canopy connection and through a landscape lens, may have a role in providing connectivity between more stable old forest patches. Increasing connectivity will improve the adaptive capacity of those units rated as having moderate resiliency. Facilitating connectivity among population areas and units will require cooperative and collaborative planning among multiple stakeholders and land managers.

LITERATURE CITED

- Abatzoglou, J.T., D.E. Rupp, L.W. O'Neill, and M. Sadegh. 2021. Compound Extremes Drive the Western Oregon Wildfires of September 2020. *Geophys. Res. Lett.* 48.
- Adams, D., G. Latta, R. Schillinger, and A.V. Nalts. 2002. Timber harvest projections for private land in western Oregon. Oregon State University. 1–53 pp.
- Adams, D.M., and G.S. Latta. 2007. Timber Trends on Private Lands in Western Oregon and Washington: A New Look. *West. J. Appl. For.* 22: 8–14.
- Agee, J.K. 1991. Fire History of Douglas-Fir Forests in the Pacific Northwest, pp. 25–33. *In* K.B. Aubry and M.H. Brookes [eds.], *Wildlife and Vegetation of Unmanaged Douglas-Fir Forests*. U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station.
- Agee, J.K. 1993. *Fire ecology of Pacific Northwest forests*, Island Press.
- Agee, J.K. 1997. The severe weather wildfire: too hot to handle? *Northwest Sci.* 71: 153–156.
- Alexander, L.F., B.J. Verts, and T.P. Farrell. 1994. Diet of Ringtails (*Bassariscus astutus*) in Oregon. *Northwest. Nat.* 75: 97–101.
- Allen, C.D., D.D. Breshears, and N.G. McDowell. 2015. On underestimation of global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene. *Ecosphere* 6: 1–55.
- Azuma, D.L., L.F. Bednar, B.A. Hiserote, and Veneklase. 2004. Timber resource statistics for western Oregon, 1997. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 1–136 pp.
- Bailey, V. 1936. Mammals of Oregon an Important Natural Resource: Red Tree Mouse and Dusky Tree Mouse, pp. 194–199. *In* V. Bailey [ed.], *The Mammals and Life Zones of Oregon*. United States Department of Agriculture, Bureau of Biological Survey.
- Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, K.L. Chatterjee, K.I. Ebj, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White, eds. 2014. *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press.
- Baumbusch, R.C. 2023. Foraging ecology of barred owls where they are outcompeting the threatened northern spotted owl. Ph.D. Dissertation. Oregon State University. 173 pp.
- Beever, E.A., J. O'Leary, C. Mengelt, J.M. West, S. Julius, N. Green, D. Magness, L. Petes, B. Stein, A.B. Nicotra, J.J. Hellmann, A.L. Robertson, M.D. Staudinger, A.A. Rosenberg, E. Babij, J. Brennan, G.W. Schuurman, and G.E. Hofmann. 2016. Improving Conservation Outcomes with a New Paradigm for Understanding Species' Fundamental and Realized Adaptive Capacity. *Conserv. Lett.* 9: 131–137.
- Bell, D.M., S.A. Acker, M.J. Gregory, R.J. Davis, and B.A. Garcia. 2021. Quantifying regional trends in large live tree and snag availability in support of forest management. *For. Ecol. Manag.* 479: 1–10.
- Bellinger, M.R., S.M. Haig, E.D. Forsman, and T.D. Mullins. 2005. Taxonomic relationships among *Phenacomys* voles as inferred by cytochrome b. *J. Mammal.* 86: 201–210.
- Benson, S.B., and A.E. Borell. 1931. Notes on the Life History of the Red Tree Mouse, *Phenacomys longicaudus*. *J. Mammal.* 12: 226–233.
- Biswell, B. 2010. Email. S Livingston and B Biswell RE: red tree voles and thinning.
- Biswell, B., M. Blow, R. Breckel, L. Finley, and J. Lint. 2002. Survey protocol for the Red tree vole *Arborimus longicaudus* (= *Phenacomys longicaudus* in the Record of Decision of the Northwest Forest Plan). Version 2.1. Portland, Oregon. 1–13 pp.
- Biswell, B., M. Blow, L. Finley, S. Madsen, and K. Schmidt. 2000. Survey Protocol for the Red Tree Vole *Arborimus longicaudus* (= *Phenacomys longicaudus* in the Record of Decision of the Northwest Forest Plan). Version 2.0. Bureau of Land Management. 1–34 pp.

- Biswell, B.L. 1996. Intertree movements and spatial distribution of nest trees occupied by individual red tree voles: implications for conservation. *Proceedings of the Society for Northwest Vertebrate Biology*. Abstract.
- Biswell, B.L. 2005. Email forward. B Biswell to J Swingle RE: Poster abstract for 1994 Mammal Society Meeting: Intertree movement and spatial distribution of nest trees occupied by individual red tree voles: implications for conservation.
- Black, B.A., D.C. Shaw, and J.K. Stone. 2010. Impacts of Swiss needle cast on overstory Douglas-fir forests of the western Oregon Coast Range. *For. Ecol. Manag.* 259: 1673–1680.
- Blois, J.L., and B.S. Arbogast. 2006. Conservation genetics of the Sonoma tree vole (*Arborimus pomo*) based on mitochondrial and amplified fragment length polymorphism markers. *J. Mammal.* 87: 950–960.
- Blomqvist, D., A. Pauliny, M. Larsson, and L.-Å. Flodin. 2010. Trapped in the extinction vortex? Strong genetic effects in a declining vertebrate population. *BMC Evol. Biol.* 10: 1–9.
- Bolger, D.T., A.C. Alberts, R.M. Sauvajot, P. Potenza, C. McCalvin, D. Tran, S. Mazzoni, and M.E. Soule. 1997. Response of rodents to habitat fragmentation in coastal southern California. *Ecol. Appl.* 7: 552–563.
- Borrecco, J.E. 1972. The response of animals to herbicide-induced habitat changes. PhD Dissertation. Oregon State University. 1–104 pp.
- Brong, E.M., and L. Goodman. 2006. Survey and Manage Species – Identification of Non-high Priority Sites. USDI Bureau of Land Management, USDA Forest Service. 6 pp.
- Brook, B.W., C.J.A. Bradshaw, L.W. Traill, and R. Frankham. 2011. Minimum Viable Population Size: Not Magic, but Necessary. *Trends Ecol. Evol.* 26: 619–620.
- Brown, J.H., and A. Kodric-Brown. 1977. Turnover Rates in Insular Biogeography: Effect of Immigration on Extinction. *Ecol. Durh.* 58: 445–449.
- Brown, L.N. 1964. Breeding Records and Notes on *Phenacomys silvicola* in Oregon. *J. Mammal.* 45: 647–648.
- Carey, A.B. 1991. The Biology of Arboreal Rodents in Douglas-Fir Forests. GTR 276. USDA Forest Service, Pacific Northwest Research Station. 53 pp.
- Carey, A.B. 1996. Interactions of Northwest Forest Canopies and Arboreal Mammals. *Northwest Sci.* 70: 72–78.
- Cayan, D., M. Tyree, D. Pierce, and T. Das. 2012. Climate change and sea level rise scenarios for California vulnerability and adaptation assessment. CEC500-2012-008. Scripps Institution of Oceanography. 1–36 pp.
- Chen, J., J.F. Franklin, and T.A. Spies. 1992. Vegetation Responses to Edge Environments in Old-Growth Douglas-Fir Forests. *Ecol. Appl.* 2: 387–396.
- Chen, J., J.F. Franklin, and T.A. Spies. 1993. Contrasting microclimates among clearcut, edge, and interior of old-growth Douglas-fir forest. *Agric. For. Meteorol.* 63: 219–237.
- Christensen, J.H., and B. Hewitson. 2007. Regional Climate Projections, pp. 847–892. In S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. Averyt, M. Tignor, and H. Miller [eds.], *Climate Change, 2007: The Physical Science Basis. Contribution of Working group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press.
- Clifton, P.L. 1960. Biology and Life history of the Dusky tree mouse *Phenacomys silvicola* (Howell). PhD Thesis. 1–151 pp.
- Cohen, W.B., T.A. Spies, R.J. Alig, D.R. Oetter, T.K. Maiersperger, and M. Fiorella. 2002. Characterizing 23 Years (1972-95) of Stand Replacement Disturbance in Western Oregon Forests with Landsat Imagery. *Ecosyst. N. Y.* 5: 122–137.
- Confederated Tribes of Siletz Indians. 2010. 2010-2019 Reed-Arnold Creek Management Plan. The Confederated Tribes of Siletz Indians. 188 pp.

- Confederated Tribes of Siletz Indians of Oregon. 2010. Forest Resource Management Plan 1999-2010. The Confederated Tribes of Siletz Indians. 208 pp.
- Confederated Tribes of the Grand Ronde. 2013. Natural Resources Management Plan 2013-2022. The Confederated Tribes of the Grand Ronde. 145 pp.
- Corn, P.S., and R.B. Bury. 1986. Habitat use and terrestrial activity by red tree voles (*Arborimus longicaudus*) in Oregon. *J. Mammal.* 67: 404–406.
- Corn, P.S., and R.B. Bury. 1991. Small mammal communities in the Oregon Coast Range. Pacific Northwest Research Station. 241–254 pp.
- Crandall, K.A., O.R. Bininda-Emonds, G.M. Mace, and R.K. Wayne. 2000. Considering evolutionary processes in conservation biology. *Trends Ecol. Evol.* 15: 290–295.
- Crookston, N.L., G.E. Rehfeldt, G.E. Dixon, and A.R. Weiskittel. 2010. Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. *For. Ecol. Manag.* 260: 1198–1211.
- Dalton, M.M., K.D. Dello, L. Hawkins, P.W. Mote, and D.E. Rupp. 2017. The Third Oregon Climate Assessment Report. Oregon Climate Change Research Institute, Oregon State University. 1–105 pp.
- Davies, K.F., C.R. Margules, and J.F. Lawrence. 2000. Which Traits of Species Predict Population Declines in Experimental Forest Fragments? *Ecol. Durh.* 81: 1450–1461.
- Davis, R., Z. Yang, A. Yost, C. Belongie, and W. Cohen. 2017. The normal fire environment—modeling environmental suitability for large forest wildfires using past, present, and future climate normals. *For. Ecol. Manag.* 390: 173–186.
- Davis, R.J., D.M. Bell, M.J. Gregory, Z. Yang, A.N. Gray, S.P. Healey, and A.E. Stratton. 2022. Northwest Forest Plan—the first 25 years (1994–2018): status and trends of late-successional and old-growth forests. PNW-GTR 1004. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland OR. 82 pp.
- Davis, R.J., J.L. Ohmann, R.E. Kennedy, W.B. Cohen, M.J. Gregory, Z. Yang, H.M. Roberts, A.N. Gray, and T.A. Spies. 2015. Status and Trends of Late-Successional and Old-Growth Forests. Pacific Northwest Research Station. 120 pp.
- Debinski, D.M., and R.D. Holt. 2000. A Survey and Overview of Habitat Fragmentation Experiments. *Conserv. Biol.* 14: 342–355.
- Diller, L. 2010. Phone conversation between Sue Livingston, USFWS and Lowell Dilller, Green Diamond Resource Company.
- Diller, L.V., K.A. Hamm, D.A. Early, D.W. Lamphear, K.M. Dugger, C.B. Yackulic, C.J. Schwarz, P.C. Carlson, and T.L. McDonald. 2016. Demographic response of northern spotted owls to barred owl removal. *J. Wildl. Manag.* 80: 691–707.
- Dunk, J.R. 2009. Application of an FIA/CVS-based Red tree Vole Habitat Model to FIA plot data from the Oregon Coast Range. Report Submitted to U.S. Fish and Wildlife Service. Department of Environmental and Natural Resource Sciences, Humboldt State University. 9 pp.
- Dunk, J.R., and J.J.V.G. Hawley. 2009. Red-tree vole habitat suitability modeling: Implications for conservation and management. *For. Ecol. Manag.* 258: 626–634.
- Durham, W.P. 2019. Red Tree Voles: Examining the Potential Factors Limiting Occupancy and Survival in Young Conifer Forests of the Central Oregon Coast Range. M.S. Thesis. 1–104 pp.
- Durham, W.P., J.D. Bailey, and D.B. Lesmeister. 2019. Red tree voles: examining the potential factors limiting occupancy and activity in young forests. Poster Presentation.
- Dye, A.W., B. Rastogi, R.E.S. Clemesha, J.B. Kim, R.M. Samelson, C.J. Still, and A.P. Williams. 2020. Spatial Patterns and Trends of Summertime Low Cloudiness for the Pacific Northwest, 1996–2017. *Geophys. Res. Lett.* 47: e2020GL088121.
- Eriksson, C.E., K.M. Moriarty, M.A. Linnell, and T. Levi. 2019. Biotic factors influencing the unexpected distribution of a Humboldt marten (*Martes caurina humboldtensis*) population in a young coastal forest. *PloS One* 14: 23.

- Evers, C., A. Holz, S. Busby, and M. Nielsen-Pincus. 2022. Extreme winds alter influence of fuels and topography on megafire burn severity in seasonal temperate rainforests under record fuel aridity. *Fire* 5: 1–16.
- Fahrig, L., and G. Merriam. 1994. Conservation of Fragmented Populations. *Conserv. Biol.* B: 50–59.
- Filip, G. 2009. Phone conversation RE: Lands afflicted with Swiss needle cast. Between USFWS and Greg Filip, Forest Service Regional Plant Pathologist, Portland OR.
- Flather, C.H., G.D. Hayward, S.R. Beissinger, and P.A. Stephens. 2011. Minimum viable populations: is there a ‘magic number’ for conservation practitioners? *Trends Ecol. Evol.* 26: 307–316.
- Fleishman, E. 2023. Sixth Oregon climate assessment. Oregon Climate Change Research Institute, Oregon State University, Corvallis OR. 248 pp.
- Forsman, E., and C. Maser. 1970. Saw-Whet Owl Preys on Red Tree Mice. *Murrelet* 51: 10.
- Forsman, E.D. 2009. Emails between S Livingston, USFWS, and Eric Forsman, USFS, Re: red tree vole historic collections and subspecies boundary.
- Forsman, E.D. 2010. Communications with Eric Forsman about red tree voles.
- Forsman, E.D., R.G. Anthony, and C.J. Zabel. 2004. Distribution and Abundance of Red Tree Voles in Oregon Based on Occurrence in Pellets of Northern Spotted Owls. *Northwest Sci.* 78: 294–302.
- Forsman, E.D., E.C. Meslow, and H.M. Wight. 1984. Distribution and Biology of the Spotted Owl in Oregon. *Wildl. Monogr.* 3–64.
- Forsman, E.D., J.S. Mowdy, A.L. Price, and J.K. Swingle. 2011. Red tree voles on the Weyerhaeuser Millicoma tree farm in coos and Douglas Counties, Oregon, 2011. USDA Forest Service, Pacific Northwest Research Station. 1–17 pp.
- Forsman, E.D., and A.L. Price. 2011. Water Consumption by Red Tree Voles (*Arborimus longicaudus*). *Northwest. Nat.* 92: 116–119.
- Forsman, E.D., and J. Swingle. 2006. Red tree vole retrospective surveys of historic collection sites, unpublished data provided to USFWS. 1–22.
- Forsman, E.D., and J. Swingle. 2009. Meetings between USFWS and Eric Forsman and Jim Swingle to discuss the interpretation of Miller et al (2006), feeding behavior, and data on historic and current distribution of red tree voles.
- Forsman, E.D., and J.K. Swingle. 2010. Doug Bake and Red Tree Voles: A Tale of Discovery in the Pacific Northwest. *Northwest. Nat.* 91: 102–105.
- Forsman, E.D., J.K. Swingle, R.J. Davis, B.L. Biswell, and L.S. Andrews. 2016. Tree voles: an evaluation of their distribution and habitat relationships based on recent and historical studies, habitat models, and vegetation change. General Technical Report PNW-GTR-948. USDA Forest Service, Pacific Northwest Research Station, Portland OR. 128 pp.
- Forsman, E.D., J.K. Swingle, and N.R. Hatch. 2009a. Behavior of Red Tree Voles (*Arborimus longicaudus*) Based on Continuous Video Monitoring of Nests. *Northwest Sci.* 83: 262–272.
- Forsman, E.D., J.K. Swingle, D.B. Lesmeister, C.A. Marks-Fife, and M.A. Linnell. 2019. A tale of two voles: A response to Rosenberg 2019. *For. Ecol. Manag.* 451: 1–7.
- Forsman, E.D., J.K. Swingle, M.A. McDonald, S.A. Graham, and N.R. Hatch. 2009b. Red Tree Voles in the Columbia River Gorge and Hood River Basin, Oregon. *Northwest. Nat.* 90: 227–232.
- Forsman, E.D., J.K. Swingle, and W.W. Price. 2008. Red Tree Vole (*Arborimus longicaudus*) Surveys at Oswald West, Ecola, and Fort Stevens State Parks, 26–28 April, 2008. PNW Research Station, USDA Forest Service. 8 pp.
- Frankham, R. 1995. Effective population size/adult population size ratios in wildlife: a review. *Genet. Res.* 66: 95–107.
- Frankham, R., J.D. Ballou, and D.A. Briscoe. 2007. Effect of population bottlenecks on quantitative genetic diversity, pp. 187–241. *In* R. Frankham, J.D. Ballou, and D.A. Briscoe [eds.]. Cambridge University Press.

- Frankham, R., C.J.A. Bradshaw, and B.W. Brook. 2014a. Genetics in conservation management: Revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. *Biol. Conserv.* 170: 56–63.
- Frankham, R., C.J.A. Bradshaw, and B.W. Brook. 2014b. 50/500 rules need upward revision to 100/1000 – response to Franklin et al. *Biol. Conserv.* 176: 286.
- Frankham, R., B.W. Brook, C.J.A. Bradshaw, L.W. Trail, and D. Spielman. 2013. 50/500 rule and minimum viable populations: response to Jamieson and Allendorf. *Trends Ecol. Evol.* 28: 187–188.
- Franklin, I.R. 1980. Evolutionary Change in Small Populations, pp. 135–149. *In* M.E. Soule and B. Wilcox [eds.]. Sinauer Associates, U.S.A.
- Franklin, I.R., F.W. Allendorf, and I.G. Jamieson. 2014. The 50/500 rule is still valid – Reply to Frankham et al. *Biol. Conserv.* 176: 284–285.
- Franklin, J.F., and C.T. Dyrness. 1988. Natural vegetation of Oregon and Washington, Repr. with new bibliographic suppl. Oregon State University Press, Corvallis OR.
- Gaines, W.L., A.L. Lyons, L.H. Suring, and C.S. Hughes. 2023. Ecosystem Conditions That Influence the Viability of an Old-Forest Species with Limited Vagility: The Red Tree Vole. *Animals* 13: 1166.
- Gao, P., A.J. Terando, J.A. Kupfer, J. Morgan Varner, M.C. Stambaugh, T.L. Lei, and J. Kevin Hiers. 2021. Robust projections of future fire probability for the conterminous United States. *Sci. Total Environ.* 789: 147872.
- Gedalof, Z., D.L. Peterson, and N.J. Mamtua. 2005. Atmospheric, Climatic, and Ecological Controls on Extreme Wildfire Years in the Northwestern United States. *Ecol. Appl.* 15: 154–174.
- Gillesberg, A.-M., and A.B. Carey. 1991. Arboreal Nests of *Phenacomys longicaudus* in Oregon. *J. Mammal.* 72: 784–787.
- Gilpin, M.E. 1987. Spatial structure and population vulnerability, pp. 125–139. *In* M.E. Soule [ed.]. Cambridge University Press.
- Gilpin, M.E., and M.E. Soule. 1986. Minimum Viable Populations: Processes of Species Extinction, p. 584. *In* M.E. Soule [ed.]. Sinauer Associates, Inc.
- Golightly, R.T., T.F. Penland, W.J. Zielinski, and J.M. Higley. 2006. Fisher Diet in the Klamath / North Coast Bioregion. Humboldt State Sponsored Programs Foundation. 1–56 pp.
- Gomez, D.M., and R.G. Anthony. 1998. Small Mammal Abundance in Riparian and Upland Areas of Five Seral Stages in Western Oregon. *Northwest Sci.* 72: 293–302.
- Gostin, M. 2009. RE: FW: dusky tree vole listing status.
- Graham, S.A., and G.W. Mires. 2005. Predation on red tree voles by owls and diurnal raptors. *Northwest. Nat.* 86: 38–40.
- Hall, E.R. 1981. The Mammals of North America, second edition, p. 1175. *In* E.R. Hall [ed.]. John Wiley & Sons.
- Halofsky, J.E., D.L. Peterson, K.A. O'Halloran, and C.H. Hoffman. 2011. Adapting to Climate Change at Olympic National Forest and Olympic National Park. U.S. Department of Agriculture, Forest Service Pacific Northwest Research Station. 1–144 pp.
- Halofsky, J.S., D.R. Conklin, D.C. Donato, J.E. Halofsky, and J.B. Kim. 2018. Climate change, wildfire, and vegetation shifts in a high-inertia forest landscape: Western Washington, U.S.A. *PLoS ONE* 13: 1–23.
- Hamilton, W.J. 1962. Reproductive Adaptations of the Red Tree Mouse. *J. Mammal.* 43: 486–504.
- Hansen, E.M., J.K. Stone, B.R. Capitano, P. Rosso, W. Sutton, and L. Winton. 2000. Incidence and Impact of Swiss Needle Cast in Forest Plantations of Douglas-fir in Coastal Oregon. *Plant Dis.* 84: 773–778.
- Hanski, I., and M. Gilpin. 1991. Metapopulation dynamics: brief history and conceptual domain. *Biol. J. Linn. Soc.* 42: 3–16.
- Hanski, I., A. Moilanen, and M. Gyllenberg. 1996. Minimum Viable Metapopulation Size. *Am. Nat.* 147: 527–541.

- Harcombe, P.A., S.E. Greene, M.G. Kramer, S.A. Acker, T.A. Spies, and T. Valentine. 2004. The influence of fire and windthrow dynamics on a coastal spruce–hemlock forest in Oregon, USA, based on aerial photographs spanning 40 years. *For. Ecol. Manag.* 194: 71–82.
- Harmon, M., and R. Pabst. 2019. The Long-Term Effects of Wind Disturbance on a Sitka Spruce–Western Hemlock Forest. *Forests* 10: 1–19.
- Harrison, S. 1991. Local extinction in a metapopulation context: an empirical evaluation. *Biol. J. Linn. Soc.* 42: 73–88.
- Hayes, J.P. 1996. *Arborimus longicaudus*. *Mamm. Species* 1–5.
- Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneider, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan, and J.H. Verville. 2004. Emissions Pathways, Climate Change, and Impacts on California. *Proc. Natl. Acad. Sci. PNAS* 101: 12422–12427.
- Heinrichs, J.A., B.G. Marcot, M.A. Linnell, and D.B. Lesmeister. 2023. Characterizing long-term population conditions of the elusive red tree vole with dynamic individual-based modeling. *Conserv. Sci. Pract.* n/a: 1–15.
- Hember, R.A., W.A. Kurz, and N.C. Coops. 2017. Relationships between individual-tree mortality and water-balance variables indicate positive trends in water stress-induced tree mortality across North America. *Glob. Change Biol.* 23: 1691–1710.
- Henderson, M.T., G. Merriam, and J. Wegner. 1985. Patchy environments and species survival: Chipmunks in an agricultural mosaic. *Biol. Conserv.* 31: 95–105.
- Henein, K., and G. Merriam. 1990. The elements of connectivity where corridor quality is variable. *Landsc. Ecol.* 4: 157–170.
- Hopkins, S. 2010. Phone conversation between Sue Livingston, USFWS, and Scott Hopkins, BLM.
- Howell, A.B. 1921. Description of a New Species of *Phenacomys* from Oregon. *J. Mammal.* 2: 98–100.
- Howell, A.B. 1926. Voles of the genus *phenacomys*. *North Am. Fauna* 1–67.
- Huff, M.H., R.S. Holthausen, and K.B. Aubry. 1992. Habitat management for red tree voles in Douglas-fir forests. U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. 24 pp.
- Huff, R. 2016. High-Priority Site Management Recommendations for the Red Tree Vole (*Arborimus longicaudus*). U.S. Department of Agriculture, Forest Service. 1–46 pp.
- Impara, P.C. 1997. Spatial and Temporal Patterns of Fire in the Forests of the Central Oregon Coast Range. PhD Thesis. 1–372 pp.
- IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC. 151 pp.
- IPCC. 2023. Longer Report: Synthesis Report of the IPCC Sixth Assessment Report (AR6). 1–85 pp.
- Jamieson, I.G., and F.W. Allendorf. 2012. How does the 50/500 rule apply to MVPs? *Trends Ecol. Evol.* 27: 578–584.
- Jamieson, I.G., and F.W. Allendorf. 2013. A school of red herring: reply to Frankham et al. *Trends Ecol. Evol.* 28: 188–189.
- Jayawickrama, K.J.S., D. Shaw, and T.Z. Ye. 2012. Genetic Selection in Coastal Douglas-fir for Tolerance to Swiss Needle Cast Disease. USDA FS Pacific SW Research Station. 256–261 pp.
- Jewett, S.G. 1920. Notes on Two Species of *Phenacomys* in Oregon. *J. Mammal.* 1: 165–168.
- Jewett, S.G. 1930. A nest of *Phenacomys silvicola* in Oregon. *J. Mammal.* 11: 81–83.
- Jobanek, G.A. 1988. Searching for the Tree Vole: An Episode in the 1914 Biological Survey of Oregon. *Or. Hist. Q.* 89: 369–400.
- Johnson, G.R. 2002. Genetic Variation in Tolerance of Douglas-fir to Swiss Needle Cast as Assessed by Symptom Expression. *Silvae Genet.* 51: 80–88.
- Johnson, K.N., P. Bettinger, J.D. Kline, T.A. Spies, M. Lennette, G. Lettman, B. Garber-Yonts, and T. Larsen. 2007. Simulating Forest Structure, Timber Production, and Socioeconomic Effects in a Multi-Owner Province. *Ecol. Appl.* 17: 34–47.

- Johnson, M.L. 1968. Application of Blood Protein Electrophoretic Studies to Problems in Mammalian Taxonomy. *Syst. Zool.* 17: 23–30.
- Johnson, M.L. 1973. Characters of the Heather Vole, *Phenacomys*, and the Red Tree Vole, *Arborimus*. *J. Mammal.* 54: 239–244.
- Johnson, M.L., and S.B. George. 1991. Species limits within the *Arborimus longicaudus* species-complex (mammalia: rodentia) with a Description of a new species from California. *Contrib. Sci.* 429: 1–16.
- Johnston, A.N., and M.L. Moskal. 2017. High-Resolution Habitat Modeling With Airborne LiDAR for Red Tree Voles. *J. Wildl. Manag.* 81: 58–72.
- Jones, J.M. 2003. Habitat associations and ecology of the Sonoma tree vole (*Arborimus pomo*) in northwestern California. M.S. Thesis. 1–64 pp.
- Karl, T.R., J.M. Melillo, and T.C. Peterson, eds. 2009. *Global Climate Change Impacts in the United States*, Cambridge University Press.
- Kelsey, R.G., E.D. Forsman, and J.K. Swingle. 2009. Terpenoid Resin Distribution in Conifer Needles with Implications for Red Tree Vole, *Arborimus longicaudus*, Foraging. *Can. Field-Nat.* 123: 12–18.
- Lan, Y.-H., D.C. Shaw, P.A. Beedlow, E.H. Lee, and R.S. Waschmann. 2019. Severity of Swiss needle cast in young and mature Douglas-fir forests in western Oregon, USA. *For. Ecol. Manag.* 442: 79–95.
- Lande, R. 1994. Risk of population extinction from fixation of new deleterious mutations. *Soc. Study Evol.* 48: 1460–1469.
- Lee, E.H., P.A. Beedlow, R.S. Waschmann, C.A. Burdick, and D.C. Shaw. 2013. Tree-ring analysis of the fungal disease Swiss needle cast in western Oregon coastal forests. *Can. J. For. Res.* 43: 677–690.
- Lee, E.H., P.A. Beedlow, R.S. Waschmann, D.T. Tingey, S. Cline, M. Bollman, C. Wickham, and C. Carlile. 2017. Regional patterns of increasing Swiss needle cast impacts on Douglas-fir growth with warming temperatures. *Ecol. Evol.* 7: 11167–11196.
- Lehmkuhl, J.F., and L.F. Ruggiero. 1991. Forest fragmentation in the Pacific Northwest and its potential effects on wildlife. USDA For. Serv. Gen. Tech. Rep. PNW-GTR - Pac. Northwest Res. Stn. USA 35–46.
- Lesmeister, D., M. Linnell, R. Davis, and J. Swingle. 2016. Distribution of habitats for red tree voles (*Arborimus longicaudus*) in the North Coast Range of Oregon. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR. 32 pp.
- Lesmeister, D.B., R.J. Davis, S.G. Sovern, and Z. Yang. 2021. Northern spotted owl nesting forests as fire refugia: a 30-year synthesis of large wildfires. *Fire Ecol.* 17: 32.
- Lesmeister, D.B., and M.A. Linnell. 2019. Habitat clusters for red tree voles in the Coast Range of Oregon. Final Report U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR. 19 pp.
- Lesmeister, D.B., S.G. Sovern, R.J. Davis, D.M. Bell, M.J. Gregory, and J.C. Vogeler. 2019. Mixed-severity wildfire and habitat of an old-forest obligate. *Ecosphere* 10: 1–22.
- Lesmeister, D.B., and J.K. Swingle. 2017. Field guide to red tree vole nests, U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Levine, J.I., B.M. Collins, Z.L. Steel, P. de Valpine, and S.L. Stephens. 2022. Higher incidence of high-severity fire in and near industrially managed forests. *Front. Ecol. Environ.* 20: 397–404.
- Linnell, M.A. 2022. GIS data. An update of red tree vole habitat layers from Linnell et al 2017 habitat model.
- Linnell, M.A., R.J. Davis, D.B. Lesmeister, and J.K. Swingle. 2017a. Conservation and relative habitat suitability for an arboreal mammal associated with old forest. *For. Ecol. Manag.* 402: 1–11.

- Linnell, M.A., C.W. Epps, E.D. Forsman, and W.J. Zielinski. 2017b. Space use, movements, and rest site use by short-tailed weasels *Mustela erminea* in managed forests of western Oregon. *Wildl. Biol.* 2017: 1–10.
- Linnell, M.A., and D.B. Lesmeister. 2019a. Community response to increase in nest sites and arboreal mammals. USDA Forest Service, Pacific Northwest Research Station. 47 pp.
- Linnell, M.A., and D.B. Lesmeister. 2019b. Landscape connectivity and conservation prioritization for an old forest species with limited vagility. *Anim. Conserv.* 22: 568–578.
- Linnell, M.A., and D.B. Lesmeister. 2020. Predator–prey interactions in the canopy. *Ecol. Evol.* 10: 8610–8622.
- Linnell, M.A., D.B. Lesmeister, J.D. Bailey, E.D. Forsman, and J.K. Swingle. 2018. Response of arboreal rodents to increased availability of nest substrates in young forests. *J. Mammal.* 99: 1174–1182.
- Linnell, M.A., D.B. Lesmeister, Z. Yang, and R.J. Davis. 2023. Timber harvest and wildfires drive long-term habitat dynamics for an arboreal rodent. *Biol. Conserv.* 279: 1–9.
- Littell, J.S., M.M. Elsner, G. Mauger, E. Lutz, A.F. Hamlet, and E. Salathé. 2011. Regional Climate and Hydrologic Change in the Northern US Rockies and Pacific Northwest: Internally Consistent Projections of Future Climate for Resource Management. Climate Impacts Group University of Washington College of the Environment. 1–109 pp.
- Littell, J.S., J.A. Hicke, S.L. Shafer, S.M. Capalbo, L.L. Houston, and P. Glick. 2013. Ch. 5: Forest Ecosystems Vegetation, Disturbance, and Economics, pp. 110–148. *In* Climate Change in the Northwest Implications for Our Landscapes, Waters, and Communities. Island Press.
- Liu, Y., S.L. Goodrick, and J.A. Stanturf. 2013. Future U.S. wildfire potential trends projected using a dynamically downscaled climate change scenario. *For. Ecol. Manag.* 294: 120–135.
- Long, C.J., and C. Whitlock. 2002. Fire and Vegetation History from the Coastal Rain Forest of the Western Oregon Coast Range. *Quat. Res.* 58: 215–225.
- Long, C.J., C. Whitlock, P.J. Bartlein, and S.H. Millsaugh. 1998. A 9000-year fire history from the Oregon Coast Range, based on a high-resolution charcoal study. *Can. J. For. Res.* 28: 774–787.
- Maguire, D.A., A. Kanaskie, W. Voelker, R. Johnson, and G. Johnson. 2002. Growth of young Douglas-fir plantations across a gradient in Swiss needle cast severity. *West. J. Appl. For.* 172 86–95.
- Maguire, D.A., D.B. Mainwaring, and A. Kanaskie. 2011. Ten-year growth and mortality in young Douglas-fir stands experiencing a range in Swiss needle cast severity. *Can. J. For. Res.* 41: 2064–2076.
- Mahan, C.G., and R.H. Yahner. 1999. Effects of forest fragmentation on behaviour patterns in the eastern chipmunk (*Nitimus striatus*). *Can. J. Zool.* 77: 1991–1997.
- Mainwaring, D.B., D.A. Maguire, A. Kanaskie, and J. Brandt. 2005. Growth responses to commercial thinning in Douglas-fir stands with varying severity of Swiss needle cast in Oregon, USA. *Can. J. For. Res.* 35: 2394–2402.
- Mangel, M., and C. Tier. 1993. A simple direct method for finding persistence times of populations and application to conservation problems. *Proc. Natl. Acad. Sci.* 90: 1083–1086.
- Manning, T., and C.C. Maguire. 1999. A New Elevation Record for the Red Tree Vole in Oregon: Implications for National Forest Management. *Am. Midl. Nat.* 142: 421–423.
- Marks-Fife, C.A. 2016. Estimation of population age structure, detection probability, and density of red tree voles in oregon. M.S. Thesis. 1–150 pp.
- Marks-Fife, C.A., E.D. Forsman, and K.M. Dugger. 2020. Age Distribution of Red Tree Voles in Northern Spotted Owl Pellets Estimated from Molar Tooth Development. *Northwest Sci.* 93: 193.
- Martin, K.J., and W.C. McComb. 2002. Small mammal habitat associations at patch and landscape scales in Oregon. *For. Sci.* 48: 255–264.
- Martin, K.J., and W.C. McComb. 2003. Small mammals in a landscape mosaic: implications for conservation, pp. 567–586. *In* C.J. Zabel and R.G. Anthony [eds.]. Cambridge University Press.
- Maser, C. 1965a. Spotted Owl Preys on Dusky Three Mice. *The Murrelet* 46: 46.
- Maser, C. 1965b. Notes on the Contents of Owl Pellets Found in Oregon. *The Murrelet* 46: 44.

- Maser, C. 1998. Mammals of the Pacific Northwest: from the Coast to the High Cascades, Oregon State University Press.
- Maser, C. 2009. Phone conversation with Chris Maser, independent consultant and published author on red tree voles.
- Maser, C., B.R. Mate, J.F. Franklin, and C.T. Dyrness. 1981. Natural History of Oregon Coast Mammals. General Technical Report GTR-PNW-133. Pacific Northwest Forest and Range Experiment Station, Portland OR. 496 pp.
- Maser, C.O. 1966. Life histories and ecology of *Phenacomys albipes*, *Phenacomys longicaudus*, *Phenacomys silvicola*. M.S. Thesis. Oregon State University. 238 pp.
- Mathys, A.S., N.C. Coops, and R.H. Waring. 2016. An ecoregion assessment of projected tree species vulnerabilities in western North America through the 21st century. *Glob. Change Biol.* 23: 920–932.
- May, C., C.H. Luce, J.H. Casola, M. Chang, J. Cuhaciyan, M. Dalton, S.E. Lowe, G.S. Morishima, P.W. Mote, A.S. Petersen, G. Roesch-McNally, and E.A. York. 2018. Chapter 24 : Northwest. Impacts, Risks, and Adaptation in the United States: The Fourth National Climate Assessment, Volume II. U.S. Global Change Research Program.
- McAllister, J.A., and R.S. Hoffmann. 1988. *Phenacomys intermedius*. *Mamm. Species* 305: 1–8.
- McCoy, M., J. Piasecki, K. Moriarty, J. Bailey, and K. Dugger. 2023. Searching for nests in the canopy: an elevated challenge.
- Meiselman, N., and A.T. Doyle. 1996. Habitat and Microhabitat Use by the Red Tree Vole (*Phenacomys longicaudus*). *Am. Midl. Nat.* 135: 33–42.
- Meyn, A., P.S. White, C. Buhk, and A. Jentsch. 2007. Environmental drivers of large, infrequent wildfires: the emerging conceptual model. *Prog. Phys. Geogr.* 31: 287–312.
- Mildrexler, D.J., D.C. Shaw, and W.B. Cohen. 2019. Short-term climate trends and the Swiss needle cast epidemic in Oregon’s public and private coastal forestlands. *For. Ecol. Manag.* 432: 501–513.
- Miller, G.S.J. 1923. List of North American recent mammals, Government Printing Office.
- Miller, G.S.J. 1933. The red tree-moose preyed upon by the spotted owl. *J. Mammal.* 14: 162.
- Miller, M., S. Haig, and B. Marcot. 2009. Meeting notes. USFWS, USFS, USGS RE: possible evidence for subspecies of the red tree vole (*Phenacomys longicaudus*) based on Miller et al. 2006.
- Miller, M.P., M.R. Bellinger, E.D. Forsman, and S.M. Haig. 2006. Effects of historical climate change, habitat connectivity, and vicariance on genetic structure and diversity across the range of the red tree vole (*Phenacomys longicaudus*) in the Pacific Northwestern United States. *Mol. Ecol.* 15: 145–159.
- Miller, M.P., E.D. Forsman, J.K. Swingle, S.A. Miller, and S.M. Haig. 2010. Size-Associated Morphological Variation in the Red Tree Vole (*Arborimus longicaudus*). *Northwest. Nat.* 91: 63–73.
- Moeur, M., T.A. Spies, M. Hemstrom, J.R. Martin, J. Alegria, J. Browning, J. Cissel, W.B. COhen, T.E. Demeo, S. Healey, and R. Warington. 2005. Status and Trend of Late-Successional and Old-Growth Forest. U.S. Dept. of Agriculture, Forest Service, Pacific Northwest Research Station. 1–151 pp.
- Molina, R., B.G. Marcot, and R. Leshner. 2006. Protecting Rare, Old-Growth, Forest-Associated Species under the Survey and Manage Program Guidelines of the Northwest Forest Plan. *Conserv. Biol.* 20: 306–318.
- Moriarty, K.M. 2023. Red tree vole preliminary nest detectability information provided as comment in review of draft red tree vole SSA version 2.0.
- Morris, W.G. 1934. Forest fires in western Oregon and western Washington. *Or. Hist. Q.* 35: 313–339.
- Mote, P., and E.P. Salathé Jr. 2010. Future climate in the Pacific Northwest. *Clim. Change* 102: 29–50.
- Mote, P., A.K. Snover, S. Capalbo, S.D. Eigenbrode, P. Glick, J. Littell, R. Raymondi, and S. Reeder. 2014. Ch. 21: Northwest. *Climate Change Impacts in the United States: The Third National Climate Assessment*. Ch 21 North-West.

- Mulvey, R.L., D.C. Shaw, and D.A. Maguire. 2013. Fertilization impacts on Swiss needle cast disease severity in western Oregon. *For. Ecol. Manag.* 287: 147–158.
- Murray, M.A. 1995. Biochemical systematics of the genus *Arborimus*. M.A. Thesis. Humboldt State University. 46 pp.
- Naficy, C.E., G.W. Meigs, M.J. Gregory, R. Davis, D.M. Bell, K. Dugger, J.D. Wiens, and M.A. Krawchuk. 2021. Fire Refugia in Old-Growth Forests: Predicting Habitat Persistence to Support Land. Final Report Final report to the USGS Northwest Climate Adaptation Center Oregon State University. 1–39 pp.
- Naficy, R. Davis, J.T. Rockweit, G.W. Meigs, M.J. Reilly, Z. Yang, S. Drury, and M.A. Krawchuk. 2023. Fire refugia, old forests, and northern spotted owls: a synthesis of key concepts, trends, and toolsets for local to regional conservation planning. Presentation. Oregon Post-Fire Research and Monitoring Symposium, Oregon State University, Corvallis OR.
- Natural Resources Canada. 2022. Canada's Plant Hardiness Zones, species specific models and maps. <http://planthardiness.gc.ca/?m=23>.
- NCASI. 2022a. Red tree vole density data.
- NCASI. 2022b. Red tree voles in working forests: Response to USFWS request for information. 41 pp.
- Nicotra, A.B., E.A. Beever, A.L. Robertson, G.E. Hofmann, and J. O'Leary. 2015. Assessing the components of adaptive capacity to improve conservation and management efforts under global change. *Conserv. Biol.* 29: 1268–1278.
- Nunney, L., and K.A. Campbell. 1993. Assessing minimum viable population size: demography meets population genetics. *Trends Ecol. Evol.* TREE 8: 234–239.
- Oregon Department of Fish and Wildlife. 2016a. Sensitive Species List. Oregon Department of Fish and Wildlife. 11 pp.
- Oregon Department of Fish and Wildlife. 2016b. The Oregon Conservation Strategy - Foothill Yellow-legged Frog. 2019.
- Oregon Department of Forestry. 2003. Western Lane District Implementation Plan. Lane County. 1–43 pp.
- Oregon Department of Forestry. 2009. Tillamook District Implementation Plan. Tillamook District. 1–68 pp.
- Oregon Department of Forestry. 2010. Northwest Oregon State Forests Management Plan Revised Plan April 2010 Oregon Department of Forestry. Oregon Department of Forestry. 1–581 pp.
- Oregon Department of Forestry. 2011a. Approval of Forest Grove and Astoria Implementation Plans. Department of Forestry. 1–102 pp.
- Oregon Department of Forestry. 2011b. Forest Grove District Implementation Plan. Forest Grove District. 1–85 pp.
- Oregon Department of Forestry. 2012. Approval of North Cascade and West Oregon Implementation Plans. Oregon Department of Forestry. 1–96 pp.
- Oregon Department of Forestry. 2013a. Northern Spotted Owl Operational Policies. Oregon Department of Forestry. 9 pp.
- Oregon Department of Forestry. 2013b. Marbled Murrelet Operational Policies. Oregon Department of Forestry. 1–11 pp.
- Oregon Department of Forestry. 2023a. ODF Land Management GIS Layers and Information.
- Oregon Department of Forestry. 2023b. Oregon Department of Forestry Forest Practice Administrative Rules and Forest Practices Act. CHAPTER 629 Forest Practices Administration. Oregon Department of Forestry. 1–151 pp.
- Pardini, R. 2004. Effects of forest fragmentation on small mammals in an Atlantic Forest landscape. *Biodiversity and Conservation* 2567–2586.
- Pardini, R., A. de Arruda Bueno, T.A. Gardner, P.I. Prado, and J.P. Metzger. 2010. Beyond the Fragmentation Threshold Hypothesis: Regime Shifts in Biodiversity Across Fragmented Landscapes. *PLoS ONE* 5: 1–10.

- Peterson, D.W., B.K. Kerns, and E.K. Dodson. 2014. Climate change effects on vegetation in the Pacific Northwest: a review and synthesis of the scientific literature and simulation model projections. General Technical Report PNW-GTR-900. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland OR. 183 pp.
- Piasecki, J. 2022a. Email between USFWS and Jason Piasecki with NCASI regarding red tree vole survey search hours.
- Piasecki, J. 2022b. Email between USFWS and Jason Piasecki, NCASI/OSU RE: Red tree vole confirmation techniques.
- Piasecki, J., J. Bailey, K. Dugger, and K. Moriarty. 2022. Arboreal nest survival and red tree vole use in forests that differ in age. Presentation. The Wildlife Society Annual Meeting, Spokane WA.
- Pierce, D.W., T. Das, D.R. Cayan, E.P. Maurer, N.L. Miller, Y. Bao, • M. Kanamitsu, K. Yoshimura, M.A. Snyder, L.C. Sloan, G. Franco, and M. Tyree. 2013. Probabilistic estimates of future changes in California temperature and precipitation using statistical and dynamical downscaling. *Springer* 40: 839–856.
- Powers, M.D., and J. Kertis. 2022. Fuel Treatment Impacts on Landscape-Scale Wildfire Behavior in Moist, Westside Pacific Northwest Forests: A Summary of Relevant Literature. 52.
- Price, A.L., J.S. Mowdy, J.K. Swingle, and E.D. Forsman. 2015. Distribution and Abundance of Tree Voles in the Northern Coast Ranges of Oregon. *Northwest. Nat.* 96: 37–49.
- Prugh, L.R., K.E. Hodges, A.R.E. Sinclair, and J.S. Brashares. 2008. Effect of Habitat Area and Isolation on Fragmented Animal Populations. *Proc. Natl. Acad. Sci. PNAS* 105: 20770–20775.
- Pyne, S.J. 1982. *Fire in America: A Cultural History of Wildland and Rural Fire*, Princeton University Press.
- Redford, K.H., G. Amato, J. Baillie, P. Beldomenico, E.L. Bennett, N. Clum, R. Cook, G. Fonseca, S. Hedges, F. Launay, S. Lieberman, G.M. Mace, A. Murayama, A. Putnam, J.G. Robinson, H. Rosenbaum, E.W. Sanderson, S.N. Stuart, P. Thomas, and J. Thorbjarnarson. 2011. What Does It Mean to Successfully Conserve a (Vertebrate) Species? *Bioscience* 61: 39–48.
- Reed, D.H., and R. Frankham. 2003. Correlation between Fitness and Genetic Diversity. *Conserv. Biol.* 17: 230–237.
- Reilly, M.J., J.E. Halofsky, M.A. Krawchuk, D.C. Donato, P.F. Hessburg, J.D. Johnston, A.G. Merschel, M.E. Swanson, J.S. Halofsky, and T.A. Spies. 2021. Fire ecology and management in Pacific Northwest forests, pp. 393–435. *In* Fire ecology and management: Past, present, and future of US forested ecosystems. *Managing Forest Ecosystems*. Vol. 39. Springer, Cham: 393-435. Chapter 10.
- Reilly, M.J., A. Zuspan, J.S. Halofsky, C. Raymond, A. McEvoy, A.W. Dye, D.C. Donato, J.B. Kim, B.E. Potter, N. Walker, R.J. Davis, C.J. Dunn, D.M. Bell, M.J. Gregory, J.D. Johnston, B.J. Harvey, J.E. Halofsky, and B.K. Kerns. 2022. Cascadia Burning: The historic, but not historically unprecedented, 2020 wildfires in the Pacific Northwest, USA. *Ecosphere* 13.
- Reynolds, R.T. 1970. Nest Observations of the Long-Eared Owl (*Asio otus*) in Benton County, Oregon, with Notes on Their Food Habits. *Murrelet* 51: 8–9.
- Ritóková, G., D.B. Mainwaring, D.C. Shaw, and Y.-H. Lan. 2021. Douglas-fir foliage retention dynamics across a gradient of Swiss needle cast in coastal Oregon and Washington. *Can. J. For. Res.* 51: 573–582.
- Ritóková, G., D. Shaw, G. Filip, A. Kanaskie, J. Browning, and D. Norlander. 2016. Swiss needle cast in western Oregon Douglas-fir plantations: 20-year monitoring results. *Forests* 7: 2–11.
- Ritóková, G., and H. Stevens. 2022. 2022 Swiss Needle Cast Aerial Survey. Oregon Department of Forestry.
- Robbins, W.G. 1997. *Landscapes of Promise: The Oregon Story, 1800-1940*, University of Washington Press.

- Rogers, B.M., R.P. Neilson, R. Drapek, J.M. Lenihan, J.R. Wells, D. Bachelet, and B.E. Law. 2011. Impacts of climate change on fire regimes and carbon stocks of the U.S. Pacific Northwest. *J. Geophys. Res. Biogeosciences* 116: 1–13.
- Rosenberg, D.K. 2019. A tale of two voles: The challenge of the commonness-rarity continuum in conservation planning. *For. Ecol. Manag.* 434: 165–171.
- Rosenberg, D.K., R.J. Davis, K.J.V. Norman, J.R. Dunk, E.D. Forsman, and R.D. Huff. 2016. Patterns of red tree vole distribution and habitat suitability: implications for surveys and conservation planning. *Ecosphere* Wash. DC 7: 1–24.
- Rosenberg, D.K., B.R. Noon, and E.C. Meslow. 1997. Biological Corridors: Form, Function, and Efficacy. *BioScience* 47: 677–687.
- Rosenberg, K.V., A.M. Dokter, P.J. Blancher, J.R. Sauer, A.C. Smith, P.A. Smith, J.C. Stanton, A. Panjabi, L. Helft, M. Parr, and P.P. Marra. 2019. Decline of the North American avifauna. *Science* 366: 120–124.
- Rosenfeld, J.S. 2014. 50/500 or 100/1000? Reconciling short- and long-term recovery targets and MVPs. *Biol. Conserv.* 176: 287–288.
- Ruggiero, L.F., L.L.C. Jones, and K.B. Aubry. 1991. Plant and animal habitat associations in Douglas-fir forests of the Pacific Northwest: an overview. PNW-GTR-285. USDA Forest Service. 447–462 pp.
- Salathé, E., L. Leung, Y. Qian, and Y. Zhang. 2010a. Regional climate model projections for the State of Washington. *Clim. Change* 102: 51–75.
- Salathé, E., L.R. Leung, Y. Qian, and Y. Zhang. 2010b. Regional climate model projections for the State of Washington. *Clim. Change* 102: 51–75.
- Saunders, D.A., R.J. Hobbs, and C.R. Margules. 1991. Biological consequences of ecosystem fragmentation: a review. *Conserv. Biol.* 5: 18–32.
- Scoresby, S., J. Piasecki, and K. Moriarty. 2022. Red tree vole nest density and stand age. Poster. The Wildlife Society Annual Meeting, Spokane WA.
- Sgrò, C.M., A.J. Lowe, and A.A. Hoffmann. 2011. Building evolutionary resilience for conserving biodiversity under climate change. *Evol. Appl.* 4: 326–337.
- Shafer, S.L., M.E. Harmon, R.P. Neilson, R. Seidl, B.S. Clair, and A. Yost. 2010. 5. The Potential Effects of Climate Change on Oregon's Vegetation. Oregon Climate Change Research Institute. 173–208 pp.
- Shaffer, M.L. 1981. Minimum Population Sizes for Species Conservation. *BioScience* 31: 131–134.
- Shaffer, M.L., and F.B. Samson. 1985. Population Size and Extinction: A Note on Determining Critical Population Sizes. *Am. Nat.* 125: 144–152.
- Shaffer, M.L., and B.A. Stein. 2000. Safeguarding Our Precious Heritage, pp. 301–321. *In* B.A. Stein, L.S. Kutner, and J.S. Adams [eds.]. Oxford University Press.
- Shaw, D. 2008. Swiss needle cast of Douglas-fir in Oregon. *For. Health FACT SHEET* 1–4.
- Shaw, D. 2009. Swiss needle cast (SNC). 1.
- Shaw, D.C., G.M. Filip, A. Kanaskie, D.A. Maguire, and W.A. Littke. 2011. Managing an Epidemic of Swiss Needle Cast in the Douglas-Fir Region of Oregon: The Role of the Swiss Needle Cast Cooperative. *J. For.* 109: 109–119.
- Shaw, D.C., G. Ritóková, Y.-H. Lan, D.B. Mainwaring, A. Russo, R. Comeleo, S. Navarro, D. Norlander, and B. Smith. 2021. Persistence of the Swiss needle cast outbreak in Oregon Coastal Douglas-fir and new insights from research and monitoring. *J. For.* 119: 407–421.
- Sheehan, T., D. Bachelet, and K. Ferschweiler. 2015. Projected major fire and vegetation changes in the Pacific Northwest of the conterminous United States under selected CMIP5 climate futures. *Ecol. Model.* 317: 16–29.
- Shuman, J.K., J.K. Balch, R.T. Barnes, and others. 2022. Reimagine fire science for the anthropocene. *PNAS Nexus* 20221 1-14 2022: 1–14.

- Smith, D.R., N.L. Allan, C.P. McGowan, J.A. Szymanski, S.R. Oetker, and H.M. Bell. 2018. Development of a Species Status Assessment Process for Decisions under the U.S. Endangered Species Act. *J. Fish Wildl. Manag.* 9: 302–320.
- Smith, W.P., R.G. Anthony, J.R. Waters, N.L. Dodd, and C.J. Zabel. 2003. Ecology and conservation of arboreal rodents of western coniferous forests, pp. 156–206. *In* C.J. Zabel and R.G. Anthony [eds.], *Mammal Community Dynamics: Management and Conservation in The Coniferous Forests of Western North America*. Cambridge U. Press.
- Soule, M.E., and D. Simberloff. 1986. What do genetics and ecology tell us about the design of nature reserves? *Biol. Conserv.* 35: 19–40.
- Spies, T.A., and J.F. Franklin. 1991. The Structure of Natural Young, Mature, and Old-Growth Douglas-Fir Forests in Oregon and Washington, pp. 91–109. *In* L.F. Ruggiero, K.B. Aubry, A.B. Carey, and M.H. Huff [eds.], *Pacific Northwest Research Station*.
- Spies, T.A., K.N. Johnson, K.M. Burnett, J.L. Ohmann, B.C. McComb, G.H. Reeves, P. Bettinger, J.D. Kline, and B. Garber-Yonts. 2007a. Cumulative Ecological and Socioeconomic Effects of Forest Policies in Coastal Oregon. *Ecol. Appl.* 17: 5–17.
- Spies, T.A., B.C. McComb, R.S.H. Kennedy, M.T. McGrath, K. Olsen, and R.J. Pabst. 2007b. Potential Effects of Forest Policies on Terrestrial Biodiversity in a Multi-Ownership Province. *Ecol. Appl.* 17: 48–65.
- Spies, T.A., P.A. Stine, R. Gravenmier, J.W. Lang, and M.J. Reilly. 2018. Synthesis of Science to Inform Land Management Within the Northwest Forest Plan Area. U.S. Department of Agriculture Forest Service, Pacific Northwest Research Station. 1–99 pp.
- Stone, J.K., L.B. Coop, and D.K. Manter. 2008. Predicting effects of climate change on Swiss needle cast disease severity in Pacific Northwest forests. *Can J Plant Pathol* 30: 169–176.
- Swingle, J. 2010. Email exchanges between USFWS and Jim Swingle in 2010.
- Swingle, J. 2019. Peer review of DRAFT red tree vole SSA.
- Swingle, J.K. 2005. Daily activity patterns, survival, and movements of red tree voles (*Arborimus longicaudus*) in western Oregon. M.S. Thesis. 1–135 pp.
- Swingle, J.K. 2023. Red tree vole feeding behavior geography.
- Swingle, J.K., and E.D. Forsman. 2009. Home Range Areas and Activity Patterns of Red Tree Voles (*Arborimus longicaudus*) in Western Oregon. *Northwest Sci.* 83: 273–286.
- Swingle, J.K., and E.D. Forsman. 2016. Annotated Bibliography of the Red Tree Vole (*Arborimus longicaudus*), Sonoma Tree Vole (*A. pomosus*), and White-Footed Vole (*A. albipes*). U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 1–184 pp.
- Swingle, J.K., E.D. Forsman, and R.G. Anthony. 2010. Survival, Mortality, and Predators of Red Tree Voles (*Arborimus longicaudus*). *Northwest Sci.* 84: 255–265.
- Swingle, J.K., E.D. Forsman, and S.G. Sovern. 2004. A method for live-trapping tree voles. *Northwest. Nat.* 85: 134–135.
- Taylor, W.P. 1915. Description of a new subgenus (*arborimus*) of *phenacomys*, with a contribution to knowledge of the habits and distribution of *phenacomys longicaudus* true. *Calif. Acad. Sci.* V: 111–161.
- Tebaldi, C., K. Hayhoe, J.M. Arblaster, and G.A. Meehl. 2006. Going to the Extremes. *Clim. Change* 79: n/a.
- Teensma, Dr.P.D.A., J.T. Rienstra, and M.A. Yelter. 1991. Preliminary Reconstruction and Analysis of Change in Forest Stand Age Classes of the Oregon Coast Range From 1850 to 1940. United States Bureau of Land Management. 1–25 pp.
- Thompson, J.L., and L.V. Diller. 2002. Relative Abundance, Nest Site Characteristics, and Nest Dynamics of Sonoma Tree Voles on Managed Timberlands in Coastal Northwest California. *Northwest. Nat. Olym. Wash* 83: 91–100.
- Thompson, J.R., T.A. Spies, and L.M. Ganio. 2007. Reburn severity in managed and unmanaged vegetation in a large wildfire. *Proc. Natl. Acad. Sci.* 104: 10743–10748.

- Traill, L.W., B.W. Brook, R.R. Frankham, and C.J.A. Bradshaw. 2010. Pragmatic population viability targets in a rapidly changing world. *Biol. Conserv.* 143: 28–34.
- True, F.W. 1890. Description of a new species of mouse, *phenacomys longicaudus*, from Oregon. *Smithsonian* 13: 303–304.
- U.S. Fish and Wildlife Service. 2011. Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition to List a Distinct Population Segment of the Red Tree Vole as Endangered or Threatened. Part II: Proposed Rules. *Fed. Regist.* Vol 76 No 198 63537–63815.
- U.S. Fish and Wildlife Service. 2016. USFWS Species Status Assessment Framework: an integrated analytic framework for conservation. Version 3.4 dated August 2016. U.S. Fish and Wildlife Service. 21 pp.
- U.S. Fish and Wildlife Service. 2019. Species Assessment and Listing Priority Assignment Form for *Arborimus longicaudus*. U.S. Fish and Wildlife Service, Region 1, Portland OR. 48 pp.
- USDA Forest Service and USDI Bureau of Land Management. 2003. Supplemental direction for identification of non-high priority sites for red tree vole within the Pilot area. Instructional memo 2630(FS)/1736PFP(BLM)(OR-935)P. April 22, 2003.
- USDA FS. 2007. Final supplement to the 2004 Final supplemental environmental impact statement to remove or modify the survey and manage mitigation measure standards and guidelines. Forest Service National Forests in Regions 5 and 6 and Bureau of Land Management Districts in Washington, Oregon, and California Within the Range of the Northern Spotted Owl. 450 + Appendices pp.
- USDA FS. 2021. GIS Data: Map of Potential Natural Vegetation. U.S. Department of Agriculture, Forest Service. ecoshare.info.
- USDA FS. 2022. Forest Service information for the U.S. Fish and Wildlife Service status review of the North Oregon Coast DPS of the red tree vole (*Arborimus longicaudus*). U.S. Department of Agriculture, Forest Service. 7 pp.
- USDA FS and USDI BLM. 1994a. Record of Decision for Amendments to Forest Service and Bureau of Land Management Planning Documents within the Range of the Northern Spotted Owl. U.S. Dept. of Agriculture, Forest Service : U.S. Dept. of the Interior, Bureau of Land Management. 74 pp.
- USDA FS, and USDI BLM. 1994b. Standards and Guideline for Management of Habitat for Late-Successional and Old-Growth Forest Related Species Within the Range of the Northern Spotted Owl. U.S. Dept. of Agriculture, Forest Service : U.S. Dept. of the Interior, Bureau of Land Management. 154 pp.
- USDA FS and USDI BLM. 2000. Management recommendations for the Oregon red tree vole *Arborimus longicaudus*. Version 2.0. U.S. Dept. of Agriculture, Forest Service : U.S. Dept. of the Interior, Bureau of Land Management. 28 pp.
- USDA FS and USDI BLM. 2001. Record of decision and Standards and Guidelines: for amendments to the survey and manage, protection buffer, and other mitigation measures standards and guidelines. U.S. Dept. of Agriculture, Forest Service : U.S. Dept. of the Interior, Bureau of Land Management. 154 pp.
- USDA FS and USDI BLM. 2011. 2011 Settlement Agreement in Litigation over the Survey and Manage Mitigation Measure in Conservation Northwest et al. v. Sherman et al., Case No. 08-1067-JCC (W.D. Wash.),.
- USDI BLM. 2016. Northwestern and Coastal Oregon record of decision and approved resource management plan: Coos Bay, Eugene, Salem Districts, and Swiftwater Field Office of Roseburg District. U.S. Department of the Interior, Bureau of Land Management, Oregon State Office, Portland OR.
- Verts, B.J., and L.N. Carraway. 1998. Land mammals of Oregon, 1st ed. University of California Press.
- Vrieze, J.M. 1980. Spatial patterning of red tree mouse, *Arborimus longicaudus*, nest. M.A. Thesis. 1–42 pp.

- Walker, A. 1930. Notes on the Forest *Phenacomys*. J. Mammal. 11: 233–235.
- Wang, W., C. Peng, D.D. Kneeshaw, G.R. Larocque, and Z. Luo. 2012. Drought-induced tree mortality: ecological consequences, causes, and modeling. Environ. Rev. 20: 109–121.
- Weisberg, P.J., and F.J. Swanson. 2003. Regional synchronicity in fire regimes of western Oregon and Washington, USA. For. Ecol. Manag. 172: 17–28.
- Wiens, J.D. 2012. Competitive interactions and resource partitioning between northern spotted owls and barred owls in western Oregon. PhD Thesis. 1–156 pp.
- Wilson, M. 2019. Email from ODF discussing SSA 1.0 comments.
- Wilson, T.M., and E.D. Forsman. 2012. Thinning effects and long-term management strategies for spotted owl prey and other forest-dwelling small mammals. Northwest. Nat. 93: 185–186.
- Wilson, T.M., and E.D. Forsman. 2013. Thinning Effects on Spotted Owl Prey and Other Forest-Dwelling Small Mammals, pp. 79–90. In P.D. Anderson and K.L. Ronnenberg [eds.], Density management for the 21st century: west side story. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station.
- Wimberly, M., and J. Ohmann. 2004. A multi-scale assessment of human and environmental constraints on forest land cover change on the Oregon (USA) coast range. Landsc. Ecol. 19: 631–646.
- Wimberly, M.C. 2002. Spatial simulation of historical landscape patterns in coastal forests of the Pacific Northwest. Can. J. For. Res. 32: 1316–1328.
- Wimberly, M.C., T.A. Spies, C.J. Long, and C. Whitlock. 2000. Simulating Historical Variability in the Amount of Old Forests in the Oregon Coast Range. Conserv. Biol. 14: 167–180.
- Wimberly, M.C., T.A. Spies, and E. Nonaka. 2004. Using Criteria Based on the Natural Fire Regime to Evaluate Forest Management in the Oregon Coast Range of the United States, p. 352. In A.H. Perera, L.J. Buse, and M.G. Weber [eds.]. Columbia University Press.
- With, K.A., and T.O. Crist. 1995. Critical Thresholds in Species' Responses to Landscape Structure. Ecol. Durh. 76: 2446–2459.
- Wooster, T., and P. Town. 2002. Newly discovered food and habitat use by California red tree voles. California Fish Game 88: 181–185.
- Yahner, R.H. 1988. Changes in Wildlife Communities Near Edges. Conserv. Biol. 2: 333–339.
- Zald, H.S.J., and C.J. Dunn. 2018. Severe fire weather and intensive forest management increase fire severity in a multi-ownership landscape. Ecol. Appl. 28: 1068–1080.

APPENDICES

Appendix A

Approach to Analytical Units and Condition Analyses for North
Oregon Coast DPS of Red Tree Vole
Species Status Assessment Version 2.0

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1. Introduction

In the 2019 Species Status Assessment (SSA) for the Northern Oregon Coast Distinct Population Segment (DPS) of red tree voles (U.S. Fish and Wildlife Service 2019, entire), analyses of the current and future condition of red tree voles (hereafter, tree voles) relied on a habitat cluster analysis focused on a model of predicted habitat (Linnell et al. 2017, entire; Lesmeister and Linnell 2019, entire). New information has become available since 2019, including a new habitat model (Linnell et al. 2023, entire) and information from recent vole nest surveys (USDI BLM 2022, in litt.; USDA FS 2022, in litt.; NCASI 2022a, in litt.). In response to this new information, and to better reflect past, current, and future estimations of tree vole habitat in the DPS, we have revised our approach to delineating the boundaries of analytical units and our approach for current and future condition analyses. This approach includes all potential tree vole habitat inside and outside of the current tree vole distribution previously mapped (Forsman et al. 2016, p. 83). This appendix explains the processes we used to delineate analytical units for the SSA 2.0 update, apply this information to estimate the range of population sizes and effective population sizes that might be supported by the habitat available in each analytical unit, and analyze current and future condition.

2. Delineation of Analytical Units

Our analytical units are geographic areas containing modeled blocks of habitat within which we expect that genetic and demographic connectivity is possible, though it may be judged to be high (more likely) or low (less likely), depending on criteria discussed below. We refer to these geographic areas as geographic units (units). The modeled blocks of connected habitat within each unit are referred to as population areas. Geographic units and population areas with known occupancy or potential future occupancy of tree voles were moved forward in current and future condition analyses, respectively.

2.1. Habitat Blocks

We intended habitat blocks to be similar to habitat clusters used in the 2019 SSA, in that each habitat block consists of patches of modeled habitat within close enough proximity that tree voles would be functionally connected by occasional genetic and demographic interchange between habitat patches within that block. However, because of differences between the new habitat model (Linnell et al. 2023, entire) and the habitat cluster analysis (Lesmeister and Linnell 2019, entire) that was based on a previous model (Linnell et al. 2017, entire) and our desire to incorporate all forests that might be habitat (e.g. younger tree plantations), the procedure used to delineate the habitat blocks differed from the procedure used to delineate the habitat clusters used in the 2019 SSA.

The previous model (Linnell et al. 2017, entire) used as input known tree vole locations from 2000 through 2015 and a combination of airborne light detecting and ranging (LiDAR) data, disturbance history (1984 through 2015) from Landsat satellite imagery, and a vegetation model that combines 2015 Landsat imagery with on-the-ground measurements of forest structure

(Ohmann and Gregory 2002, entire) (Figure A–1). The habitat cluster analysis (Lesmeister and Linnell 2019, entire) derived from that model identified old forest (> 80 years) patches of sufficient size and distance to potentially support a viable tree vole population.

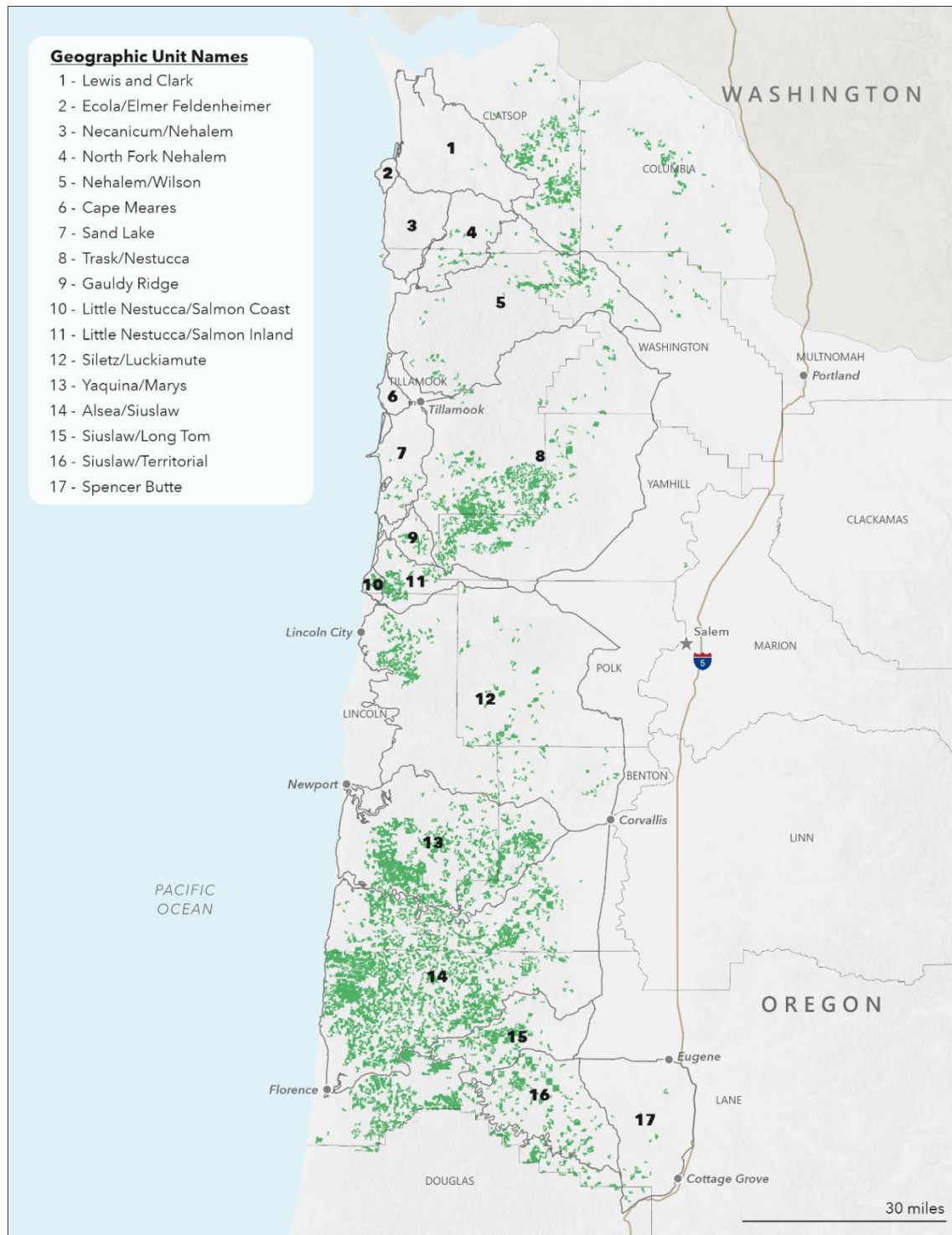


Figure A – 1. Old forest patches based on the 2017 model (Linnell et al. 2017, entire) using updated data (Linnell 2022, in litt.).

The new model (Linnell et al. 2023, pp. 3–5) uses as input known tree vole locations from 1995–2019 and an updated vegetation model that combines 2017 Landsat imagery with on-the-ground Forest Inventory and Analysis National Program plot data (Bell et al. 2021, pp. 2–5) and uses the Maxent machine learning algorithm to discover statistical associations between features in the satellite image and tree vole presence. Tree vole “presences” were where tree vole nests were found during ground-based surveys then confirmed by tree-climbing to identify a positive sign of tree vole presence (Linnell et al. 2023, p. 4). Due to uneven sampling and to ensure presences represented conditions where tree voles occurred across regions in the model, the data was thinned and scaled and the model output was interpreted as relative habitat suitability (Linnell et al. 2023, p. 4). The model classifies each 30 m by 30 m pixel in a geographic information system (GIS; ArcGIS® Pro 2.9.5 from ESRI™) into non-habitat, or habitat of low, moderate, or high relative habitat suitability. For the purposes of delineating habitat blocks, we categorized each pixel as either habitat (all suitability categories grouped together) or non-habitat (see Figure A–2).

We assumed that tree voles would be able to travel, at least sometimes, between habitat pixels located within 200 m of one another. Published data on home range sizes and dispersal is sparse (Swingle and Forsman 2009, pp. 276–277). Dispersal from natal nests to a new nest for juveniles and subadults ranged from 3 to 75 m, averaging 56 m (Swingle 2005, p. 63). The longest documented subadult dispersal distance was for a male who traveled 340 m (Biswell 1996, entire; USDA FS and USDI BLM 2000, p. 8). Voles have been observed moving freely between nest sites which have isolated canopies, crossing small forest roads, streams, and canopy gaps of 30 m, which necessitates movement on the ground (Biswell 1996, entire, 2005, in litt.). Voles have been documented within clearcuts (Borrecco 1972, pp. 34, 36; Corn and Bury 1986, pp. 404–405; Verts and Carraway 1998, p. 310), with one observation at least 200 m from the forest edge (Corn and Bury 1986, p. 404). Therefore, we assume that even when habitat is separated, voles may be able to cross the matrix between habitat patches when they are less than 200 m in width.

We identified all habitat pixels within 100 m of a pixel containing habitat, effectively buffering each pixel of habitat by 100 m. Where these buffers overlap or meet, the habitat pixels are 200 m or less apart. Habitat blocks consisted of aggregations of habitat pixels 200 m or less apart plus the buffers around those habitat pixels. The 200 m distance we used to aggregate habitat blocks differs from the 2 km distance previously used in the 2019 SSA to aggregate habitat clusters. This is because the 2019 habitat cluster analysis identified clusters of presumed occupied old-forest (>80 years old) patches with at least 1 detection of a tree vole or their sign in the previous 20 years and of sufficient extent to potentially support a small, viable population. Each cluster was defined as an aggregation of old-forest (> 80 years old) patches located < 2 km from the nearest adjacent old-forest patch. The 2 km threshold was based on the modeled distance from patches of old forest of > 2 km (Linnell et al. 2017, p. 5; Linnell and Lesmeister 2019, p. 271) at which the model predicted young forest (< 80 years old), functioning as

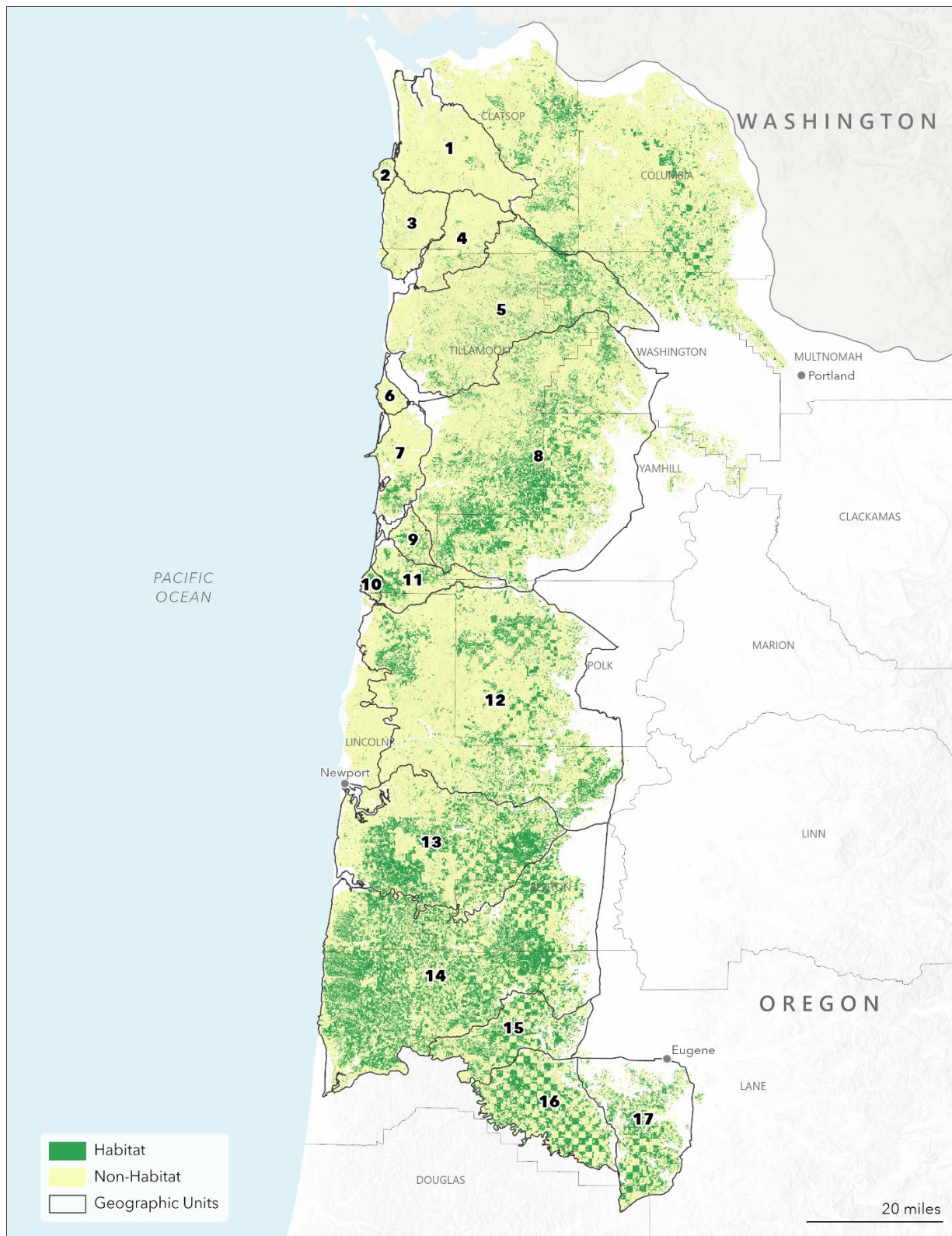


Figure A – 2. Map of tree vole habitat model (Linnell et al. 2023) showing habitat grouped into binary (habitat and non-habitat) categories across the DPS

occasional connecting habitat, would become unsuitable based on tree vole occurrence data. The 2023 model depicts habitat within young forest (20-80 years) as well as old forest. It would not be appropriate to use the same 2 km distance to aggregate habitat around these young forest habitat areas and we found it more appropriate to use the 200 m distance representing dispersal. However, for comparison purposes, and recognizing that both models provide information, we did look at a version of the old forest layer used in the 2019 cluster analysis, updated to remove polygons that were subject to harvest between 2015 and 2022 (Linnell 2022, in litt.; Figure A–1) and included habitat blocks of sufficient size identified in that model to move forward in the analysis.

2.2. Geographic Units

We divided the DPS into geographic units, which include areas inside and outside of habitat blocks. This allows us to refine expectations of connectivity within habitat blocks. It also allows us to explore future scenarios of habitat growth or decline in areas adjacent to current habitat blocks (i.e., expansion and reduction of habitat areas) and potential for connectivity between currently disconnected habitat blocks.

We assume that rivers can constitute strong filters or obstacles (not necessarily barriers) to tree vole movement. For example, no tree voles have been discovered north of the Columbia River, the northern boundary of the DPS and of the species range. The Siuslaw River, the southern boundary of the DPS, is not considered a geographic barrier to gene exchange, but is an identifiable feature that appears to be approximately coincident with the genetic haplotype group (Miller et al. 2006, p. 151) which distinguishes the DPS from the rest of the species range (U.S. Fish and Wildlife Service 2011, p. 63731). Similarly, we assume that large roads, such as State and Federal highways, can impede tree vole movement between habitat patches. Therefore, we used State and Federal highways and rivers to divide the DPS into geographic units (see SSA Section 3.9.4 for more on dispersal and movement).

We visually examined aerial (satellite) imagery of each road or river used to divide geographic units from one another. If, in some areas, a given road or river was not visible on the image due to connected canopy crossing the road or river, and especially if this occurred in an area of tree vole habitat or in multiple places along the length of the road, we assumed that road or river was not a strong filter to tree vole movement and did not use that road or river to divide geographic units. In some cases, the road or river was not visible, but this appeared to be due to shadows, the angle of steep ground, or both, with respect to the camera. In these cases, we still assumed that the road or river could divide geographic units.

2.3. Population Areas

We delineated potential population areas by overlaying habitat blocks with geographic units. We assumed that tree voles, if present, would be able to move freely within each population area, but that movement between population areas would be greatly reduced by large (> 200 m) distances between habitat blocks, or by the necessity of crossing large roads or rivers.

Some habitat blocks were located entirely within one geographic unit. In these cases, the habitat block was equivalent to a population area, as we assumed that voles would be able to move freely within the entire habitat block. Some habitat blocks crossed several geographic units. In these cases, the habitat block was divided into multiple population areas, using the same roads and rivers that divided geographic units. Geographic units might contain zero, one, or multiple population areas.

Population areas were further divided into categories of potential occupancy to determine which populations areas would be considered in current and future condition analyses. These categories were based on the survey and other detection results in our possession, which include: positive detections from BLM lands, May 1990 through January 2022 (USDI BLM 2022, in litt.); undated positive detections from U.S. Forest Service lands, undated positive detections from pre-project surveys on the Hebo Ranger District of the Siuslaw National Forest, positive detections from U.S. Forest Service lands dated August 1991 through April 2019, and a compilation of positive and negative detections that were used in Linnell et al. 2023, some undated and others dated 1997 through 2018 (USDA FS 2022, in litt.); positive and negative detections from NCASI dated 2019 through 2022 (NCASI 2022a, in litt.); as well as the positive and negative detections, dated 1986 through 2018, that were compiled for the 2019 SSA (U.S. Fish and Wildlife Service 2019). Positive detections are most commonly from surveys where voles or recent sign of voles (active nests) are observed but may include incidental sightings, carcasses, tree vole remains found in owl pellets, or other observations.

- Known occupied population areas are those with the most recent detections, defined as positive survey results during or after the year 2010.
- Presumed occupied population areas have a positive survey detection from 1995 through 2009 or may be unsurveyed but are < 2 km from a neighboring population area in the same unit with positive survey results during or after 1995.
- Presumed unoccupied population areas are those which have only negative detection surveys during or after 1995 or are unsurveyed and the nearest positive survey is in a population area > 2 km distance away.

Tree voles are challenging to survey. Surveys have been patchy, dependent on land ownership, not consistent through time, and non-existent in some areas where models show potential habitat. We used 2 km as a distance to assess whether an unsurveyed population area could be potentially occupied because tree vole nests have been observed in young forests (20–80 years old) where those forests are within 2 km of old forest (> 80 years) (Forsman et al. 2016, p. 32,45; Lesmeister et al. 2016, pp. 14–15; Linnell et al. 2017, p. 5) and young forest may at least function as connectivity habitat in those situations (Lesmeister et al. 2016, p. 15).

3. Estimating Habitat Capacity of Population Areas

Habitat capacity is the potential species carrying capacity based on the modeled suitability of vegetation cover. We estimated habitat capacity of each population area based on two different population density estimates, including a low-density and a high-density estimate, and two

different habitat models (Linnell 2022, in litt.; Linnell et al. 2023, entire). This process generated a range of estimates which provides a measure of confidence that we have included actual habitat capacity within the range despite the uncertainty we acknowledge exists with respect to the habitat capacity of each population area. We then used these habitat capacity estimates to generate a range of effective population sizes, i.e., the size of an ideal population that would result in the same level of inbreeding or genetic drift as that of the population in question (Jamieson and Allendorf 2012, p. 578) that might be supported by the habitat in each population area. We called this range the effective population size capacity.

We note that these are estimates of habitat capacity and not estimates of current population size or current effective population size. We do not have information allowing for estimates of the number of individuals currently present, or the actual effective population size in any given area. We also acknowledge there is a lack of information regarding the actual minimum patch size needed to support short-term local persistence of tree voles.

3.1. Red Tree Vole Density Estimates

In our 2019 analyses, we based our estimate of tree vole density on the average of the only two estimates of tree vole density then available. The low estimate was based on a population density of 0.97 adults/ha (Maser 1966, p. 217), and the high estimate was based on a population density of 1.91 adults/ha (Marks-Fife 2016, p. 79), with an average of the two estimates at 1.5/ha. Both estimates are likely high, as these studies were targeted at areas where tree voles were abundant, though the estimate of 1.91 ± 0.97 (mean $\pm$ 1 standard error, $n = 31$ ($df = 30$)) was referred to by the author as overall minimum density of occupied nest trees (Marks-Fife 2016, p. 79).

New information from NCASI (NCASI 2022a, in litt.) allowed us to generate an additional estimate of tree vole density. These data were collected via thorough searches within a stand or a portion of a stand across varying stand ages from young to old forest (NCASI 2022b, pp. 5–6). The researchers attempted to locate every tree vole nest within their search area, and categorized nests as occupied (tree vole presence confirmed via camera or capture), recent (with green resin ducts or green conifer cuttings present), or old sign (likely occupied within the last few years) (NCASI 2022b, p. 12). For each stand that had any evidence of tree vole occupancy, we used the Minimum Bounding Geometry tool in ArcGIS® Pro 2.9.5 from ESRI™ to generate a minimum convex hull polygon including all positive and negative detections. We then calculated the tree vole density of that stand as the maximum number of occupied and recent nests detected in a single year, assumed one tree vole per nest, and divided by the area of the convex hull. We calculated the mean density across surveyed stands, weighted by the convex hull area within each stand. The tree vole density varied from 0 (stands where only old sign was detected) to 5.4/ha, and the weighted mean was 0.56/ha. Potential sources of error in this estimate include surveyors may not have detected some proportion of occupied nests (and we have no occupancy model to estimate this proportion); the convex hull method may over- or under-represent the area surveyed (areas outside the convex hull were likely visible to the surveyors, but some areas

within the convex hull may have had limited visibility, and visibility could be different between stand ages); and we assume here that one nest contains one vole, with the recognition that one nest could contain multiple voles and one vole could have multiple nests.

As the density generated from the NCASI data, 0.56/ha, was lower than either of the previously reported densities, we used it as our low-density estimate. For our high-density estimate, we used 1.91/ha (Marks-Fife 2016, p. 79). We acknowledge the high estimate is likely an overestimate but is the best information that we have to date.

3.2. Habitat Capacity Based on 2023 Habitat Model

We based one estimate of habitat capacity on a version of the 2023 habitat model in which habitat pixels were classified into the following categories (Linnell 2022, in litt.; Linnell et al. 2023, Fig. 2):

- 1) Core habitat, defined as habitat pixels surrounded on all sides (eight neighboring pixels) by other habitat pixels;
- 2) Edge habitat, defined as habitat pixels adjacent to core habitat pixels, but which do not, themselves, meet the definition of core habitat pixels;
- 3) Finger habitat, defined as habitat pixels that are connected to core habitat pixels by a chain of other habitat pixels, but do not meet the definition of core or edge pixels; and
- 4) Scatter habitat, defined as habitat pixels that are not connected to core habitat pixels.

Our estimate of habitat capacity is based on core and edge habitat, rather than all habitat pixels (Figure A–3). This is because finger and especially scatter habitat pixels are more likely to represent false positives (i.e., the model shows habitat present, but habitat is not present in reality), compared with core and edge pixels.

We estimated the amount of core and edge habitat present in each population area, then combined these estimates with the low and high population density estimates to generate low and high habitat capacity estimates. For each combination, habitat capacity is the habitat amount multiplied by the population density estimate.

3.3. Habitat Capacity Based on Updated 2017 Habitat Model

The authors of the habitat model used in the 2019 SSA (Linnell et al. 2017) provided an updated version of the habitat map, which flagged habitat patches that have since been removed by harvest up to 2022 (Linnell 2022, in litt.). We estimated the amount of habitat remaining in each population area, but we note that this update would not account for habitat recruitment since 2015. However, the 2023 model also does not account for potential habitat ingrowth since 2015.

As we did for the 2023 habitat model, we combined the updated 2019 habitat amounts with the low and high population density estimates to generate a low and high habitat capacity estimates. For each combination, habitat capacity is the habitat amount multiplied by the population density estimate.



Figure A – 3. Map of tree vole habitat model (Linnell et al. 2023) showing four classes of habitat across the DPS.

3.4. Range of Habitat Capacity Estimates

The habitat capacity estimation described above resulted in four different estimates of habitat capacity for each population area. Using a range of estimates provides a measure of confidence that actual habitat capacity is within the range given the uncertainty of habitat capacity of each population area. For example, in cases where all four estimates are very small (i.e., less than 100), we would be fairly confident that the habitat capacity is very low. On the other hand, where the estimates span a wide range (e.g., estimates range from 80 to 800), we would have greater uncertainty about the habitat capacity.

3.5. Effective Population Size Capacity Estimates

The effective population size is the size of an idealized population that would lose genetic diversity (or become inbred) at the same rate as the actual population (Frankham et al. 2007, pp. 188–190). An idealized population is one where, among other things, mating is random, all individuals are potential breeders, all breeders contribute equally to the gene pool, and mutations are ignored (Frankham et al. 2007, pp. 188–189). Such assumptions are rarely if ever met, and hence, wild populations need to maintain population sizes larger than idealized populations sizes in order to retain genetic behavior similar to the idealized population. In general, the effective population size is much smaller than the actual number of individuals in the population, often between 10 and 20 percent of the census population size, based on meta-analyses of different animal and plant populations (Frankham 1995, p. 100; Frankham et al. 2014, p. 56). Effective population sizes can be calculated based on genetic information, or estimated from demographic information such as sex ratios, variance in family size, and population size fluctuations over generations (Frankham et al. 2007, p. 241; García-Navas et al. 2015, p. 171). However, we lack that information for tree voles. Therefore, we use the range of 10 to 20 percent of our tree vole habitat capacity values to estimate the range of potential effective population size capacities. For reference, in another species of voles, the ratio of effective population size to the total number of individuals varied between 10 percent and 42 percent over time and depending on method used to estimate the effective population size, with genetic methods producing higher ratios (García-Navas et al. 2015, p. 171). Note that genetic estimates of the effective population size do not necessarily relate to the current population size, but rather integrate information about population size over multiple past generations (Frankham 1995, pp. 97–100).

Similar to the habitat capacity estimates, we generated a range of effective population size capacity estimates to encompass the full scope of our confidence or uncertainty regarding the effective population size capacity. For each population area, the range of estimates for effective population size capacity would fall somewhere between 10 percent of the minimum population capacity, and 20 percent of the maximum population capacity. Note that, similar to the habitat capacity estimates, the effective population size capacity estimates do not estimate the effective population size of the actual red tree vole population, but rather, the potential effective population size of a population that could be supported by the habitat in a given population area.

4. Results

4.1. Delineation of Analytical Units

4.1.1. *Habitat Blocks*

Our delineation of habitat blocks resulted in thousands of mapped habitat blocks; however, most of these were very small and were not located near vole detections. For example, the vast majority of blocks were less than 20 ha total, including a buffer. We carried forward our analysis of habitat blocks that met one or more of the following criteria:

- Positive vole detections (from 1995–2022) located inside or within 100 m of the habitat block.
- The 2023 habitat model indicated that the habitat block contained at least 52.5 ha of core habitat (the minimum amount of habitat to support 100 individual voles at the higher population density estimate).
- The updated 2017 habitat model indicated that the habitat block contained at least 52.5 ha of habitat (the minimum amount of habitat to support 100 individual voles at the higher population density estimate).
- Where vole detections (1995–2022) were present, and the nearest habitat block did not meet criteria 1–3 above, in order to best represent the use of the landscape by voles, we carried forward the analysis of either:
 - the nearest habitat block with a non-zero amount of core habitat, provided that it was within 1 km, or if not available then
 - the nearest habitat block, provided it was within 1 km.

There were 59 habitat blocks meeting one or more of those criteria. Habitat blocks, along with occupancy status, are listed in Table A–1 and shown in Figure A–4.

Table A – 1. Habitat blocks.

Name	Last survey	Last vole detection
South	2022	2022
Nestucca	2022	2022
Skunk Creek ⁴	2022	2022
S. Fork Teal Creek ¹	2022	2022
No-Name ¹	2022	2022 ⁵
Tierra Del Mar	2022	2021
Dry Creek	2021	2021 ²
BLM Checkerboard	2021	2018
Deadwood Mountain	2018	2018
Neskowin Creek West	2018	2018
Neskowin Creek East	2018	2018
Till. SF Kichlis S	2018	2018
Till. SF Kichlis M	2018	2018
Till. SF Kichlis N	2018	2018
Andy Creek	2018	2018
South of Sandlake	2018	2018
Cape Lookout South	2018	2018 ⁶
Treat River	2018 ⁷	2018 ⁴
East Beaver Creek	2018	2011
Spencer Butte	2011	2011
North Fork Siletz	2011	2011
Cape Lookout West	2011	2011
Tillamook SF Nehalem S	2011	2011
Tillamook SF Nehalem N	2011	2011
Oswald West	2011	2011
Saddle Mountain Rd	2011	2011
Elmer Feldenheimer N	2011 ⁸	2011 ⁵
Fall Short	2011 ⁹	2011 ⁶
“2006”	2006	2006
Cape Lookout North	2003	2003
Hodgdon Creek	2003 ¹⁰	2003 ⁷

Name	Last survey	Last vole detection
O’Hara Creek	2003 ⁷	2003 ⁷
Middle Ridge ¹	2002 ¹¹	Unkn ⁸
McTimmonds Creek ¹	1996	1996
Moon Creek ¹²	1996	1996
Cape Meares	1996	1996
Bay City Electric	2018	none
Clatsop Buster Creek	2011	1994
Four Seven Ridge	2011	none
Rector Ridge	2011	none
Chehalem Mountains	2011	none
Clatsop Columbia	2011	none
Forest Park	2010	none
Wirtz Branch	2006	none
Crawford Creek	1995	none
Bull Run Creek ¹	none	none
Norton	none	none
Potter Creek	none	none
Salt Creek	none	none
Saddle Bag Mountain	none	none
Pheasant Creek	none	none
Valley Junction	none	none
Bower Creek	none	none
Gopher	none	none
Fawcett Creek	none	none
Anderson Creek	none	none
Cronin Creek	none	none
Timber Road	none	none
Cole Mountain Road	none	none
Scout Lake	none	none
Wickiup Ridge	none	none
Skunk Cabbage	none	none
Big Noise Creek	none	none

⁴ Partially or completely surrounded by the South Block.

⁵ Old sign, indicating presence within the last few years.

⁶ Surveyed in 2018. One negative detection located within the mapped block, and vole sign was detected just over 100 m away, with no other habitat nearby.

⁷ Nearest block, approximately 200 m away, to a 2018 vole detection with little other modeled habitat nearby.

⁸ Nearest with core habitat, ~ 500 m away, to a 2011 vole detection with little other modeled habitat nearby.

⁹ Nearest block, ~140 m away, to 2011 vole detection with little other modeled habitat nearby.

¹⁰ Nearest blocks to two 2003 vole detections, with little other modeled habitat nearby.

¹¹ Vole detections undated, 2002 survey result negative.

¹² Surrounded by the Nestucca Block.

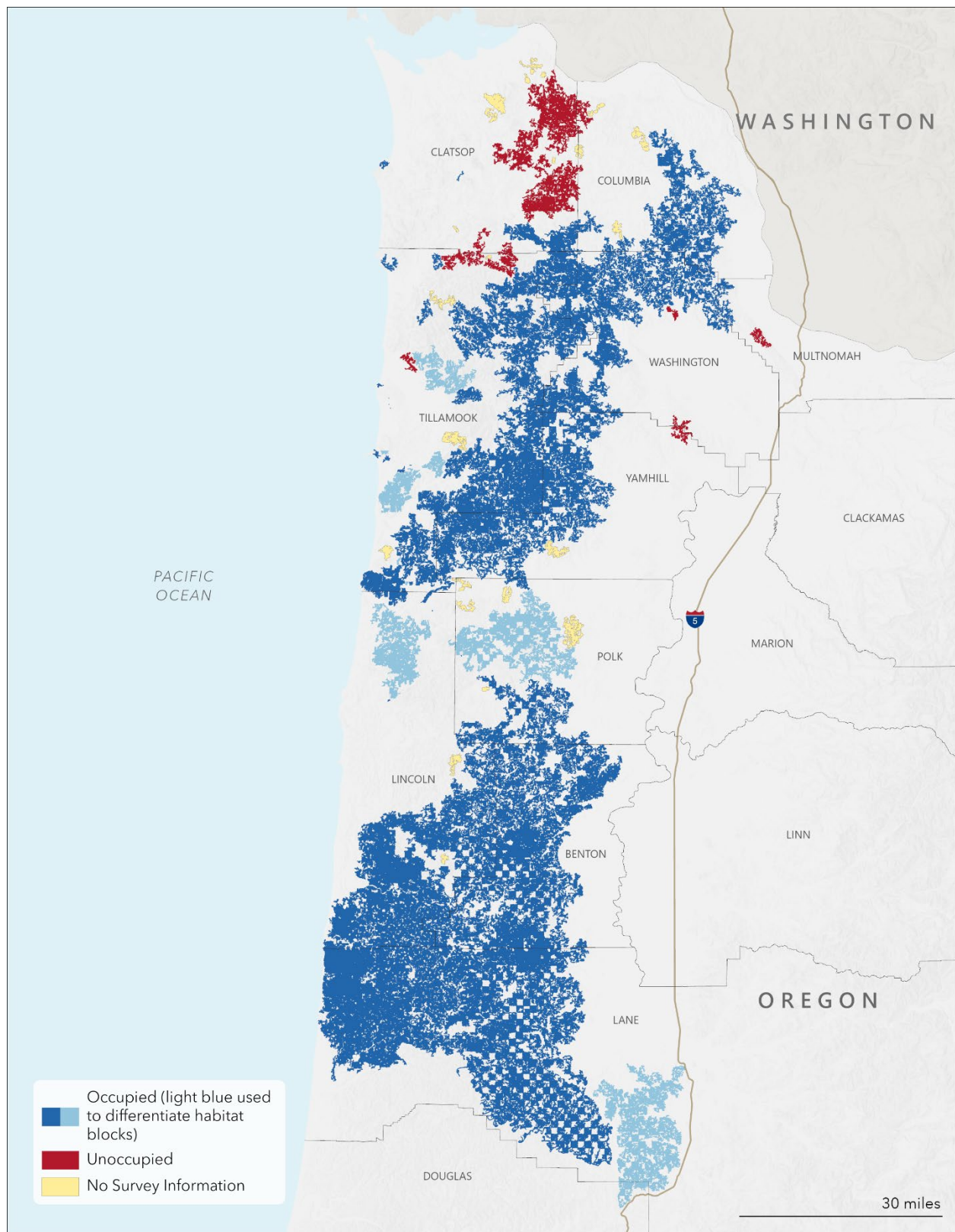


Figure A – 4. Tree vole habitat blocks with occupancy status.

4.1.2. Geographic Units

Our delineation of geographic units resulted in 25 interim geographic units distributed across the DPS that contained vole survey locations (1995–2022, positive or negative) or at least some core habitat. We did not map geographic units with little modeled habitat and no survey information in the more urbanized eastern portion of the DPS, or small geographic units lacking in both surveys and modeled habitat to the west of Highway 101. These 25 geographic units, representing the most conservative estimate of areas of current or future potential tree vole habitat areas, are shown in Figure A–5. The list of geographic units in Table A–2 describes the highways and rivers bounding each unit, as well as the survey status of the unit as a whole.

Table A – 2. Boundaries and most recent tree vole survey status for the 25 interim geographic units.

Unit Name	Bounded by	Survey status (most recent)
Parrett Mountain	OR 219, Willamette River, I–5, OR 141, Tualatin River, OR 99W	No survey information
Red Hills of Dundee	OR 47, OR 240, OR 99W, OR 18	No survey information
Short Mountain	Willamette River, Coast Fork Willamette River, OR 58, I–5	No survey information
Columbia	John Day River, US 30, Columbia River	Negative surveys (2011)
Wallooskee	OR 202, Nehalem River, OR 47, US 26	Negative surveys (2011)
Clatskanie	OR 47, Nehalem River, US 26, I–5, Columbia River, US 30	Negative surveys (2011)
Tualatin	OR 47, OR 240, OR 99W, Tualatin River, OR 210, OR 219	Negative surveys (2011)
Ecola/ Elmer Feldenheimer	Pacific Coast, US 101, Necanicum River	Positive surveys (2011)
Lewis and Clark	US 101, Necanicum River, US 26, Nehalem River, OR 202, North Fork Klaskanine River, Klaskanine River, Youngs River, OR 104	Positive surveys (2011)
Necanicum/ Nehalem	US 101, Nehalem River, North Fork Nehalem River, OR 53, Necanicum River, US 26	Positive surveys (2011)
North Fork Nehalem	OR 53, Nehalem River, US 26, Necanicum River	Positive surveys (2011)
Nehalem	US 26, OR 47, Nehalem River	Positive surveys (1994) Negative surveys (2011)
Nehalem/ Wilson	US 101, Wilson River, OR 6, OR 47, US 26, Nehalem River, OR 53	Positive surveys (2018)
Cape Meares	Pacific Coast, OR 131, Tillamook River	Positive surveys (2011)
Sand Lake	Pacific Coast, Nestucca River, US 101, Trask River, OR 131	Positive surveys (2022)
Gauldy Ridge	US 101, OR 130, OR 22	Positive surveys (2018)

Unit Name	Bounded by	Survey status (most recent)
Trask/Nestucca	US 101, OR 22, OR 18, OR 99W, OR 47, OR 8, OR 6	Positive surveys (2022)
Little Nestucca/ Salmon Coast	Pacific Coast, Salmon River, US 101, Little Nestucca River	Positive surveys (2018)
Little Nestucca/ Salmon Inland	US 101, OR 18, OR 22, OR 130	Positive surveys (2018)
Siletz/ Luckiamute	US 101, Siletz River, OR 229, US 20, OR 99, Luckiamute River, Little Luckiamute River, OR 223, OR 22, OR 18	Positive surveys (2022)
Yaquina/ Marys	US 101, Alsea River, OR 501, OR 34, US 20	Positive surveys (2022)
Alsea/ Siuslaw	US 101, Siuslaw River, OR 36, OR 200, OR 99W, US 20	Positive surveys (2022)
Siuslaw/ Long Tom	Siuslaw River, OR 126, Long Tom River, OR 200, OR 36	Positive surveys (2021)
Siuslaw/ Territorial	Siuslaw River, OR 22, OR 126	Positive surveys (2022)
Spencer Butte	OR 200, OR 99W, OR 126	Positive surveys (2011)



Figure A – 5. Interim geographic units. These units contain vole survey information or some core habitat.

4.1.3. Population Areas

When a habitat block was contained within a single geographic area, that habitat block was carried forward as a population area. Habitat blocks crossing the boundaries of one or more geographic area were divided into multiple population areas along those boundaries. This procedure resulted in the delineation of 83 population areas, including five population areas with “orphaned” vole locations nearby, but more than 100 m away. Of the 83 population areas, 37 were considered to have known occupancy, 15 were presumed occupied, and 31 were presumed unoccupied. The population areas are listed in Table A–3 with their corresponding geographic unit, tree vole survey status, and potential occupancy status. Geographic units are color blocked together in gray fill. These 83 population areas, depicted by their occupancy status, are shown in Figure A–6.

Table A – 3. Tree vole survey status and potential occupancy status by population area

Population Area	Geographic Unit	Last survey	Last vole detection	Potential Occupancy Status
Clatsop Columbia	Wallooskee	2011	none	Presumed Unoccupied
Wickiup Ridge		none	none	Presumed Unoccupied
Skunk Cabbage		none	none	Presumed Unoccupied
Big Noise Creek		none	none	Presumed Unoccupied
Shingle Mill Road		none	none	Presumed Unoccupied
Rock Creek		none	none	Presumed Unoccupied
North Fork Klaskanine		none	none	Presumed Unoccupied
Mulak Creek		none	none	Presumed Unoccupied
Crawford Creek		1995 ¹³	none	Presumed Unoccupied
Grub Creek		none	none	Presumed Unoccupied
Clatsop Buster Creek Fragment		none	none	Presumed Unoccupied
Scout Lake	Clatskanie	none	none	Presumed Unoccupied
Wirtz Branch		2006	none	Presumed Unoccupied

¹³ Owl pellet

Population Area	Geographic Unit	Last survey	Last vole detection	Potential Occupancy Status
Forest Park		2010	none	Presumed Unoccupied
Nestucca Block Clatskanie		2011	none	Presumed Unoccupied
Chehalem Mountains	Tualatin	2011	none	Presumed Unoccupied
Elmer Feldenheimer North	Ecola/ Elmer Feldenheimer	2011 ¹⁴	2011 ¹⁹	Known Occupied
Saddle Mountain Road	Lewis and Clark	2011	2011	Known Occupied
Oswald West	Necanicum/ Nehalem	2011	2011	Known Occupied
Tillamook South Fork Nehalem North	North Fork Nehalem	2011	2011	Known Occupied
Rector Ridge		2011	none	Presumed Unoccupied
Cole Mountain Road		none	none	Presumed Unoccupied
Clatsop Buster Creek Main	Nehalem	2011	1994 ¹⁵	Presumed Unoccupied
Nestucca Block Nehalem North		2011	none	Presumed Unoccupied
Nestucca Block Nehalem South		none	none	Presumed Unoccupied
Timber Road		none	none	Presumed Unoccupied
Tillamook South Fork Kichlis Middle	Nehalem/ Wilson	2018	2018	Known Occupied
Tillamook South Fork Kichlis North		2018	2018	Known Occupied
Bay City Electric		2018	none	Presumed Unoccupied
Tillamook South Fork Nehalem South		2011	2011	Known Occupied
Anderson Creek		none	none	Presumed Occupied
Cronin Creek		none	none	Presumed Unoccupied
Four Seven Ridge		2011	none	Presumed Unoccupied

¹⁴ Vole detection was around 500 m from this population area, not near other core habitat.

¹⁵ Several negative detections in area from 2011; several negative 1994 detections from owl pellets, plus one positive 1994 detection from an owl pellet

Population Area	Geographic Unit	Last survey	Last vole detection	Potential Occupancy Status
Nestucca Block Wilson		2011	none	Presumed Unoccupied
Cape Meares	Cape Meares	1996	1996	Presumed Occupied
Fall Short		2011 ¹⁶	2011 ¹⁸	Known Occupied
Hodgdon Creek		2003 ¹⁸	2003 ¹⁸	Presumed Occupied
O'Hara Creek		2003 ¹⁸	2003 ¹⁸	Presumed Occupied
Tierra Del Mar	Sand Lake	2022	2022 ¹⁷	Known Occupied
Andy Creek		2018	2018	Known Occupied
South of Sandlake		2018	2018	Known Occupied
Cape Lookout West		2011	2011	Known Occupied
Cape Lookout North		2003	2003	Presumed Occupied
Cape Lookout South		2018	2018 ¹⁸	Known Occupied
Nestucca Block Gauldy	Gauldy Ridge	2018	2018	Known Occupied
Nestucca Block Trask	Trask/ Nestucca	2022	2022	Known Occupied
Moon Creek Nestucca Block Inclusion ¹⁹		1996	1996	Presumed Occupied
East Beaver Creek		2018	2011	Known Occupied
Gopher		none	none	Presumed Occupied
Fawcett Creek		2018	none	Presumed Unoccupied
Tillamook South Fork Kichlis South		2018	2018	Known Occupied
Nestucca Block Salmon Coast	Little Nestucca/ Salmon Coast	2018	2018	Known Occupied
Bower Creek	Little Nestucca/ Salmon Inland	none	none	Presumed Occupied
Nestucca Block Salmon West		2018	2018	Known Occupied
Nestucca Block Salmon East		2018	2018	Known Occupied
"2006"		2006	2006	Presumed Occupied
Neskowin Creek West		2018	2018	Known Occupied
Neskowin Creek East		2018	2018	Known Occupied
South Block Luckiamute	Siletz/ Luckiamute	2022	2022	Known Occupied
South Fork Teal Creek South Block Inclusion ²⁰		2022	2022	Known Occupied
No-Name South Block Inclusion ¹²		2022	2022 ¹⁰	Known Occupied

¹⁶ One vole detection between ~150 m and 400 m from each of these population areas, not near other habitat.

¹⁷ Old sign was detected in 2022. Recent sign was detected in 2021.

¹⁸ Negative survey was within the population area, positive vole detection was just over 100 m outside of population area boundary.

¹⁹ This population area is surrounded by Nestucca Block Trask

²⁰ This population area is nearly or completely surrounded by South Block Luckiamute.

Population Area	Geographic Unit	Last survey	Last vole detection	Potential Occupancy Status
Middle Ridge South Block Inclusion ¹²		2002 ²¹	unknown	Presumed Occupied
McTimmonds Creek South Block Inclusion ¹²		1996	1996	Presumed Occupied
Norton		none	none	Presumed Occupied
Potter Creek		none	none	Presumed Occupied
BLM Checkerboard		2021	2018	Known Occupied
Salt Creek		none	none	Presumed Occupied
Nestucca Block Luckiamute		2011	2011	Known Occupied
Treat River		2018 ²²	2018 ¹⁴	Known Occupied
Deadwood Mountain		2018	2018	Known Occupied
Dry Creek		2021	2021 ¹⁰	Known Occupied
North Fork Siletz		2011	2011	Known Occupied
Saddle Bag Mountain		none	none	Presumed Unoccupied
Pheasant Creek		none	none	Presumed Unoccupied
Valley Junction		none	none	Presumed Unoccupied
South Block Yaquina	Yaquina/ Marys	2022	2022	Known Occupied
Skunk Creek South Block Inclusion ²³		2022	2022	Known Occupied
Bull Run Creek South Block Inclusion ¹¹		none	none	Presumed Occupied
South Block Alsea	Alsea/ Siuslaw	2022	2022	Known Occupied
South Block Long Tom	Siuslaw/ Long Tom	2021	2021	Known Occupied
South Block Territorial	Siuslaw/ Territorial	2022	2022 ²⁴	Known Occupied
Spencer Butte	Spencer Butte	2011	2011	Known Occupied
South Block Fragment		2011	none	Presumed Unoccupied

²¹ One negative survey dated 2002 and several undated vole detections inside this population area.

²² Vole detection was ~200 m from this population area, not near other habitat.

²³ This population area is surrounded by South Block Yaquina.

²⁴ Old sign was detected at the last survey. Since nests can sometimes remain present for several years after they are abandoned (Piasecki et al. 2022, pp. 24–36), it is possible that voles were last present several years prior.

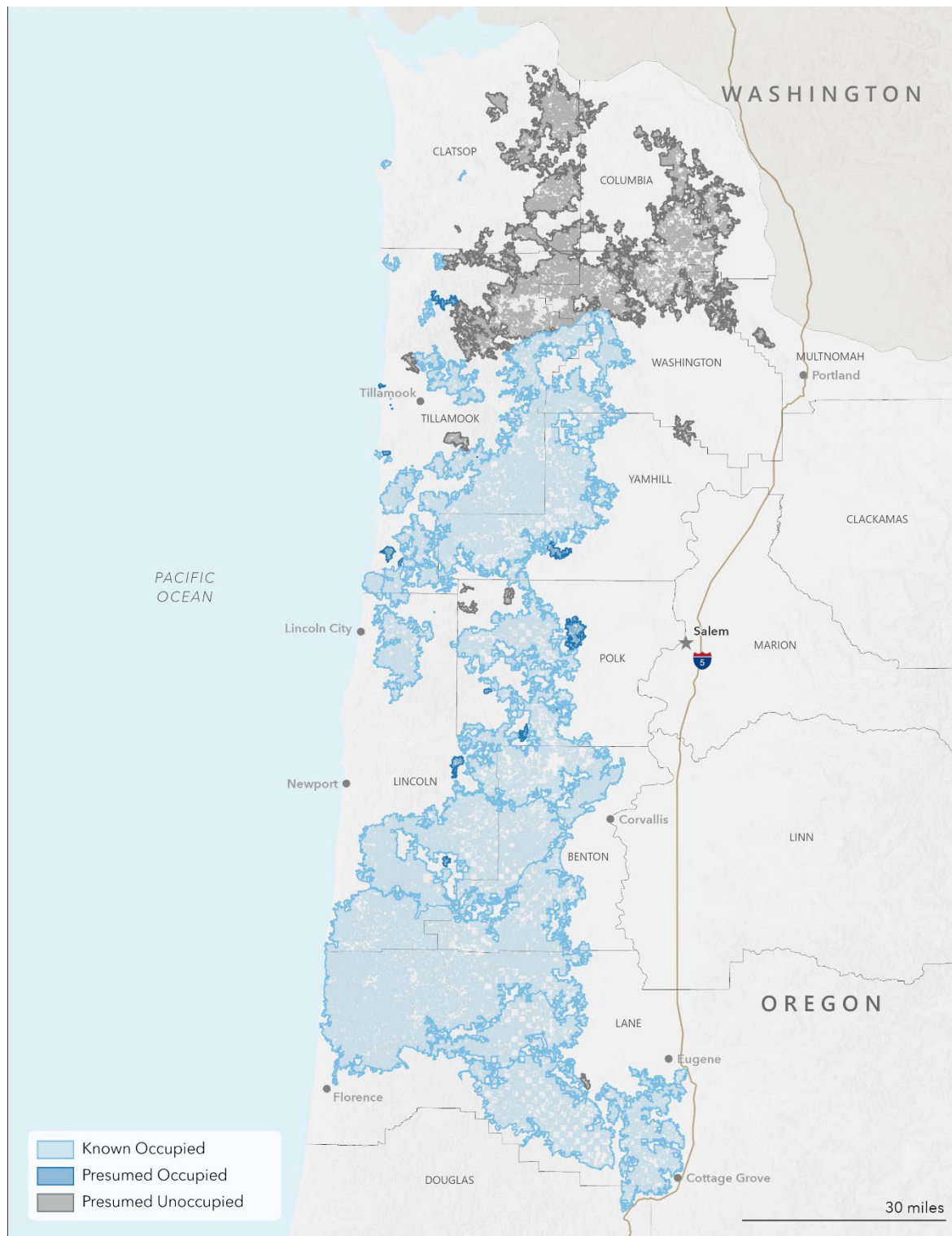


Figure A – 6. Tree vole population areas depicted by their occupancy status. Known occupied population areas are shown in dark blue, presumed occupied areas are shown in light blue, and presumed unoccupied areas are shown in gray.

4.2. Estimating Habitat Capacity of Population Areas

If a geographic unit did not contain any occupied (known or presumed, hereafter referred to as occupied) population areas, those units were not moved forward in the habitat capacity analyses for current or future condition. Out of 25 geographic units, 17 moved forward in the analysis. Out of 83 original population areas, 52 occupied population areas moved forward to the habitat capacity analyses below. These occupied population areas and final geographic units used in the analysis are shown in Figure A–7. There were 11 individual population areas that are presumed unoccupied, but in a unit with other population areas that were occupied. They were not moved forward in the current condition analysis, but we reconsider them in the future condition analysis.

4.2.1. Habitat Capacity Based on 2023 Habitat Model

According to the 2023 habitat model, the amount of core and edge habitat in our 52 delineated population areas ranged from 0 ha to 51,632 ha. Population areas with no core habitat in the 2023 habitat model were carried forward to this point in the analysis under two conditions: they may have intersected at least 52.5 ha of old forest according to the 2017 habitat model, or they may have been associated with a positive vole detection since 1995.

Depending on the assumptions about potential vole population density, if every acre of core and edge habitat were occupied, the modeled habitat capacity of individual population areas would range from 0 to 98,617 individual voles. Estimates of core and edge habitat, and corresponding minimum (i.e., with population density of 0.56 voles/ha) and maximum (i.e., with population density of 1.91 voles/ha) habitat capacity estimates, are shown in Table A–4.

Table A – 4. Habitat capacity of population areas, based on the 2023 habitat model. Gray fill indicates population areas that had zero habitat in both the 2017 (see Table A–5) and 2023 habitat models (this table).

Population Area	Geographic Unit	Modeled Core and Edge Habitat (ha)	Minimum Habitat Capacity (voles)	Maximum Habitat Capacity (voles)
Saddle Mountain Road	Lewis and Clark	0	0	0
Elmer Feldenheimer North	Ecola/ Elmer Feldenheimer	3	1	5
Oswald West	Necanicum/ Nehalem	8	4	15
Tillamook South Fork Nehalem North	North Fork Nehalem	1	1	2
Anderson Creek	Nehalem/ Wilson	2	1	3
Tillamook South Fork Nehalem South		8	5	15
Tillamook South Fork Kichlis North		128	72	244
Tillamook South Fork Kichlis Middle		270	151	516

Population Area	Geographic Unit	Modeled Core and Edge Habitat (ha)	Minimum Habitat Capacity (voles)	Maximum Habitat Capacity (voles)
O'Hara Creek	Cape Meares	0	0	0
Hodgdon Creek		0	0	0
Fall Short		0	0	0
Cape Meares		0	0	0
Cape Lookout South	Sand Lake	1	0	2
Cape Lookout North		7	4	13
Cape Lookout West		7	4	14
South of Sandlake		0	0	0
Andy Creek		2	1	3
Tierra Del Mar		800	448	1,529
Nestucca Block Gauldy	Gauldy Ridge	557	312	1,064
Tillamook South Fork Kichlis South	Trask/ Nestucca	188	105	359
Gopher		75	42	143
East Beaver Creek		133	74	254
Moon Creek Nestucca Block Inclusion ²⁵		0	0	0
Nestucca Block Trask		23,962	13,419	45,768
Nestucca Block Salmon Coast	Little Nestucca/ Salmon Coast	463	259	884
Neskowin Creek East	Little Nestucca/ Salmon Inland	1	0	2
Neskowin Creek West		4	2	7
"2006"		0	0	0
Nestucca Block Salmon East		401	224	766
Nestucca Block Salmon West		1,138	637	2,174
Bower Creek		115	64	220
North Fork Siletz	Siletz/ Luckiamute	0	0	0
Dry Creek		0	0	0
Deadwood Mountain		2,623	1,469	5,010
Treat River		0	0	0
Nestucca Block Luckiamute		20	11	39
Salt Creek		106	59	202
BLM Checkerboard		4,345	2,433	8,299
Potter Creek		28	16	53
Norton		70	39	134
McTimmonds Creek South Block Inclusion ²²		0	0	0

²⁵ This population area is surrounded by Nestucca Block Trask.

Population Area	Geographic Unit	Modeled Core and Edge Habitat (ha)	Minimum Habitat Capacity (voles)	Maximum Habitat Capacity (voles)
Middle Ridge South Block Inclusion ²²		29	16	54
No-Name South Block Inclusion ²²		0	0	0
South Fork Teal Creek South Block Inclusion ²⁶		0	0	0
South Block Luckiamute		8,652	4,845	16,526
Bull Run Creek South Block Inclusion ²¹	Yaquina/Marys	77	43	146
Skunk Creek South Block Inclusion ²⁷		0	0	0
South Block Yaquina		23,762	13,307	45,386
South Block Long Tom	Siuslaw/Long Tom	8,319	4,659	15,890
South Block Alsea	Alsea/Siuslaw	51,632	28,914	98,617
South Block Territorial	Siuslaw/Territorial	13,775	13,362	26,311
Spencer Butte	Spencer Butte	7,364	4,124	14,064

²⁶ This population area is completely or nearly surrounded by South Block Luckiamute.

²⁷ This population area surrounded by South Block Yaquina.



Figure A – 7. Map of final 17 geographic units and 52 population areas used in condition analyses.

4.2.2. Habitat Capacity Based on 2017 Habitat Model

According to the updated 2017 habitat model (Linnell 2022, entire), the amount of old forest habitat in our delineated population areas ranged from 0 ha to 59,171 ha. Population areas with no core habitat in the 2017 habitat model were carried forward to this point in the analysis under two conditions: they may have included at least 52.5 ha of core and edge habitat according to the 2023 habitat model, or they may have been associated with a positive vole detection since 1995.

Depending on the assumptions about potential vole population density, if every acre of modeled habitat were occupied, the modeled habitat capacity of individual population areas would range from 0 to 113,017 voles. Estimates of habitat, and corresponding minimum (i.e., with population density of 0.56 voles/ha) and maximum (i.e., with population density of 1.91 voles/ha) habitat capacity estimates, are shown in Table A–5.

Table A – 5. Habitat capacity of population areas, based on old forest blocks from updated 2017 habitat model. Gray fill indicates population areas that had zero habitat in both the 2017 (this table) and 2023 (see Table A–4) habitat models.

Population Area	Geographic Unit	Modeled Habitat (ha)	Minimum Habitat Capacity	Maximum Habitat Capacity
Saddle Mountain Road	Lewis and Clark	0	0	0
Elmer Feldenheimer North	Ecola/ Elmer Feldenheimer	0	0	0
Oswald West	Necanicum/ Nehalem	0	0	0
Tillamook S. Fork Nehalem N	North Fork Nehalem	102	57	196
Anderson Creek	Nehalem/ Wilson	64	36	122
Tillamook South Fork Nehalem South		113	63	215
Tillamook S. Fork Kichlis N.		263	147	502
Tillamook S. Fork Kichlis Middle		467	261	892
O'Hara Creek	Cape Meares	0	0	0
Hodgdon Creek		0	0	0
Fall Short		0	0	0
Cape Meares		0	0	0
Cape Lookout South	Sand Lake	28	16	54
Cape Lookout North		0	0	0
Cape Lookout West		27	15	51
South of Sandlake		0	0	0
Andy Creek		0	0	0
Tierra Del Mar		709	397	1,354
Nestucca Block Gauldy	Gauldy Ridge	924	517	1,765
Tillamook S. Fork Kichlis S.	Trask/ Nestucca	184	103	352
Gopher		0	0	0
East Beaver Creek		126	70	240

Population Area	Geographic Unit	Modeled Habitat (ha)	Minimum Habitat Capacity	Maximum Habitat Capacity
Moon Creek Nestucca Block Inclusion ²⁸		0	0	0
Nestucca Block Trask		20,769	11,631	39,669
Nestucca Block Salmon Coast	Little Nestucca/ Salmon Coast	496	278	947
Neskowin Creek East	Little Nestucca/ Salmon Inland	0	0	0
Neskowin Creek West		0	0	0
“2006”		0	0	0
Nestucca Block Salmon East		606	339	1,157
Nestucca Block Salmon West		2,226	1,246	4,251
Bower Creek	Siletz/ Luckiamute	131	73	250
North Fork Siletz		0	0	0
Dry Creek		0	0	0
Deadwood Mountain		4,985	2,792	9,522
Treat River		0	0	0
Nestucca Block Luckiamute		0	0	0
Salt Creek		0	0	0
BLM Checkerboard		833	467	1,592
Potter Creek		62	35	119
Norton		0	0	0
McTimmonds Creek South Block Inclusion ²⁵		0	0	0
Middle Ridge South Block Inclusion ²⁵		0	0	0
No-Name South Block Inclusion ²⁵		0	0	0
South Fork Teal Creek South Block Inclusion ²⁹		0	0	0
South Block Luckiamute		3,934	2,203	7,513
Bull Run Creek South Block Inclusion ²⁴	Yaquina/Marys	126	70	240
Skunk Creek South Block Inclusion ³⁰		0	0	0
South Block Yaquina		25,442	14,248	48,594
South Block Long Tom	Siuslaw/Long Tom	6,026	3,375	11,510
South Block Alsea	Alsea/Siuslaw	59,171	33,136	113,017
South Block Territorial	Siuslaw/Territorial	7,049	3,947	13,463
Spencer Butte	Spencer Butte	866	485	1,654

²⁸ This population area is surrounded by Nestucca Block Trask.

²⁹ This population area is completely or nearly surrounded by South Block Luckiamute.

³⁰ This population area surrounded by South Block Yaquina.

4.2.3. Range of Habitat Capacity Estimates

Population areas varied greatly in the degree of uncertainty among habitat capacity estimates, as shown in Tables A–4 and A–5. In 15 population areas, neither model shows any habitat to support a population, and the minimum and maximum population estimates are both zero, indicating high certainty of no habitat capacity. However, there is still uncertainty with regard to these population areas; in each, the most recent survey detected vole presence, and these surveys range in date from 1996 to 2022. Given recent vole detections, it is likely that some habitat is present that is not well captured by the available models. Therefore, we will continue to carry these population areas through the analyses. In other population areas, the models showed a great deal of uncertainty. In 9 population areas, the minimum and maximum habitat capacity estimates differed by more than 5,000 individuals across the two models. However, in 7 of these 9 population areas, all population estimates were above 1,000, so while there is uncertainty in the exact habitat capacity, there is greater certainty that these population areas have adequate habitat to support at least a moderately sized population. In the other 2 of the 9 population areas (Spencer Butte and BLM Checkerboard), the minimum estimate was less than 500 individuals, and the maximum estimate was well over 5,000 individuals, indicating more than an order of magnitude difference between minimum and maximum population estimates.

4.3. Estimating Effective Population Size Capacity

Because the minimum and maximum effective population size capacity estimates are derived from the minimum and maximum habitat capacity estimates, there is similar uncertainty in the effective population size capacity estimates as reported above for habitat capacity estimates. However, uncertainty in effective population size capacity is compounded because we do not know the exact relationship between population size and effective population size for tree voles. The minimum and maximum effective population size capacity estimates for each of the 52 population areas are shown in Table A–6. Each population area is categorized as follows:

- 1) If all estimates of effective population size capacity were less than 100, the population area was categorized as having low resiliency with relatively lower uncertainty, and was color coded red. The majority of the population areas, 37 areas, fell into this category.
- 2) If one or more estimates of effective population size capacity was less than 100, and the maximum estimate fell between 100 and 1,000, the population area was categorized as having low or moderate resiliency, with higher uncertainty, and was color coded orange. Seven population areas were in this category.
- 3) If all estimates of effective population size capacity fell between 100 and 1,000, the population area was categorized as having moderate resiliency, with relatively low uncertainty, and was color coded yellow. However, no population areas fell into this category.
- 4) If the minimum estimate of effective population size capacity fell between 100 and 1,000, and one or more of the estimates was greater than 1,000, the population area was categorized as having moderate to high resiliency, with higher uncertainty, and was color coded green. There were four population areas in this category.

- 5) If all estimates of effective population size capacity were greater than 1,000, the population area was categorized as having high resiliency, with relatively low uncertainty, and was color coded blue. Three population areas fell into the high resiliency category.
- 6) If one or more of the estimates of effective population size capacity was less than 100, and one or more of the estimates was greater than 1,000, the population area was categorized as having unknown resiliency, and the highest degree of uncertainty, and was color coded purple. Two population areas fell into this category of highest uncertainty.

We refer to these categories as the population area resiliency ratings. Population areas are also mapped by population area resiliency rating in Figure A–8, with the fill for each population area corresponding to the color coding described above.

Table A – 6. Resiliency and uncertainty ratings based on range of effective population size (N_e) capacity estimates for each population area. PA = population area.

Population Area	Geographic Unit	Minimum N_e Capacity	Maximum N_e Capacity	Resiliency Category	Uncertainty Category
Saddle Mountain Road	Lewis and Clark	0	0	low	lower
Elmer Feldenheimer North	Ecola/ Elmer Feldenheimer	0	1	low	lower
Saddle Mountain Road	Lewis and Clark	0	0	low	lower
Oswald West	Necanicum/ Nehalem	0	3	low	lower
Tillamook South Fork Nehalem North	North Fork Nehalem	0	39	low	lower
Anderson Creek	Nehalem/ Wilson	0	24	low	lower
Tillamook South Fork Nehalem South		0	43	low	lower
Tillamook S.Fork Kichlis North		7	100	low/ moderate	higher
Tillamook S. Fork Kichlis Middle		15	178	low/ moderate	higher
O'Hara Creek	Cape Meares	0	0	low	lower
Hodgdon Creek		0	0	low	lower
Fall Short		0	0	low	lower
Cape Meares		0	0	low	lower
Cape Lookout South	Sand Lake	0	11	low	lower

Population Area	Geographic Unit	Minimum N _e Capacity	Maximum N _e Capacity	Resiliency Category	Uncertainty Category
Cape Lookout North		0	3	low	lower
Cape Lookout West		0	10	low	lower
South of Sandlake		0	0	low	lower
Andy Creek		0	1	low	lower
Tierra Del Mar		40	306	low/ moderate	higher
Nestucca Block Gaudy	Gauldy Ridge	31	353	low/ moderate	higher
Tillamook South Fork Kichlis South	Trask/ Nestucca	10	72	low	lower
Fawcett Creek		0	28	low	lower
Gopher		0	29	low	lower
East Beaver Creek		7	51	low	lower
Moon Creek Nestucca Block Inclusion ³¹		0	0	low	lower
Nestucca Block Trask		1,163	9,154	high	lower
Nestucca Block Salmon Coast	Little Nestucca/ Salmon Coast	26	189	low/ moderate	higher
Neskowin Creek East	Little Nestucca/ Salmon Inland	0	0	low	lower
Neskowin Creek West		0	1	low	lower
“2006”		0	0	low	lower
Nestucca Block Salmon East		22	231	low/ moderate	higher
Nestucca Block Salmon West		64	850	low/ moderate	higher
Bower Creek		6	50	low	lower
North Fork Siletz	Siletz/ Luckiamute	0	0	low	lower
Dry Creek		0	0	low	lower
Deadwood Mountain		147	1,904	moderate/ high	higher
Treat River		0	0	low	lower
Nestucca Block Luckiamute		0	8	low	lower
Salt Creek		0	40	low	lower
BLM Checkerboard		47	1,660	unknown	highest
Potter Creek		2	24	low	lower

³¹ This population area is surrounded by Nestucca Block Trask

Population Area	Geographic Unit	Minimum N_e Capacity	Maximum N_e Capacity	Resiliency Category	Uncertainty Category
Norton		0	27	low	lower
McTimmonds Creek South Block Inclusion ²⁸		0	0	low	lower
Middle Ridge South Block Inclusion ²⁸		0	11	low	lower
No-Name South Block Inclusion ²⁸		0	0	low	lower
SF Teal Creek South Block Inclusion ³²		0	0	low	lower
South Block Luckiamute		220	3,305	moderate/ high	higher
Bull Run Creek South Block Inclusion ²⁷	Yaquina/ Marys	4	48	low	lower
Skunk Creek South Block Inclusion ³³		0	48	low	lower
South Block Yaquina		1,331	9,719	high	lower
South Block Long Tom	Siuslaw/ Long Tom	337	3,178	moderate/ high	higher
South Block Alsea	Alsea/ Siuslaw	2,891	22,603	high	lower
South Block Territorial	Siuslaw/ Territorial	395	5,262	moderate/ high	higher
Spencer Butte	Spencer Butte	48	2,813	unknown	highest

³² This population area is completely or nearly surrounded by South Block Luckiamute

³³ This population is surrounded by South Block Yaquina

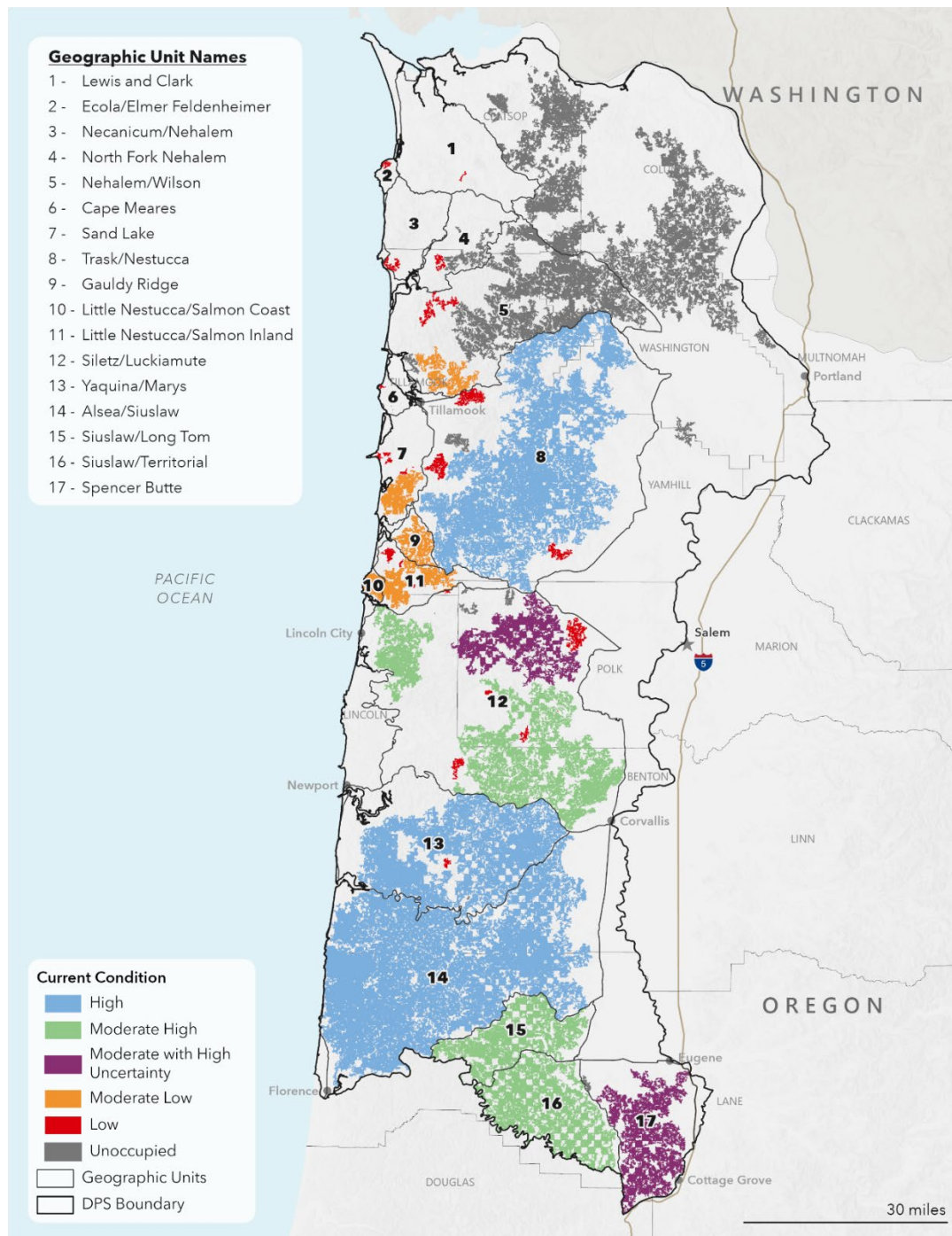


Figure A – 8. Population area resiliency ratings for current condition.

4.4. Summary of Condition by Geographic Unit

A summary of the condition of each geographic unit in terms of its survey status and total habitat estimates, as well as the number, occupancy status, survey status, and resiliency condition of population areas within each geographic unit is shown in Table A–7.

Table A – 7. Condition of population areas grouped by geographic unit with survey status and occupancy status. Those population areas determined to be unoccupied and not carried forward in current condition are included in this list but noted.

Geographic Unit Name	Survey Status (most recent)	2023 Habitat Core + Edge (ha)	Updated 2017 Habitat (ha)	Population Areas Summary
1. Lewis and Clark	2011 positive	112	45	1 known occupied, low resiliency, low uncertainty, occupied 2011
2. Ecola/ Elmer Feldenheimer	2011 positive	3	0	1 known occupied, low resiliency, low uncertainty, occupied 2011
3. Necanicum/ Nehalem	2011 positive	11	0	1 known occupied, low resiliency, low uncertainty, occupied 2011
4. North Fork Nehalem	2011 positive	97	937	1 known occupied, low resiliency, low uncertainty, occupied 2011 1 presumed unoccupied, low resiliency, low uncertainty, unsurveyed 1 presumed unoccupied, low/mod resiliency, higher uncertainty, negative survey 2011
5. Nehalem/ Wilson	2018 positive	4,329	5,082	2 known occupied, low/moderate resiliency, higher uncertainty, occupied 2018 1 known occupied low resiliency, low uncertainty, occupied 2011 1 presumed occupied low resiliency, low uncertainty, unsurveyed 1 presumed unoccupied, mod/high resiliency, higher uncertainty, negative survey 2011 2 presumed unoccupied, low resiliency, low uncertainty, negative surveys 2011+ 1 presumed unoccupied, low resiliency, low uncertainty, unsurveyed
6. Cape Meares	2011 positive	0	0	3 presumed occupied low resiliency, low uncertainty, occupied 1996+ 1 known occupied, low resiliency, low uncertainty, occupied 2011
7. Sand Lake	2022 positive	827	764	1 low/moderate resiliency, higher uncertainty, occupied 2021+ 4 low resiliency, low uncertainty, occupied 2011+ 1 presumed occupied, low resiliency, low uncertainty, occupied 2003

Geographic Unit Name	Survey Status (most recent)	2023 Habitat Core + Edge (ha)	Updated 2017 Habitat (ha)	Population Areas Summary
8. Trask/Nestucca	2022 positive	24,787	21,158	1 known occupied, high resiliency, low uncertainty, occupied 2022 2 known occupied, low resiliency, low uncertainty, occupied 2011+ 1 presumed occupied, low resiliency, low uncertainty, occupied 1996 inclusion 1 presumed occupied, low resiliency, low uncertainty, unsurveyed 1 presumed unoccupied, low resiliency, low uncertainty, unsurveyed
9. Gauldy Ridge	2018 positive	558	923	1 known occupied, low/moderate resiliency, higher uncertainty, occupied 2018
10. Little Nestucca/ Salmon Coast	2018 positive	463	495	1 known occupied, low/moderate resiliency, higher uncertainty, occupied 2018
11. Little Nestucca/ Salmon Inland	2018 positive	1,810	3,009	2 known occupied, low/moderate resiliency, higher uncertainty, occupied 2018 2 known occupied, low resiliency, low uncertainty, occupied 2006+ 1 presumed occupied, low resiliency, low uncertainty, occupied 2006 1 presumed occupied, low resiliency, low uncertainty, unsurveyed
12. Siletz/Luckiamute	2022 positive	16,673	10,015	2 known occupied, moderate/high resiliency, higher uncertainty, occupied 2018+ 1 known occupied, unknown resiliency, highest uncertainty, occupied 2018 4 know occupied, low resiliency, low uncertainty, occupied 2011+ 2 known occupied, low resiliency, low uncertainty, occupied 2022 inclusions 2 presume occupied, low resiliency, low uncertainty, occupied 1996+ inclusions 3 presumed occupied, low resiliency, low uncertainty, unsurveyed 3 presumed unoccupied, low resiliency, low uncertainty, unsurveyed

Geographic Unit Name	Survey Status (most recent)	2023 Habitat Core + Edge (ha)	Updated 2017 Habitat (ha)	Population Areas Summary
13. Yaquina/Marys	2022 positive	23,989	25,620	1 known occupied, high resiliency, low uncertainty, occupied 2022 1 known occupied, low resiliency, low uncertainty, occupied 2002 inclusion 1 presumed occupied, low resiliency, low uncertainty, unsurveyed inclusion
14. Alsea/Siuslaw	2022 positive	51,758	59,130	1 known occupied, high resiliency, low uncertainty, occupied 2022
15. Siuslaw/Long Tom	2021 positive	8,335	6,056	1 known occupied, moderate/high resiliency, higher uncertainty, occupied 2021
16. Siuslaw/Territorial	2022 positive	13,813	7,043	1 known occupied, moderate/high resiliency, higher uncertainty, occupied 2018+
17. Spencer Butte	2011 positive	7,598	865	1 known occupied, unknown resiliency, highest uncertainty, occupied 2011 1 presumed unoccupied, low resiliency, low uncertainty, negative survey 2011

5. Analysis of Resiliency—Current Condition

Resiliency is positively related to population size and may be influenced by connectivity among populations. For current condition, only population areas with a known or presumed positive occupancy status were considered. A total current condition resiliency rating for each geographic unit was derived by combining the population area resiliency ratings (see previous section) and connectivity, measured both within and between geographic units. Connectivity within geographic units is based on the potential for connectivity of population areas as measured by the presence of forested lands between population areas no further than 2 km apart. We used 2 km because tree vole nests have been observed in young forests (20–80 years old) where those forests are within 2 km of old forest (Forsman et al. 2016, 32, 45; Lesmeister et al. 2016, pp. 14–15; Linnell et al. 2017, p. 5) and young forest may function as connectivity habitat in those situations (Lesmeister et al. 2016, p. 15). The potential for connectivity between geographic units was assessed in terms of whether habitat blocks spanned the boundary of geographic units and both sides of the unit boundary were considered population areas. For example, if a population area was connected to a geographic unit boundary via an underlying habitat block, but the habitat block on the other side did not meet our definition of a population area, then it would not count as connected.

Table A–8 summarizes the metrics used in combination to assess the overall resiliency of each unit. Table A–9 and Figure A–9 show the final rating by geographic units for current condition.

Table A – 8. Current condition rating key for assessing overall resiliency of geographic units.

Condition Category	Estimated Effective Population Size (N_e) Capacity (Population Area Resiliency)	Connectivity Potential Within Geographic Units	Connectivity Potential Between Geographic Units	Overall Resiliency Condition <i>At least one population area in the unit meets the following criteria:</i>
High	Range is > 1000	Another population area is within 2 km and separated by forested lands	Population areas on either side of a geographic unit boundary are connected by the same habitat block.	N_e range is high or N_e range is moderate high and at least one connectivity factor is high
Moderate High	Range is >100 to > 1,000			N_e range is moderate high and both connectivity factors are low or N_e range is moderate and at least one connectivity factor is high

Moderate	Range is >100 and < 1000 or			N _e range is moderate and both connectivity factors are low or N _e range is moderate low and at least one connectivity factor is high
	Range is <100 to >1000 (high uncertainty)			
Moderate Low	Range is 0 to >100 but <1,000	Population area >2 km or <2 km but the area in between is not forested	Habitat block does not span unit boundary or spans unit boundary but either side is not a population area	N _e range is moderate low and both connectivity factors are low or N _e range is low and at least one connectivity factor is high
Low	Range is <100			N _e range is low and both connectivity factors are low

Table A – 9. Current condition resiliency rating by geographic unit, showing the population area resiliency rating and connectivity components, from north to south. Population area resiliency ratings are color coded according to Table A – 8 as blue = high (HI), green = moderate high (MOD HI), yellow = moderate (MOD), purple = moderate with high uncertainty (MOD High Uncertainty), orange = moderate low (MOD LO), and red = low (LO). Results of population area analysis are shown in Figure A – 8. Geographic unit ratings are color-coded according to Table A – 8 as blue = high (HI) or generally secure, yellow = moderate or marginally secure (MOD), and red = low or generally insecure (LO). Results of geographic units analysis are shown in Figure A – 9.

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
1. Lewis and Clark	Saddle Mountain Road	LO	LO	LO	LO
2. Ecola/ Elmer Feldenheimer	Elmer Feldenheimer North	LO	LO	LO	LO
3. Necanicum/ Nehalem	Oswald West	LO	LO	LO	LO
4. North Fork Nehalem	Tillamook South Fork Nehalem	LO	LO	LO	LO

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
5. Nehalem/ Wilson	Tillamook South Fork Kichlis Middle	MOD LO	HI	LO	MOD
	Tillamook South Fork Kichlis North	MOD LO	HI	LO	
	Tillamook South Fork Nehalem	LO	HI	LO	
	Anderson Creek	LO	HI	LO	
6. Cape Meares	Cape Meares	LO	LO	LO	MOD LO
	Fall Short	LO	HI	LO	
	Hodgdon Creek	LO	HI	LO	
	O'Hara Creek	LO	HI	LO	
7. Sand Lake	Tierra Del Mar	MOD LO	HI	LO	MOD
	Andy Creek	LO	HI	LO	
	South of Sandlake	LO	HI	LO	
	Cape Lookout West	LO	HI	LO	
	Cape Lookout North	LO	HI	LO	
	Cape Lookout South	LO	HI	LO	
8. Trask/Nestucca	Nestucca Block Trask	HI	HI	HI	HI

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
	Moon Creek Nestucca Block Inclusion	LO	HI	LO	
	East Beaver Creek	LO	HI	LO	
	Gopher	LO	HI	LO	
	Tillamook South Fork Kichlis South	LO	LO	LO	
9. Gaudy Ridge	Nestucca Block Gaudy	MOD LO	LO	HI	MOD
10. Little Nestucca/Salmon	Nestucca Block Salmon Coast	MOD LO	LO	HI	MOD
11. Little Nestucca/Salmon Inland	Bower Creek	LO	HI	LO	MOD
	Nestucca Block Salmon West	MOD LO	HI	HI	
	Nestucca Block Salmon East	MOD LO	HI	HI	
	“2006”	LO	HI	LO	
	Neskowin Creek West	LO	HI	LO	
	Neskowin Creek East	LO	HI	LO	
12. Siletz/ Luckiamute	South Block Luckiamute	MOD HI	HI	HI	HI
	South Fork Teal Creek South Block Inclusion ³⁴	LO	HI	LO	

³⁴ This population area is nearly or completely surrounded by South Block Luckiamute.

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
	No-Name South Block Inclusion ¹²	LO	HI	LO	
	Middle Ridge South Block Inclusion ¹²	LO	HI	LO	
	McTimmonds Creek South Block Inclusion ¹²	LO	HI	LO	
	Norton	LO	HI	LO	
	Potter Creek	LO	HI	LO	
	BLM Checkerboard	MOD (High)	HI	LO	
	Salt Creek	LO	HI	LO	
	Nestucca Block Luckiamute	LO	LO	HI	
	Treat River	LO	LO	LO	
	Deadwood Mountain	MOD HI	HI	LO	
	Dry Creek	LO	HI	LO	
	North Fork Siletz	LO	HI	LO	
13. Yaquina/Marys	South Block Yaquina	HI	HI	HI	HI
	Skunk Creek South Block Inclusion ³⁵	LO	HI	LO	
	Bull Run Creek South Block	LO	HI	LO	

³⁵ This population area is surrounded by South Block Yaquina.

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Overall Resiliency Rating for Unit
14. Alsea/ Siuslaw	South Block Alsea	HI	LO	HI	HI
15. Siuslaw/ Long Tom	South Block Long Tom	MOD HI	LO	HI	HI
16. Siuslaw/ Territorial	South Block Territorial	MOD HI	LO	HI	HI
17. Spencer Butte	Spencer Butte	MOD (High	LO	LO	HI

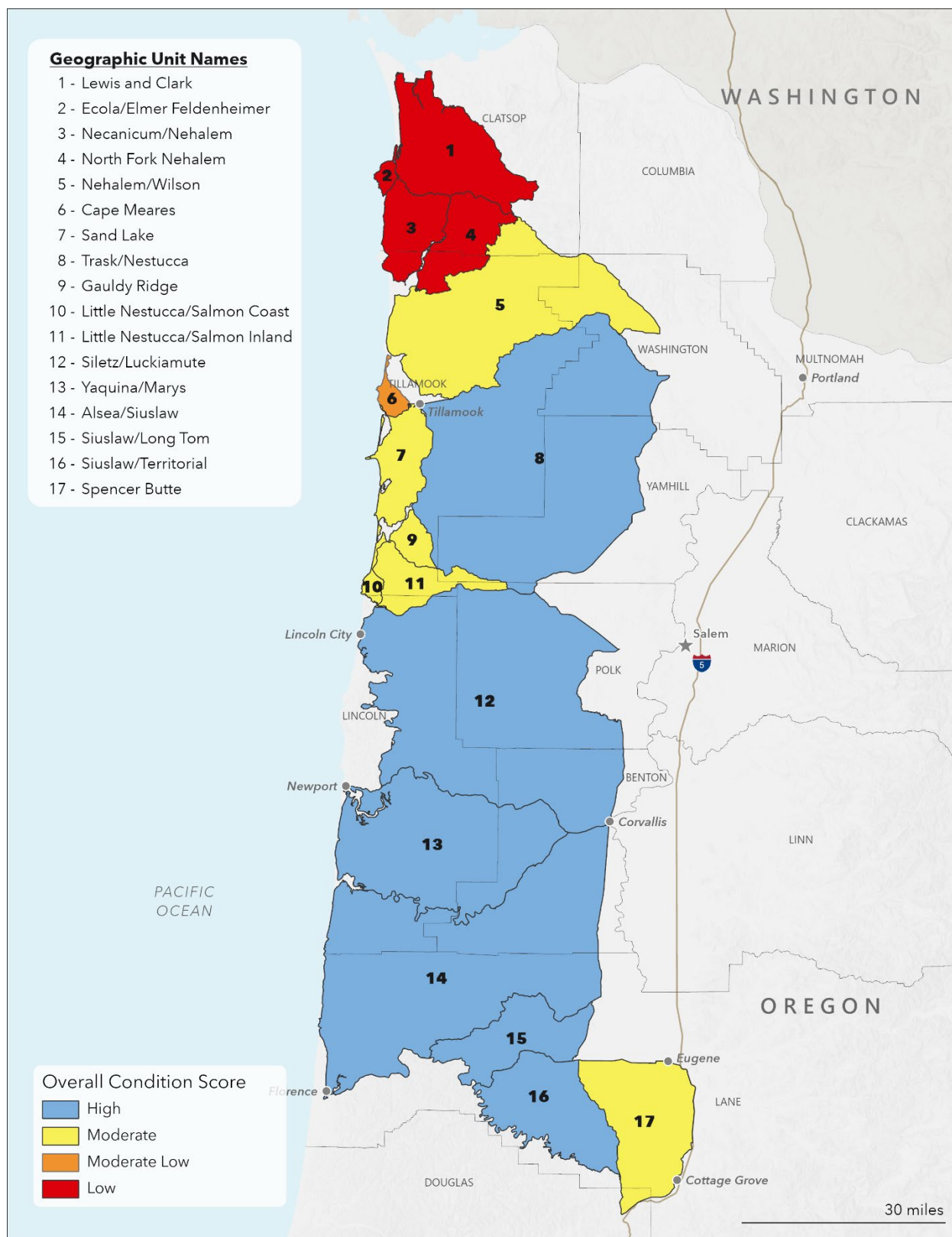


Figure A – 9. Current condition of red tree vole geographic units depicted by their overall resiliency rating .

6. Analysis of Resiliency – Future Condition

A future condition resiliency rating for each geographic unit was derived based on combining population area resiliency ratings based on estimates of future habitat capacity and effective population size capacity, ratings from key stressors for which we could make reasonable assumptions to carry into future scenarios (i.e., shifts in vegetation and Swiss needle cast), and connectivity ratings from both within and between geographic units representing potential for timber harvest derived from land management status. The rationale and rating for each of these is described below.

We developed two scenarios which represent plausible sideboards of our demographic parameters and identified threats. The lower plausible future condition scenario (hereafter lower scenario) incorporates lower values of the demographic features (habitat capacity, population density, and effective population size ratio), assumptions of less connectivity, and assumptions of higher potential impacts from Swiss needle cast and vegetation shifts. The upper plausible future condition scenario (hereafter upper scenario) incorporates the higher values of the demographic features, a higher connectivity assumption, and lower potential impacts from Swiss needle cast and vegetation shifts.

Factors that were considered in the future condition resiliency analysis but ultimately not moved forward as distinct, assessed factors included trends in timber harvest and wildfire. We assumed the trends in timber harvest would be similar in future scenarios. We did include timber harvest trends in the overall assessment of resiliency by assuming constrained lands would remain constrained and habitat would continue to grow, and unconstrained lands may not be habitat in the future. We also included timber harvest in connectivity. For example, we assumed population areas separated by constrained lands would be connected in the future. We define constrained as those lands identified as Federal reserved land use allocations and State constrained lands (see SSA Table 1 and sections 7.2.1 and 7.2.2). With wildfire, we recognize that resiliency is more about a populations' ability to deal with high-frequency, relatively low-impact events, whereas redundancy is more about low-frequency, high-impact ("catastrophic") events. The fires that have historically occurred in this region and are likely to occur in the future are in the catastrophic category. Frequent, low-severity fire is not something that happens in the DPS and is unlikely to happen in the foreseeable future timeframe (see SSA section 5.1.2 and 7.1.5) and, so we moved the fire considerations to the redundancy section.

Because of the potential for habitat recruitment over the approximate 60-year analysis period (to approximately 2080), population areas with presumed unoccupied status were included in the analysis if they met the following conditions:

- Another population area in the same geographic unit is connected by constrained³⁶ land, or

³⁶ We define constrained as those lands identified as Federal reserved land use allocations and State constrained lands (see Table 1 and sections 7.2.1, 7.2.2 in the SSA).

- Another population area in an adjacent geographic unit is connected by constrained land and a current habitat block.

Four of 11 presumed unoccupied population areas met the conditions above and were moved forward in all the future condition analyses. Those population areas are indicated by gray fill in the tables. These population areas were within a unit that was considered in the current condition analyses, in other words, none of the previously eliminated geographic units were brought back for future condition analyses.

6.1. Effective Population Size Capacity

Similar to current condition, our analysis of future condition was based on habitat, wherein we revised our estimates of effective population size capacity based on assumed changes in tree vole habitat condition consistent with harvest patterns by land ownership and land use allocation. We used both the 2023 and 2017 (updated in 2022) habitat models, two population densities, and two values for the ratio of effective population size to actual population size. Instead of a range, we chose one of each of these factors for each of the scenarios.

Because the 2023 model habitat capacity estimates were generally higher overall (e.g., 164,718 ha versus 153,226 ha of habitat in the DPS) and also higher in presumed occupied habitat (149,057 ha versus 135,728 ha) than the 2017 model, we chose the 2023 model for the upper scenario and the 2017 model for the lower scenario. We chose 1.91 voles/ha for the upper scenario and 0.56 voles/ha for the lower scenario for vole population density. We chose 20 percent of the habitat capacity for the upper scenario and 10 percent of the habitat capacity for the lower scenario for effective population size capacity.

We assumed constrained lands would remain constrained in either scenario and the status of unconstrained lands would vary by scenario.

Upper Scenario: If a population area currently intersects with a constrained lands polygon, its potential future habitat capacity is based on 90% (see rationale in SSA section 7.2) of the amount of area in the constrained lands polygon, within that geographic unit. If a population area intersects with unconstrained lands, we assume the same proportion of habitat as current condition (based on the 2023 model and current population area), within the same boundaries as the current population area. If a population area intersects with both constrained and unconstrained, we assume the unconstrained portion remains as habitat (i.e., does not expand or contract) and the constrained portion can expand into (90% of) the constrained polygon. If 2 or more population areas share the same constrained lands polygon, we awarded the habitat amount in the polygon proportionally based on current habitat amount in each population area. For example, a 1000 ha population area and a 2000 ha population area share the same constrained lands polygon. The first gets 33% and the second gets 66% of the habitat area in the polygon.

Lower Scenario: If a population area intersects with constrained lands, we assume it will have the same proportion of habitat in the constrained lands that is present in the whole population

area now, based on the 2017 habitat model. Population areas intersecting unconstrained lands will be assumed to no longer be habitat.

After calculating the upper plausible future potential area and lower plausible future potential area amounts as described above, we calculated habitat capacity estimates for each future population area polygon using population density of 0.56 voles/ha for the lower scenario and 1.91 voles/ha for the upper scenario, multiplied by the corresponding potential future areas. We then calculated the effective population size capacity estimates by multiplying the habitat capacity by 10% for the lower scenario and the habitat capacity by 20% for the upper scenario to arrive at a final resiliency rating for the population area.

Under each scenario, if the estimate of effective population size capacity was less than 100, the population area was categorized as having low resiliency. If it was between 100 and 1000, it was categorized as having moderate resiliency. Population areas with estimated effective population size capacity of over 1000 were categorized as having high resiliency. Results are shown in Table A–10.

Table A – 10. Estimates of habitat area, habitat capacity, and effective population size capacity, with resiliency ratings for each population area under upper and lower future scenarios. Categories include high (HI), moderate (MOD), and low (LO). Population area names with gray fill had unoccupied status and were not analyzed in current condition but are considered as potentially occupied in future condition.

	Upper Scenario				Lower Scenario			
Population Area	Habitat Area (ha)	Habitat Capacity (voles)	N _e Capacity	Resiliency Rating	Habitat Area (ha)	Habitat Capacity (voles)	N _e Capacity	Resiliency Rating
Elmer Feldenheimer N	1	3	1	LO	0	0	0	LO
Saddle Mountain Road	0	0	0	LO	0	0	0	LO
Oswald West	5	10	2	LO	0	0	0	LO
Rector Ridge	2364	4516	903	MOD	223	22	LO	223
Tillamook S Fork Nehalem N	0	0	0	LO	0	0	LO	0
Nestucca Block Wilson	17630	33674	6735	HI	1823	1021	102	MOD
Anderson Creek	899	1717	343	MOD	33	18	2	LO
Tillamook S Fork Nehalem S	8592	16410	3282	HI	106	59	6	LO
Bay City Electric	209	398	80	LO	39	22	2	LO
Tillamook S Fork Kichlis N	1414	2700	540	MOD	162	91	9	LO
O'Hara Creek	0	0	0	LO	0	0	0	LO
Hodgdon Creek	0	0	0	LO	0	0	0	LO
Fall Short	0	0	0	LO	0	0	0	LO

	Upper Scenario				Lower Scenario			
Population Area	Habitat Area (ha)	Habitat Capacity (voles)	N _e Capacity	Resiliency Rating	Habitat Area (ha)	Habitat Capacity (voles)	N _e Capacity	Resiliency Rating
Cape Meares	0	0	0	LO	0	0	0	LO
Cape Lookout South	1	1	0	LO	0	0	0	LO
Cape Lookout North	6	11	2	LO	0	0	0	LO
Cape Lookout West	6	11	2	LO	0	0	0	LO
South of Sandlake	0	0	0	LO	0	0	0	LO
Andy Creek	1	3	1	LO	0	0	0	LO
Tierra Del Mar	718	1371	274	MOD	64	36	4	LO
Nestucca Block Gaudy	485	927	185	MOD	81	45	5	LO
Tillamook S Fork Kichlis S	698	1333	267	MOD	124	70	7	LO
Fawcett Creek	394	752	150	MOD	0	0	0	LO
Gopher	0	0	0	LO	0	0	0	LO
East Beaver Creek	139	265	53	LO	55	31	3	LO
Moon Creek Nestucca Block Incl.	67	128	26	LO	0	0	0	LO
Nestucca Block Trask	16960	32393	6479	HI	5271	2952	295	MOD
Nestucca Block Salmon Coast	417	796	159	MOD	0	0	0	LO
Neskowin Creek East	1	1	0	LO	0	0	0	LO
Neskowin Creek West	4	7	1	LO	0	0	0	LO
“2006”	0	0	0	LO	0	0	0	LO
Nestucca Block Salmon E	332	634	127	MOD	122	68	7	LO
Nestucca Block Salmon W	1001	1912	382	MOD	64	36	4	LO
Bower Creek	52	99	20	LO	0	0	0	LO
North Fork Siletz	0	0	0	LO	0	0	0	LO
Dry Creek	0	0	0	LO	0	0	0	LO
Deadwood Mountain	1705	3256	651	MOD	2533	1419	142	MOD
Treat River	18	35	7	LO	0	0	0	LO
Nestucca Block Luckiamute	1	2	0	LO	0	0	0	LO
Salt Creek	0	0	0	LO	0	0	0	LO

	Upper Scenario				Lower Scenario			
Population Area	Habitat Area (ha)	Habitat Capacity (voles)	N _e Capacity	Resiliency Rating	Habitat Area (ha)	Habitat Capacity (voles)	N _e Capacity	Resiliency Rating
BLM Checkerboard	1445	2760	552	MOD	173	97	10	LO
Potter Creek	11	21	4	LO	16	9	1	LO
Norton	32	61	12	LO	0	0	0	LO
McTimmonds Creek S Block Incl.	0	0	0	LO	0	0	0	LO
Middle Ridge S Block Incl.	4	7	1	LO	0	0	0	LO
No-Name S Block Incl.	0	0	0	LO	0	0	0	LO
SF Teal Creek S Block Incl.	0	0	0	LO	0	0	0	LO
South Block Luckiamute	1870	3571	714	MOD	383	215	21	LO
Bull Run Cr. S Block Incl.	53	101	20	LO	102	57	6	LO
Skunk Creek S Block Incl.	0	0	0	LO	0	0	0	LO
South Block Yaquina	4908	9375	1875	HI	14232	7970	797	MOD
South Block Long Tom	1671	3193	639	MOD	2354	1318	132	MOD
South Block Alsea	12897	24633	4927	HI	37860	21202	2120	HI
South Block Territorial	1599	3053	611	MOD	3240	1815	181	MOD
Spencer Butte	620	1185	237	MOD	94	53	5	LO

6.2. Connectivity – Timber Harvest and Land Ownership

Connectivity within geographic units is based on the potential for connectivity of population areas as measured by the presence of constrained or unconstrained forested lands between population areas. We define constrained as those lands identified as Federal reserved land use allocations and State constrained lands (see SSA Table 1 and sections 7.2.1 and 7.2.2). We assume under either upper or lower scenarios that constrained lands would remain forested and potential habitat. We did not apply a minimum distance between population areas separated by constrained lands. We assumed that unconstrained forests lands <2km would remain connected only under the upper scenario. We note that while unconstrained lands could provide young forest for potential habitat and dispersal (within a certain distance of old forest), we have greater certainty that constrained lands will expand and connect as habitat in the future.

The potential for connectivity between geographic units was assessed by the following factors:

1) if habitat blocks spanned the boundary of geographic units, 2) if both sides of the unit

boundary were considered population areas and at least one of those was presumed occupied, and 3) if population areas were on constrained or unconstrained lands. Similar to the within unit analysis, under the upper scenario there would be connectivity if two population areas connected via constrained lands or through unconstrained lands with an underlying current habitat block. In the lower scenario, connectivity would occur only between constrained lands that connect the unit between two population areas.

6.3. Vegetation Shifts

As described in the SSA (section 7.1.2.1) there is considerable variability in the projections of vegetation shifts in the Pacific Northwest as a result of climate change. We examined models for two tree species germane to tree voles in the DPS and most likely to experience significant changes within our analysis period, western hemlock and Sitka spruce.

6.3.1. Western hemlock

For western hemlock across the maritime forests of the Pacific Northwest, projected response of the species to climate change by the end of the 21st century based on a multiple model output ranged from an increase to total loss, with some shifts (Peterson et al. 2014, p. 102). We examined maps of model outputs based on a various climate models, emissions scenarios, and vegetation models. Several models projected a complete loss of suitable climate for western hemlock within the DPS by the later part of the 21st century (2071–2100, or 2085–2095) (Crookston et al. 2010, GIS data, see Figure A-10), and another projected loss of all but a small area of lower-suitability conditions along the northern coastal portion of the DPS (Natural Resources Canada 2022). All models projected some loss at least of higher-suitability conditions, with contractions coastward, upslope, and northward (Crookston et al. 2010, GIS data; DellaSala et al. 2018, GIS data, see Figure A-11; Natural Resources Canada 2022), but one model projected that the western hemlock range would continue to cover the entire DPS (Natural Resources Canada 2022).

6.3.2. Sitka spruce

For Sitka spruce, projected responses to climate change by the late 21st century ranged from little change in range (Peterson et al. 2014, p. 111), to complete loss within the DPS (Mathys et al. 2016, pp. 7–8, Fig. 4c). We examined maps of model outputs based on a various climate models, emissions scenarios, and vegetation models. Several models projected a complete loss of suitable climate for Sitka spruce within the DPS by the later part of the 21st century (2071–2100, or 2085–2095) (Crookston et al. 2010, GIS data, see Figure A-12; Natural Resources Canada 2022), and several more projected loss of all but a small area of lower-suitability conditions along the northern coastal portion of the DPS, or in small higher-elevation areas in the north (Crookston et al. 2010, GIS data; Natural Resources Canada 2022). Most models projected a complete loss of higher-suitability conditions, and all projected contractions in climatically suitable habitat, with shifts northward, coastward, and upslope (Crookston et al. 2010, GIS data; DellaSala et al. 2018, GIS data, see Figure A-13; Natural Resources Canada 2022).

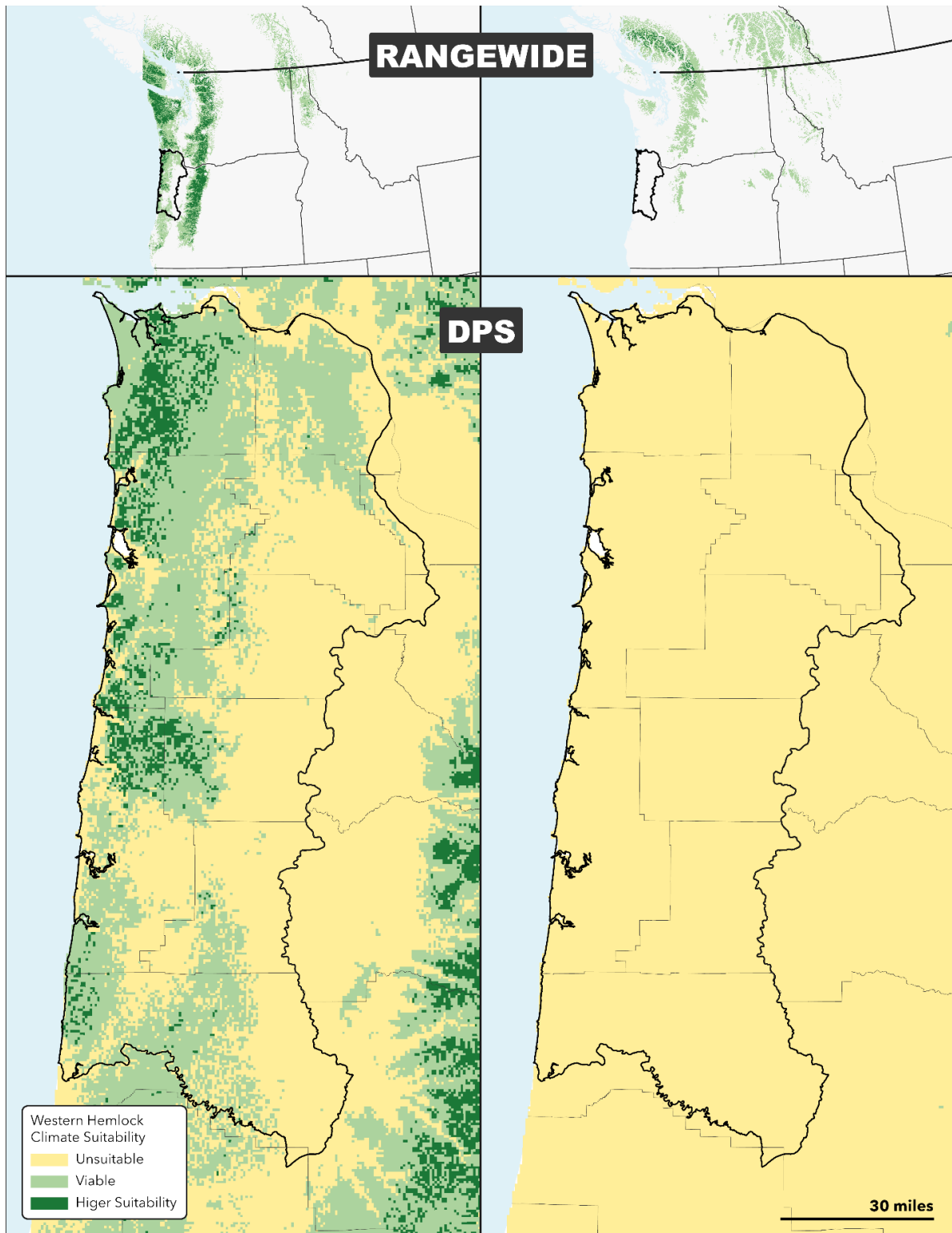


Figure A – 10. Suitability of climate conditions for western hemlock in 2010 (left) and late-century (right, 2090 projected with Canadian Center of Climate Modeling and Analysis general circulation model (CGCM3) and A2 emission scenario) (Crookston et al. 2010, GIS data).

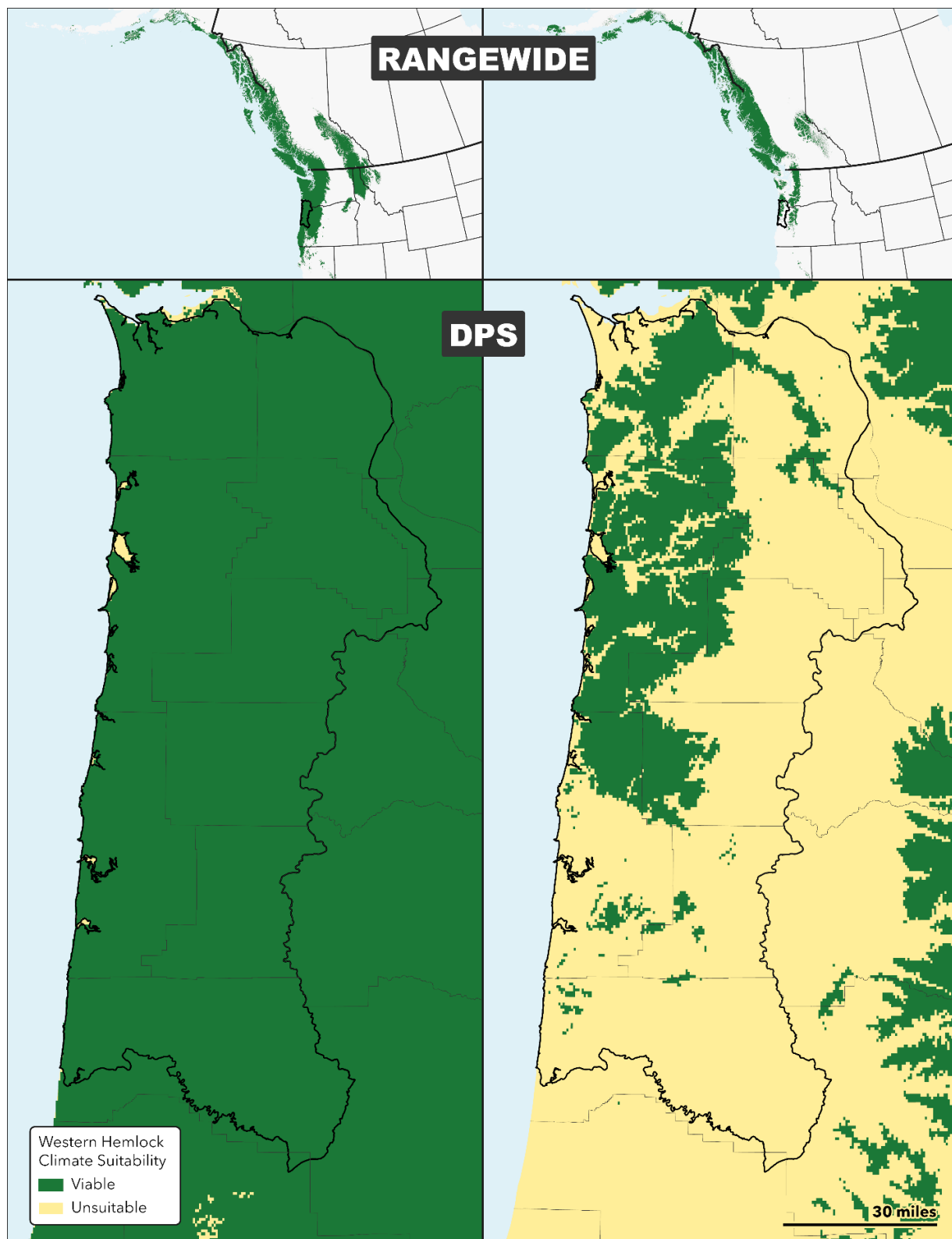


Figure A – 11. Suitability of climate conditions for western hemlock in 2010 (left) and late-century (right, 2080 projected with the CSIRO climate model and A1B emissions scenario) (DellaSala et al. 2018, GIS data).

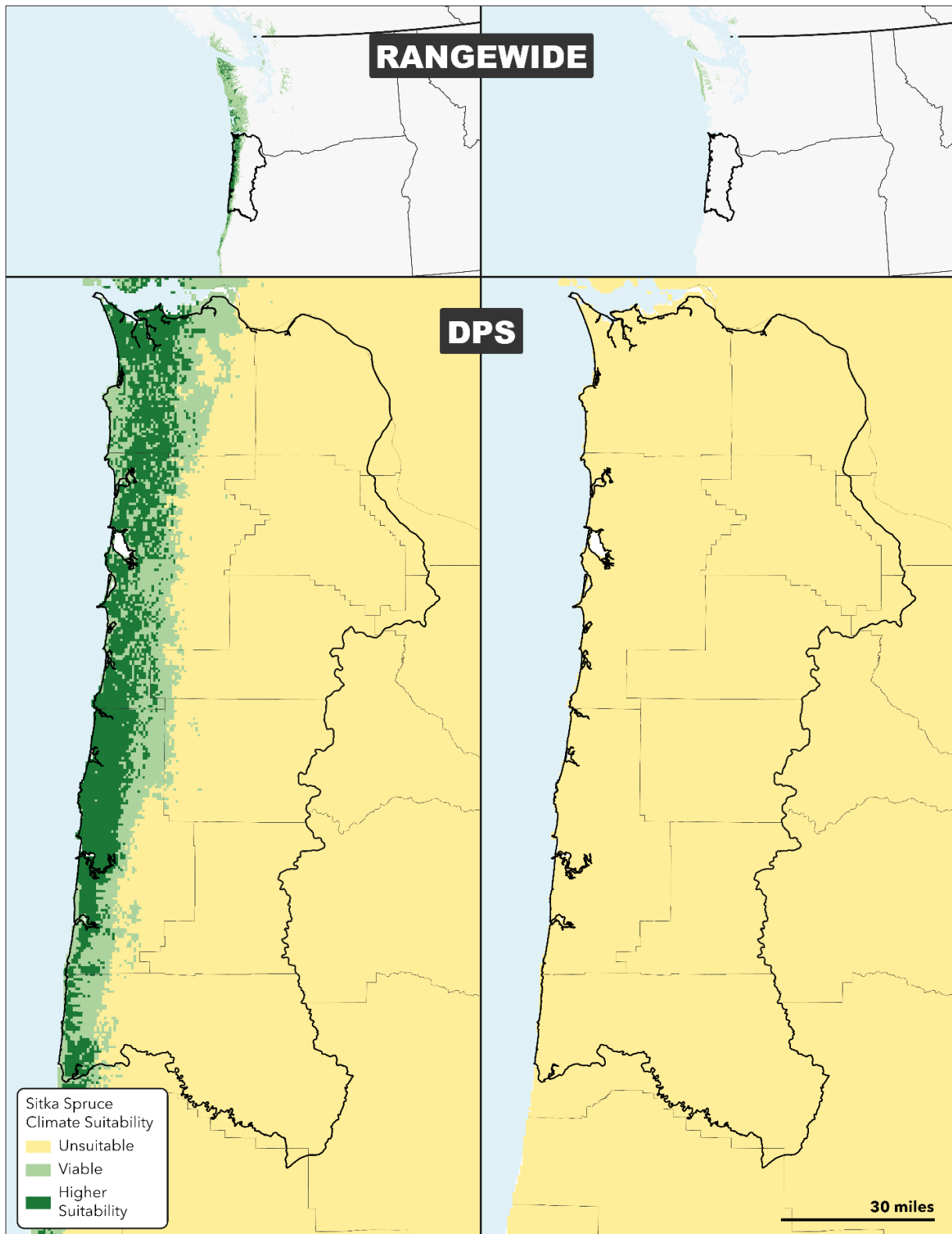


Figure A – 12. Suitability of climate conditions for Sitka spruce in 2010 (left) and late-century (right, 2090 projected with Geophysical Fluid Dynamics Laboratory general circulation model (GFDLCM 21) and A2 emission scenario) (Crookston et al. 2010, GIS data).

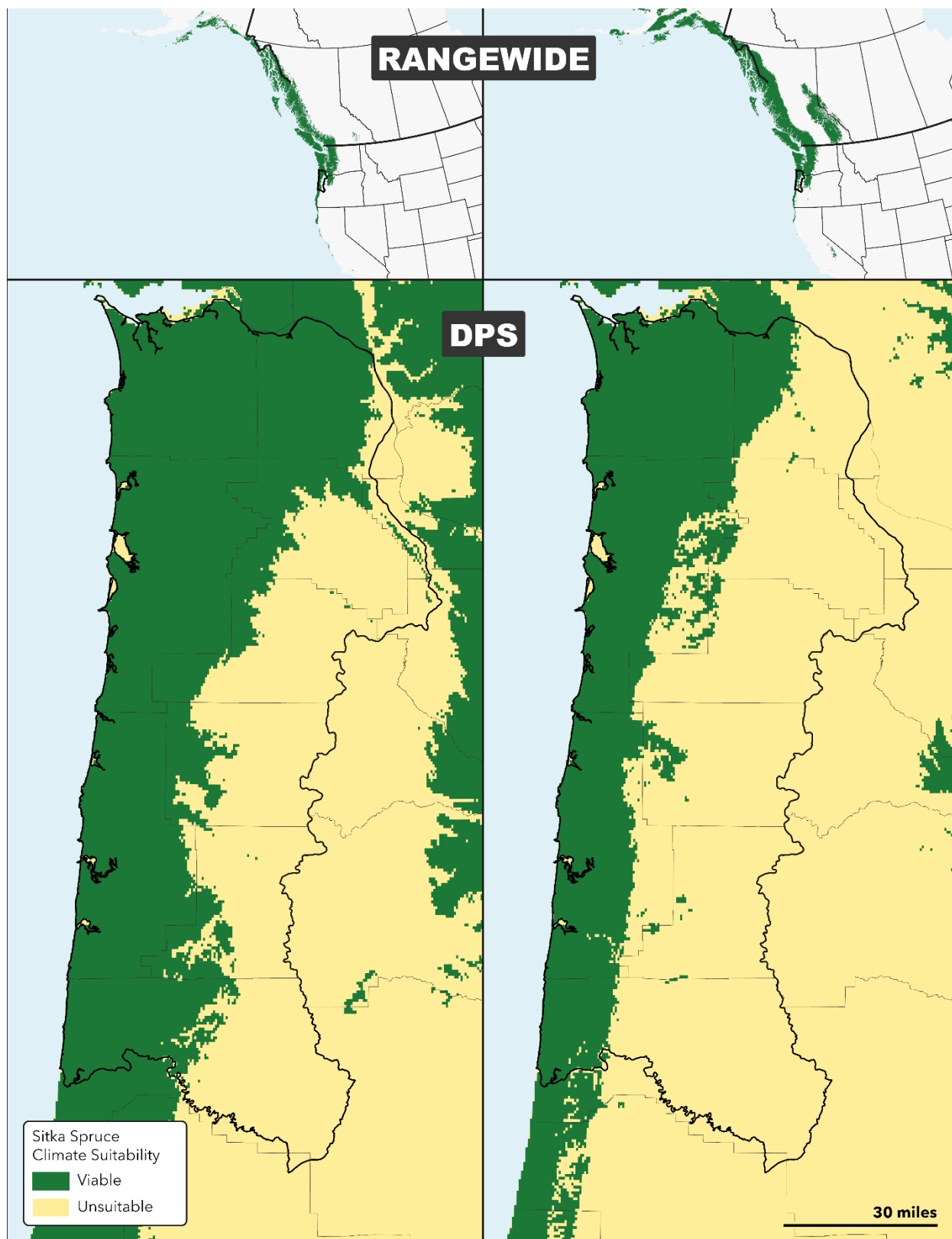


Figure A – 13. Suitability of climate conditions for Sitka spruce in 2010 (left) and late-century (right, 2080 projected with CSIRO climate model and A2A emissions scenario) (DellaSala et al. 2018, GIS data).

6.3.3. *Summary*

Under an upper future scenario, vegetation shifts would be unlikely to occur at a pace or scale that would affect the health or distribution of Douglas-fir, western hemlock, or Sitka spruce tree species. Population areas would retain the representation status they have currently (see Table A-13) and there would be no effect to resiliency. Under a lower future scenario, the climatic suitability for western hemlock and Sitka spruce would change such that both tree species would be lost from the area over the 60-year analysis time period (Crookston et al. 2010, GIS data). We would assume that tree voles which have the behavior trait to feed on these species would not be able to adapt quickly enough and those voles would be lost. Therefore, a high resiliency rating for this factor indicates a population area which is primarily in the western hemlock zone. A low resiliency rating indicates a population area which is primarily in the Sitka spruce vegetation zone. A moderate resiliency rating indicates population areas which contain both vegetation zones and thus are likely to contain both feeding behaviors. We assume, under the lower scenario, that some voles with the western hemlock and Sitka spruce feeding behavior may be lost, but voles with Douglas-fir feeding behavior would remain in those population areas.

6.4. **Swiss Needle Cast**

As described in SSA (section 7.1.4), Swiss needle cast is expected to increase in intensity and expand its distribution in the Oregon Coast Range. Under an upper future scenario, Swiss needle cast will be present at current or lower levels than today across the DPS, thus all ratings for this factor are high. Under the lower scenario, we assume Swiss needle cast will increase in severity and extent all areas of the DPS, thus all ratings for this factor are low.

6.5. **Future Condition Ratings for Upper and Lower Scenarios**

6.5.1. *Rating Rationale:*

Similar to current condition, a high future population area resiliency rating would indicate high resilience to most threat factors considered in the future condition rating. There are two exceptions. The first exception is when the population area also has a low rating for vegetation shift (i.e., population areas in the Sitka spruce zone in the lower scenario), where we presume the population area would become extirpated due to loss of the primary food source. The second exception is where a population area with high resiliency rating would have a low Swiss needle cast rating. In this case we assume the tree disease could reduce overall future condition to a moderate level by reducing overall habitat quality in the unit. Population areas would also rate high if they had moderate resiliency rating, at least one high connectivity rating, and a high rating for vegetation shift and Swiss needle cast. The rationale is that while the population area is moderately resilient, there would be connectivity to other population areas which could increase future condition.

Population areas would rate moderate if they had a moderate population area resiliency rating, at least one high rating for connectivity, a high rating for vegetation shift, and low Swiss needle cast since that disease could impact the entire habitat to some degree. Population areas would also rate moderate if at least one connectivity rating was high, the vegetation shift rating was

either moderate or high, and Swiss needle cast was high. The rationale is that moderately resilient populations with some connectivity could maintain a moderate future condition if shifts in vegetation and threat from Swiss needle cast were not a factor.

A low condition category was given to population areas with a moderate population area resiliency rating with only one high connectivity rating, a moderate or high vegetation shift rating, and a low Swiss needle cast rating; or two low connectivity ratings, moderate or high vegetation shift ratings, and a high or low Swiss needle cast rating. The rationale is that while the population area has the capacity for a moderately resilient effective population size, it will either lack some connectivity or be negatively affected by Swiss needle cast so that it could not maintain moderate future condition. A low overall condition rating was also given to population areas with low resiliency rating that had at least one high connectivity rating, a high or moderate vegetation shift rating, and a high Swiss needle cast rating. The rationale is that if a low resiliency population area is still connected and not affected from vegetation shifts or Swiss needle cast, it could retain that low condition status, rather than becoming extirpated.

Population areas were presumed extirpated in the future if either they continued to be presumed unoccupied after the occupancy test; they had low population area resiliency rating and low connectivity, regardless of other high ratings; they had low population area resiliency rating and low Swiss needle cast, regardless of other high ratings; or they had low vegetation shift ratings, regardless of other high ratings. In each of these situations, population areas would either lack connectivity or be threatened by habitat changes such that their low condition could not be maintained or improve.

Rating rationale is summarized in Table A-11 and the results are presented in Tables A-12-14 and shown in Figures A-14-15.

Table A – 11. Future condition rating key. Ratings are assigned to each population area, except for overall future resiliency condition, which is an aggregated rating for the geographic unit. Some ratings, denoted in *italic font*, are specific to upper or lower scenarios. WH = western hemlock; SS = Sitka spruce; PA = population area.

Condition Category	Effective Population Size (N_e) Capacity (PA Rating)	Connectivity Potential Within Geographic Units	Connectivity Potential Between Geographic Units	Vegetation Shift	Swiss Needle Cast (SNC)	Overall Future Resiliency Condition <i>At least one population area (PA) in the unit meets the following criteria:</i>
High	> 1000	Separated from another population area by constrained forested lands, or (<i>in upper scenario only</i>) by <2 km of currently forested land	Another population area in adjacent unit is separated by constrained forested lands	Currently WH zone; <i>All ratings high in upper scenario</i>	<i>All ratings high in upper scenario</i>	1. N_e is high, vegetation shift is high or moderate and SNC is high, or 2. N_e is moderate, at least one connectivity factor is high, vegetation shift is high, and SNC is high
Moderate	> 100 and < 1000			Currently both WH and SS zones		1. N_e is high, vegetation shift is high or moderate, and SNC is low, or 2. N_e is moderate, at least one connectivity factor is high, vegetation shift is moderate or high, and SNC is high or low
Low	< 100	Separated from another population area by unconstrained forested lands	Another population area in adjacent unit is separated by unconstrained forested lands	Currently SS zone	<i>All ratings low in lower scenario</i>	1. N_e is moderate, at least one connectivity factor is high, vegetation shift is moderate or high, and SNC is low, or 2. N_e is moderate, both connectivity factors are low, vegetation shift is moderate or high, and SNC is high or low, or 3. N_e is low, at least one connectivity factor is high, and vegetation shift is moderate or high, and SNC is high
Presumed Extirpated						1. All PAs in the unit presumed unoccupied, or 2. All PAs low N_e and both connectivity factors are low, regardless of vegetation shift or SNC rating, or 3. All PAs low N_e low and SNC is low, regardless of other ratings, or 4. All PAs low vegetation shift ratings, regardless of other factors

Table A – 12. Upper scenario future condition rating results. Population area names with gray fill had unoccupied status and were not analyzed in current condition but are considered as potentially occupied in future condition. Blue represents a high rating (HI), yellow a moderate rating (MOD), red a low rating (LO), and dark gray presumed extirpated (EXT).

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
1. Lewis and Clark	Saddle Mountain Road	LO	LO	LO	HI	HI	EXT
2. Ecola/ Elmer Feldenheimer	Elmer Feldenheimer North	LO	LO	LO	HI	HI	EXT
3. Necanicum/ Nehalem	Oswald West	LO	LO	LO	HI	HI	EXT
4. North Fork Nehalem	Tillamook South Fork Nehalem North	LO	HI	LO	HI	HI	HI
	Rector Ridge	MOD	HI	LO	HI	HI	
5. Nehalem/Wilson	Tillamook South Fork Kichlis Middle	HI	HI	LO	HI	HI	HI
	Tillamook South Fork Kichlis North	MOD	HI	LO	HI	HI	
	Bay City Electric	LO	HI	LO	HI	HI	
	Tillamook South Fork Nehalem South	HI	HI	LO	HI	HI	
	Anderson Creek	MOD	HI	LO	HI	HI	
	Nestucca Block Wilson	HI	HI	HI		HI	
6. Cape Meares	Cape Meares	LO	LO	LO	HI	HI	LO

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
	Fall Short	LO	HI	LO	HI	HI	
	Hodgdon Creek	LO	HI	LO	HI	HI	
	O'Hara Creek	LO	HI	LO	HI	HI	
7. Sand Lake	Tierra Del Mar	MOD	HI	LO	HI	HI	HI
	Andy Creek	LO	HI	LO	HI	HI	
	South of Sandlake	LO	HI	LO	HI	HI	
	Cape Lookout West	LO	HI	LO	HI	HI	
	Cape Lookout North	LO	HI	LO	HI	HI	
	Cape Lookout South	LO	HI	LO	HI	HI	
8. Trask/Nestucca	Nestucca Block Trask	HI	HI	HI	HI	HI	HI
	Moon Creek Nestucca Block Inclusion	LO	HI	LO	HI	HI	
	East Beaver Creek	LO	HI	LO	HI	HI	
	Gopher	LO	HI	LO	HI	HI	
	Fawcett Creek	MOD	HI	LO	HI	HI	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
	Tillamook South Fork Kichlis South	MOD	LO	LO	HI	HI	
9. Gauldy Ridge	Nestucca Block Gauldy	MOD	LO	HI	HI	HI	HI
10. Little Nestucca/Salmon	Nestucca Block Salmon Coast	MOD	LO	HI	HI	HI	HI
11. Little Nestucca/Salmon Inland	Bower Creek	LO	HI	LO	HI	HI	HI
	Nestucca Block Salmon West	MOD	HI	HI	HI	HI	
	Nestucca Block Salmon East	MOD	HI	HI	HI	HI	
	“2006”	LO	HI	LO	HI	HI	
	Neskowin Creek West	LO	HI	LO	HI	HI	
	Neskowin Creek East	LO	HI	LO	HI	HI	
12. Siletz/Luckiamute	South Block Luckiamute	MOD	HI	HI	HI	HI	HI
	South Fork Teal Creek South Block Inclusion	LO	HI	LO	HI	HI	
	No-Name South Block Inclusion	LO	HI	LO	HI	HI	
	Middle Ridge South Block Inclusion	LO	HI	LO	HI	HI	
	McTimmonds Creek South Block Inclusion	LO	HI	LO	HI	HI	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
	Norton	LO	HI	LO	HI	HI	
	Potter Creek	LO	HI	LO	HI	HI	
	BLM Checkerboard	MOD	HI	LO	HI	HI	
	Salt Creek	LO	HI	LO	HI	HI	
	Nestucca Block Luckiamute	LO	LO	HI	HI	HI	
	Treat River	LO	LO	LO	HI	HI	
	Deadwood Mountain	MOD	HI	LO	HI	HI	
	Dry Creek	LO	HI	LO	HI	HI	
	North Fork Siletz	LO	HI	LO	HI	HI	
13. Yaquina/ Marys	South Block Yaquina	HI	HI	HI	HI	HI	HI
	Skunk Creek South Block Inclusion	LO	HI	LO	HI	HI	
	Bull Run Creek South Block Inclusion	LO	HI	LO	HI	HI	
14. Alsea/ Siuslaw	South Block Alsea	HI	LO	HI	HI	HI	HI
15. Siuslaw/ Long Tom	South Block Long Tom	MOD	LO	HI	HI	HI	HI

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
16. Siuslaw/Territorial	South Block Territorial	MOD	LO	HI	HI	HI	HI
17. Spencer Butte	Spencer Butte	MOD	LO	LO	HI	HI	LO

Table A – 13. Lower scenario future condition rating results. Population area names with gray fill indicate those which had unoccupied status and were not analyzed in current condition but are considered as potentially occupied in future condition. Blue represents a high rating (HI), yellow a moderate rating (MOD), red a low rating (LO), and dark gray presumed extirpated (EXT).

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
1. Lewis and Clark	Saddle Mountain Road	LO	LO	LO	MOD	LO	EXT
2. Ecola/ Elmer Feldenheimer	Elmer Feldenheimer North	LO	LO	LO	LO	LO	EXT
3. Necanicum/ Nehalem	Oswald West	LO	LO	LO	LO	LO	EXT
4. North Fork Nehalem	Tillamook South Fork Nehalem North	LO	HI	LO	LO	LO	
	Rector Ridge	LO	HI	LO	MOD	LO	
5. Nehalem/Wilson	Tillamook South Fork Kichlis Middle	LO	HI	LO	MOD	LO	MOD
	Tillamook South Fork Kichlis North	LO	HI	LO	MOD	LO	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
	Bay City Electric	LO	HI	LO	LO	LO	
	Tillamook South Fork Nehalem South	LO	HI	LO	MOD	LO	
	Anderson Creek	LO	HI	LO	MOD	LO	
	Nestucca Block Wilson	MOD	HI	HI	HI	LO	
6. Cape Meares	Cape Meares	LO	LO	LO	LO	LO	EXT
	Fall Short	LO	LO	LO	LO	LO	
	Hodgdon Creek	LO	LO	LO	LO	LO	
	O'Hara Creek	LO	LO	LO	LO	LO	
7. Sand Lake	Tierra Del Mar	LO	LO	LO	LO	LO	EXT
	Andy Creek	LO	LO	LO	LO	LO	
	South of Sandlake	LO	LO	LO	LO	LO	
	Cape Lookout West	LO	LO	LO	LO	LO	
	Cape Lookout North	LO	LO	LO	LO	LO	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
	Cape Lookout South	LO	LO	LO	LO	LO	
8. Trask/Nestucca	Nestucca Block Trask	MOD	HI	HI	HI	LO	MOD
	Moon Creek Nestucca Block Inclusion	LO	HI	LO	HI	LO	
	East Beaver Creek	LO	LO	LO	MOD	LO	
	Gopher	LO	LO	LO	HI	LO	
	Fawcett Creek	LO	HI	LO	MOD	LO	
	Tillamook South Fork Kichlis South	LO	LO	LO	MOD	LO	
9. Gauldy Ridge	Nestucca Block Gauldy	LO	LO	LO	MOD	LO	EXT
10. Little Nestucca/Salmon Coast	Nestucca Block Salmon Coast	LO	LO	LO	LO	LO	EXT
11. Little Nestucca/Salmon Inland	Bower Creek	LO	LO	LO	LO	LO	EXT
	Nestucca Block Salmon West	LO	LO	LO	LO	LO	
	Nestucca Block Salmon East	LO	LO	LO	MOD	LO	
	“2006”	LO	LO	LO	LO	LO	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
	Neskowin Creek West	LO	LO	LO	MOD	LO	
	Neskowin Creek East	LO	LO	LO	MOD	LO	
12. Siletz/ Luckiamute	South Block Luckiamute	LO	LO	LO	HI	LO	
	South Fork Teal Creek South Block Inclusion	LO	LO	LO	HI	LO	
	No-Name South Block Inclusion	LO	LO	LO	HI	LO	
	Middle Ridge South Block Inclusion	LO	LO	LO	HI	LO	
	McTimmonds Creek South Block Inclusion	LO	LO	LO	HI	LO	
	Norton	LO	LO	LO	MOD	LO	
	Potter Creek	LO	LO	LO	HI	LO	
	BLM Checkerboard	LO	LO	LO	HI	LO	
	Salt Creek	LO	LO	LO	HI	LO	
	Nestucca Block Luckiamute	LO	LO	LO	LO	LO	
	Treat River	LO	LO	LO	MOD	LO	

Geographic Unit	Population Area	Population Area Resiliency	Connectivity Within Geographic Unit	Connectivity Between Geographic Units	Vegetation Shift	Swiss Needle Cast	Overall Resiliency Rating for Unit
	Deadwood Mountain	MOD	LO	LO	MOD	LO	
	Dry Creek	LO	LO	LO	LO	LO	
	North Fork Siletz	LO	LO	LO	HI	LO	
13. Yaquina/ Marys	South Block Yaquina	MOD	LO	HI	HI	LO	MOD
	Skunk Creek South Block Inclusion	LO	LO	LO	HI	LO	
	Bull Run Creek South Block Inclusion	LO	LO	LO	HI	LO	
14. Alsea/ Siuslaw	South Block Alsea	HI	LO	HI	MOD	LO	MOD
15. Siuslaw/ Long Tom	South Block Long Tom	MOD	LO	HI	HI	LO	MOD
16. Siuslaw/ Territorial	South Block Territorial	MOD	LO	HI	HI	LO	MOD
17. Spencer Butte	Spencer Butte	LO	LO	LO	HI	LO	LO

Table A – 14. Current and future condition summary by geographic unit. Blue represents a high rating (HI), yellow a moderate rating (MOD), orange a moderate low rating (MOD LO – used in current condition only), red a low rating (LO), and dark gray represents presumed extirpated (EXT).

Geographic Unit	Current	Future Upper Scenario	Future Lower Scenario
1. Lewis and Clark	LO	EXT	EXT
2. Ecola/ Elmer Feldenheimer	LO	EXT	EXT
3. Necanicum/ Nehalem	LO	EXT	EXT
4. North Fork Nehalem	LO	HI	EXT
5. Nehalem/Wilson	MOD	HI	MOD
6. Cape Meares	MOD LO	LO	EXT
7. Sand Lake	MOD	HI	EXT
8. Trask/Nestucca	HI	HI	MOD
9. Gauldy Ridge	MOD	HI	EXT
10. Little Nestucca/Salmon Coast	MOD	HI	EXT
11. Little Nestucca/Salmon Inland	MOD	HI	EXT
12. Siletz/ Luckiamute	HI	HI	LO
13. Yaquina/ Marys	HI	HI	MOD
14. Alsea/ Siuslaw	HI	HI	MOD
15. Siuslaw/ Long Tom	HI	HI	MOD
16. Siuslaw/ Territorial	HI	HI	MOD
17. Spencer Butte	MOD	LO	LO

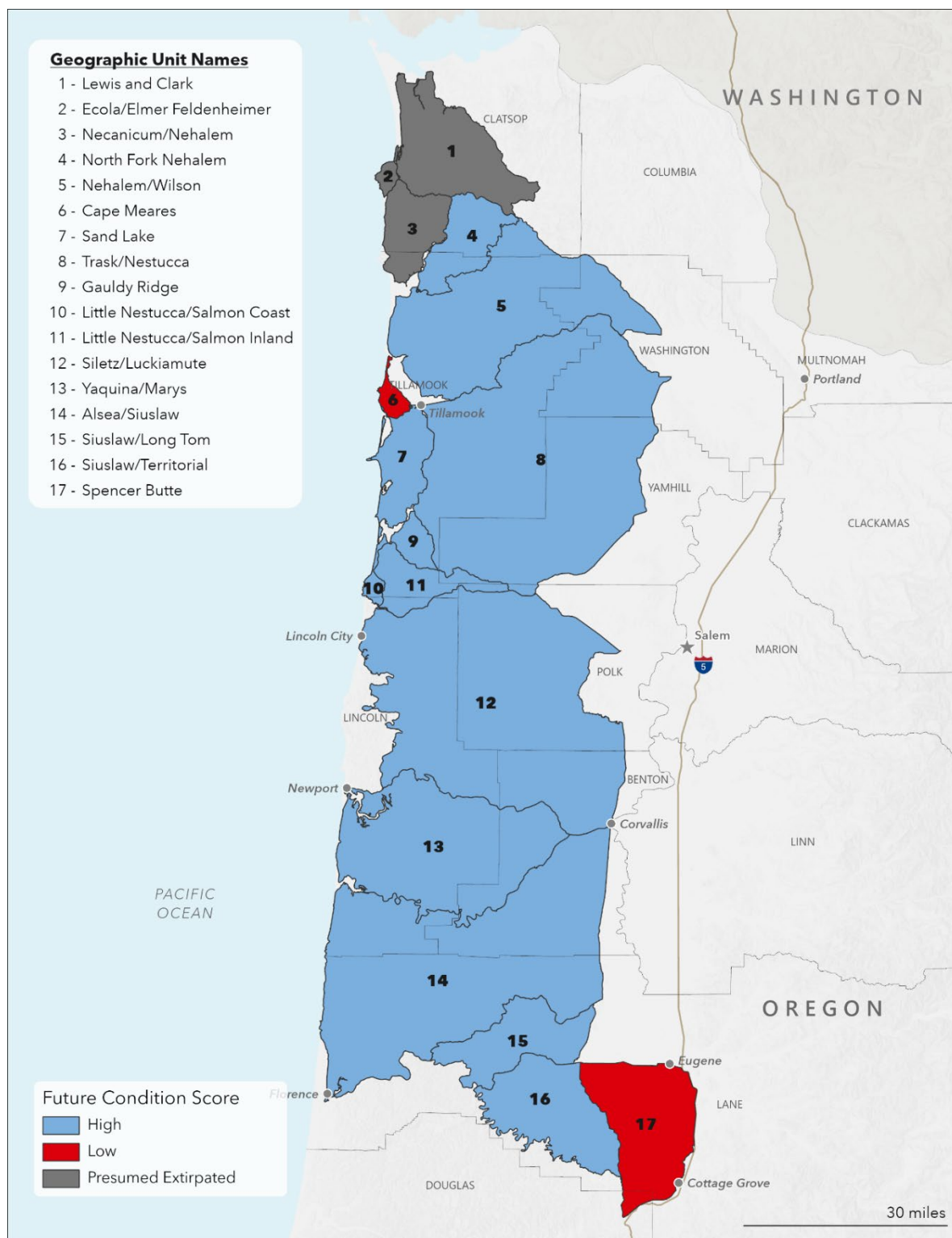


Figure A – 14. Future condition upper scenario ratings by geographic unit. The upper plausible future condition scenario incorporates the higher values of the demographic features, a higher connectivity assumption, and lower potential impacts from Swiss needle cast and vegetation shifts..

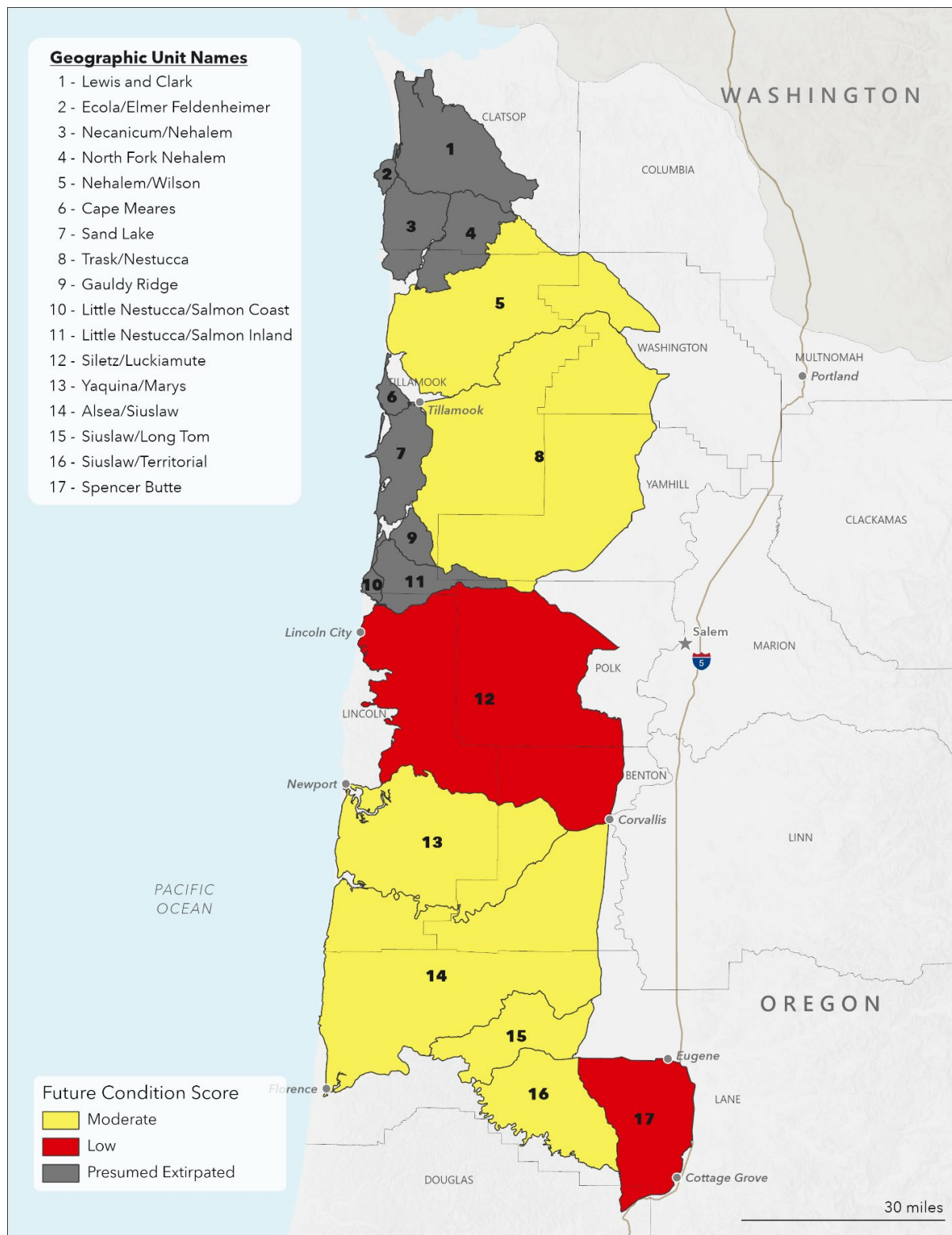


Figure A – 15. Future condition lower scenario ratings by geographic unit. The lower plausible future condition scenario incorporates lower values of the demographic features, assumptions of less connectivity, and assumptions of higher potential impacts from Swiss needle cast and vegetation shifts.

7. Analysis of Vegetation Zones for Representation

We used Potential Natural Vegetation (USDA FS 2021, in litt.) vegetation zones (Figure A–16) to determine which of population areas and geographic units contained the behavioral diversity in foraging capability in response to the availability of different coniferous species (see SSA section 3.4.2 Diet). We considered a population area containing a vegetation zone if >10% of the area was in that zone. For population areas with >10% of both vegetation zones, we recorded it having both zones. To derive a unit rating we aggregated the population area ratings.

For current representation, we used the 52 population areas and 17 geographic units considered in the current condition. For future potential representation, we included the same four previously unoccupied population areas in current condition that moved forward in the future condition resiliency analysis and rescored representation. Note that the inclusion of the four previously considered unoccupied population areas ultimately did not change any of the geographic unit results. In the North Fork Nehalem unit, the addition of the Rector Ridge population area did not change the overall rating of that unit as Sitka spruce zone, even though Rector Ridge was determined to contain both zones. This is because the source population for Rector Ridge would be the Tillamook South Fork Nehalem North population area, which is in the Sitka spruce zone. Results are shown in Tables A–15 and A–16 and Figures A–17–20.

Table A – 15. Representation for current condition. Yellow represents areas primarily in the western hemlock zone, green represents areas primarily in the Sitka spruce zone and purple represents areas or units with both western hemlock and Sitka spruce zones.

Geographic Unit	Population Area	Population Area Vegetation Zone	Geographic Unit Representation
1. Lewis and Clark	Saddle Mountain Road	Both	Both
2. Ecola/ Elmer Feldenheimer	Elmer Feldenheimer North	Sitka Spruce	Sitka Spruce
3. Necanicum/ Nehalem	Oswald West	Sitka Spruce	Sitka Spruce
4. North Fork Nehalem	Tillamook South Fork Nehalem North	Sitka Spruce	Sitka Spruce
5. Nehalem/Wilson	Tillamook South Fork Kichlis Middle	Both	Both
	Tillamook South Fork Kichlis North	Both	
	Tillamook South Fork Nehalem South	Both	
	Anderson Creek	Both	
6. Cape Meares	Cape Meares	Sitka Spruce	Sitka Spruce
	Fall Short	Sitka Spruce	
	Hodgdon Creek	Sitka Spruce	
	O'Hara Creek	Sitka Spruce	
7. Sand Lake	Tierra Del Mar	Sitka Spruce	Sitka Spruce

Geographic Unit	Population Area	Population Area Vegetation Zone	Geographic Unit Representation
	Andy Creek	Sitka Spruce	
	South of Sandlake	Sitka Spruce	
	Cape Lookout West	Sitka Spruce	
	Cape Lookout North	Sitka Spruce	
	Cape Lookout South	Sitka Spruce	
8. Trask/Nestucca	Nestucca Block Trask	Western Hemlock	Both
	Moon Creek Nestucca Block Inclusion	Western Hemlock	
	East Beaver Creek	Both	
	Gopher	Western Hemlock	
	Tillamook South Fork Kichlis South	Both	
9. Gauldy Ridge	Nestucca Block Gauldy	Both	Both
10. Little Nestucca/ Salmon Coast	Nestucca Block Salmon Coast	Sitka Spruce	Sitka Spruce
11. Little Nestucca/Salmon Inland	Bower Creek	Sitka Spruce	Both
	Nestucca Block Salmon West	Sitka Spruce	
	Nestucca Block Salmon East	Both	
	“2006”	Sitka Spruce	
	Neskowin Creek West	Both	
	Neskowin Creek East	Both	
12. Siletz/ Luckiamute	South Block Luckiamute	Western Hemlock	Both
	South Fork Teal Creek South Block Inclusion	Western Hemlock	
	No-Name South Block Inclusion	Western Hemlock	
	Middle Ridge South Block Inclusion	Western Hemlock	
	McTimmonds Creek South Block Inclusion	Western Hemlock	
	Norton	Both	
	Potter Creek	Western Hemlock	
	BLM Checkerboard	Western Hemlock	
	Salt Creek	Western Hemlock	
	Nestucca Block Luckiamute	Sitka Spruce	
	Treat River	Both	
	Deadwood Mountain	Both	
	Dry Creek	Sitka Spruce	
	North Fork Siletz	Western Hemlock	
13. Yaquina/ Marys	South Block Yaquina	Both	Both

Geographic Unit	Population Area	Population Area Vegetation Zone	Geographic Unit Representation
	Skunk Creek South Block Inclusion	Western Hemlock	
	Bull Run Creek South Block Inclusion	Western Hemlock	
14. Alsea/ Siuslaw	South Block Alsea	Both	Both
15. Siuslaw/ Long Tom	South Block Long Tom	Western Hemlock	Western Hemlock
16. Siuslaw/ Territorial	South Block Territorial	Western Hemlock	Western Hemlock
17. Spencer Butte	Spencer Butte	Western Hemlock	Western Hemlock

Table A – 16. Representation for future condition. Yellow represents areas primarily in the western hemlock zone, green represents areas primarily in the Sitka spruce zone and purple represents areas or units with both zones. Note that the inclusion of the four previously considered unoccupied population areas (shown by gray fill) changed only one roll-up result, for the North Fork Nehalem unit.

Geographic Unit	Population Area	Population Area Vegetation Zone	Geographic Unit Potential Representation
1. Lewis and Clark	Saddle Mountain Road	Both	Both
2. Ecola/ Elmer Feldenheimer	Elmer Feldenheimer North	Sitka Spruce	Sitka Spruce
3. Necanicum/ Nehalem	Oswald West	Sitka Spruce	Sitka Spruce
4. North Fork Nehalem	Tillamook South Fork Nehalem North	Sitka Spruce	Sitka Spruce
	Rector Ridge	Both	
5. Nehalem/Wilson	Tillamook South Fork Kichlis Middle	Both	Both
	Tillamook South Fork Kichlis North	Both	
	Bay City Electric	Sitka Spruce	
	Tillamook South Fork Nehalem South	Both	
	Anderson Creek	Both	
	Nestucca Block Wilson	Western Hemlock	
6. Cape Meares	Cape Meares	Sitka Spruce	Sitka Spruce
	Fall Short	Sitka Spruce	
	Hodgdon Creek	Sitka Spruce	
	O'Hara Creek	Sitka Spruce	
7. Sand Lake	Tierra Del Mar	Sitka Spruce	Sitka Spruce

Geographic Unit	Population Area	Population Area Vegetation Zone	Geographic Unit Potential Representation
	Andy Creek	Sitka Spruce	
	South of Sandlake	Sitka Spruce	
	Cape Lookout West	Sitka Spruce	
	Cape Lookout North	Sitka Spruce	
	Cape Lookout South	Sitka Spruce	
8. Trask/Nestucca	Nestucca Block Trask	Western Hemlock	Both
	Moon Creek Nestucca Block Inclusion	Western Hemlock	
	East Beaver Creek	Both	
	Gopher	Western Hemlock	
	Fawcett Creek	Both	
	Tillamook South Fork Kichlis South	Both	
9. Gauldy Ridge	Nestucca Block Gauldy	Both	Both
10. Little Nestucca/Salmon Coast	Nestucca Block Salmon Coast	Sitka Spruce	Sitka Spruce
11. Little Nestucca/Salmon Inland	Bower Creek	Sitka Spruce	Both
	Nestucca Block Salmon West	Sitka Spruce	
	Nestucca Block Salmon East	Both	
	“2006”	Sitka Spruce	
	Neskowin Creek West	Both	
	Neskowin Creek East	Both	
12. Siletz/Luckiamute	South Block Luckiamute	Western Hemlock	
	South Fork Teal Creek South Block Inclusion	Western Hemlock	
	No-Name South Block Inclusion	Western Hemlock	
	Middle Ridge South Block Inclusion	Western Hemlock	
	McTimmonds Creek South Block Incl.	Western Hemlock	
	Norton	Both	
	Potter Creek	Western Hemlock	
	BLM Checkerboard	Western Hemlock	
	Salt Creek	Western Hemlock	
	Nestucca Block Luckiamute	Sitka Spruce	
	Treat River	Both	
	Deadwood Mountain	Both	
	Dry Creek	Sitka Spruce	
	North Fork Siletz	Western Hemlock	
13. Yaquina/	South Block Yaquina	Both	Both

Geographic Unit	Population Area	Population Area Vegetation Zone	Geographic Unit Potential Representation
Marys	Skunk Creek South Block Inclusion	Western Hemlock	
	Bull Run Creek South Block Inclusion	Western Hemlock	
14. Alsea/ Siuslaw	South Block Alsea	Both	Both
15. Siuslaw/ Long Tom	South Block Long Tom	Western Hemlock	Western Hemlock
16. Siuslaw/ Territorial	South Block Territorial	Western Hemlock	Western Hemlock
17. Spencer Butte	Spencer Butte	Western Hemlock	Western Hemlock

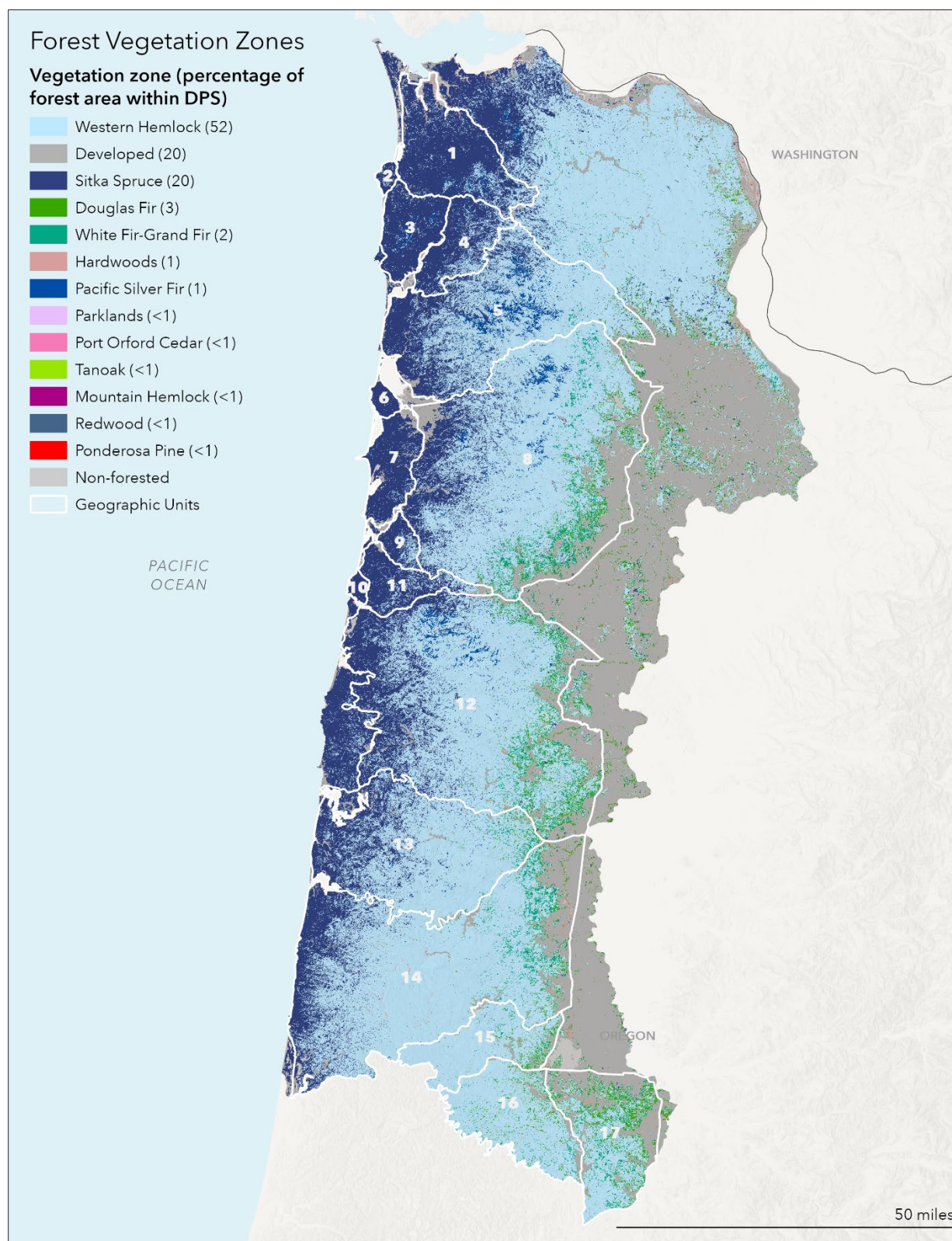


Figure A – 16. Potential Natural Vegetation (USDA FS 2021, in litt.) vegetation zones in the DPS by tree vole geographic unit.

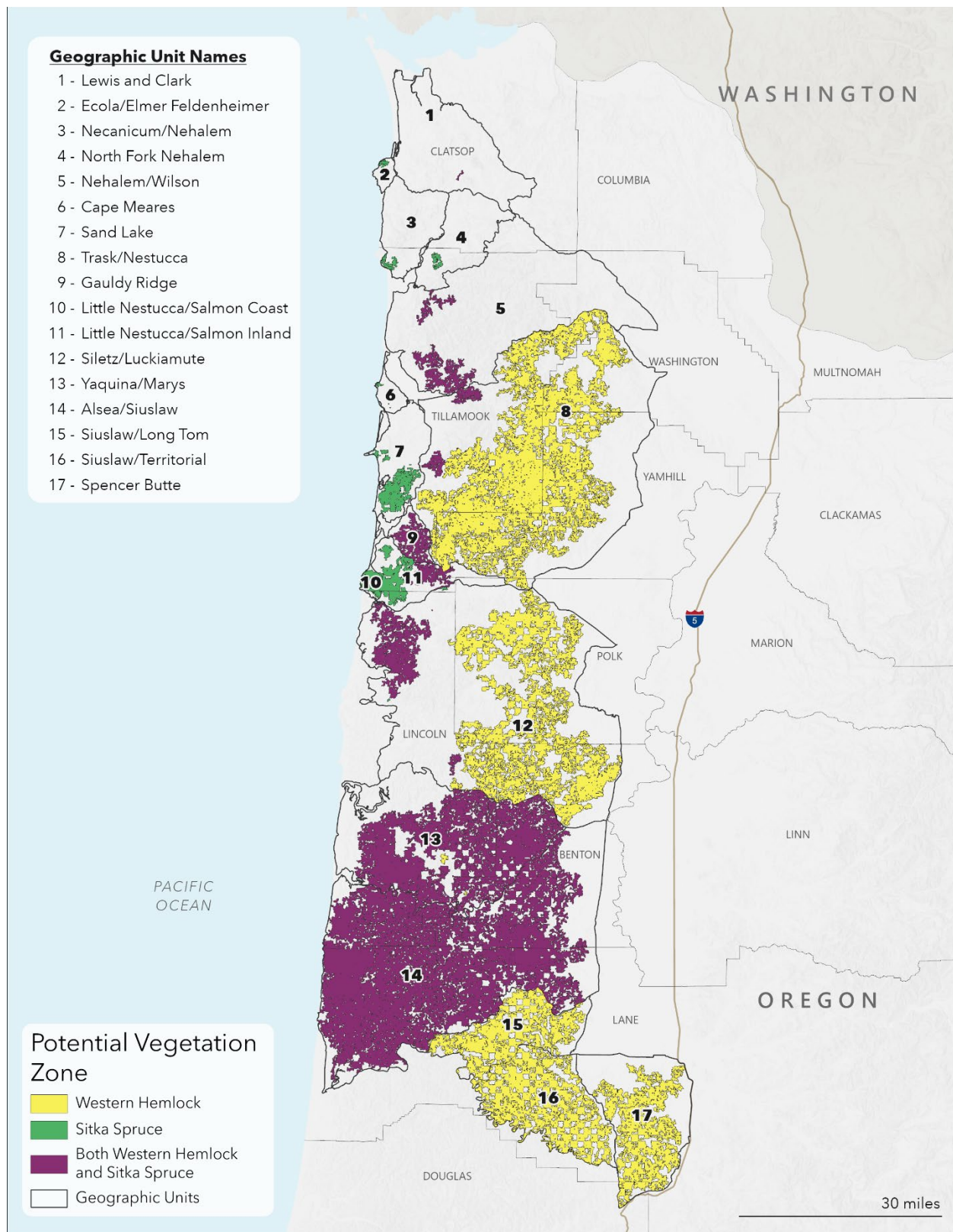


Figure A – 17. Representation in current condition by population area.



Figure A – 18. Representation in current condition by geographic unit.

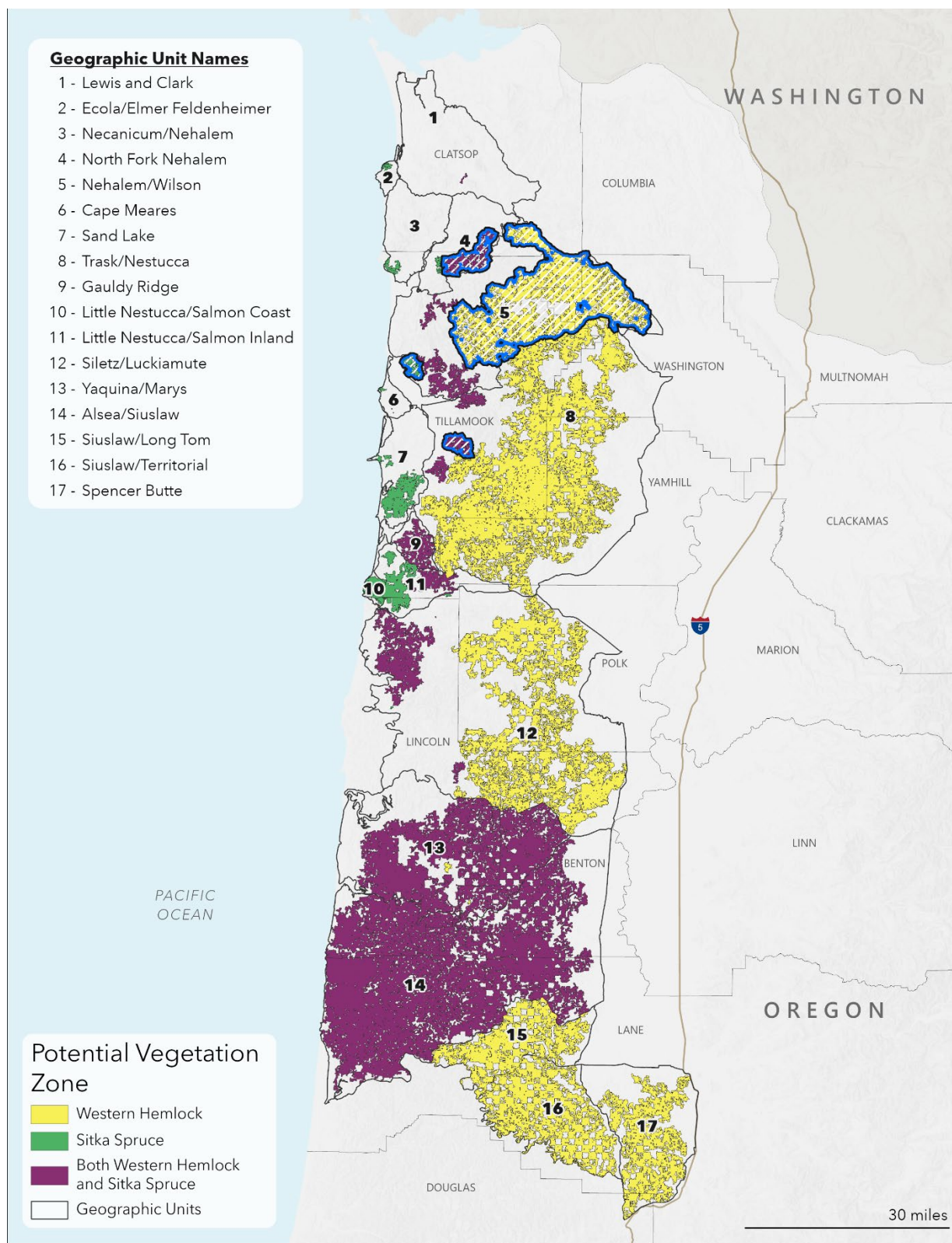


Figure A – 19. Representation in future condition by population area. Note the four additional population areas in darker blue outline in units 4, 5, and 8 that were added to the future condition analysis.

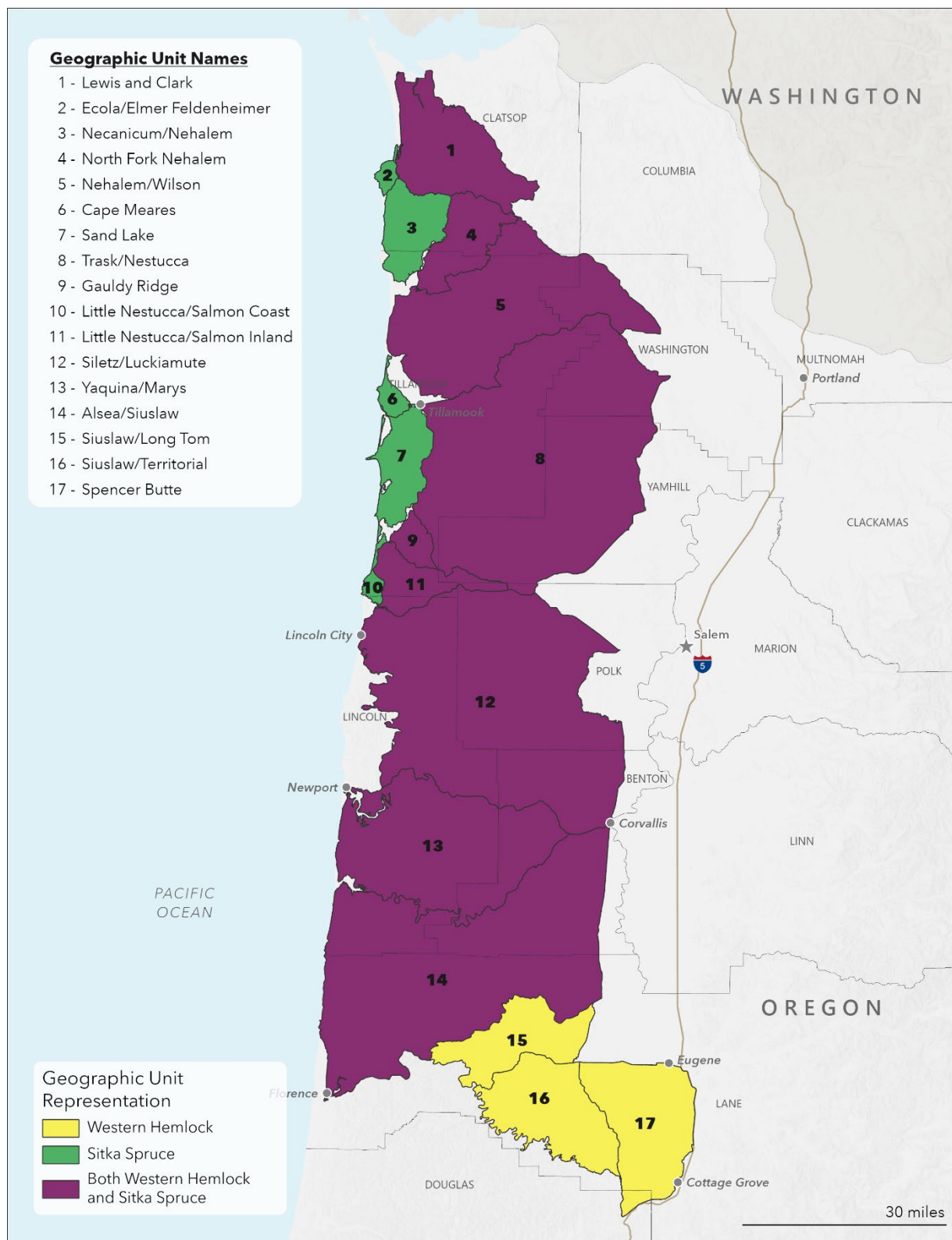


Figure A – 20. Representation in future condition by geographic unit.

8. Analysis of Wildfire for Redundancy

Redundancy is similar in current and future conditions in that the species is vulnerable to catastrophic, stand-replacing events such as wildfire. However, the size, likelihood and severity of wildfires is likely to change in the future given climate change projections. We analyzed potential fire size, relative suitability for fire, and potential severity as measured by the land management type and at the geographic unit scale, in an upper and lower scenario. This provided sideboards to discuss a qualified range of plausible wildfire risk to redundancy.

We assumed that fire suppression would continue to occur and to be effective in typical fire season conditions. However, under extreme fire conditions, which are the conditions most likely to lead to large, severe fires like those that have occurred historically in the Oregon Coast Range (Abatzoglou et al. 2021, pp. 6–7; Reilly et al. 2022, pp. 5–7), firefighting is more dangerous and less effective, and firefighting resources may already be strained by fires occurring in more fire-prone areas, as occurred with the 2020 Labor Day fires in western Oregon (Abatzoglou et al. 2021, p. 1; Shuman et al. 2022, p. 3). Therefore, we did not assume that large severe fires would be effectively suppressed in the future.

8.1. Size

We used the larger and smaller of two fires from the past 200 years of the most catastrophic wildfires, the Nestucca fire of the mid-1800s (1,200 km²) and a 3,250 km² fire from the mid-1800s (Figure A–21). This represents a plausible range of catastrophic fires based on historical events. We juxtaposed a fire of the appropriate size on each geographic unit. Each unit has varying amounts of current habitat so we assume in the future it could mostly be habitat for some of the units or at the very least a large severe fire would inhibit growth of habitat for many decades. A low rating (LO) was given for a fire that would be larger than a unit, a moderate rating (MOD) for a fire size that could encompass more than half of unit size, and a high rating (HI) for a fire size that would cover less than half of unit size (Table A–17).

Table A – 17. Potential effect of future fire sizes on geographic units under two fire sizes scenarios.

Unit Number and Name		Unit Size km ²	Upper Scenario Rating	Lower Scenario Rating
1	Lewis and Clark	582	LO	LO
2	Ecola/Elmer Feldenheimer	30	LO	LO
3	Necanium/Nehalem	256	LO	LO
4	North Fork Nehalem	282	LO	LO
5	Nehalem/Wilson	1292	MOD	LO
6	Cape Meares	46	LO	LO
7	Sand Lake	261	LO	LO
8	Trask/Nestucca	2661	HI	LO
9	Gauldy Ridge	85	LO	LO

10	Little Nestucca/Salmon Coast	36	<i>LO</i>	<i>LO</i>
11	Little Nestucca/Salmon Inland	225	<i>LO</i>	<i>LO</i>
12	Siletz/Luckiamute	2571	<i>HI</i>	<i>LO</i>
13	Yaquina/Marys	1246	<i>MOD</i>	<i>LO</i>
14	Alsea/Siuslaw	2415	<i>HI</i>	<i>LO</i>
15	Siuslaw/Long Tom	411	<i>LO</i>	<i>LO</i>
16	Siuslaw/Territorial	561	<i>LO</i>	<i>LO</i>
17	Spencer Butte	641	<i>LO</i>	<i>LO</i>

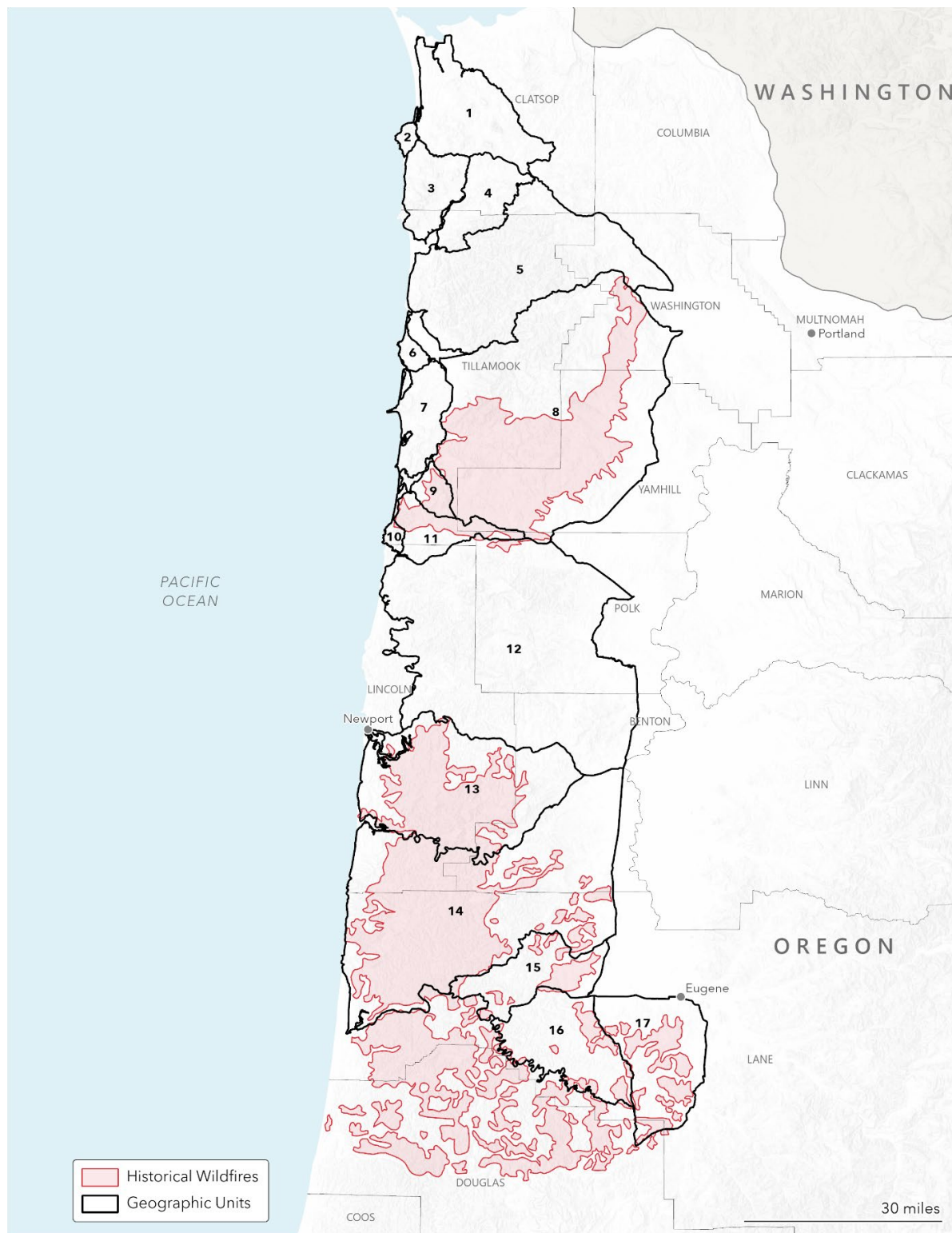


Figure A – 21. Historical (last 200 years) fire sizes used in redundancy analysis. The northern fire perimeter is the Nestucca fire of the mid-1800s (1,200 km²). The southern fire represents the fires or fire complex from the mid-1800s fires (3,250 km²), the most catastrophic series of fires in the past 200 years.

8.2. Relative Suitability

The likelihood of large fires may vary across the DPS, especially given the relatively warmer and drier conditions in the southeastern portion of the DPS (i.e., Spencer Butte, Siuslaw/Territorial, and Siuslaw/Long Tom geographic units), compared with the wetter and cooler conditions along the coast and in the northern portion of the DPS. To help us understand the magnitude of this variability, we used a model of suitability for large fires, projected to the climate period surrounding 2080 for the RCP 8.5 scenario (Davis et al. 2017 and associated GIS data). We also ran the current (2020) time period as a comparison. This model provides a relative suitability rating for large fires for each 30 m x 30 m pixel across the DPS. We averaged the pixel scores across each geographic unit, then categorized each unit as having low, moderate, or high suitability as follows: a high rating (HI) was given for geographic units with low average suitability (less than 0.37), where large wildfires are projected to occur less often than expected if wildfires were randomly distributed; a moderate rating (MOD) for geographic units with moderate average suitability (between 0.37 and 0.65) where large wildfires are projected to occur slightly more often than expected; and a low rating (LO) for geographic units with high average suitability (greater than 0.65), where large wildfires are projected to occur much more often than expected (Davis et al. 2017, pp. 177–178) (Table A–18).

Table A – 18. Ratings for relative suitability by geographic units to current (2020) and future (2080) large fires.

Unit Number and Name		Suitability Value 2020	Suitability Rating 2020	Suitability Value 2080	Suitability Rating 2080
1	Lewis and Clark	0.016	HI	0.054	HI
2	Ecola/ Elmer Feldenheimer	0.022	HI	0.067	HI
3	Necanium/ Nehalem	0.018	HI	0.063	HI
4	North Fork Nehalem	0.028	HI	0.095	HI
5	Nehalem/Wilson	0.098	HI	0.240	HI
6	Cape Meares	0.018	HI	0.056	HI
7	Sand Lake	0.023	HI	0.069	HI
8	Trask/Nestucca	0.108	HI	0.231	HI
9	Gauldy Ridge	0.037	HI	0.108	HI
10	Little Nestucca/ Salmon Coast	0.040	HI	0.115	HI
11	Little Nestucca/ Salmon Inland	0.034	HI	0.089	HI
12	Siletz/Luckiamute	0.112	HI	0.240	HI
13	Yaquina/Marys	0.119	HI	0.263	HI
14	Alsea/Siuslaw	0.171	HI	0.330	HI
15	Siuslaw/Long Tom	0.281	HI	0.470	MOD
16	Siuslaw/Territorial	0.258	HI	0.434	MOD
17	Spencer Butte	0.153	HI	0.277	HI

8.3. Severity

Different forest management regimes can affect fire severity (see SSA section 7.1.5). In general, fire is more severe on early seral forests on private land. While we expect that catastrophic large fires within the DPS will generally be severe, with stand replacement occurring in a large proportion of the burned area, public lands may include some fire refugia that provide pockets of reduced burn severity, primarily because they contain old forest (see SSA section 7.1.5). Therefore, we assume units with primarily public land will have less severe wildfires than those with primarily private land and that the severity of fires in those units with a mixture of both land types would be intermediate.

We included State lands as public because of ODF's goal for a 70 to 90-year timber harvest rotation and planting multiple tree species. A high rating (HI) was given for a unit with a majority of public land (greater than 65%), a moderate rating (MOD) was given for a unit with a moderate amount of public land (33-65%), and a low rating (LO) was given for a unit with a minor amount (less than 33%) of public land (Table A-19).

Table A – 19. Ratings for potential future fire severity by geographic unit.

Unit Number and Name		Percent of unit in public land	Percent of unit in private land	Severity Rating
1	Lewis and Clark	6.1	93.9	<i>LO</i>
2	Ecola/Elmer Feldenheimer	2.0	98.0	<i>LO</i>
3	Necanium/Nehalem	4.6	95.4	<i>LO</i>
4	North Fork Nehalem	54.0	46.0	<i>MOD</i>
5	Nehalem/Wilson	65.3	34.7	<i>HI</i>
6	Cape Meares	1.1	98.9	<i>LO</i>
7	Sand Lake	25.9	74.1	<i>LO</i>
8	Trask/Nestucca	43.2	55.2	<i>MOD</i>
9	Gauldy Ridge	63.9	36.1	<i>MOD</i>
10	Little Nestucca/Salmon Coast	68.0	32.0	<i>HI</i>
11	Little Nestucca/Salmon Inland	37.5	61.3	<i>MOD</i>
12	Siletz/Luckiamute	17.2	82.0	<i>LO</i>
13	Yaquina/Marys	43.7	56.3	<i>MOD</i>
14	Alsea/Siuslaw	57.8	42.1	<i>MOD</i>
15	Siuslaw/Long Tom	38.3	61.7	<i>MOD</i>
16	Siuslaw/Territorial	38.1	61.9	<i>MOD</i>
17	Spencer Butte	8.7	91.3	<i>LO</i>

8.4. Synthesis of Fire Information and Redundancy

We assume that a unit will have the greatest contribution to redundancy if it includes highly resilient tree vole populations, is large enough that substantial amounts of habitat will be outside of even very large fire perimeters, will maintain low suitability for large fires, and is primarily made up of public lands that will provide some degree of fire refugia. We considered that units would have a high contribution to redundancy if they were highly resilient and rated well on two of the three fire factors, and moderate on the third. We considered that units would have a moderate to high contribution if they had good ratings on three of the resiliency and fire factors and a poor rating on the last factor, or good ratings on two factors and moderate ratings on two factors. We considered that units would have a moderate contribution toward redundancy if two ratings were good, and the remaining two were moderate and poor. We considered that units would have a moderate to low contribution if they had two high ratings and two low ratings, if they had two moderate ratings and the remaining two were high and low, or if they had three moderate ratings and one low rating. We expect only a weak contribution toward redundancy from units with three low ratings and one higher rating. Finally, we did not expect extirpated units to contribute at all. Tables A–20 and A–21 and Figures A–22 and 23 summarize this information for the upper and lower scenarios, respectively.

Table A – 20. Summary of fire ratings under the upper scenario.

Unit Number and Name		<i>Upper Resiliency Rating</i>	<i>Upper Size Rating</i>	<i>Suitability Rating</i>	<i>Severity Rating</i>	<i>Upper Summary</i>
1	Lewis and Clark	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>EXT</i>
2	Ecola/Elmer Feldenheimer	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>EXT</i>
3	Necanium/Nehalem	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>EXT</i>
4	North Fork Nehalem	<i>HI</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>MOD</i>
5	Nehalem/Wilson	<i>HI</i>	<i>MOD</i>	<i>HI</i>	<i>HI</i>	<i>HI</i>
6	Cape Meares	<i>LO</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>LO</i>
7	Sand Lake	<i>HI</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>MOD LO</i>
8	Trask/Nestucca	<i>HI</i>	<i>HI</i>	<i>HI</i>	<i>MOD</i>	<i>HI</i>
9	Gauldy Ridge	<i>HI</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>MOD</i>
10	Little Nestucca/Salmon Coast	<i>HI</i>	<i>LO</i>	<i>HI</i>	<i>HI</i>	<i>MOD HI</i>
11	Little Nestucca/Salmon Inland	<i>HI</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>MOD</i>
12	Siletz/Luckiamute	<i>HI</i>	<i>HI</i>	<i>HI</i>	<i>LO</i>	<i>MOD HI</i>
13	Yaquina/Marys	<i>HI</i>	<i>MOD</i>	<i>HI</i>	<i>MOD</i>	<i>MOD HI</i>
14	Alsea/Siuslaw	<i>HI</i>	<i>HI</i>	<i>HI</i>	<i>MOD</i>	<i>HI</i>
15	Siuslaw/Long Tom	<i>HI</i>	<i>LO</i>	<i>MOD</i>	<i>MOD</i>	<i>MOD LO</i>
16	Siuslaw/Territorial	<i>HI</i>	<i>LO</i>	<i>MOD</i>	<i>MOD</i>	<i>MOD LO</i>
17	Spencer Butte	<i>LO</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>LO</i>

Table A – 21. Summary of fire ratings under the lower scenario.

Unit Number and Name		<i>Lower Resiliency Rating</i>	<i>Lower Size Rating</i>	<i>Suitability Rating</i>	<i>Severity Rating</i>	<i>Lower Summary</i>
1	Lewis and Clark	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>EXT</i>
2	Ecola/Elmer Feldenheimer	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>EXT</i>
3	Necanium/Nehalem	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>EXT</i>
4	North Fork Nehalem	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>EXT</i>
5	Nehalem/Wilson	<i>MOD</i>	<i>LO</i>	<i>HI</i>	<i>HI</i>	<i>MOD</i>
6	Cape Meares	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>EXT</i>
7	Sand Lake	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>EXT</i>
8	Trask/Nestucca	<i>MOD</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>MOD LO</i>
9	Gauldy Ridge	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>EXT</i>
10	Little Nestucca/Salmon Coast	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>HI</i>	<i>EXT</i>
11	Little Nestucca/Salmon Inland	<i>EXT</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>EXT</i>
12	Siletz/Luckiamute	<i>LO</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>LO</i>
13	Yaquina/Marys	<i>MOD</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>MOD LO</i>
14	Alsea/Siuslaw	<i>MOD</i>	<i>LO</i>	<i>HI</i>	<i>MOD</i>	<i>MOD LO</i>
15	Siuslaw/Long Tom	<i>MOD</i>	<i>LO</i>	<i>MOD</i>	<i>MOD</i>	<i>MOD LO</i>
16	Siuslaw/Territorial	<i>MOD</i>	<i>LO</i>	<i>MOD</i>	<i>MOD</i>	<i>MOD LO</i>
17	Spencer Butte	<i>LO</i>	<i>LO</i>	<i>HI</i>	<i>LO</i>	<i>LO</i>

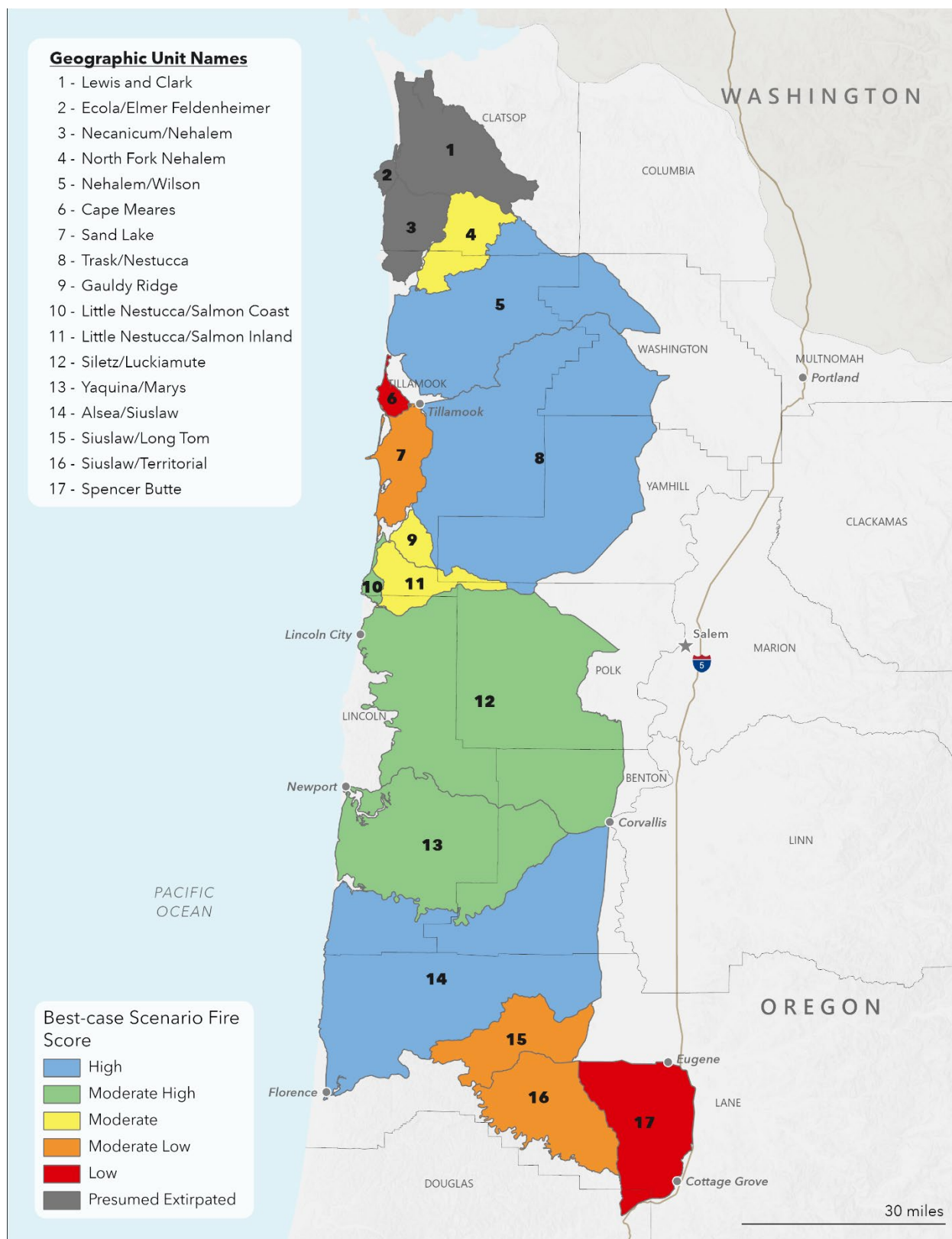


Figure A – 22. Wildfire synthesis ratings for upper scenario.

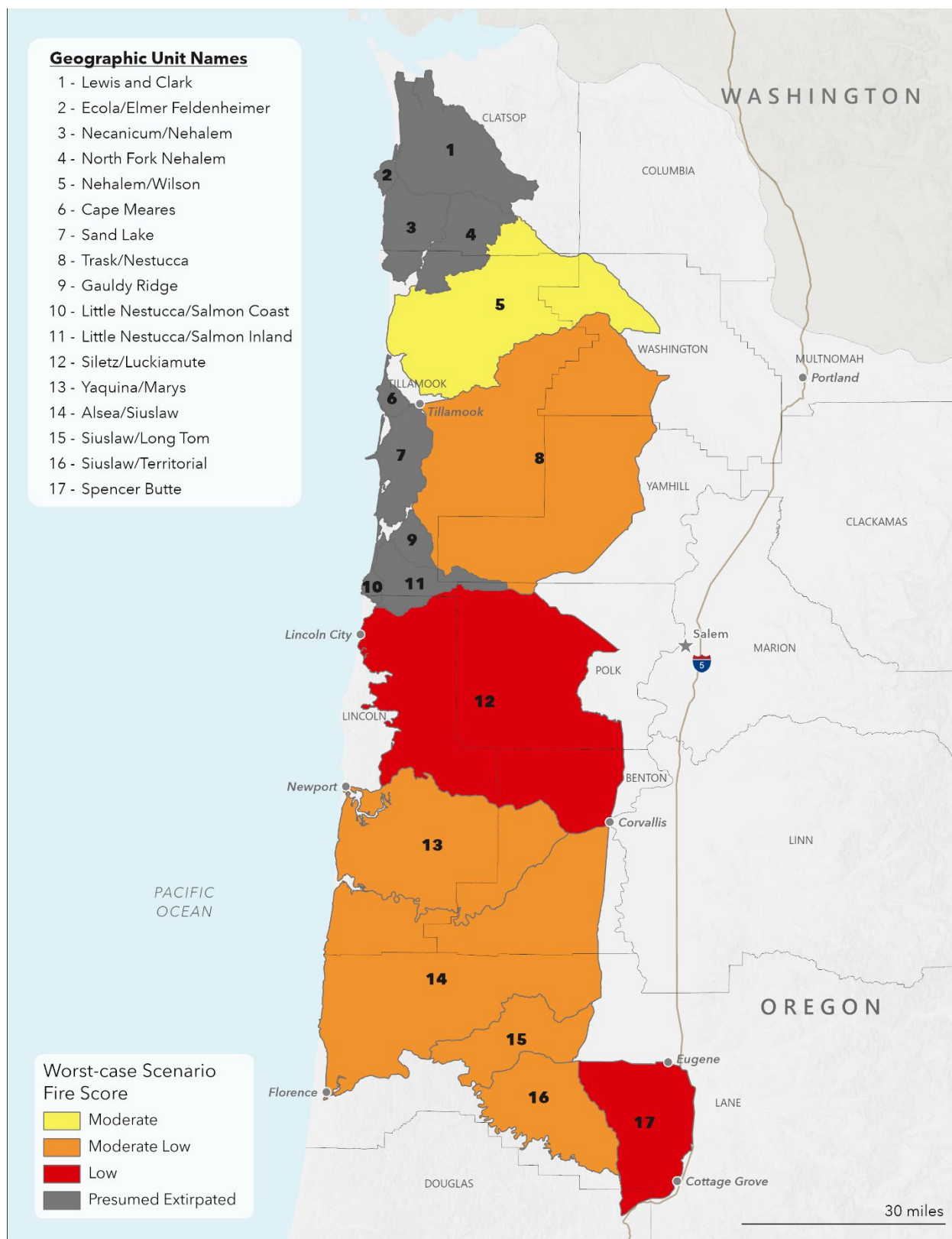


Figure A – 23. Wildfire synthesis ratings for lower scenario.

Literature Cited

- Bell, D.M., S.A. Acker, M.J. Gregory, R.J. Davis, and B.A. Garcia. 2021. Quantifying regional trends in large live tree and snag availability in support of forest management. *For. Ecol. Manag.* 479: 1–10.
- Biswell, B.L. 1996. Intertree movements and spatial distribution of nest trees occupied by individual red tree voles: implications for conservation. *Proceedings of the Society for Northwest Vertebrate Biology*. Abstract.
- Biswell, B.L. 2005. Email forward. B Biswell to J Swingle RE: Poster abstract for 1994 Mammal Society Meeting: Intertree movement and spatial distribution of nest trees occupied by individual red tree voles: implications for conservation.
- Borrecco, J.E. 1972. The response of animals to herbicide-induced habitat changes. PhD Thesis. Oregon State University. 1–104 pp.
- Corn, P.S., and R.B. Bury. 1986. Habitat use and terrestrial activity by red tree voles (*Arborimus longicaudus*) in Oregon. *J. Mammal.* 67: 404–406.
- Crookston, N.L., G.E. Rehfeldt, G.E. Dixon, and A.R. Weiskittel. 2010. Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. *For. Ecol. Manag.* 260: 1198–1211.
- Davis, R., Z. Yang, A. Yost, C. Belongie, and W. Cohen. 2017. The normal fire environment—modeling environmental suitability for large forest wildfires using past, present, and future climate normals. *For. Ecol. Manag.* 390: 173–186.
- DellaSala, D.A., P. Brandt, M. Koopman, J. Leonard, C. Meisch, P. Herzog, P. Alaback, M.I. Goldstein, S. Jovan, A. MacKinnon, and H. von Wehrden. 2018. Climate Change May Trigger Broad Shifts in North America’s Pacific Coastal Rainforests, pp. 233–244. *In* D.A. Dellasala and M.I. Goldstein [eds.], *Encyclopedia of the Anthropocene*. Elsevier.
- Forsman, E.D., J.K. Swingle, R.J. Davis, B.L. Biswell, and L.S. Andrews. 2016. Tree voles: an evaluation of their distribution and habitat relationships based on recent and historical studies, habitat models, and vegetation change. General Technical Report PNW-GTR-948. USDA Forest Service, Pacific Northwest Research Station, Portland OR. 128 pp.
- Frankham, R. 1995. Effective population size/adult population size ratios in wildlife: a review. *Genet. Res.* 66: 95–107.
- Frankham, R., J.D. Ballou, and D.A. Briscoe. 2007. Effect of population bottlenecks on quantitative genetic diversity, pp. 187–241. *In* R. Frankham, J.D. Ballou, and D.A. Briscoe [eds.]. Cambridge University Press.
- Frankham, R., C.J.A. Bradshaw, and B.W. Brook. 2014. Genetics in conservation management: Revised recommendations for the 50/500 rules, Red List criteria and population viability analyses. *Biol. Conserv.* 170: 56–63.
- García-Navas, V., T. Bonnet, D. Waldvogel, P. Wandeler, G. Camenisch, and E. Postma. 2015. Gene flow counteracts the effect of drift in a Swiss population of snow voles fluctuating size. *Biol. Conserv.* 191: 168–177.

- Jamieson, I.G., and F.W. Allendorf. 2012. How does the 50/500 rule apply to MVPs? *Trends Ecol. Evol.* 27: 578–584.
- Lesmeister, D., M. Linnell, R. Davis, and J. Swingle. 2016. Distribution of habitats for red tree voles (*Arborimus longicaudus*) in the North Coast Range of Oregon. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR. 32 pp.
- Lesmeister, D.B., and M.A. Linnell. 2019. Habitat clusters for red tree voles in the Coast Range of Oregon. Final Report U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Corvallis, OR. 19 pp.
- Linnell, M.A. 2022. GIS data. An update of red tree vole habitat layers from Linnell et al 2017 habitat model.
- Linnell, M.A., R.J. Davis, D.B. Lesmeister, and J.K. Swingle. 2017. Conservation and relative habitat suitability for an arboreal mammal associated with old forest. *For. Ecol. Manag.* 402: 1–11.
- Linnell, M.A., and D.B. Lesmeister. 2019. Landscape connectivity and conservation prioritization for an old forest species with limited vagility. *Anim. Conserv.* 22: 568–578.
- Linnell, M.A., D.B. Lesmeister, Z. Yang, and R.J. Davis. 2023. Timber harvest and wildfires drive long-term habitat dynamics for an arboreal rodent. *Biol. Conserv.* 279: 1–9.
- Marks-Fife, C.A. 2016. Estimation of population age structure, detection probability, and density of red tree voles in Oregon. PhD Thesis. 1–150 pp.
- Maser, C.O. 1966. Life histories and ecology of *Phenacomys albipes*, *Phenacomys longicaudus*, *Phenacomys silvicola*. M.S. Thesis. Oregon State University. 238 pp.
- Mathys, A.S., N.C. Coops, and R.H. Waring. 2016. An ecoregion assessment of projected tree species vulnerabilities in western North America through the 21st century. *Glob. Change Biol.* 23: 920–932.
- Miller, M.P., M.R. Bellinger, E.D. Forsman, and S.M. Haig. 2006. Effects of historical climate change, habitat connectivity, and vicariance on genetic structure and diversity across the range of the red tree vole (*Phenacomys longicaudus*) in the Pacific Northwestern United States. *Mol. Ecol.* 15: 145–159.
- Natural Resources Canada. 2022. Canada's Plant Hardiness Zones, species specific models and maps. <http://planthardiness.gc.ca/?m=23>.
- NCASI. 2022a. GIS data. RTV recent locations dated 2019-2022.
- NCASI. 2022b. Red tree voles in working forests: Response to USFWS request for information. 41 pp.
- Ohmann, J.L., and M. Gregory. 2002. Predictive mapping of forest composition and structure with direct gradient analysis and nearest neighbor imputation in coastal Oregon, U.S.A. *Can. J. For. Res.* 32: 725–741.
- Peterson, D.W., B.K. Kerns, and E.K. Dodson. 2014. Climate change effects on vegetation in the Pacific Northwest: a review and synthesis of the scientific literature and simulation model projections. General Technical Report PNW-GTR-900. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland OR. 183 pp.
- Piasecki, J., J. Bailey, K. Dugger, and K. Moriarty. 2022. Arboreal nest survival and red tree vole use in forests that differ in age. Presentation. The Wildlife Society Annual Meeting, Spokane WA.

- Swingle, J.K. 2005. Daily activity patterns, survival, and movements of red tree voles (*Arborimus longicaudus*) in western Oregon. PhD Thesis. 1–135 pp.
- Swingle, J.K., and E.D. Forsman. 2009. Home Range Areas and Activity Patterns of Red Tree Voles (*Arborimus longicaudus*) in Western Oregon. Northwest Sci. 83: 273–286.
- U.S. Fish and Wildlife Service. 2011. Endangered and Threatened Wildlife and Plants; 12-Month Finding on a Petition to List a Distinct Population Segment of the Red Tree Vole as Endangered or Threatened. Part II: Proposed Rules. Fed. Regist. Vol 76 No 198 63537–63815.
- U.S. Fish and Wildlife Service. 2019. Species status assessment for the north Oregon coast population of the red tree vole (*Arborimus longicaudus*). Version 1.0. U.S. Fish and Wildlife Service, Region 1, Portland OR. 115 pp.
- USDA FS. 2021. GIS Data: Map of Potential Natural Vegetation. U.S. Department of Agriculture, Forest Service. ecoshare.info.
- USDA FS. 2022. USFS GIS data. RTV locations up to 2019 across USFS lands and pre-project data specific to Hebo Range District. U.S. Department of Agriculture, Forest Service.
- USDA FS and USDI BLM. 2000. Management recommendations for the Oregon red tree vole *Arborimus longicaudus*. Version 2.0. U.S. Dept. of Agriculture, Forest Service : U.S. Dept. of the Interior, Bureau of Land Management. 28 pp.
- USDI BLM. 2022. BLM Oregon/Washington response for information regarding the North Oregon Coast Distinct Population Segment (DPS) of the red tree vole (*Arborimus longicaudus*). GIS data. RTV locations 2018-2022.
- Verts, B.J., and L.N. Carraway. 1998. Land mammals of Oregon, 1st ed. University of California Press.

Appendix B

Intermediate Future Condition Time Step (~2050) for North Oregon Coast DPS of Red Tree Vole Species Status Assessment Version 2.0

Contents

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1. Factors Influencing Future Condition

Below we describe the primary stressors expected to drive red tree vole DPS viability in the future to inform analysis at an intermediate time step of approximately 30 years or to around the year 2050. The 2050 timeframe was chosen as the halfway point between current time and 2080, the foreseeable future timeframe analyzed in the species status assessment (SSA).

1.1 Timber Harvest Trends

As summarized in SSA (Section 7.1.1), timber production in the Oregon Coast Range is declining on Federal lands and increasing on private lands, and overall production is projected to stay at recent harvest levels.

For the 2080 time step, we assumed nearly all lands under the Northwest Forest Plan (NWFP) (USDA and USDI 1994, entire) late-successional reserves (LSR) land use allocation would be at least 80 years old (SSA section 7.2). The youngest stands at the time of LSR designation in 1994 would be over 80 years old by approximately 2080, so the only stands younger than 80 years would be in areas disturbed after 1994, or areas that cannot support old forests. Overall, land management policies in the Oregon Coast Range Physiographic Province which includes the

DPS, are projected to provide an approximately 20 percent increase of red tree vole habitat by approximately 2100, primarily on Federal and State lands (Spies et al. 2007, pp. 53, Figure 2). By mid-century, this increase in tree vole habitat is approximately 15% (Spies et al. 2007, Figure 2). For the 2050 timestep, the youngest stands under the NWFP or BLM Resource Management Plans (RMPs) (USDI BLM 2016, entire) LSR designations would not yet be 80 years old, but there would be some increase from the present time to mid-century in the number and total area of stands older than 80 years.

1.2 Vegetation Shifts

As described in the SSA (section 7.1.2.1), projections of vegetation shifts in the Pacific Northwest vary due to climate change. Models suggest that maritime coniferous forests in the range of the DPS may be vulnerable to future climate change, with tree species distribution models projecting most tree species to have less suitable habitat by the end of the 21st century with changes also occurring by the midcentury, even with models that project less warming (Peterson et al. 2014, pp. 111–112). Multiple projections, based on a variety of climate models, emissions scenarios, and vegetation models, show a complete or nearly complete loss of climatically suitable habitat for western hemlock and Sitka spruce within the DPS by the end of the 21st century (Crookston et al. 2010, p. 1208, GIS data; Peterson et al. 2014, p. 102; Mathys et al. 2016, p. 927; Natural Resources Canada 2022, in litt.). If the loss of climatically suitable habitat leads to large-scale mortality events or widespread decreases in survival rates of mature trees, a relatively rapid contraction of a tree species' range may result. Some, though fewer models show only minor losses (DellaSala et al. 2018, GIS data; Natural Resources Canada 2022, in litt.), and maritime forests found in the DPS may remain relatively stable over the 21st century (Halofsky et al. 2018, p. 13).

1.2.1. Western Hemlock

For western hemlock across the maritime forests of the Pacific Northwest, projected response to climate change by the end of the 21st century based on a multiple model output ranged from an increase to total loss, with some shifts (Peterson et al. 2014, p. 102). For mid-century (2041-2070, or 2055-2065), one model projected a complete loss of suitable climate within the DPS, and two others projected a loss of all but a few small areas of lower-suitability conditions at high elevation or along the coast in the north (Crookston et al. 2010, GIS data)(see Figure B–1). As was the case for the end of the century, all models showed at least some loss of higher-suitability conditions, with contractions coastward, upslope, and northward (Crookston et al. 2010, GIS data; DellaSala et al. 2018, GIS data; Natural Resources Canada 2022, in litt.)(see Figure B–2), but several models projected that the western hemlock range would continue to cover the entire DPS (Natural Resources Canada 2022, in litt.).

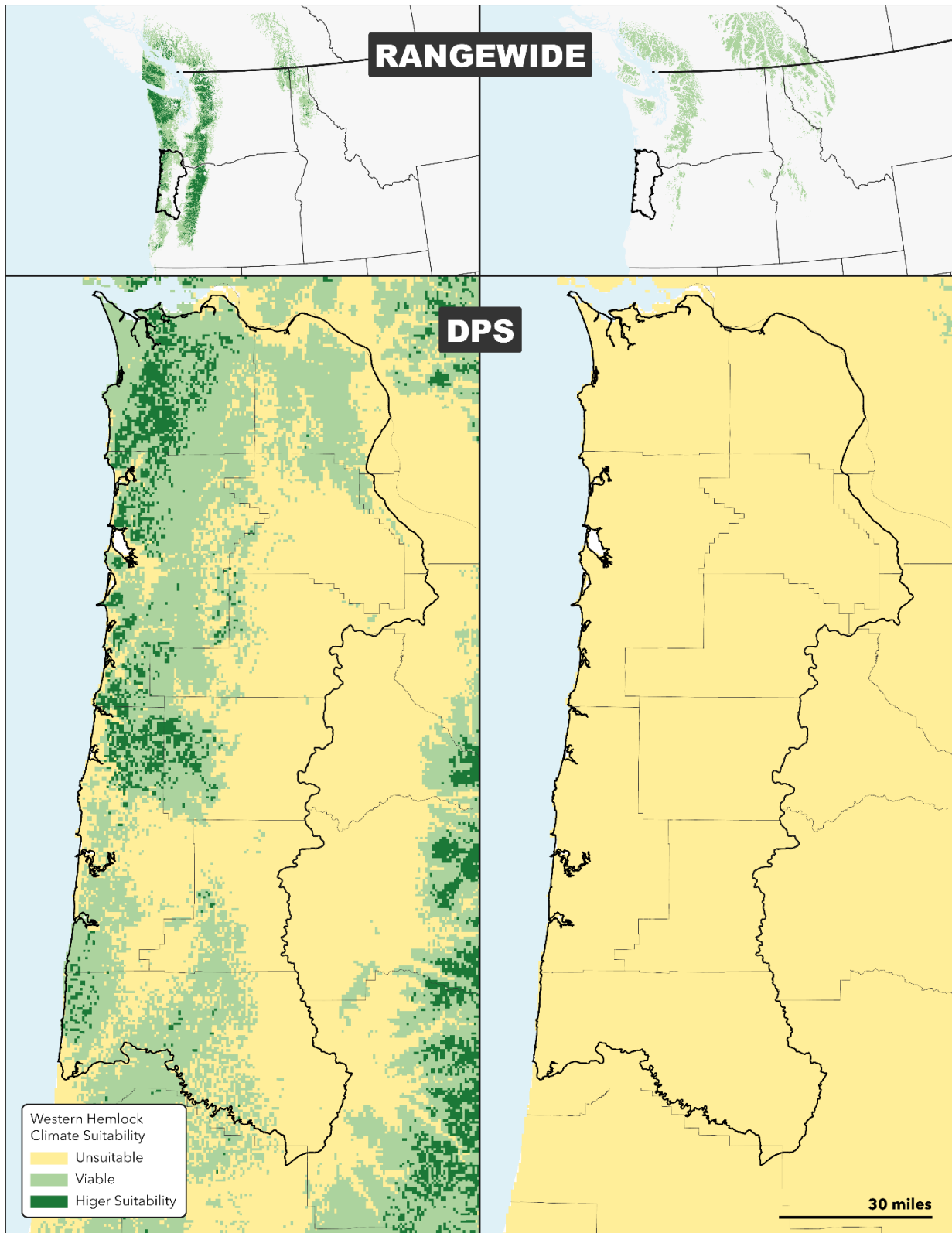


Figure B–1. Suitability of climate conditions for western hemlock in 2010 (left) and mid-century (right, 2060 projected with Hadley climate model and A2 emissions scenario) (Crookston et al. 2010, GIS data).

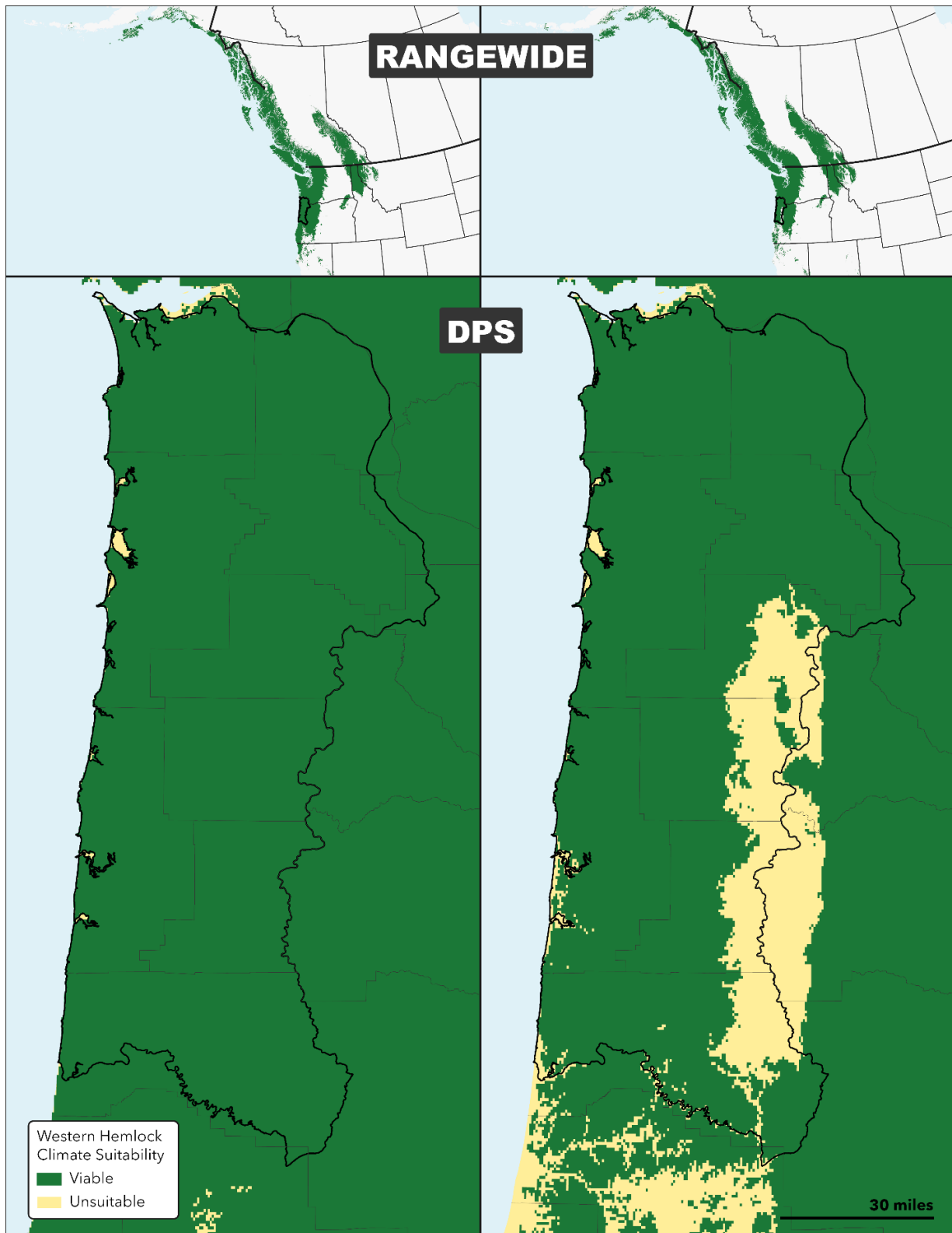


Figure B-2. Suitability of climate conditions for western hemlock in 2010 (left) and mid-century (right, 2050 projected with Canadian Centre for Climate Modelling and Analysis (CCCma) climate model and A2A emissions scenario) (DellaSala et al. 2015 GIS data).

1.2.2. Sitka Spruce

For Sitka spruce, projected responses to climate change by the late 21st century ranged from little change in range (Peterson et al. 2014, p. 111) and some contraction (see Figure A-13, DellaSala et al. 2018, GIS data), to complete loss within the DPS (see Figure A-12, Crookston et al. 2010, GIS data; Mathys et al. 2016, pp. 7–8, Fig. 4c). For mid-century (2041-2070, or 2055-2065), two models projected a complete loss of suitable climate within the DPS, and two others projected a loss of all but a small area of lower-suitability conditions at high elevation in the north of the DPS (see Figure B–3, Crookston et al. 2010, GIS data; Natural Resources Canada 2022, in litt.). Most models for mid-century showed a complete loss of higher-suitability conditions, and nearly all showed contractions in the range of suitable climate conditions within the DPS, with contractions coastward, upslope, and northward (Crookston et al. 2010, GIS data; DellaSala et al. 2018, GIS data; Natural Resources Canada 2022, in litt.). However, one model did project a slight expansion in climatically suitable area within the DPS for the mid-century period (see Figure B–4, DellaSala et al. 2018, GIS data).

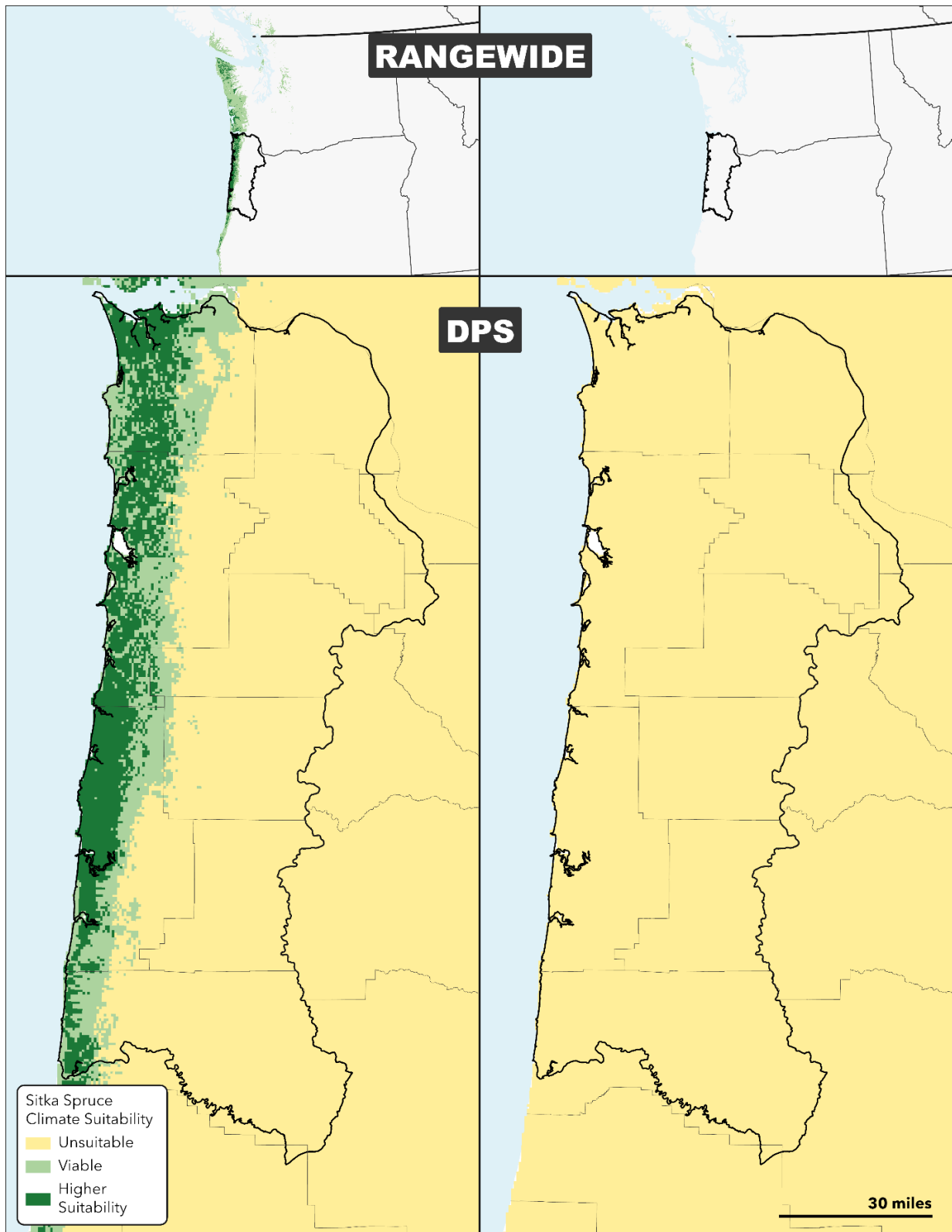


Figure B-3. Suitability of climate conditions for Sitka spruce in 2010 (left) and mid-century (right, 2060 projected with Hadley climate model and A2 emissions scenario) (Crookston et al. 2010, GIS data).

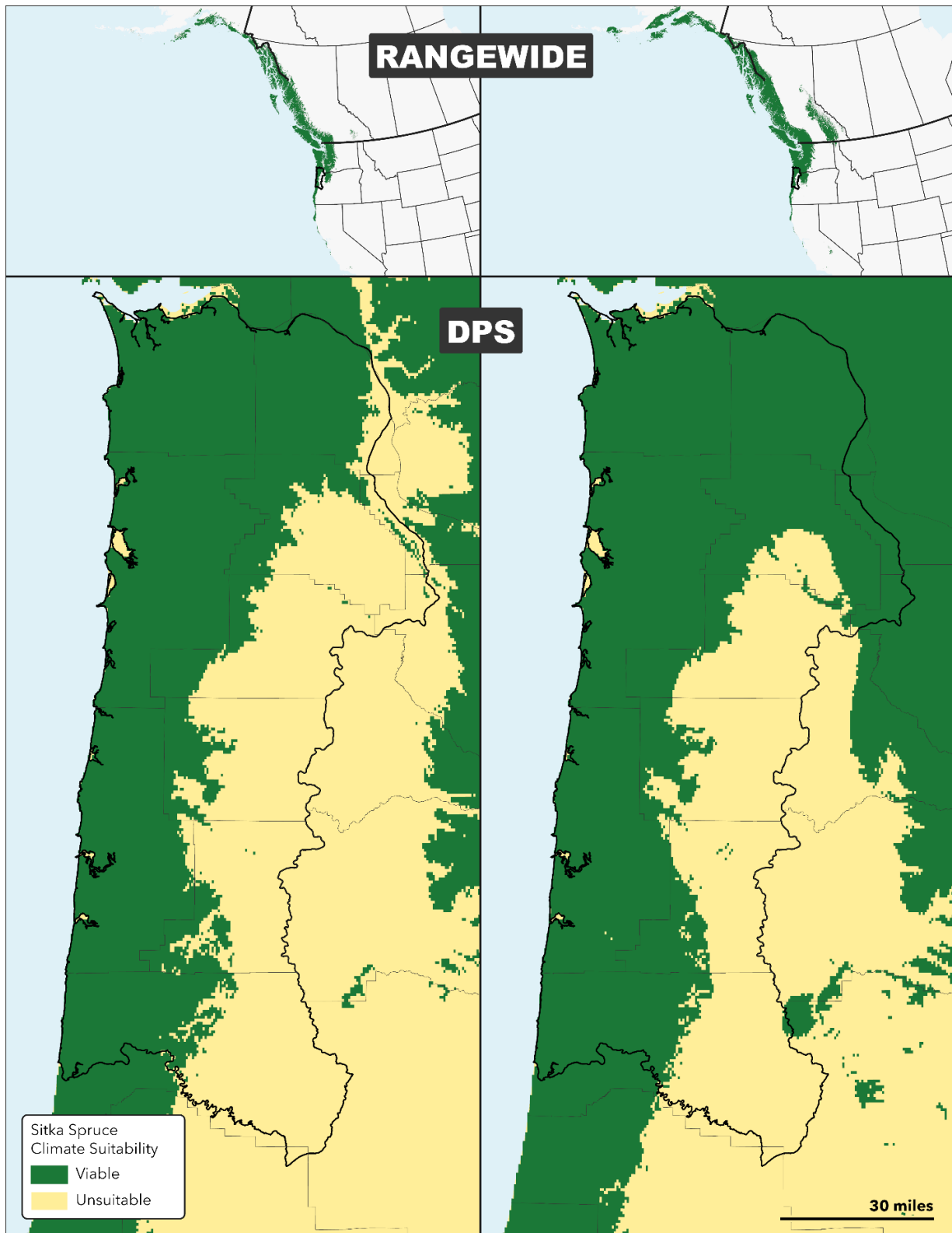


Figure B–4. Suitability of climate conditions for Sitka spruce in 2010 (left) and mid-century (right, 2050 projected with CSIRO climate model and A2A emissions scenario) (DellaSala et al. 2018, GIS data).

1.2.3. Vegetation Shift Summary

Under a lower scenario for the 2080 timeframe, we concluded that vegetation shifts would be unlikely to occur at a pace or scale that would affect the health or distribution of tree species important to voles. Therefore, tree vole population areas would retain current resiliency, and vegetation shifts would not affect representation across the DPS. Based on review of the models at the 2050 timeframe, we assume the same parameters would hold for a 2050 timeframe.

Under an upper scenario for the 2080 timeframe, we concluded that it is plausible that western hemlock and Sitka spruce may be nearly or entirely lost from the DPS as the climate becomes increasingly unsuitable for those species. We assume that red tree voles in the coastal Sitka spruce vegetation zone which have the behavioral trait to feed on these two tree species would not be able to adapt quickly enough, and therefore those voles would be lost. This scenario remains a plausible upper for the 2050 timeframe.

1.3 Swiss Needle Cast

The primary impact of increasing Swiss needle cast to red tree vole habitat is likely a reduction in overall habitat quality and ingrowth in infected areas. Swiss needle cast is already present throughout most of the DPS (Ritóková et al. 2021, p. 18). As described in the SSA (section 7.1.2.2), the disease is expected to increase in intensity and expand its distribution in the Oregon Coast Range, spreading inland, north, and to higher elevations under projected climate change scenarios of warmer winter temperatures (Lee et al. 2013, p. 688). Future winter, spring, and summer weather in Oregon is predicted to be warmer under both the RCP 4.5 and RCP 8.5 scenarios, but future precipitation patterns are less clear (see Table 10 in section 7.1.2) (Fleishman 2023, p. 11). While warmer summer temperatures are expected to inhibit the fungus that causes the disease, impacts from Swiss needle cast could increase in areas where summer precipitation frequently exceeds the fungus's limiting threshold (Hood 1982, p. 422; Lee et al. 2017, p. 11184). Additionally, increased drought in the future may lead to mortality of Swiss needle cast infected Douglas-fir trees, as was seen during the 2015-2018 drought near Tillamook, Oregon (Shaw et al. 2021, pp. 414–415).

Under a lower future scenario for the 2080 timeframe, we assumed Swiss needle cast would be present at current or lower levels than today across the DPS. We assume the same parameters would hold for a 2050 timeframe.

Under an upper scenario for the 2080 timeframe, we assume Swiss needle cast will increase in severity and extent across all areas of the DPS, primarily in response to the predicted warming winter temperatures under two plausible climate scenarios (RCP 4.5 and RCP 8.5) for the 2080s time period. For a 2050 timeframe, temperatures are also expected to increase under both RCP 4.5 and RCP 8.5 and given the fungus's sensitivity to winter temperatures, and the uncertainty of

predicted future precipitation in the range of the DPS, we also assume the same parameters would hold for a 2050 timeframe under an upper scenario.

1.4 Wildfire

As summarized in the SSA (section 7.1.2.3), projected impacts of climate change are expected to increase the risk of large-scale wildfires in Pacific Northwest forests. While specific predictions of how climate change may affect wildfires in the coastal Oregon forests are variable, climate regimes for the Oregon Coast Range are projected to include increased temperatures with increased drought conditions which is likely to increase the size, likelihood, and severity of wildfires in the future. We analyzed potential fire size, relative suitability for fire, and potential severity as measured by the land management type and at the geographic unit scale, in a lower and upper scenario through the 2080 timeframe (see Appendix A, Section 8 for detailed methods).

1.4.1. Size

We superimposed fire sizes from the past 200 years and assigned ratings to geographic units in a lower and upper scenario. A catastrophic fire of these sizes could happen at any time, thus our scoring would be the same for a 2050 timeframe.

1.4.2. Relative Suitability

To help us understand the magnitude of the variability in the likelihood of large fires, we used a model of suitability for large fires projected in the late-century period surrounding 2080 for the RCP 8.5 scenario (Davis et al. 2017 and associated GIS data). We ran the analysis at a mid-century 2050 timestep, and the results were similar to the current (2020) timeframe. The two geographic units with moderate fire suitability ratings in 2080 have lower fire suitability under a 2050 timeframe (i.e., are rated “HI”). Remaining units were already at the lowest fire suitability (i.e., rated “HI”) (Table B–1).

Table B–1. Ratings for relative suitability by geographic units to current and future large fires for the 2020, 2050, and 2080 approximate time frames. A high rating (HI) was given for geographic units with low average suitability (less than 0.37), where large fires are projected to occur less often than they would if randomly distributed across the landscape; a moderate rating (MOD) for geographic units with moderate average suitability (between 0.37 and 0.65), where large fires are projected to occur slightly more often than they would at random; and a low rating (LO) for geographic units with high average suitability (greater than 0.65), where large fires are projected to occur much more often than they would at random (Davis et al. 2017, pp. 177–178).

Unit Number and Name		2020 Value	2020 Rating	2050 Value	2050 Rating	2080 Value	2080 Rating
1	Lewis and Clark	0.016	HI	0.026	HI	0.054	HI
2	Ecola/ Elmer Feldenheimer	0.022	HI	0.034	HI	0.067	HI
3	Necanium/ Nehalem	0.018	HI	0.027	HI	0.063	HI
4	North Fork Nehalem	0.028	HI	0.042	HI	0.095	HI
5	Nehalem/Wilson	0.098	HI	0.129	HI	0.240	HI
6	Cape Meares	0.018	HI	0.026	HI	0.056	HI
7	Sand Lake	0.023	HI	0.033	HI	0.069	HI
8	Trask/Nestucca	0.108	HI	0.131	HI	0.231	HI
9	Gauldy Ridge	0.037	HI	0.052	HI	0.108	HI
10	Little Nestucca/ Salmon Coast	0.040	HI	0.055	HI	0.115	HI
11	Little Nestucca/ Salmon Inland	0.034	HI	0.045	HI	0.089	HI
12	Siletz/Luckiamute	0.112	HI	0.134	HI	0.240	HI
13	Yaquina/Marys	0.119	HI	0.144	HI	0.263	HI
14	Alsea/Siuslaw	0.171	HI	0.200	HI	0.330	HI
15	Siuslaw/Long Tom	0.281	HI	0.317	HI	0.470	MOD
16	Siuslaw/Territorial	0.258	HI	0.289	HI	0.434	MOD
17	Spencer Butte	0.153	HI	0.174	HI	0.277	HI

1.4.3. Severity

We did not have the data to predict fire severity under lower or upper scenarios and instead looked at the underlying land ownership based on recent studies showing how different forest management regimes affect fire severity (Zald and Dunn 2018, p. 1075; Evers et al. 2022, pp. 8, 11; Levine et al. 2022, pp. 1, 4). We assume land ownership will not change drastically over either timeframe, thus this rating would not change over time and the 2050 timeframe and 2080 timeframe would have the same rating.

1.4.4. Synthesis of Fire Information

We assumed that a unit would have the greatest contribution to redundancy if it includes highly resilient tree vole populations, is large enough that substantial amounts of habitat will be outside

of even very large fire perimeters, will maintain low suitability for large fires, and is primarily made up of public lands that will provide some degree of fire refugia. We use the same overall scoring rubric for the 2050 timeframe as the 2080 timeframe. Only the fire suitability rating changed between the mid-century and 2080 timeframe, and only for two geographic units (Siuslaw/Long Tom and Siuslaw/Territorial units in the southeastern part of the DPS). Those units have a lower fire suitability under a 2050 scenario, the same as current (2020) ratings, which raises the overall fire ratings for these units from moderate low to moderate under a lower scenario and does not change from the moderate low ratings under the upper scenario. The overall conclusion would remain the same for the 2050 as for 2080 timeframe; that these units will retain a moderate ability to contribute to redundancy.

While our scoring results for wildfire are similar under either a current (2020), mid-century (2050) or late century (2080) timeframe, we recognize that the longer the timeframe that is considered, the higher the likelihood of a catastrophic fire or fires occurring.

2. Summary

Under the lower and upper scenarios used in our future condition analysis, adding the mid-century time step would not change scoring for future effective population size or future connectivity within or between geographic units. Future effective population size resiliency is based on current modeled habitat and estimated vole population density (see Section 7.2 SSA). Connectivity is based on land management designation (see Section 7.2 SSA).

Climate change has a significant effect on the chosen stressors in our analysis. We recognize that there is variability in climate change projections over time. Most of the information we used in our analysis comes from studies which employ a variety of climate change models and project out to approximately the end of the 21st century. For vegetation shift, we were able to find information specific to mid-century, but it did not change our results. For Swiss needle cast, because warming is expected in the mid-century timeframe under both RCP 4.5 and RCP 8.5 scenarios, and warming temperatures in the winter are predicted to increase the range and intensity of the disease, we assume the impacts to the red tree vole from Swiss needle cast at the 2050 timestep will be similar to the 2080 timestep.

We did not include wildfire in future condition scoring for resiliency, but we did consider it as a factor influencing redundancy. Red tree vole redundancy is similar under current and future conditions in that the species is vulnerable to catastrophic, stand-replacing wildfire. Adding an intermediate time step does not change our projections of redundancy for red tree vole in the future.

While our scoring for each timestep is similar, we recognize that an upper scenario is more likely to be realized by 2080 than by 2050 simply given the longer period of time over which to produce that result; however, an upper scenario under either timestep is plausible. We have more

confidence, however, in forest ingrowth projections reaching the point of becoming tree vole habitat at 2080 than we do at 2050. It is more likely that forest on constrained lands, particularly LSRs, will develop into tree vole habitat by 2080 than by 2050. Because we have greater confidence in forest ingrowth projections and red tree vole habitat availability at 2080, while our confidence in most of the other factors that influence red tree vole viability varies little between 2050 and 2080, we chose 2080 as the future timeframe for consideration in the SSA.

3. Literature Cited

- Crookston, N.L., G.E. Rehfeldt, G.E. Dixon, and A.R. Weiskittel. 2010. Addressing climate change in the forest vegetation simulator to assess impacts on landscape forest dynamics. *For. Ecol. Manag.* 260: 1198–1211.
- Davis, R., Z. Yang, A. Yost, C. Belongie, and W. Cohen. 2017. The normal fire environment—modeling environmental suitability for large forest wildfires using past, present, and future climate normals. *For. Ecol. Manag.* 390: 173–186.
- DellaSala, D.A., P. Brandt, M. Koopman, J. Leonard, C. Meisch, P. Herzog, P. Alaback, M.I. Goldstein, S. Jovan, A. MacKinnon, and H. von Wehrden. 2018. Climate Change May Trigger Broad Shifts in North America’s Pacific Coastal Rainforests, pp. 233–244. *In* D.A. Dellasala and M.I. Goldstein [eds.], *Encyclopedia of the Anthropocene*. Elsevier.
- Evers, C., A. Holz, S. Busby, and M. Nielsen-Pincus. 2022. Extreme winds alter influence of fuels and topography on megafire burn severity in seasonal temperate rainforests under record fuel aridity. *Fire* 5: 1–16.
- Fleishman, E. 2023. Sixth Oregon climate assessment. Oregon Climate Change Research Institute, Oregon State University, Corvallis OR. 248 pp.
- Halofsky, J.S., D.R. Conklin, D.C. Donato, J.E. Halofsky, and J.B. Kim. 2018. Climate change, wildfire, and vegetation shifts in a high-inertia forest landscape: Western Washington, U.S.A. *PLoS ONE* 13: 1–23.
- Hood, I. 1982. *Phaeocryptopus gaeumannii* on *Pseudotsuga menziesii* in southern British Columbia, New Zealand. *N. Z. J. For. Sci.* 12: 415–424.
- Lee, E.H., P.A. Beedlow, R.S. Waschmann, C.A. Burdick, and D.C. Shaw. 2013. Tree-ring analysis of the fungal disease Swiss needle cast in western Oregon coastal forests. *Can. J. For. Res.* 43: 677–690.
- Lee, E.H., P.A. Beedlow, R.S. Waschmann, D.T. Tingey, S. Cline, M. Bollman, C. Wickham, and C. Carlile. 2017. Regional patterns of increasing Swiss needle cast impacts on Douglas-fir growth with warming temperatures. *Ecol. Evol.* 7: 11167–11196.
- Levine, J.I., B.M. Collins, Z.L. Steel, P. de Valpine, and S.L. Stephens. 2022. Higher incidence of high-severity fire in and near industrially managed forests. *Front. Ecol. Environ.* 20: 397–404.

Mathys, A.S., N.C. Coops, and R.H. Waring. 2016. An ecoregion assessment of projected tree species vulnerabilities in western North America through the 21st century. *Glob. Change Biol.* 23: 920–932.

Natural Resources Canada. 2022. Canada's Plant Hardiness Zones, species specific models and maps. <http://planthardiness.gc.ca/?m=23>.

Peterson, D.W., B.K. Kerns, and E.K. Dodson. 2014. Climate change effects on vegetation in the Pacific Northwest: a review and synthesis of the scientific literature and simulation model projections. General Technical Report PNW-GTR-900. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland OR. 183 pp.

Ritóková, G., D.B. Mainwaring, D.C. Shaw, and Y.-H. Lan. 2021. Douglas-fir foliage retention dynamics across a gradient of Swiss needle cast in coastal Oregon and Washington. *Can. J. For. Res.* 51: 573–582.

Shaw, D.C., G. Ritóková, Y.-H. Lan, D.B. Mainwaring, A. Russo, R. Comeleo, S. Navarro, D. Norlander, and B. Smith. 2021. Persistence of the Swiss needle cast outbreak in Oregon Coastal Douglas-fir and new insights from research and monitoring. *J. For.* 119: 407–421.

Spies, T.A., B.C. McComb, R.S.H. Kennedy, M.T. McGrath, K. Olsen, and R.J. Pabst. 2007. Potential Effects of Forest Policies on Terrestrial Biodiversity in a Multi-Ownership Province. *Ecol. Appl.* 17: 48–65.

USDI BLM. 2016. Northwestern and Coastal Oregon record of decision and approved resource management plan: Coos Bay, Eugene, Salem Districts, and Swiftwater Field Office of Roseburg District. U.S. Department of the Interior, Bureau of Land Management, Oregon State Office, Portland OR.

Zald, H.S.J., and C.J. Dunn. 2018. Severe fire weather and intensive forest management increase fire severity in a multi-ownership landscape. *Ecol. Appl.* 28: 1068–1080.