Species Status Assessment

North Oregon Coast Population of the Red Tree Vole *(Arborimus longicaudus)* Version 1.0

Photo by Patrick Wright

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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. We considered what the red tree vole needs to maintain viability by characterizing the status of the species in the DPS in terms of its resiliency, redundancy, and representation. For the purpose of this assessment, we generally define viability as the likelihood of the species to sustain populations over time within a biologically meaningful timeframe: in this case, 60 years. We chose 60 years because we have data to reasonably predict the potential significant effects of influence factors 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 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.

Red tree voles are conifer-obligate, arboreal rodents, found in western Oregon south to northwestern California. They are generally associated with old forests, either nesting within or in the vicinity of forests with sufficient structures to support nests. Examples of such structures include large or palmate limbs, cavities, sloughing bark, or forked tree boles. We used a published habitat model done for red tree voles in our analysis area (which covers a slightly larger area than the DPS) to derive 11 occupied red tree vole habitat clusters based on habitat patches sufficiently large enough to accommodate an estimated >=100 individuals. These clusters represented tree vole assemblages that we evaluated for resiliency, redundancy, and representation. Habitat loss and modification through timber harvest over much of the 20th century, exacerbated by episodic large wildfire events, played the greatest role in removing habitat and contracting tree voles to their current range in the analysis area. The prevalence of the tree pathogen, Swiss needle cast, has forestalled the development of habitat ingrowth. Tree voles are restricted to existing habitat that is mostly on Federal and some State lands. In the north coast subregion of the analysis area, voles are isolated in small patches, almost completely removed from much of the area despite existing habitat. This fragmentation and isolation limits the resiliency of many of the vole habitat clusters. Population isolation is further exacerbated by the limited home range size and dispersal capability of red tree voles, as well as their low survival rates. Low numbers of voles moving very short distances severely limits the capability of vole clusters to expand across the landscape and connect with other clusters.

In modeling current resiliency of individual vole habitat clusters, we derived an imputed population range, based on an estimated carrying capacity and effective population size of the cluster. We also assessed the connectivity potential to neighboring clusters to derive an overall relative resiliency condition score. Finally, we assessed representation and redundancy for each vole cluster. The largest two of the eleven clusters have high resiliency scores under the current condition. They also encompass both coastal and interior Coast Range vegetation zones in the analysis area and hence, improved representation of the behavioral capacity of tree voles to

forage on different coniferous species that are prevalent in the different zones. In addition, they also strongly provide for population redundancy simply due to their size, being large enough to withstand most events except for the largest of catastrophic wildfires. Hence, these two clusters are essential to the persistence of red tree voles in the analysis area. The remaining clusters are scattered across the analysis area, except for the northern portion of the north coast subregion; although this area has blocks of tree vole habitat on the Clatsop State Forest, surveys have not yielded any voles. Four vole clusters have overall moderate resiliency scores; these include the only two clusters primarily on State forest land, as well as two clusters located on Bureau of Land Management (BLM) checkerboard ownership between the two largest clusters. The remaining five clusters have overall low resiliency scores and are located near the edges of the analysis area, either along coastal headlands or the Willamette Valley margin.

We reassessed overall resiliency scores under four future scenarios that considered estimated habitat ingrowth and loss as a result of existing management plans and regulations. The two largest clusters, at 1,480 km^2 (571 mi^2) and 4,425 km^2 (1,708 mi^2), respectively, retain their high resiliency score under all four future scenarios. Wildfires represent the single natural disturbance that can occur at a scale large enough to consume all or substantial portions of these two clusters, which contain the most contiguous and largest patches of habitat and where most of the tree voles occur. Though infrequent, large-scale severe wildfires have and will continue to occur in the Oregon Coast Range. It is expected that weather conditions conducive to producing past large-scale wildfires will increase with predicted climate change, thereby increasing the chances for wildfires and loss of either or both of these habitat clusters. However, due to the episodic nature of wildfires in the Coast Range, we cannot readily predict when one will occur.

We predict that of the five habitat clusters with overall low resiliency scores, all but one will become extirpated over time, thus losing their contribution to representation and to redundancy. The four habitat clusters with overall moderate resiliency scores retain their scores through the future scenarios. While voles in these clusters may be less susceptible to inbreeding compared to clusters that ranked low, they have a reduced evolutionary capacity to adapt to ecological changes over time. This effect is exacerbated in those habitat clusters that are furthest removed from neighboring clusters. While these clusters currently contribute to redundancy in terms of providing a wider distribution of red tree voles across the analysis area, they are not large enough to withstand a catastrophic event such as a wildfire, and continue to remain isolated to the degree that providing or receiving genetic or demographic support is limited.

Land management has shaped the current distribution of red tree vole populations in the analysis area. Tree voles are overwhelmingly restricted to State and Federal lands, where existing management plans and policy either explicitly manage for red 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 of land-use allocations where programmed timber harvest does not occur, should allow for maintenance of the species in all but perhaps the more isolated checkerboard blocks of ownership. Opportunities exist on State forest land to develop red tree vole habitat through their existing management plans and expand existing clusters on their ownership. Current management of lands under the Oregon Forest Practices Act is expected to continue to contribute to habitat removal and isolation of existing clusters of red tree voles.

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1 INTRODUCTION

On June 18, 2007, the U.S. Fish and Wildlife Service (Service) received a petition to list the dusky tree vole (*Arborimus longicaudus silvicola*) in all of 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 of 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, and we therefore focused our analysis, instead, on the northern Oregon Coast Range population of the red tree vole. 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 is 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.

2 ANALYTIC FRAMEWORK

The Species Status Assessment (SSA) report, the product of conducting a SSA, is intended to be a concise review of the species' biology and factors influencing the species, an evaluation of its biological status, and an assessment of the resources and conditions needed to maintain long-term viability. The intent is for the SSA report to be easily updated as new information becomes available, and to support all functions of the Endangered Species Program. As such, the SSA report will be a living document upon which other documents, such as any resulting listing rules, recovery plans, and 5-year reviews, would be based if the species warrants listing under the Act. Furthermore, the SSA can inform proactive conservation agreements, or development of conservation assessments or strategies whether or not the species is listed.

This SSA report for the northern Oregon Coast Range population of the red tree vole is intended to provide the biological support for the decision on whether or not to propose to list the DPS as threatened or endangered and if so, whether or not to propose designating critical habitat. The analytic process and this SSA report do not represent a decision by the Service whether or not to list a species under the Act. Instead, this SSA report provides a review of the best available information strictly related to the biological status of the red tree vole. The listing decision will be made by the Service after reviewing this document and all relevant laws, regulations, and policies, and a decision will be announced in the Federal Register.

Within the SSA we consider what a species needs to maintain viability. For the purpose of this assessment, we generally define viability as the likelihood of the species to sustain populations over the course of a biologically meaningful timeframe, in this case, 60 years. We chose 60 years because it is the time at which most of the area that is in reserve land-use allocations under Federal management would reach 80 years old, barring intervening disturbances. Reserve land-use allocations are those Federal lands not managed for regulated timber harvest (USDA and USDI 1994, pp. A-4 to A-5; USDI 2016, pp. 55-59) (see section 3.2.4.2 Ownership Patterns and

Associated Regulatory Mechanisms). Habitat models indicate a strong association between red tree voles and characteristics of old forests (80 years old or older) where structural features generally begin to develop (Davis *et al*. 2015, p. 18; Dunk and Hawley 2009, pp. 627, 632; Forsman *et al.* 2016, pp. 45, 77-80; Linnell *et al*. 2017, pp. 2, 4). Most of the area in reserve land-use allocations would reach 80 years old by this time, and by then we would expect 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 and much older forests are likely where tree voles reach maximum capacity and provide the most stable habitat. The available data does not allow us to reasonably predict the potential significant effects of stressors within the range of the red tree vole beyond this timeframe of 60 years.

Using the SSA framework (Figure 1), we assess viability by characterizing the biological status of the species in terms of its resiliency, redundancy, and representation (Smith *et al*. 2018, entire). Resiliency, redundancy, and representation are defined as follows:

- *Resiliency* means having sufficiently large populations for the species to withstand stochastic events (arising from random factors). We can measure resiliency based on metrics of population health; for example, birth versus death rates and population size, if that information exists. Resiliency can also be measured based on metrics of habitat quality and distribution. Resilient populations are better able to withstand disturbances such as random fluctuations in birth rates (demographic stochasticity), variations in rainfall (environmental stochasticity), or the effects of human activities.

- *Redundancy* means having a sufficient number of populations for the species to withstand catastrophic events (such as a rare destructive natural event or episode involving many populations). Redundancy is about spreading the risk and can be measured through the duplication and distribution of populations across the range of the species. Generally, the greater the number of populations a species has distributed over a larger landscape, the better it can withstand catastrophic events.

- *Representation* means having the breadth of genetic makeup of the species to adapt to changing environmental conditions. Representation can be measured through: 1) genetic diversity within and among populations; 2) ecological diversity (also called environmental variation or diversity); 3) behavioral diversity; and 4) morphological diversity of populations across the species' range. The more representation, or diversity, a species has, the more it is capable of adapting to changes (natural or human caused) in its environment. In the absence of species-specific genetic and ecological diversity information, we evaluate representation based on the extent and variability of habitat characteristics within the geographical range.

The decision whether to list 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 under a range of scenarios to account for the uncertainty of the species' future. We evaluate the current biological status of the red tree vole by assessing the primary factors negatively and positively affecting the species to describe its current condition in terms of resiliency, redundancy, and representation (together, the 3Rs). We then evaluate the future biological status of the red tree vole by describing a range of plausible future scenarios representing a range of conditions for the primary factors affecting the species, and forecasting the most likely future condition for each scenario in terms of the 3Rs. As a matter of practicality, the full range of potential future scenarios and the range of potential future conditions for each potential scenario are too large to individually describe and analyze. These scenarios do not include all possible futures, but rather include specific plausible scenarios that represent examples from the continuous spectrum of possible futures. Consequently, the results of this SSA do not describe the overall risk to the species. Recognizing these limitations, the results of this SSA nevertheless provide a framework for considering the overall risk to the species in listing decisions.

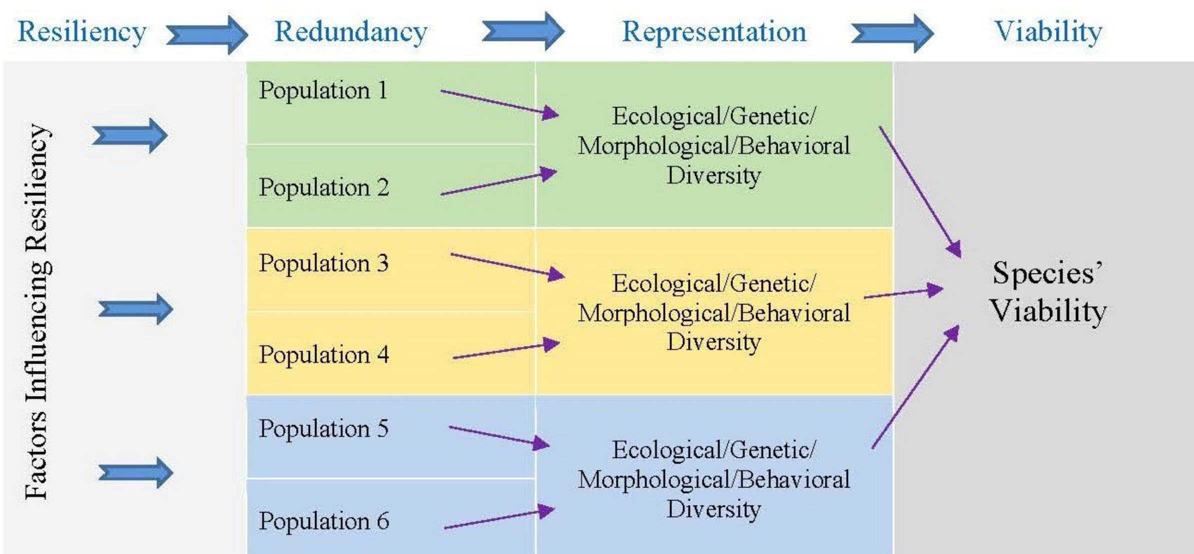

Figure 1. The species status assessment (SSA) framework.

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 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.* 2010, pp. 64-65; 76 FR 76 63720). 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*. Johnson (1968, p. 27; 1973, p. 243) proposed the genus be reclassified to *Arborimus*. 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 do as well.

The dusky tree vole was originally classified as a distinct species, *P. silvicolus* (Howell 1921, entire), later renamed *P. silvicola* (Miller 1924, p. 400), then changed to a subspecies (*A. l. silvicola*) (Johnson 1968, p. 27; Hall 1981, p. 788). Subsequent research has put doubt on whether distinctions between the dusky and red tree vole warrant any separate taxonomic designation. Bellinger *et al.* (2005) failed to find detectible genetic differences between the two entities. Miller *et al.* (2006, p. 145) found genetic differences 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. The authors of this paper further concluded that the genetic differences among these groups were sufficient to support subspecies recognition if there were congruent differentiations in other characteristics (Miller and Haig 2009, pers. comm.). Johnson and George (1991, p. 5) were not able to detect discernable differences in morphological characteristics among tree voles found in Oregon. Miller *et al.* (2010, p. 69) reported statistical differences in some morphological features measured in red tree voles and putative dusky tree voles, but found these features of little diagnostic utility in classifying tree voles because the differences were subtle and exhibited a clinal pattern that correlated with latitude (see FR 76 63720, pp. 63726-63728 for a subspecies analysis of the dusky tree vole). Consequently, based on the best available scientific and commercial data, we have concluded that the dusky tree vole is not a valid subspecies for the purpose of this analysis and have focused our analysis, 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 (Figure 2). 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, pers. comm.). 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 (Hayes, 1996, p. 1; Swingle 2005, pp. 46, 82). They 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 infrequent, nests have been found on the ground, often occupied by males (Howell 1926, pp. 55-56; Maser 1966, 56-58 for review; Maser 1998, p. 217; Thompson and Diller 2002, p. 98). Their principle 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 twig bark and the underlying cambium (Maser 1966, pp. 143-145, 149-150; Forsman *et al.* 2009, p. 264).

Red tree voles are solitary, with single adults, or a female with young. occupying a nest. Nests are constructed of discarded resin ducts, conifer cuttings, vole fecal pellets, and sticks (Figure 3). Tree voles may also occupy nests constructed by other mammals or birds (Maser 1966, pp. 90-96). 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 1926, 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).


Figure 2. Red tree vole. Photo by Nick Hatch.

3.2 Distribution and Range

3.2.1 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.* 2016, pp. 80-83), covering approximately 66,000 square kilometers (km^2) (25,500 square miles (mi^2)) across multiple ownerships (USDA and USDI 2007, pp. 287, 294-296) (Figure 4). 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.* 2016, p. 19). No tree voles have been detected in recent search efforts in Clatsop and Columbia counties (Forsman *et al.* 2016, 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 extensive forests conducive to tree vole habitat (Robbins 1997, pp. 205-206), and tree vole habitat modeling indicates as much as 60 percent of the forested area was tree vole habitat in 1914 (Forsman *et al.* 2016, 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.* 2016, 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 *et al.* 2009b, 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.* 2016, p. 36).

Figure 3. 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).

3.2.2 Current Range and Distribution

Red tree voles continue to occur throughout much of their historical range, with the exception of the northern Coast Range and the northern Cascade Range (Figure 4). 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; USDA and USDI 2007, pp. 289, 294-296; Price *et al.* 2015, p. 43; Forsman *et al.* 2016, p. 36). On the northern end of the Coast Range, recent surveys on the Tillamook and Clatsop State Forests yielded tree vole nests in 4 (5 percent) of the 86 plots surveyed. 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 in this region also found red tree voles, indicating that local populations persist in some patches of habitat (Forsman *et al.* 2016, 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). While tree vole habitat occurs in several large patches across the State forests, it is largely absent in the area of the Tillamook Burn. The Tillamook Burn was a stand-replacing wildfire that burned over 1,200 km^2 (460 mi^2) in 1933, then reburned in three successive fires over the next 18 years, for a combined total burn area of 1,400 km^2 (540 mi^2) (Pyne 1982, pp. 330-331). 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).

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 Oregon 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; USDA and USDI 2007, pp. 289, 294-296; Forsman *et al.* 2016, p. 83). In California, red tree vole distribution is primarily limited to Del Norte and Humboldt counties north of the Klamath River (Forsman *et al.* 2016, 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, entire; Forsman *et al.* 2004, p. 300; Forsman *et al.* 2016, p. 36). Hamilton (1962, p. 503) suggested red tree voles may be limited to lower elevations because their nests do not provide adequate insulation to withstand higher-elevation winters. 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*).

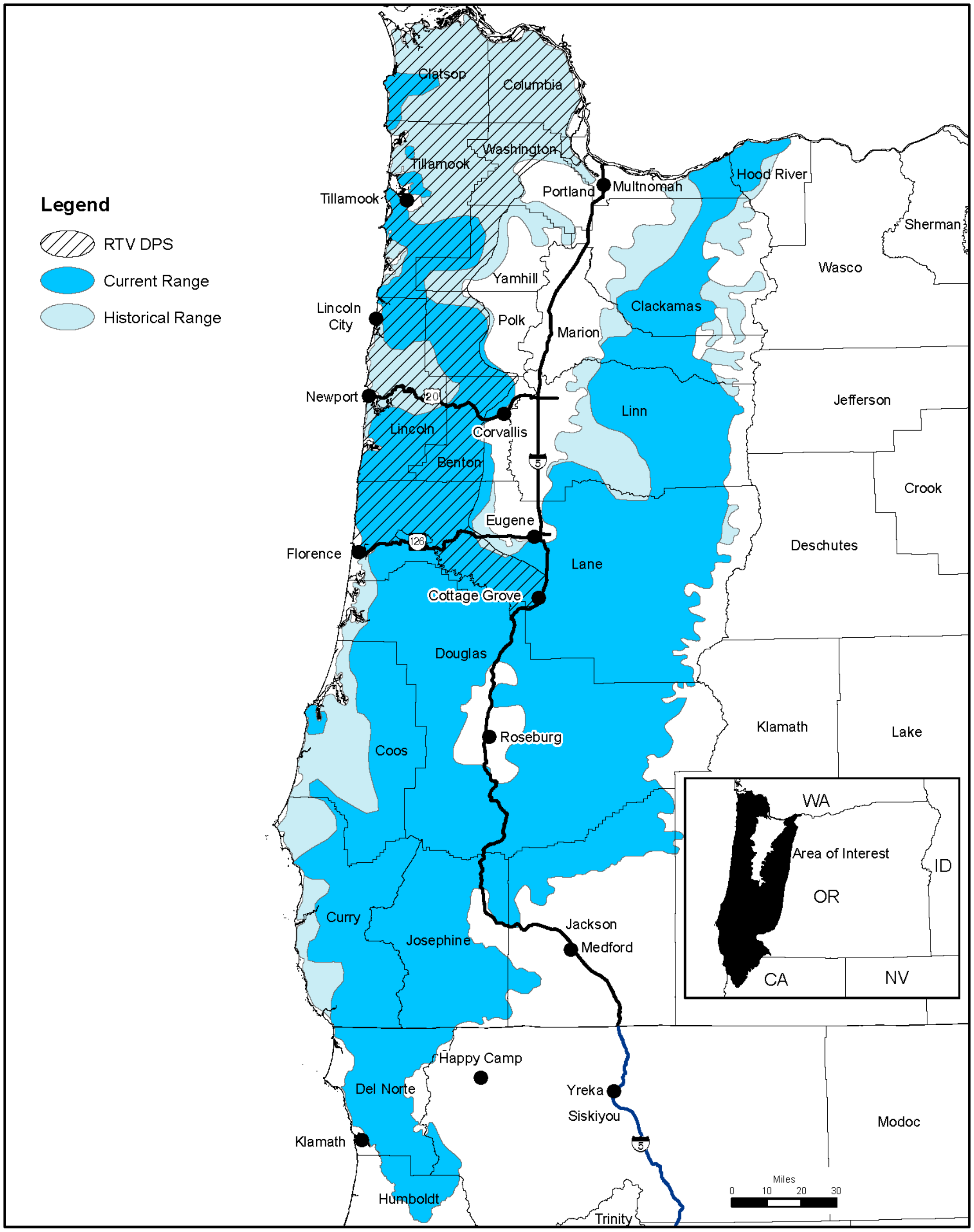

Figure 4. Historical and current range of the red tree vole (Forsman *et al.* 2016, p. 83) and the north Oregon coast distinct population segment (hashed area) (76 FR, 63720).

3.2.3 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. 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.* 2016, 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 (*e.g.*, Jobanek 1988, p. 391). Howell (1921, p. 99) noted that there was little hope for finding tree voles in virgin timber because large trees and the abundant moss often concealed hidden nests. 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, the most prolific early collector of tree voles (1957-1985), spent most of his time searching in young forests because he could not climb big trees (Forsman 2010, pers. comm.; Forsman *et al.* 2016, p. 19; Swingle and Forsman 2016, p. 72).

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 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 1926, pp. 42-43; Clifton 1960, pp. 24-30; Maser 1966, pp. 170, 216-217; Maser 2009, pers. comm.; Forsman and Swingle 2010, p. 104). For example, Clifton (1960, p. 25) averaged one day of searching for every red tree vole cluster found in the Chehalem Mountains (Yamhill County, Oregon), and Howell described more than 50 Sonoma tree voles being collected over 2 days near Carlotta, California in 1913 (Howell 1926, p. 43). In contrast, between 2002 and 2006, 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 vole found.

In considering search effort in recent decades for tree vole nests, 21 person-hours have been spent searching for each nest found in the north coast portion of the DPS, and 3.8 person-hours in the south 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. Across the red tree vole range in Oregon and California, Forsman *et al.* (2016, pp. 9-10, 28) found tree vole evidence at 66 percent of historical sites (those occupied prior to 1984); 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.* 2016, 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.* 2016, p. 28).

The weight of evidence suggesting that tree voles are less abundant now increases upon considering that most historical observations were by naturalists who primarily collected voles from younger forests where nests were more easily observable and accessible by free-climbing (*e.g.*, Howell 1926, p. 42; Clifton 1960, p. 34; Maser 2009, pers. comm.; Forsman 2010, pers. comm.). These early naturalists were limited in their sampling by the size and form (*e.g.*, presence of low-lying limbs that allowed for free-climbing) of trees they could climb, yet found many voles with relatively little effort. In contrast, researchers in recent years searching 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 2009, pers. comm.; Forsman and Swingle 2006, unpublished data; 2009, pers. comm.). Furthermore, Forsman *et al.* (2016, p. 41) believe their retrospective surveys overestimate the proportion of historical sites still occupied by tree voles. They base this on not limiting their surveys to historical nest groves, but instead also including large areas around the historical site; 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. Although we have no population estimates, the evidence suggests that red tree voles are now much less abundant within the DPS than they were historically. Within the north 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 remnant stands of old forest on Federal and State lands.

3.2.4 North Oregon Coast Distinct Population Segment and Analysis Area Description

This species status assessment looks at red tree voles in the northern Oregon Coast Range, in response to our finding that the northern Oregon Coast Range distinct population segment of red tree voles warranted listing under the Act. That finding provided a map with a defined DPS boundary (Figure 5). However, since that finding, we have learned of substantive tree vole nest observations outside of the DPS boundary, on the margin of the Willamette Valley to the east (*e.g.*, the Spencer Butte cluster, see Section 3.3 Analytical Units—Occupied Red Tree Vole Habitat Clusters). Also, parts of the estimated current range in the north Coast Range area are outside of the designated DPS boundary (Figure 6). For this assessment, we have included the current range and associated voles as part of our analysis, even though they are outside of the mapped DPS. Hence, we define our analysis area for this assessment to include the DPS as well as forested areas east to the Willamette River and the Coast Fork of the Willamette River (Figure 5). We also recommend that the north Oregon Coast Range DPS be revised to include all known red tree vole occupied habitat clusters, and suggest describing the DPS as conifer-forested areas starting in Lane County north of the Siuslaw River and east of the Willamette River and Coast

Fork of the Willamette River. The area would extend north to the Columbia River. For the purposes of this SSA, however, DPS refers to that described in the 2011 finding (76 FR, 63720).

Throughout this analysis we also refer to other regions in the vicinity of the analysis area on a regular basis (Figure 5). 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).

3.2.4.1 Vegetation

With the exception of 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 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.* 2004, 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 7). 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).

3.2.4.2 Ownership Patterns and Associated Regulatory Mechanisms

In computing area of ownership, so as not to flood our analysis with non-capable forest lands in the Willamette Valley, we used the original DPS (76 FR 63720) to determine ownership area. Consequently, this excludes some pockets and fingers of forested area that extend into the valley.

Federal lands make up 22 percent of the DPS (Table 1). The Siuslaw National Forest comprises over half of the Federal land within the DPS, and the Northwest Oregon District of the BLM makes up 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 1 percent of the remaining Federal ownership in the DPS. Tribal lands also make up less than 1 percent of the DPS.

Private lands make up 61 percent of the ownership in the DPS, with a mix of individual and industrial forest owners (Table 1). Another 1 percent of the DPS is comprised of county and other local government lands. State lands comprise 16 percent of the DPS. Most of the State ownership (14 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. State parks and other lands make up the rest of the State ownership.

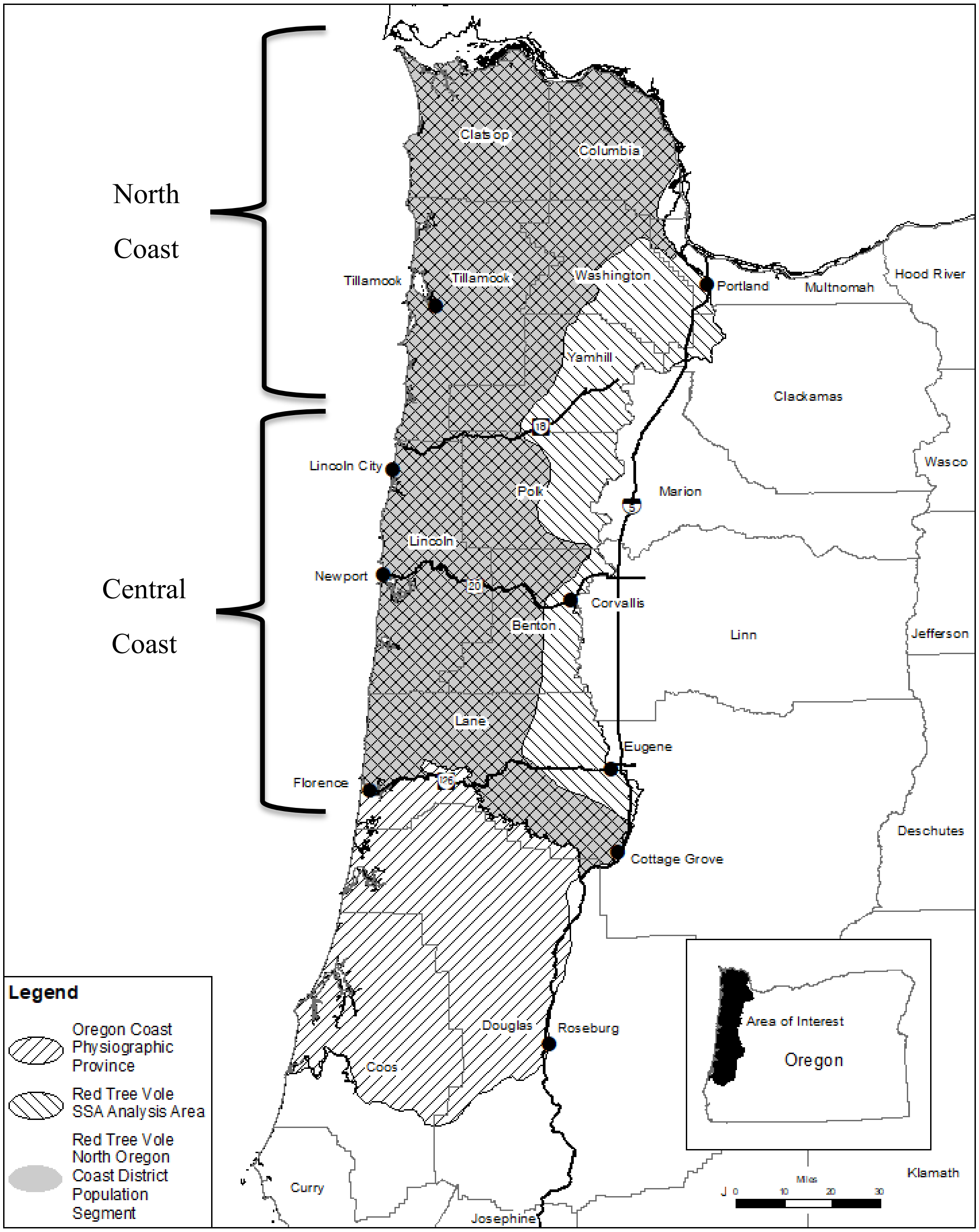

Figure 5. Geographic regions referred to in this analysis. The red tree vole north Oregon coast distinct population segment is from the 2011 12-month petition finding (76 FR, 63720) and lies entirely within the Oregon Coast Physiographic Province. "North Coast" and "Central Coast" are subregions used by Forsman *et al.* (2016, p. 3) and referenced in this document.

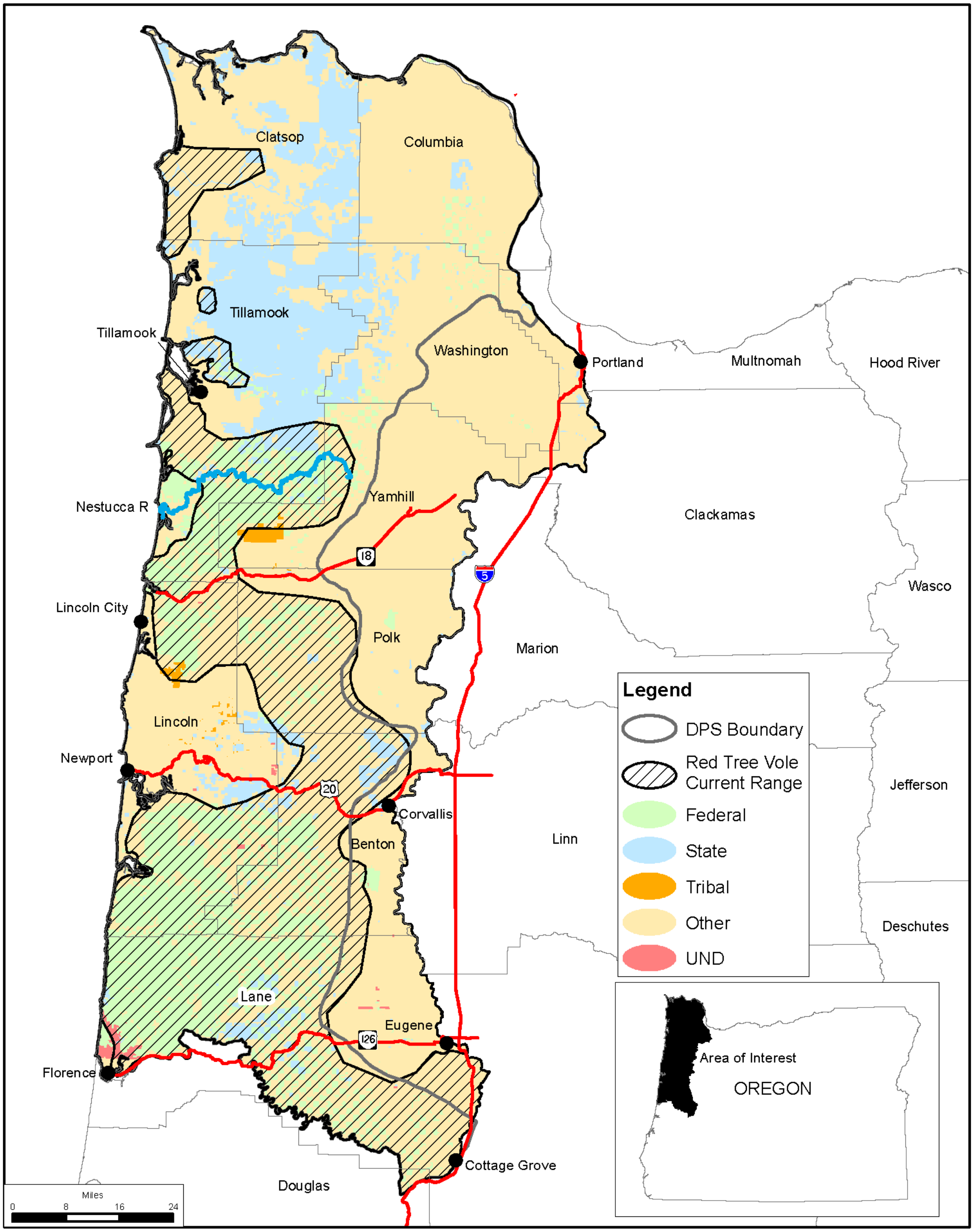

Figure 6. Ownership patterns within the north Oregon coast red tree vole analysis area. Approximate current red tree vole range from Forsman *et al.* (2016, p. 83, Figure 4-5). Distinct population segment (DPS) boundary from 2011 status assessment (76 FR 63720).

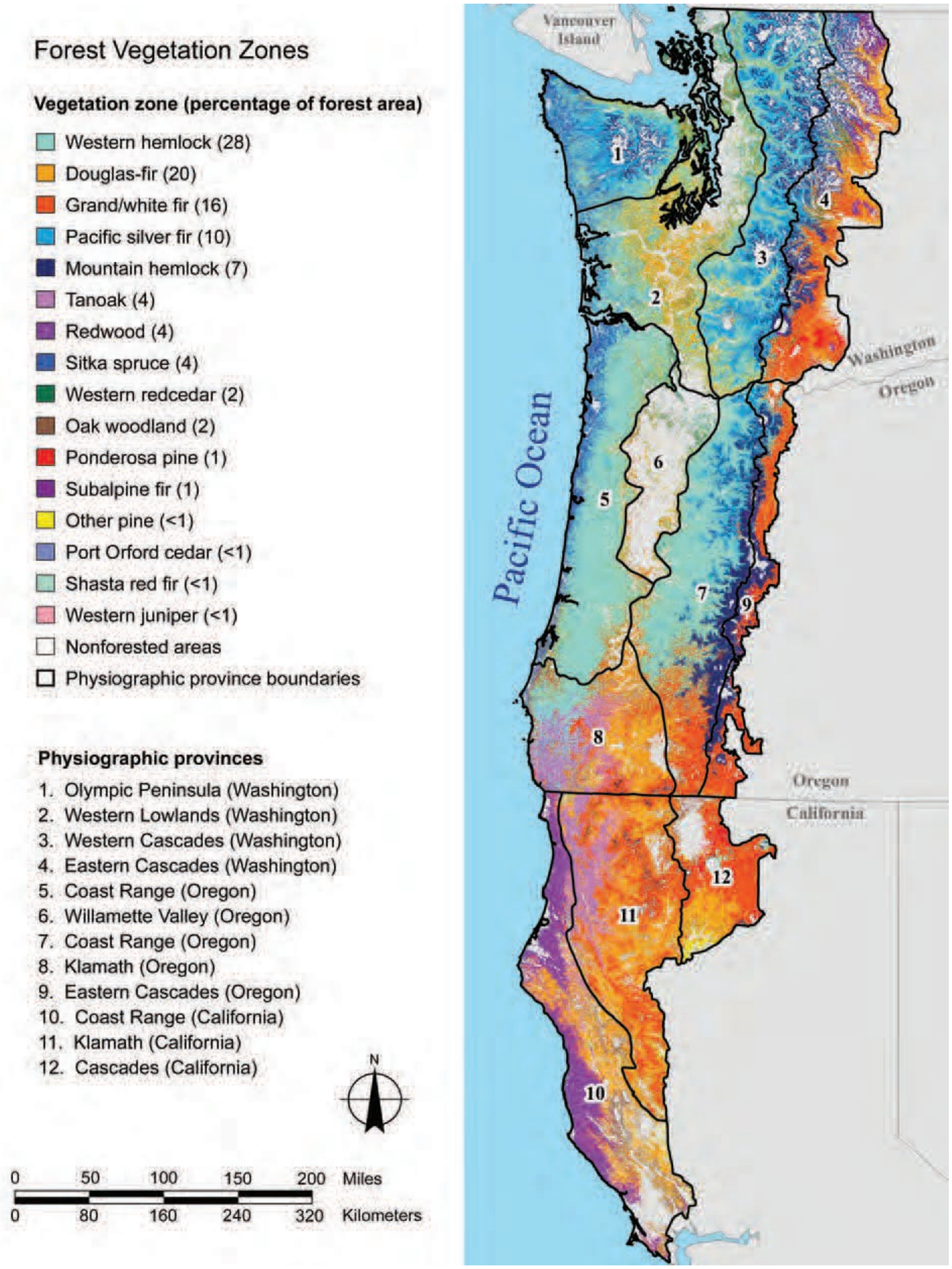

Figure 7. Vegetation zones in the Pacific northwest. Note physiographic province number five, the Coast Range province in Oregon, which encompasses the red tree vole distinct population segment (Figure 5). Most of the province in the analysis area is in the Western hemlock zone, with a narrow band of 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. Figure is from Reilly *et al.* (2018, p. 31, Figure 2-1).

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 of 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 (*e.g.* 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 and USDI 2000b, 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. Standards and Guidelines-10). The agency has developed a process for identifying high-priority sites to conserve the red tree vole (Huff 2016, entire). 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 is no longer under the NWFP, it manages for red tree voles similarly for its lands north of U.S. Highway 20. South of Highway 20, there are no survey requirements, and only known tree vole sites within reserve land-use allocations receive protective measures (USDI 2016, pp. 101).

State forest lands in the analysis area are managed under the Northwest Oregon Forest Management Plan (ODF 2003, entire; 2009, entire; 2010b entire; 2011a, entire; 2011b, 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 the Oregon Department of Forestry, 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 (ODF 2010, pp. 4-82 to 4-83, E-42), although thinning may occur. Reserve areas 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 reserve areas (ODF 2013a entire; 2013c, 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 (ODF 2010, p. 4-48), each representing stands with larger trees and more complex structural conditions. Attaining these objectives would benefit the red tree vole.

Table 1. Ownership within north coast range red tree vole distinct population segment by Federal agency and by land-use category for Forest Service, Bureau of Land Management, and Oregon Department of Forestry. Private ownership includes small amounts of other ownership such as municipal and county. Area is in km^2 (mi^2).

Ownership	Ownership Area	Percent of Area	Agency	Agency Area	Land-use Category[a]	Category Area
Federal	3,408 (1,316)	22	Forest Service	1,984 (766)	Reserve	1,616 (624)
					Non-Reserve	368 (142)
			Bureau of Land Management	1,421 (549)	Reserve	1,168 (451)
					Non-Reserve	254 (98)
			Other Federal Agencies	3 (1)		
State	2,448 (945)	16	Oregon Department of Forestry	2,266 (875)	Constrained	1,186 (458)
					Non-Constrained	1,080 (417)
			Other State agencies	183 (71)	Constrained	183 (71)
Tribal	58 (22)	<1				
Private and local government	9,752 (3,765)	62				
Total	15,667 (6,049)	100				

[a]"Reserve" and "Non-reserve" are categories of 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 restricts timber harvest (Constrained); they may include land-use allocations, as well as other areas removed from the timber harvest landbase (see section 7.2.1.2 State lands). We also applied the "constrained" category to other State agencies as most, if not all, of these lands are managed for recreation (e.g. State parks) or other resource retention that would likely retain tree vole habitat.

Private forests must meet the standards under the Oregon Administrative Rules (OARs), Oregon Revised Statutes (ORS) and the Oregon Forest Practices Act (ODF 2018, entire), which provides no protections for red tree voles or their habitat unless voles are opportunistically located in buffers set aside to protect other species, such as northern spotted owls, bald eagles (*Haliaeetus leucocephalus*), osprey (*Pandeon haliaetus*), and great blue herons (*Ardea herodias*) (OAR 629-

665-0110, 629-665-0120, 629-665-0130, 629-665-0210). 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.* 2004, 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.* 2004, 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 8).

Two federally recognized American Indian tribes actively manage forest lands within the analysis area. The Confederated Tribes of Grand Ronde manage 40 km^2 (15 mi^2), and the Confederated Tribes of Siletz Indians manage 16 km^2 (6 mi^2) 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 the Grand Ronde Reservation 2013, entire; Confederated Tribes of the Siletz Indians 2010a, entire; 2010b, 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 ownership acreages in Table 1, the Siletz Tribe also manages an additional 16 km^2 (6 mi^2) to conserve and develop marbled murrelet habitat over time (Confederated Tribes of the Siletz Indians 2010b, p. 1-2). Retention and development of suitable murrelet habitat would be beneficial to red tree voles.

3.3 Analytical Units—Occupied Red Tree Vole Habitat Clusters

Although we have designated a distinct population segment 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, combined with data from extensive surveys done for red tree voles across the analysis area, allowed for a habitat-based approach to identify occupied clusters of red tree vole habitat that could serve to represent assemblages of red tree voles within the analysis area which we can evaluate under the species status assessment 3R framework. Eleven red tree vole occupied habitat clusters (habitat clusters, vole clusters, or clusters) were identified based on this analysis (Figure 9) (Lesmeister and Linnell 2019, entire; see Appendix A). Clusters comprise aggregates of old-forest patches >20 ha (49 ac) within 2 kilometers (km) (1.2 miles (mi)) of each other (see Appendix A for details). All identified clusters were occupied by red tree voles (*i.e.*, a recently active tree vole nest was found), and all had to have enough old forest (>80 years) to support >100 individuals. A tree vole density estimate of 0.6 voles/ac (1.5 voles/ha), was used to determine sufficient habitat amount, and is the mean of 2 available, estimated densities (Maser 1966, pp. 170–205, 216-217; Marks-Fife 2016, p. 79) (see Section 6.2 Difficulties in Estimating Tree Vole Abundance). The 100 individual threshold was based on a minimum effective population size estimated to limit inbreeding depression (Frankham *et al.* 2014b). 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).

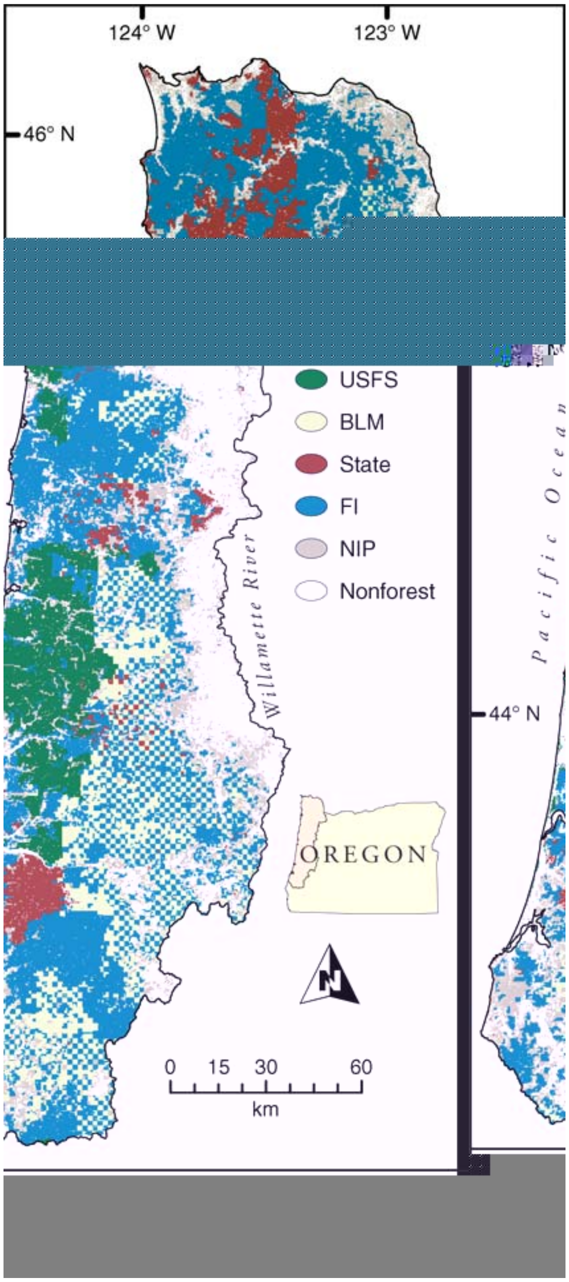

Figure 8. Ownership classes for forested land in the Coast Range physiographic province in Oregon. Abbreviations in legend are: USFS, U.S. Forest Service; BLM, Bureau of Land Management; State, State of Oregon; FI, forest industry; NIP, nonindustrial private forest and other miscellaneous ownership; nonforest, other land uses. Figure is from Spies *et al.* (2007a, Figure 1, p. 7).

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 in general, 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 2012, entire; Frankham *et al.* 2013, entire; Jamieson and Allendorf 2013, entire; Frankham *et al.* 2014a and b, entire; Franklin *et al.* 2014, entire; Rosenfeld 2014, entire). The resiliency analysis done for this assessment used an effective population size threshold of 100 as 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.* 2014b, pp. 58-59). 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 occupied tree vole habitat clusters.

Eleven red tree vole habitat clusters were identified based on habitat distribution and tree vole occupancy (Lesmeister and Linnell 2019, entire; see Appendix A). Almost all clusters encompass areas with State or Federal land (Figure 9), which is where the majority of red tree vole habitat occurs (Figure 10). Red tree vole habitat was modeled by Linnell *et al.* (2017, entire) and includes stands of old coniferous forests (>80 years old) or young forests adjacent to old forests that tend to have the structural features necessary to support tree vole nests (see section 3.4.4 Habitat). Individual unit descriptions are below (Table 2), with units presented generally from north to south. By design, clusters closely encompass areas of occupied tree vole habitat (Figure 11), although there are extensive areas of unoccupied habitat on State forest lands in the northernmost extent of the study area (*e.g.*, Clatsop County) (Figures 10 and 11).

1 Oswald West (7 km^2 (3 mi^2))
This habitat cluster is the smallest of all identified. It comprises mostly State land (87 percent), with the remainder private. Oswald West State Park makes up the State ownership. This area lies along the coastal headlands in the Sitka spruce vegetation zone, where western hemlock and Sitka spruce are the dominant coniferous species.

2 Tillamook State Forest Nehalem (88 km^2 (34 mi^2))
This habitat cluster lies along the western edge of the Tillamook State Forest, which makes up 81 percent of the area. The remaining ownership is private. The area is along the western flank of the Tillamook Burn and encompasses older forests that escaped the series of wildfires that occurred in the mid-20th century. This area is located within the Sitka spruce zone.

3 Tillamook State Forest Kilchis (138 km^2 (53 mi^2))
This habitat cluster lies along the southwestern edge of the Tillamook State Forest, which makes up 48 percent of the area. The BLM manages another 21 percent of the area, and the remaining 31 percent is in private ownership. Similar to the Tillamook State Forest cluster, this area encompasses some older forests that escaped the Tillamook Burn. It lies in the Sitka spruce vegetation zone.

4 Cape Lookout (19 km^2 (7 mi^2))
This habitat cluster also occurs along the coastal headlands and encompasses Cape Lookout State Park (19 percent), the Siuslaw National Forest (34 percent) and private land (47 percent). It lies in the Sitka spruce vegetation zone.

Table 2. Ownership in occupied red tree vole habitat clusters identified in the analysis area. Private ownership may also include minor amounts of other ownerships such as municipal or county. Green shading represents the majority ownership for the habitat cluster, orange shading represents second largest ownership.

Habitat Cluster	Area in km^2 (mi^2)	Ownership Percentage of Habitat Cluster Area				Percent Habitat
		Federal	State	Tribal	Private	
1-Oswald West	7 (3)	0	86	0	14	65
2-Tillamook State Forest Nehalem	88 (34)	0	81	0	19	28
3-Tillamook State Forest Kilchis	138 (53)	21	49	0	30	36
4-Cape Lookout	19 (7)	32	21	0	47	37
5-Nestucca Block	1,480 (571)	56	3	3	38	45
6-BLM Checkerboard East	60 (23)	48	0	0	53	46
7-BLM Checkerboard West	26 (10)	54	0	0	42	47
8-South Block	4,425 (1,708)	49	5	<1	45	46
9-OSU[a] Forest	103 (40)	5	38	0	57	21
10-Junction City	29 (11)	17	0	0	83	19
11-Spencer Butte	15 (6)	0	0	0	100	24

[a]OSU-Oregon State University

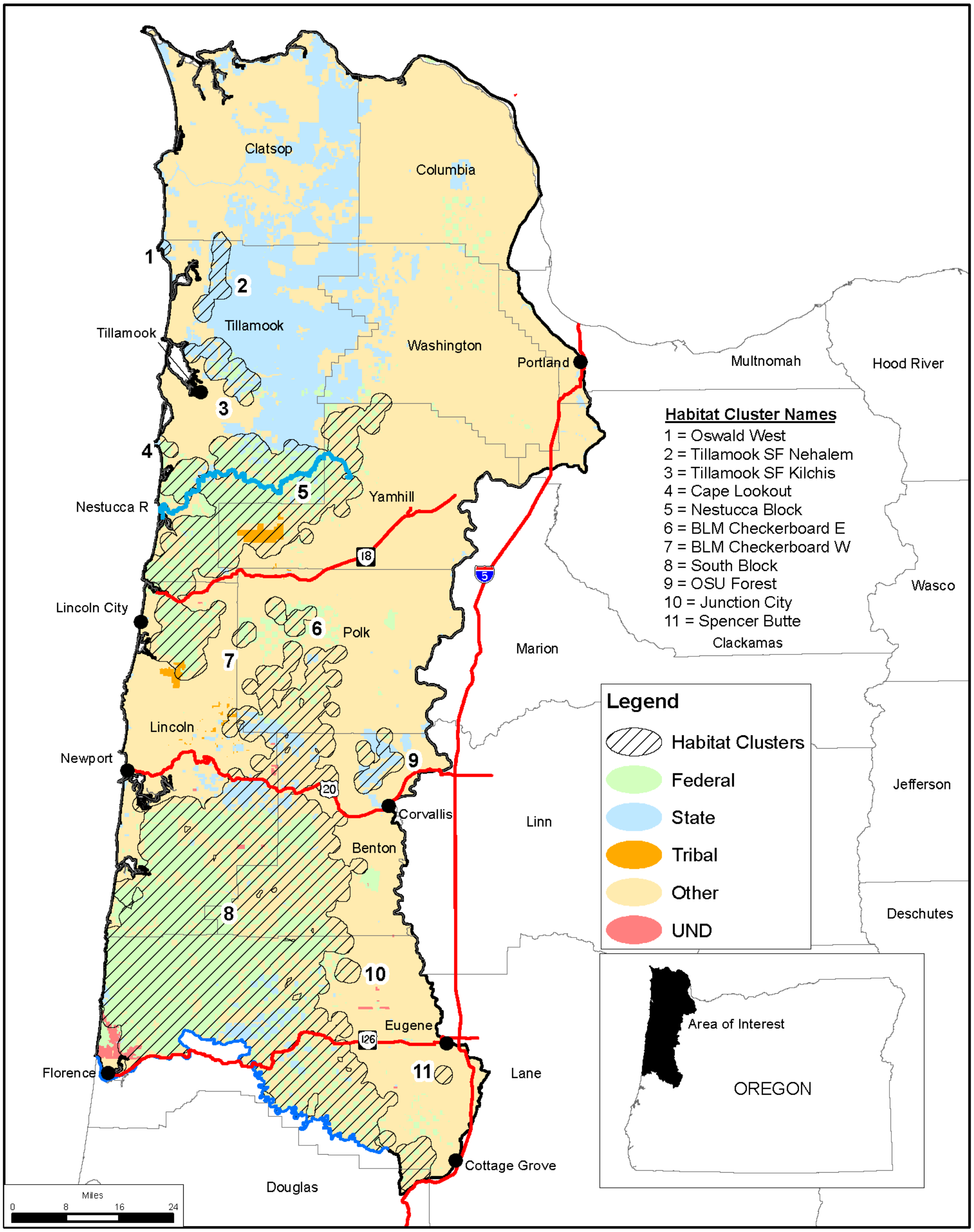

Figure 9. Red tree vole occupied habitat clusters and associated ownership. Clusters are derived from Lesmeister and Linnell (2019, entire) (see Appendix A).

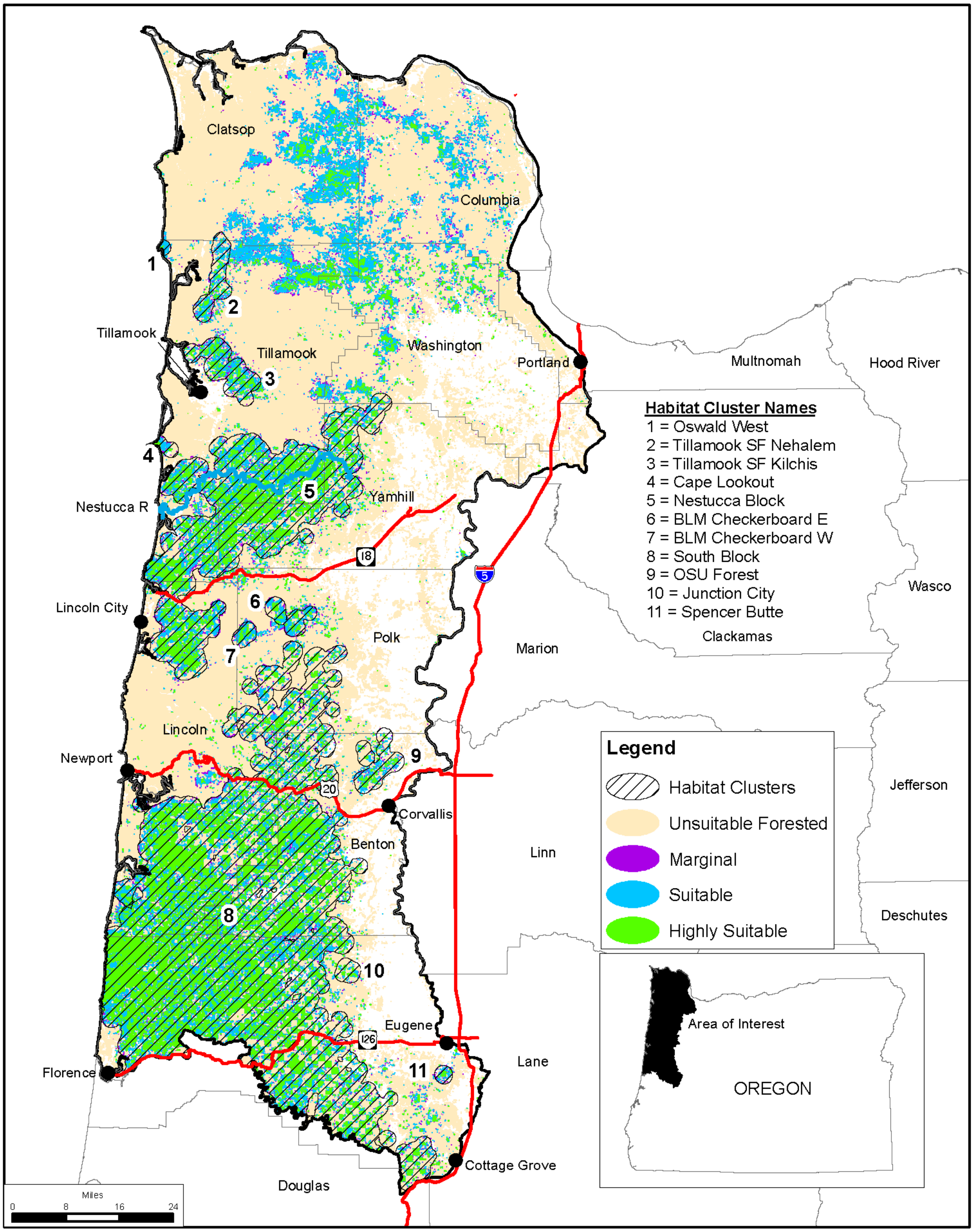

Figure 10. Red tree vole occupied habitat clusters and associated red tree vole habitat suitability from Linnell *et al.* (2017 entire). Clusters are derived from Lesmeister and Linnell (2019, entire; see Appendix A).

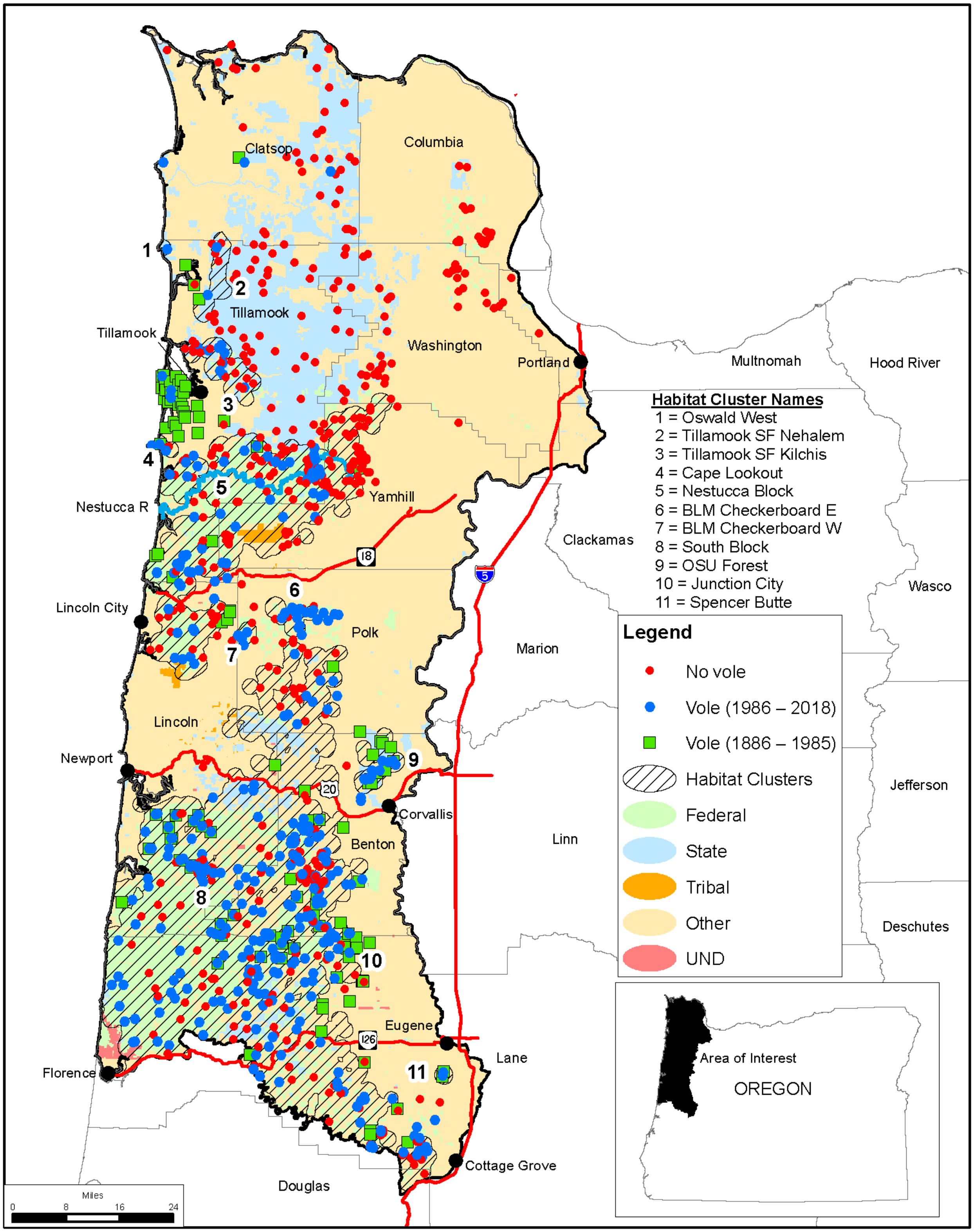

Figure 11. Red tree vole occupied habitat clusters and red tree vole survey results. Clusters are derived from Lesmeister and Linnell (2019, entire; see Appendix A).

5 Nestucca Block (1,480 km^2 (571 mi^2))
This is the second-largest identified habitat cluster, with 56 percent of the area comprising BLM and National Forest land. Much of the Federal ownership is relatively contiguous. There is scattered checkerboard ownership (Federal and non-Federal intermixed, usually every other square mile or Public Land Survey section) in the northeastern arm of this cluster in Yamhill County in which no tree voles have been detected after extensive surveys (Figure 11). Private land makes up 38 percent of the area, with State and Tribal lands making up 3 percent each. Most of the Tribal lands here are managed by the Confederated Tribes of Grand Ronde. Another approximately 1,000 acres is part of the Reed Creek block managed by the Confederated Tribes of Siletz Indians; though noted here and mapped in Figure 9 and other maps showing ownership, we did not have the spatial data available when we did our analysis. However, this amount of ownership is too small to influence our overall condition analysis. The western portion of this cluster is in the Sitka spruce zone, generally restricted to a few kilometers from the coast line. Most of the this cluster lies in the western hemlock vegetation zone, where Douglas-fir is the predominant coniferous species.

6 BLM Checkerboard East (60 km^2 (23 mi^2))
This is one of two smaller clusters located between the two largest habitat clusters in the analysis area. It encompasses a checkerboard ownership pattern, with BLM managing 47 percent of the area, and the rest in private ownership. It lies in the western hemlock vegetation zone.

7 BLM Checkerboard West (26 km^2 (10 mi^2))
This is the second of two smaller habitat clusters located between the two largest habitat clusters in the analysis area. It encompasses a checkerboard ownership pattern, with BLM managing 56 percent of the area, and the rest in private ownership. It lies in the western hemlock vegetation zone.

8 South Block (4,425 km^2 (1,708 mi^2))
This habitat cluster encompasses the largest area of all clusters identified, and encompasses much of the southern quarter of the analysis area. Federal lands make up 49 percent of the area, private lands 46 percent, and the remainder is State forest land. Small parcels of Tribal ownership (Confederated Tribes of Siletz Indians) make up less than 1 percent of the area. The Sitka spruce zone lies along the western edge of this habitat cluster, but the vast majority is in the western hemlock zone. Federal lands are distributed throughout the portion of this cluster that lies south of U.S. Highway 20, with the Siuslaw National Forest managing relatively contiguous blocks of land and red tree vole habitat in the western half, and BLM managing primarily checkerboard ownership in the eastern half of the area. This cluster extends north of Highway 20, but is most likely a loose affiliation of small habitat parcels; habitat in this portion of the cluster is scattered and few voles have been found compared to the rest of the habitat cluster. Given the ownership and habitat condition in the portion of this unit north of Highway 20, this area probably functions more as connectivity between the portion of the area to the south of Highway 20 and the Nestucca Block cluster. This is also the only vole cluster with connectivity to tree voles outside of the DPS. The Siuslaw River, which makes up much of the southern boundary of the DPS is likely a strong filter to movement, though we cannot conclude it is impenetrable to tree voles. More connection opportunities to red tree vole populations to the

south exist near the southern end of the Willamette Valley, at the southeastern portion of the DPS.

9 OSU (Oregon State University) Forest (103 km^2 (40 mi^2))
This habitat cluster encompasses the McDonald Dunn Research Forest, managed by Oregon State University. The research forest makes up 38 percent of the area, private lands account for 57 percent, and the remainder is Federal. This cluster is in the western hemlock vegetation zone, but lies on the western edge of the Willamette Valley. Vole nests on the McDonald Dunn Forest are concentrated in a few locations, suggesting there is not a uniform distribution across the forest (Forsman *et al.* 2016, p. 33).

10 Junction City (29 km^2 (11 mi^2))
This habitat cluster encompasses some small parcels of scattered BLM lands mixed in with private forest land on the edge of the Willamette Valley. Most of the area (83 percent) is private, with the remainder in Federal ownership. It is in the western hemlock vegetation zone.

11 Spencer Butte (15 km^2 (6 mi^2))
This habitat cluster encompasses a forested butte on the edge of the Willamette Valley. Approximately 1.5 km^2 (0.6 mi^2) is managed by the city of Eugene as a park, almost all of which is tree vole habitat. The cluster is in the western hemlock vegetation zone, though is on the margin of the Willamette Valley where vegetation is influenced by the drier and warmer valley climate.

3.4 Species Life History and Habitat

3.4.1 Reproduction

Red tree voles have relatively low reproductive potential compared to other vole species within the Arvicolinae subfamily (*e.g.*, see Table 3 for comparison with closely related heather vole (*Phenacomys intermedius*)). Such low reproductive rates are likely a contributing factor to maintaining tree vole populations at naturally low densities (Forsman *et al.* 2016, p. 47). 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). Forsman *et al.* (2009a, p. 270) observed 2 female voles in the wild that produced litters at 30 to 35 day intervals. In captivity, shorter gestation periods of 27-29 days may be typical, 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 1926, 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 capability between red tree voles and heather voles. Sources for red tree vole cited in text. Source for heather vole is Verts and Carraway (1998, pp. 302, 307-309) unless otherwise noted.

Reproductive Variable	Red Tree Vole	Heather Vole
Sexual maturity	10-12 weeks	4-6 weeks
Gestation period	30-41 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)

3.4.2 Diet

Tree voles are unique in that they are one of the few mammals that can persist on a diet of conifer needles. They also harvest conifer twigs and consume the tender bark, underlying cambium, or both. In most of their range, they feed primarily on Douglas-fir, although foraging on western hemlock and grand fir (*Abies grandis*) has been recorded (Jewett 1920, p. 166; Howell 1926, pp. 52-53; Walker 1930, p. 234; Benson and Borell 1931, p. 230; Maser *et al.* 1981, p. 205; Forsman *et al.* 2016, pp. 49-51). However, within the Sitka spruce vegetation zone, tree voles primarily consume needles from western hemlock and Sitka spruce (Forsman *et al.* 2016, pp. 49-50). 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.* 2016, 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; Perry 1994, pp. 453-454; Maser 1998, pp. 220-221; Kelsey *et al.* 2009, entire; Forsman *et al.* 2016, 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. As an example, 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, pers. comm.; Kelsey *et al.* 2009, entire; Forsman *et al.* 2016, pp. 51-52).

Tree vole preference for Sitka spruce and western hemlock needles within the Sitka spruce vegetation zone may be a requirement rather than a preference in some instances. 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, pers. comm.; Forsman *et al.* 2016, pp. 49-54). Maser (2009, pers. comm.) observed that tree voles adapted to a diet of western hemlock starved to death in captivity because they would not eat the Douglas-fir needles they were offered. 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 (2009, pers. comm.) suspected that voles raised in stands of western hemlock never learned the required behavior for eating Douglas-fir, although 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, pers. comm.), although voles appear to be reluctant to switch between tree species (Walker 1930, p. 234; Forsman 2010, pers. comm.; Forsman *et al.* 2016, p. 52).

Tree voles consume much less water than that 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. 148; 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 (*e.g.*, Howell 1926, 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).

3.4.3 Home Range and Dispersal

The only published data on home range sizes and dispersal come from red tree voles radio-collared outside of the analysis area, in the southern Oregon Coast Range and southern Cascade Range of Douglas County (Swingle 2005, pp. 51-63, 84-89; 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 (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 and Meslow, unpublished data referenced in USDA and USDI 2000b, p. 8).

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 and Meslow, unpublished data referenced in USDA and USDI 2000b, p. 8).

The small home ranges and limited 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 clusters of tree voles to expand and to establish new assemblages across the landscape. Because of this limited expansion capability, colonization may occur at a slow rate as multiple generations expand incrementally over time. This may also explain why tree voles tend to be found in clustered pockets across the landscape.

Given the limited 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, pp. 259, 261, 262; Rosenberg *et al.* 2016, p. 19; Johnston and Moskal 2017, p. 69; Linnell *et al.* 2017, pp. 5-6).

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 don't move far (see earlier in this section), this suggests that forest fragmentation can substantially restrict movements. Modeling of red tree vole habitat indicated that older forest cover—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 dispersal distances, this suggests that 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 and Meslow, unpublished data referenced in USDA and USDI 2000b, 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 greatly 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 1973, pp. 34, 36; 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. 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.

3.4.4 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.* 2016, p. 66). Tree vole nests are located in the forest canopy. 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 1926, p. 46; Clifton 1960, pp. 53-60; Maser 1966, pp. 94-96; Gillesberg and Carey 1991, p. 785; Forsman *et al.* 2009a, p. 266). Single large branches, dwarf mistletoe (*Arceuthobium* spp.) brooms, and re-sprouted branch clusters serve as stable foundations for vole nests in larger trees, while whorls of branches or forked tops can provide secure sites for nesting in smaller trees (USDA and USDI 2000b, p. 7). On the occasions when tree voles nest in non-conifers or snags, limbs are interconnected with adjacent live conifers where the voles can obtain food (Maser 1966, p. 78; Swingle 2005, p. 31).

With the exception of the Sitka spruce vegetation zone (see section 3.2.4.1 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, Table 2; Forsman and Swingle 2009, pers. comm.; Maser 2009, pers. comm.; Price *et al.* 2015, pp. 43, 45; Forsman *et al.* 2016, pp. 49-50), 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, pers. comm.; Price *et al.* 2015, pp. 43). When tree voles nest in a tree species that does not provide their preferred forage, (*e.g.* nesting in a Douglas-fir when western hemlock or Sitka spruce is the preferred forage species), there is almost always interconnected limbs to an adjacent tree of the preferred forage species, allowing ready access to food (Swingle 2005, p. 31; Forsman *et al.* 2016, p. 50).

Habitat modeling and other empirical evidence across the range of the species shows that tree voles are associated 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, pp. 259, 261, 262; Swingle 2005, p. 39; Dunk and Hawley 2009, p. 632; Forsman *et al.* 2016, pp. 66-67, 74; Rosenberg *et al.* 2016, pp. 13-16, 19; Johnston and Moskal 2017, pp. 65, 69-71; Linnell *et al.* 2017, p. 5).

There are several hypotheses as to why red tree voles are associated with older forests or the structural characteristics typically found in older forests. 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). Because nests can get quite large, substantial substrates are necessary. Larger and older trees typically provide a variety of substrates that can be used for nesting, such as numerous cavities, large limbs and limb platforms, broken tops, hollow trunks, and deformed bole and branch structures; these complex structures provide more protection for nests than do young trees (Forsman *et al.* 2009, p. 230). In addition, the 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). Finally, Carey (1991, p. 8) suggested that old-growth Douglas-fir forests (multi-layered stands over 200 years old) provide environmentally and structurally stable conditions compared to younger forests where trees are continuously growing and tree canopy architectures are changing. Indeed, persistence of red tree vole nests in younger stands appears to be highly ephemeral, as indicated by surveys in formerly occupied young stands yielding no detections 3-7 years later (Forsman *et al.* 2016, p. 32).

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, to name a few). In this analysis, we use these terms or specific stand ages when they appear in the cited literature. Otherwise, we use the term, "older forest," when collectively referring to these stand conditions; based on recent habitat modeling, this generally means forest stands >80 years old (Linnell *et al.* 2017, 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.* (2017, 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.* 2017, p. 9). For example, the variables strongly associated with tree vole habitat modeled by Forsman *et al.* (2016, pp. 66-67, 108-109), 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 younger stands and not in some older stands.

Tree voles can also be found in forests younger than 80 years, sometimes at relatively high densities (Forsman *et al.* undated, p. 4; Jewett 1920, p. 165; Howell 1926, pp. 41-45; Brown 1964, p. 647; Maser 1966, pp. 40, 216-217; Corn and Bury 1986, p. 404; Thompson and Diller 2002, p. 95; Swingle and Forsman 2009, p. 277; Price *et al.* 2015, pp. 43, 45). However, voles strongly select for older forests. Voles are more common and regularly occur at higher densities in older forests compared to younger forests (Corn and Bury 1986, p. 404; Corn and Bury 1991, pp. 251-252; 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.* 2016, pp. 42-45; Rosenberg *et al.* 2017, p. 19). Forsman *et al.* (2016, p. 25, Table 1-8, p. 28) found a consistent pattern of increasing density of trees with vole nests with increasing size class of forest. Furthermore, while voles were found in some younger stands in coastal Oregon, the majority of younger stands examined were not occupied by tree voles (Forsman *et al.* undated, pp. 4-5; Price *et al.* 2015, pp. 45-46). In the case of Price *et al.* (2015, 45-46), the young stands occupied by voles were adjacent to older forest stands. Finally, detection of tree vole nests in older stands is likely biased low because of greater difficulty in detecting nests in older forests (Swingle and Forsman 2009, p. 284; Marks-Fife 2016, p. 78). However, when survey plots are large enough, the probability of not detecting a vole nest in plots where tree voles occur, in both old and young forests, is considered low (Forsman *et al.* 2016, p. 43).

The suitability of younger forests as red tree vole habitat, and their role in the abundance, persistence, or dispersal of red tree voles, is unclear. Carey (1991, p. 34) suggested younger forests were population sinks for red tree voles. Based on surveys in young forests (22 to 55 years old) and observations of radio-collared tree voles, Swingle (2005, pp. 78, 94) 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, pp. 78, 94) 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 younger forest stands, occupancy may be relatively short-lived (Diller 2010, pers. comm.) or intermittent (Hopkins 2010, pers. comm.). As an example, Forsman *et al.* (2016, p. 32) found several locations where occupied tree vole nests occurred in younger forests, only to return to those stands three to seven years later and not find any occupied nests. Hopkins (2010, pers. comm.) made similar observations; he also observed that occupied nests in old-growth stands (350-400 years) or stands with old-growth structural characteristics tended to remain occupied on follow-up visits.

Habitat modeling reveals a higher probability that red tree voles will occupy younger stands the closer the stands are to older forest or tree vole habitat (Rosenberg *et al.* 2016, p. 19; Johnston and Moskal 2017, p. 66; Linnell *et al.* 2017, pp. 6, 9). Given the limited dispersal capability of red tree voles, it follows that the distance from vole habitat could affect occupancy of new sites. The distance between habitat patches should be less than 2 km (1.2 mi) to support persistent tree vole populations (Lesmeister *et al.* 2016, pp. 14-15). This suggests that young forests may complement overall habitat suitability, but only when in close proximity to older forests. The occurrence of active nests in remnant older trees in younger 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 older forest, perhaps up to some unknown threshold distance. However, it is unknown whether or not younger 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.* 2016, pp. 32-34).

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, 69) 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. Lesmeister *et al.* (2016, p. 14) suggested 20 ha (49 ac) as a minimum old-forest patch size necessary to support a breeding population of tree voles. 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, pers. comm.). Huff *et al.* (1992, pp. 6-7) compiled data on actual red tree vole presence and found the mean age of stands in which tree voles were found in the Oregon Coast Range was 340 years and the minimum stand size was 30 ha (75 ac), with mean and median stand sizes of 192 and 129 ha (475 and 318 ac), respectively. 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).

3.4.5 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, pp. 259, 261-262). 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 5.1.1 Habitat Loss, Modification, and Limitations for Restoration). 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. Swingle (2005, pp. 64, 90) found that of 25 documented cases of predation on radio-collared voles, most occurred in young (22 to 55 years old) forests (Forsman and Swingle 2009, pers. comm.). Predation by weasels (*Mustela sp.*), which accounted for 60 percent 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, pers. comm.; Swingle 2010, pers. comm.). Recent work looking at paired plots of tree vole nests on artificial nest platforms in young vs. old forests showed that predator visitation rates to nests were higher in young forests compared to old forests (Durham *et al.* 2019, unpublished data). This could suggest that predation risk may be higher in younger forests than in older 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. Swingle *et al.* (2010, p. 260) suspected weasel predation on tree voles may be inversely proportional to nest height. 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 (Zentner 1966, pp. 18-20; Vrieze 1980, pp. 18, 32-33; 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 older stands compared to younger stands. Thus, tree voles could be more prone to predation in shorter trees or younger stands where nests are typically closer to the ground. Swingle *et al.* (2010, p. 261) also suggested that 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.

In summary, tree voles depend on several forest characteristics to reduce predation risk and improve survival. They need either a connected forest canopy or a large enough tree to provide sufficient foraging and dispersal capability and to minimize the need to travel to the ground, which may increase predation risk. Nesting in older forests may also reduce predation risk because the complexity of older stands may make tree vole nests less conspicuous to predators. In addition, nesting at increased heights in trees in older forests, compared to younger 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 1926, 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, p. 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 differences 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 (*e.g.* as little 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 older forests tend to provide the structural complexity that increases the abundance of these features. Finally, red tree voles are prey to numerous predator species, ranging from terrestrial-based mustelids such as weasels and fishers (*Pekania pennanti*), to diurnal and nocturnal raptors, to other arboreal rodents such as Humboldt's flying squirrels (*Glaucomys oregonensis*) (recently split from northern flying squirrel (*G. sabrinus*)) (see section 5.2 Predation). Consequently, reducing their predation risk is important. Older forests seem more conducive to protecting red tree voles from predators.

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

<table>
<tr><th>Life Stage or Biological Process</th><th>Resource Needs</th><th>Function</th></tr>
<tr><td>Juvenile
(birth to dispersal at ~47-60 days old)</td><td>Female: Source of food and, early on, thermal protection. Maintain and develop nest. Survival education.</td><td>Shelter and Feeding</td></tr>
<tr><td rowspan="3">All life stages

Juvenile

Subadult
(dispersal period from leaving nest to establishing a new home range)

Adult
(onset of sexual maturity at ~2.5-3 months of age)</td><td>Food: Conifer boughs for food. Primarily Douglas-fir, Sitka spruce, western hemlock, and grand fir, depending on vegetation zone.</td><td>Feeding</td></tr>
<tr><td>Nest material: Conifer twigs, lichens, and resin ducts discarded from feeding.

Nest support structure: Solid structure to support a nest that can get rather large. Structures include abandoned nests of other species, large branches, mistletoe brooms, epicormic palmate branches, branch whorls, forked trunks, forked or broken tops, and cavities.</td><td>Shelter</td></tr>
<tr><td>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. Older forests where predation risk at the nest seems to be lower, based on reduced visits by predators to red tree vole nests in artificial platforms in older forests, compared to younger forests.</td><td>Shelter</td></tr>
<tr><td>Subadult

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

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 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. These features 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 such that they can withstand and rebound from random environmental, genetic, and demographic events that may temporarily reduce their overall population health. Genetic events that are abated with larger population sizes include such things as inbreeding, genetic drift, and loss of heterozygosity, which affect the species' long-term adaptability as well as individual survival as deleterious genes become expressed. Random demographic events that can reduce population resiliency include altered sex ratios or changes in birth or survival rates. Random environmental events may include such things as an extreme weather event that may reduce births or survival of young, or may reduce adult survival.

Wildlife populations, including red tree voles, are better able to rebound from the events described above if their populations are large enough and connected so as to provide genetic and demographic support to affected populations. Connectivity among red tree vole populations can be assessed by the permeability of the intervening matrix between populations. That is, how similar is this intervening landscape to occupied areas, and to what degree does it facilitate movement among populations (*e.g.* 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, so that the older the stands are and the more structure that is available, the more connected tree vole populations will be (Linnell *et al.* 2017, p. 7). 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 and slow life history 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.

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.

4.3 Species Needs—Representation and Redundancy

4.3.1 Representation

Representation is about having the breadth of genetic makeup 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 (Table 6), representation includes the behavioral diversity in foraging capability in response to the availability of different coniferous species (see section 3.4.2 Diet). This tends to be associated with the vegetation zone, which reflects the predominant tree species. 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 3.4.5 Survival), as well as climate change and its effect on forest species composition in the future (see section 7.1.2 Climate Change).

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 capacity and imputed population range)
Habitat to support healthy demography	Provides needs for enough individuals to persist as a self-sustaining group of red tree voles	Sufficient amount of older coniferous forest in large enough patches to maintain individual interaction.
Connection to other populations	Ability to maintain gene flow and provide demographic support to adjoining tree vole assemblages.	Intervening matrix between occupied tree vole habitat clusters that can facilitate movement or will grow into habitat in sufficient time to facilitate demographic support

4.3.2 Redundancy

Redundancy reflects the capacity of the species to withstand catastrophic events (*e.g.* 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 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 km^2 (460 mi^2) to 3,240 km^2 (1,250 mi^2). (see section 5.1.1.1 Wildfire). Wildfires are the greatest catastrophic event affecting 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. These storms can be large and destructive. For instance, the Columbus Day storm of 1962 brought Category 3 hurricane-force winds to the Pacific Coast from California to British Columbia (LaLande 2018, entire). 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. However, these disturbance events may be roughly equivalent in their resulting loss of standing trees. As an example, the 1962 Columbus Day storm that spanned 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, pp. 76, 78-79) 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.

The ability for tree voles to respond to these events is to have large-enough tree vole clusters in an area substantially larger than the footprint of the stand-replacing disturbance event. This would ensure that red tree vole clusters remaining after the event would still be sufficiently large to retain their resiliency until the time that the disturbed area returns to tree vole habitat (Table 6). Alternatively, red tree vole clusters may be smaller and well-distributed across the analysis area such that when a large event occurs, the remaining clusters continue to function and are connected to other remaining clusters. This would allow the vole clusters to maintain their resiliency through time until the intervening disturbed area returns to habitat that is suitable for cluster connectivity or occupancy.

5 FACTORS INFLUENCING THE SPECIES

5.1 Habitat Loss, Modification, and Fragmentation

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.* 2017, p. 6). Forsman *et al.* (2016, p. 82) estimated a 23 percent Oregon-wide reduction in the red tree vole range between 1914 and 2006. Specific to the north coast subregion of the analysis area (Figure 5) that range reduction was 80 percent. The authors attributed this substantial contraction to habitat loss and probable extirpation of tree voles in their historic range. Concurrent with the species' range contraction, red tree vole habitat models show a 65 percent reduction in habitat area rangewide (Forsman *et al.* 2016, p. 80). More specific to the analysis area, the area of red tree vole habitat has declined over 80 percent, from 56 percent of the area having old-forest cover in 1911, declining to 11 percent by 2015 (Linnell *et al.* 2017, 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.* 2016, p. 37). Landscapes throughout the Oregon Coast Range have become increasingly fragmented and dominated by younger patches of forest, as old and mature forests have been converted to younger stands through timber harvest and wildfire (Wimberly *et al.* 2000, p. 175; Martin and McComb 2002, p. 255; Wimberly 2002, p. 1322; Wimberly *et al.* 2004, p. 152; Wimberly and Ohmann 2004, pp. 631, 635, 642).

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

3Rs	Needs for long-term-viability	Description
Resiliency	Interconnected healthy tree vole clusters with habitat to provide for feeding, sheltering and protection from predators	Clusters of red tree voles with (1) sufficiently large N_e; (2) sufficient amount of older (>80 years) coniferous forest with connected tree canopy; and (3) intervening matrix between clusters that allows for occasional demographic and genetic exchange
Representation	Maintain diversity	Resilient tree vole clusters distributed across the two vegetation zones (Sitka spruce and western hemlock)
Redundancy	Sufficient distribution of healthy tree vole clusters	Sufficient distribution to guard against catastrophic events
	Sufficient number of healthy tree vole clusters	Adequate number of healthy tree vole clusters to buffer against catastrophic losses
	Sufficient size of healthy tree vole clusters (in population number and area occupied)	Adequate size of tree vole clusters corresponding to the scale of the catastrophic event such that sufficient individuals remain to persist in an area post-disturbance.

5.1.1 Habitat Loss, Modification, and Limitations for Restoration

Habitat loss and modification can be attributed to multiple sources. Wildfires were the primary disturbance type prior to European settlement, with fires as large as 3,237 km^2 (1,250 mi^2) 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. Loss of large-conifer stands to development was not considered a primary cause of forest type change during this period (Wimberly and Ohmann 2004, pp. 643-644). Where development does occur, 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). A relatively new 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*.

5.1.1.1 Wildfire

Wildfires are infrequent in the Oregon Coast Range but are typically large, stand-replacing events that kill most of the overstory (Agee 1991, pp. 28-30; Teensma *et al.* 1991, p. 3; Agee 1993, pp. 187-191, 205-212; Forsman *et al.* 2016, p. 20, Figure 1-6). 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 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 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 1991, p. 3; Gedalof *et al.* 2005, p. 170; Meyn *et al.* 2007, pp. 294, 301-303). The large amounts of contiguous fuel on these landscapes facilitates rapid fire spread and reduced success in suppression.

In the mid-1800s, a 3,240 km^2 (1,250 mi^2) fire or fire complex burned over the southern portion of the analysis area, and within a few years, the 1,200 km^2 (460 mi^2) Nestucca fire burned to the north (Figure 12). The Tillamook fires burned a combined area of 1,420 km^2 (550 mi^2) from 1933-1951, but 2 other wildfires burned concurrently with the 1933 Tillamook fire, adding an additional 400 km^2 (150 mi^2) (Teensma *et al.* 1991, p. 2). These wildfires seem to eliminate tree voles from much of the footprint, based on the absence of tree vole detections during surveys of the Tillamook Burn area in the Coast Range, as well as two fire areas in the Cascade Range from the mid-19th and early 20th centuries (Forsman *et al.* 2016, 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, pers. comm.). 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, pp. 43-44).

Conversely, other old fire areas in the 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 within the analysis area (South Block and Nestucca Block, Figure 9). Large, stand-replacing 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 *et al.* 2000, p. 172). 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.* 2016, 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. Much of the forests on non-Federal lands are managed on short-rotations, either maintaining forests in a low quality condition or precluding them from reaching habitat conditions suitable for red tree voles. The degree to which burned areas are managed will determine their ability to develop conditions suitable for red tree voles, as well as the speed with which habitat will develop.

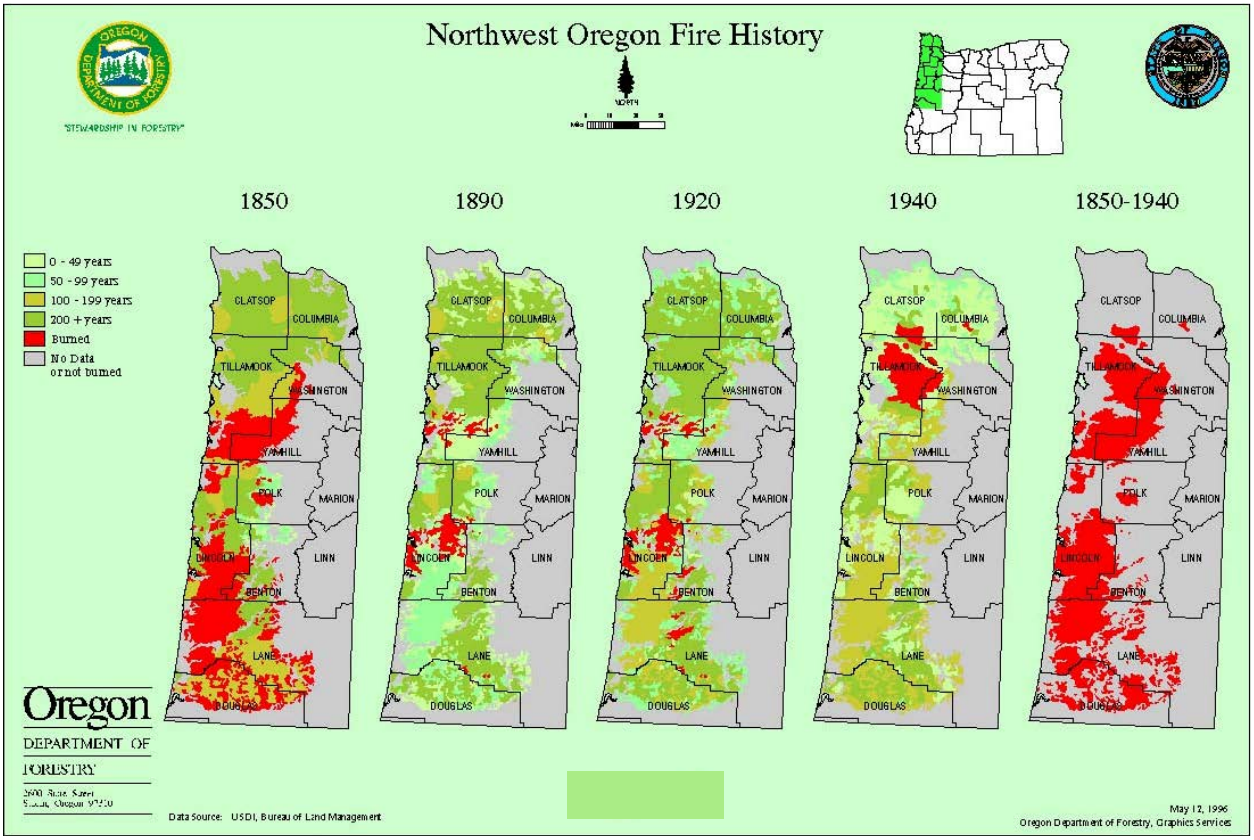

Figure 12. Pattern of wildfire history and vegetation change in the Oregon Coast Range from 1850 to 1940. Figure is from an anonymous, undated source (Anonymous, undated, p. 11), but the individual fire and vegetation maps correspond with Teensma (1991, unnumbered map section).

5.1.1.2 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 destruction of the older forest habitats favored by red tree voles; these older forest habitats now persist largely in isolated fragments across the analysis area. 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. 643). 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 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, pp. 122, 124, 128). Within the 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). During that time frame, area of older forest has actually increased on Federal lands in the Oregon Coast Range by 1 to 11 percent, depending on which older forest index is used. This has occurred in spite of losses to timber harvest and other disturbances. Conversely, net reduction in old forest on non-Federal land was 25 to 27 percent. Virtually all of the loss in both ownership categories was due to timber harvest, with nominal amounts attributed to wildfire or insects (Davis *et al.* 2015, pp. 30-33).

Timber harvest not only removes tree vole habitat, but short rotations that manage for young stands may maintain these areas as unsuitable tree vole habitat. Tree voles may be excluded from young stands because suitable nesting structures are largely 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. 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, pp. 1174, 1177-1178, 1180). However, it is not known whether voles can persist in these stands, particularly if the stands are subjected to repeated thinning activities. Anecdotal evidence indicates that thinning younger stands occupied by tree voles can reduce or eliminate voles from these stands (Biswell 2010, pers. comm.; Swingle 2010, pers. comm.; 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, Hopkins (2010, pers. comm.) continued to find signs of occupancy at these nests post-treatment, although signs of occupancy were intermittent through time.

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 (*e.g*., 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 (Biswell 2010, pers. comm.; Forsman 2010, pers. comm.; Hopkins 2010, pers. comm.; Swingle 2010, pers. comm.; Linnell *et al.* 2017, p. 5). The value of younger stands as tree vole habitat remains unclear, but suitability does appear to improve the more closely the stands are associated with old forests (*i.e.*, increase in old-forest structure and decreased distance to old-forest patches) (Linnell *et al.* 2017, pp. 5-6). Hence, younger stands may provide some value in otherwise denuded landscapes, and are more likely to complement existing older forests the closer they are and the more similar they are in structure to older forests (Linnell *et al.* 2017, p. 6). However, thinning treatments in these stands have the potential to further reduce vole numbers, 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, p. 284; Wilson and Forsman 2013, pp. 84-86). Swingle (2005, pp.

78, 94) cautions against using the presence of tree voles in young forests to refute the importance of old-forest habitats to tree voles.

5.1.1.3 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 appears to be undergoing an intensifying epidemic (Ritokova *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, the Swiss needle cast disease is typically found in Douglas-fir grown outside of its native range. In western Oregon the disease 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 (Shaw 2008, p. 1; Hansen *et al.* 2000, p. 777). Douglas-fir accounted for less than 20 percent of the forest composition prior to the 1940s in this portion of the 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, pp. 1, 3). In Oregon, Swiss needle cast is currently limited to the western part of the state. The affected area has increased from 530 km^2 (205 mi^2) in 1996 to 2,387 km^2 (922 mi^2) in 2015, mainly on the coastal side of the Coast Range (Ritokova *et al.* 2016, pp. 5-6, Figure 5). It is roughly estimated that about half of the land base is moderately afflicted by Swiss needle cast, and about 10 percent of the area is severely afflicted by this disease (Filip 2009, pers. comm.).

Swiss needle cast 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).Young Douglas-fir infected with the pathogen are not expected to outgrow the disease (Black *et al.* 2010, p. 1680). Given their reduced growth rates, 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, affecting forage availability and cover for red tree voles. Hence, Swiss needle cast does not necessarily result in loss of existing habitat, but precludes the ingrowth of tree vole habitat. Most of the research on this disease has occurred in managed plantations less than 40 years old (Shaw 2009, pers. comm.), 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). 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). Future steps needed to manage Swiss needle cast are unclear. Conflicting information exists as to whether fertilizing afflicted plantations alleviates or exacerbates disease severity (Mulvey *et al.* 2013, p. 156; Shaw *et al.* 2011, pp. 114-115). 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).

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, pers. comm.). 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 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 older forest conditions 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, entire; Jayawickrama *et al.* 2012, entire). 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.

5.1.2 Fragmentation and Isolation of Older Forest Patches

The loss of much of the older forest within the analysis area has reduced high-quality habitat for tree voles to relatively isolated patches; 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. It is estimated that old forest covered 52 to 85 percent of the 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 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, pp. 635, 639). Most of those open and young stands encompassed the 1,210 km^2 (467 mi^2) 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 (Figure 5). 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.* 2016, 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 Coast Range Province covered by large Douglas-fir (5,315 km^2 (2,052 mi^2)) and large spruce-hemlock (891 km^2 (344 mi^2)) 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 (Figure 5). 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.* 2016, p. 82).

Not only have amounts of older 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 (greater than 200 years) patches had the highest densities of all successional stages within the Coast Range Province. In addition, old-growth patch sizes were large, ranging from 2,100 to 8,500 km^2 (810 to 3,280 mi^2), with a median of 4,300 km^2 (1,660 mi^2), while patches of less than 80-year-old forests were generally less than 2,000 km^2 (770 mi^2) (Wimberly 2002, p. 1322). In the Coast Range Province today, the largest old-growth patch is 6.5 km^2 (2.5 mi^2), while the largest patch of early-seral forest (less than 30 years old) is larger than 5,000 km^2 (1,900 mi^2), and the largest patch of 30- to 80-year-old forest is larger than 3,000 km^2 (1,150 mi^2) (Wimberly *et al.* 2004, p. 152). Correspondingly, over the last century, the mean patch size of red tree vole habitat range-wide in Oregon declined by 98 percent, from 129 km^2 (50 mi^2) to 2.4 km^2 (1 mi^2) (Forsman *et al.* 2016, pp. 80-81). In summary, red tree vole habitat in the analysis area has changed from 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.* 2016, p. 80).

This increasing isolation of old-forest patches due to maintenance of younger stands in the intervening areas is a stressor for red tree voles because of their limited vagility (ability to disperse or make extensive movements across the landscape) . As noted earlier, the greatest known dispersal distance for an individual red tree vole is 340 m (1,115 ft) (Biswell and Meslow, unpublished data referenced in USDA and USDI 2000b, p. 8), but shorter distances from 3 to 75 m (10 to 246 ft) appear to be more the norm for dispersing subadults (Swingle 2005, p. 63). The current average distance between patches of old forest in the analysis area (3.4 km (2.1 mi)) far exceeds the known maximum dispersal distances of individual red tree voles (Linnell *et al.* 2018, p. 1179). A matrix of surrounding younger forest is not entirely inhospitable habitat for dispersing red tree voles, but long-term persistence in these stands is unknown and, based on anecdotal evidence, 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.* 2017, p. 7).

Historically, dispersal in areas of more contiguous older forest would not have been limiting for red tree voles, but under the current conditions of fragmentation, the ability of individuals to disperse between patches of remaining high quality habitat is restricted. The fragmented nature of existing tree vole habitat amplifies the effects of future habitat removal, because even small (*e.g.* <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.* 2017, p. 6). Limited dispersal and connectivity among subpopulations can translate into a lack of gene flow sufficient to maintain diversity and evolutionary potential within the population, leading to such consequences as inbreeding depression, reduced fitness, bottlenecks, deleterious mutations, and genetic drift (*e.g.*, Soulé 1980, entire; Terborgh and Winter 1980, pp. 129-130; Shaffer 1981, p. 131; Gilpin and Soulé 1986, pp. 26-27; Lande 1988, pp. 1457-1458; 1994, entire). Thus, there is potential for the loss of local tree vole clusters 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 local extirpation and further isolation of the remaining clusters, 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. 69). 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, pers. comm.)

5.1.3 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 (*e.g.* habitat loss and fragmentation). Isolated populations are more likely to decline than those that are not isolated (*e.g*., 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, entire; Shaffer 1981, p. 131; Gilpin and Soulé 1986, pp. 25-33; Soulé and Simberloff 1986, pp. 28-32; Lehmkuhl and Ruggiero 1991, p. 37; Lande 1994, entire). 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 (*e.g*., Shaffer 1981, p. 131; Gilpin and Soulé 1986, p. 27; Blomqvist *et al.* 2010, entire). 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 (*e.g*., Franklin 1980, pp. 140-144; Soulé and Simberloff 1986, pp. 28-29; Nunney and Campbell 1993, pp. 236-237; Reed and Frankham 2003, pp. 233-234; Blomqvist *et al.* 2010, entire). Although we do not have any information on relative levels of genetic variability in red tree vole populations, Swingle (2005, p. 82) 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) did not elaborate on his suggestion, nor account for the possibility that alternative processes may be maintaining these different color forms.

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 vole clusters and limit their recolonization capability. Small home ranges and limited dispersal distances of red tree voles, as well as their apparent reluctance to cross large openings, impedes their ability to readily recolonize isolated habitat patches. Their limited mobility, combined with their low survival rate, restricts the ability of vole clusters to expand and connect with other clusters. 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 (*i.e.*, isolated into islands of habitat) of red 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). Species that 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, pp. 136, 138; Hanski and Gilpin 1991, p. 13; Hanski *et al.* 1996, p. 539; Harrison 2008, pp. 82-83; Sodhi *et al.* 2009, p. 518). 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).

5.2 Predation

In the only quantitative study of red tree vole mortality conducted to date, Swingle *et al.* (2010, p. 258) found that weasels are the primary predators of red tree voles. However, 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), northern spotted owls (Forsman *et al.*, 1984, p. 40), barred owls (*Strix varia*) (Wiens 2012, p. 57), and a variety of other nocturnal and diurnal raptors (Miller 1933, entire; Maser 1965a, entire; Maser 1965b, entire; Forsman and Maser 1970, entire; Reynolds 1970, entire; Graham and Mires 2005, entire). Other documented predators include the Steller's jay (*Cyanocitta stelleri*) (Howell 1926, p. 60; Linnell and Lesmeister 2019, unpublished data), gopher snakes (*Pituophis catenifer*) (Swingle *et al.* 2010, p. 258), 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. Forsman (2010, pers. comm.) 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 2019, unpublished data).

Red tree voles persist in many areas despite the large numbers of predators (Forsman *et al.* 2004, p. 300). However, barred owls have recently expanded into the Pacific Northwest and are a relatively new predator of red tree voles. Red tree voles, among other mammal species, are an important prey item of barred owls, particularly during fall and winter (Wiens 2012, pp. 39, 44). 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 ratio (Wiens 2012, p. 45) increases that pressure. However, it is still not clear how the invasion of the barred owl may have changed predation pressure on the red tree vole. To answer that question, one would have to consider not only the direct effect of barred owl predation on tree voles, but the effect that barred owls have on other tree vole predators. For example, 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, pp. 3 and 4 for summary); yet spotted owls may not necessarily leave the vicinity and still remain as a tree vole predator, in addition to the invasive barred owl (Diller *et al.* 2016, p. 705). In addition, 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). Therefore, while the invasion of barred owls remains a concern, we cannot draw any conclusions as to the impact of barred owls on red tree voles in the analysis area at this time. We identify predation as a stressor to consider its potential effect on red tree voles, especially in light of the changes in the predatory community caused by the recent barred owl invasion. However, we do not have enough information to assess the level of impact on the red tree vole clusters and overall population in the analysis area and therefore meaningfully inform their current and future conditions.

5.3 Existing Regulatory Mechanisms

There are existing regulatory mechanisms in place that affect the impact of some of these stressors on red tree voles. The red tree vole is not listed on Oregon's Threatened and Endangered Species List. It is, however, identified by the Oregon Department of Fish and Wildlife (ODFW) as a sensitive species in the Oregon Coast Range (ODFW 2016, p. 11). Although the intent of the sensitive species list is to prevent species from declining to the point of qualifying as threatened or endangered, this list is not used as a candidate list for species to be considered for listing under the Oregon Endangered Species Act (ORS 496.176-192) and implementing administrative rules (OAR 635-100-0080 through 635-100-0194). 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. Sensitive species face one or more threats to their populations or habitats; they are defined as having small or declining populations, are at-risk, or are of management concern (ODFW 2016, p. 1). The red tree vole is also listed in the Oregon Conservation Strategy with specific actions believed necessary for conservation (Oregon Conservation Strategy 2016, entire). However, there are currently no State regulations protecting red tree voles or their habitat.

The Forest Service and BLM 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 (Biswell *et al.* 2000, 20002, entire; USDA and USDI 200b, entire; USDA and USDI 2011, entire; Huff 2016, entire; USDI 2016, pp. 101-102). In addition, Federal lands implement a lower level of timber harvest compared to other ownerships, and the projected management of much of their landbase as generally either undisturbed or in a late-successional condition. North of U.S. Highway 20, there are areas where Federal land is limited and there may not be enough habitat in these areas to provide for the red tree vole (USDA and USDI 2007, pp. 291-292). In addition, due to the amount and location of private lands in relation to blocks of Federal land in this area, there is restricted connectivity, with few known vole sites available to recolonize habitat.

Oregon Department of Forestry (ODF) personnel are recording tree vole nest locations as ancillary information collected during climbing inspections of marbled murrelet nests (Gostin 2009, pers. comm.), but are not implementing site-specific management or conservation measures to known sites beyond recording the nests. 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 be 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 (ODF 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. However, 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. Furthermore, the layered and older-forest structure patches are not intended to be retained through time; rather, they are 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 a few decades until other patches on the landscape reach a similar condition, at which time the original patches may be harvested

The red tree vole is not a specific species targeted for protection under the Oregon Forest Practices Administrative Rules and Forest Practices Act (OARs), which regulate timber harvest in Oregon. Due to the tree vole's relatively specialized habitat requirements and limited dispersal abilities, many of the guidelines intended to conserve other wildlife species are not sufficient to provide adequate habitat for the red tree vole. These small buffer areas are not expected to provide for long-term persistence of red tree vole clusters given their isolated nature 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 extinction events due to predation in narrow corridors or isolated fragments of habitat (*e.g.*, 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 of Older Forest Patches). Reduced survival probability for animals moving through linear corridors of habitat may potentially be offset by large numbers of dispersers, but for animals with relatively low reproductive rates and low mobility, such as the red tree vole, survival probability may be compromised under such conditions (Martin and McComb 2003, p. 578). 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). Hence, there is little regulatory protection for red tree voles under the Oregon Forest Practices Act.

5.4 Summary of Influence Factors

We described several factors that affect red tree voles in the analysis area. For the ones in which we can categorize their effects, or effects differ among red tree vole clusters, we summarize the level of impact of those effects (Table 7).

Habitat loss and modification has 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 habitat clusters. Sources of habitat loss and modification include timber harvest and management, wildfire and Swiss needle cast. Historically the agent of habitat loss has been wildfire, but over the last century, the primary agent has been timber harvest. Swiss needle cast has affected some vole clusters more than others, with 7 of the 11 clusters at least moderately impacted from reduced habitat development resulting from the fungus. Consequently, loss or reduced development of habitat has resulted in fragmentation of habitat, which impedes the ability of red tree voles to disperse and connect with other clusters. Because habitat loss and fragmentation have affected red tree voles to the same degrees (Table 7), we combine the summary of their effects here. Habitat loss and fragmentation is considered to have a moderate effect on the two largest tree vole clusters (Nestucca Block and South Block). These clusters still retain large, contiguous blocks of tree vole habitat, but are still vulnerable to the largest disturbance events such as wildfire. They are still separated from other vole clusters, however, with limited opportunities to increase in area given the primary management of lands adjoining them. The remaining vole clusters are all considered to be highly affected by habitat loss and fragmentation, given that they encompass a small area with limited capacity to support tree voles. In addition, several of them are far removed from neighboring vole clusters, with limited opportunity for connection given current land management practices on intervening lands.

Predation was not included in Table 7 because we cannot tease out any differences in predation rates among vole clusters. Though red tree voles tend to have low survival rates, they persist in areas despite the large number and variety of predators, and they are a predominant prey item for several species. Habitat condition may affect red tree vole vulnerability to predators, with older 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.

Forest regulatory mechanisms relating to timber harvest have only been in effect in the analysis area since the 1970's, when State and Federal regulations were first enacted (*e.g.*, Oregon Forest Practices Act (ODF 2017, entire), 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 plans they follow for their lands. In addition, State and Federal forests follow corresponding regulations for land management. Hence, the effects of regulatory mechanisms on tree voles corresponds to the effects of habitat loss shown in Table 7.

Table 7. Factors influencing each of the eleven occupied tree vole habitat clusters by level of impact on the cluster.

Habitat Cluster	Habitat Loss and Modification	Habitat Fragmentation	Swiss Needle Cast
1-Oswald West	High	High	Low
2-Tillamook State Forest Nehalem	High	High	High
3-Tillamook State Forest Kilchis	High	High	High
4-Cape Lookout	High	High	Moderate
5-Nestucca Block	Moderate	Moderate	High
6-BLM Checkerboard East	High	High	Moderate
7-BLM Checkerboard West	High	High	Moderate
8-South Block	Moderate	Moderate	Moderate
9-OSU Forest	High	High	Low
10-Junction City	High	High	Low
11-Spencer Butte	High	High	Low

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 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 (*i.e.*, occupied tree vole habitat clusters) based primarily on known occurrence locations and modeled habitat (Lesmeister and Linnell 2019, entire; see Appendix A).

6.2 Difficulties in Estimating Tree Vole Abundance

Historical and contemporary surveys show that tree voles typically occur at low densities, with clusters of nests patchily distributed across the landscape. Forsman *et al.* (2016, 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 (Forsman *et al.* 2016, p. 43; Swingle 2005, p. 5; Swingle *et al.* 2004, entire). Hence, survey efforts focus on searching for nests as an indirect representation of tree vole occurrence. Only two techniques are currently available to definitively determine if a tree vole nest is occupied: 1) tear the nest apart searching for tree voles or 2) gently probe a nest with a stiff piece of wire to force tree voles out (Swingle *et al.* 2004, 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, entire). 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 long periods of time if stored in the nest or out of sunlight, resulting in potential overestimates of active nest occupancy (USDA and USDI 2007, p. 290). Furthermore, no one has established a relationship between nest abundance and density of tree voles because: 1) nests can be difficult to detect, especially without climbing trees (Howell 1926, p. 45; Swingle 2005, pp. 78, 80-81; Swingle and Forsman 2009, p. 284; Forsman *et al.* 2016, p. 42; Marks-Fife 2016, p. 111); 2) tree voles can use multiple nests (Swingle 2005, p. 59); and 3) the number of tree vole nests can accumulate over multiple generations. For example, from a sample of tree vole nests in forest stands <100 years old, Thompson and Diller (2002, pp. 94–95, 97) 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. This suggests that sampled 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; Zentner 1977, pp. 44, 54; Thompson and Diller 2002, p. 99).

Consequently, abundance data for tree voles are sorely lacking. There are only two data sources that estimate tree vole density. Portions of each of these study areas occur in the south block tree vole habitat cluster. Maser (1966, pp. 170–205, 216-217) located a young forest site with a high number of tree vole nests where the trees were easy to climb. Over a 3 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. 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 ± 0.97) adult tree voles per ha (0.76 ± 0.38 voles/ac). Also in the south block habitat cluster, Linnell *et al.* (2018, pp. 1175-1177) captured 37 adult voles in a single year of their study; their study area comprised 17 young forest stands in Benton and Lane counties. However, they provided no density estimates. Thus, 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.

6.3 Condition Analysis Model

In the absence of any tree vole population estimates, we developed a coarse model to produce a qualitative "condition score" for each of the 11 occupied red tree vole habitat clusters identified in section 3.3 Analytical Units—Occupied Red Tree Vole Habitat Clusters. 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) sufficient amounts of old forest in large enough patches to maintain individual interaction within a population; and 3) an intervening matrix between populations to facilitate movement among populations. Our model incorporated the first two elements by developing an imputed population range based on existing habitat, the proportion likely occupied, an empirically derived red tree vole density estimate, and an estimate of effective population size to assess evolutionary potential and vulnerability to inbreeding (see Appendix B). We incorporate the last element by considering the likelihood of developing connectivity among vole clusters given existing ownership and land-use allocations.

The individual metrics, which we ranked and scored based on criteria described below, were then combined to produce a unitless condition score for each vole cluster (Table 8). To aid in the comparison of clusters, we categorized the final condition scores for each cluster as "high" (cluster generally secure), "moderate" (cluster marginally secure) or "low" (cluster 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.

6.3.1. Red tree vole capacity and imputed population range

To derive a condition for red tree vole capacity and associated imputed population range, we:

1. Summed the amount of red tree vole habitat within each habitat cluster;
2. Calculated a habitat-based carrying capacity of the cluster by multiplying the available habitat by an empirically derived red tree vole density estimate;
3. Adjusted the carrying capacity based on occupancy percentages obtained from protocol surveys in the NWFP;
4. Calculated an effective population size (N_e) from the adjusted carrying capacity to assess the genetic capability of the individual vole clusters; and
5. Applied the effective population size as an imputed population range upon which we scored the population size component of the overall cluster resiliency score.

We used results from red tree vole habitat modeling in the analysis area to quantify the amount of habitat within the habitat clusters, specifically, the "suitable" and "highly suitable" categories from Linnell *et al.* (2017, pp. 5-6). The model also contained a "marginal" habitat category, but use of this habitat by tree voles was indistinguishable from random chance; hence, we did not consider it tree vole habitat because voles do not select for this category. We also note that some of the remote sensing data used to develop this model is now more than 10 years old (Linnell *et al.* 2017, p. 4), and habitat loss from timber harvest has since occurred (Linnell and Lesmeister 2019, p. 8). Consequently, there may be some overestimation of current habitat condition, particularly in actively managed timberlands.

To take the total habitat and obtain an estimate of tree vole carrying capacity based on estimated tree vole densities would almost certainly provide a highly inflated value with which to assess vole clusters. This is because tree voles are not distributed "wall-to-wall" across their habitat. Relative to other vole species, they occur at low densities. Although tree voles occur throughout much of their geographical range, they are typically found as clusters of individual nests distributed in a very patchy pattern across the landscape (Forsman *et al.* 2016, p. 46). Adults rarely occupy the same nest except when males visit female nests to breed. Nests are often located in separate trees, although multiple nests in the same tree are more likely to occur in older forests (Forsman *et al.* 2016; Marks Fife 2016, pp. 73, 103). Hence, we have adjusted our tree vole carrying capacity to better reflect the patchy nature of tree vole distribution across available habitat.

We adjust the habitat carrying capacity by using an occupancy factor that is based on the proportion of red tree vole survey plots where tree vole nests were detected as part of the random plot surveys done under the NWFP. We compare these results with NWFP pre-project and strategic surveys (described in Forsman *et al.* 2016, p. 6-8) to put our results in context with other survey protocols in stands considered as tree vole habitat. The random surveys were a stratified random sample of long-term vegetation monitoring plots limited to Federal lands. Plots were stratified so that 70 percent were in stands >80 years old (Dunk and Hawley 2009, p. 627). We don't know what portion of the stands younger than 80 may not have functioned as tree vole habitat and as such, this occupancy factor may overestimate occupancy somewhat. There were two sampling units identified for the random plot surveys. Initially a 1-ha (2.5-ac) unit was used, and then a second 1-ha (2.5-ac) plot was added adjacent to the north boundary of the plot to double the sample unit size. The vegetation condition of the additional unit was not always the same as the original plot, and violations of assumptions of independence of plots caused statistical habitat modelers to reject the 2-ha (5-ac) plot size and use the original 1-ha (2.5-ac) plot size in their analyses (Dunk and Hawley 2009, p. 627; Forsman *et al.* 2016, p. 8). We, however, have chosen to use the 2-ha (5-ac) plot size analysis assuming that it reflects a survey of a larger area that is more likely to detect tree voles and less likely to represent a false negative.

Forsman *et al.* (2016, p. 27) displayed the occupancy percentages of the NWFP random survey plots by two geographic subregions: the north coast subregion, which includes our identified habitat clusters north of Oregon Highway 18, and the central coast subregion, which includes clusters south of Highway 18 (Figures 5 and 9). Note that while most of the Nestucca block lies in the north coast subregion, part of it is in the central coast subregion. For the purposes of this analysis, we used the north coast subregion occupancy percentage for this entire habitat cluster. This results in an underestimate, but ultimately would not result in a different condition score than if we had assigned the occupancy percentages proportionately. The percentage of the 2-ha (5-ac) random survey plots occupied in the north coast and central coast subregions were 23 and 55, respectively (Forsman *et al.* 2016, p. 27, Table 1-6). The mean of random surveys across the entire range is 37 and is similar to the range-wide occupancy rates of the pre-project surveys (37 percent) and strategic surveys (43 percent) (Forsman *et al.* 2017, pp. 21, 27). Data is more limited for subregion estimates for the pre-project and strategic surveys; pre-project surveys in the north coast region yielded no detections in 87 surveys, yet strategic surveys on BLM lands in the Nestucca River drainage yielded detections on 37 percent of the survey sites that targeted old forests (Forsman *et al.* 2016, p. 21). Hence, we think the lower occupancy estimate of 23 percent from the random plot surveys that we use reflects the relative condition of the north coast subregion where voles appear to be absent from most areas, yet still occupy local areas of old-forest habitat.

With the revised carrying capacity, we estimated an effective population size (N_e), which can alert us to possible genetic concerns within vole clusters that may make them more vulnerable to genetic stochasticity, inbreeding, or other reductions in genetic stability and ultimately population resiliency. 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. 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 estimate N_e as 10 to 20 percent of our red tree vole capacity value, which is an average ratio based on meta-analyses of different animal and plant populations (Frankham 1995, entire; Frankham *et al.* 2014b, p. 56). We use this range as an imputed population range (Table 8) to characterize the capability of the individual tree vole clusters to avoid inbreeding, to maintain evolutionary potential, and to ultimately provide the population component score for the overall resiliency condition of the cluster (see Appendix B for intermediate tables with detailed numbers for current and future scenarios).

As noted above (section 3.3 Analytical Units—Occupied Red Tree Vole Habitat Clusters) there has been a spirited debate in the literature about using effective population sizes as a threshold for making management decisions, as well as whether any specific threshold automatically results in deleterious population effects. However, for the purposes of our analysis in comparing occupied tree vole habitat clusters and their current and future condition, we use the N_e thresholds as a means of identifying vole clusters that may be at relatively greater or lesser risk of limited resiliency to withstand stochastic events. In general, an effective population size of >=50 was originally recommended to avoid inbreeding depression over the short term, and >=500 was recommended to retain genetic variation and evolutionary potential (see Frankham *et al.* 2014b, entire, for overview, as well as rebuttals and replies by Franklin *et al.* 2014, entire; Frankham *et al.* 2014a, entire; and Rosenfeld 2014, entire). Frankham *et al.* (2014b, entire) proposed to increase this 50/500 “rule” to 100/1000 based on evidence obtained since the original recommendation. For our analysis, we use the 100 and 1,000 thresholds for reduced inbreeding and maintaining evolutionary potential, respectively in our condition analysis. Vole clusters with an N_e range (*i.e.* imputed population range, see Table 8) 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 still had yet to meet the threshold for evolutionary potential. A range above 1,000 met both criteria and was considered high.

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 (Lesmeister and Linnell 2019, entire; Appendix A);

hence, by the nature of the analysis, occupied tree vole habitat clusters across the analysis area are isolated. Consequently, our connectivity analysis looks at the potential for connectivity of these currently isolated clusters to their neighboring clusters by looking at the intervening land ownership and its potential to develop habitat in the future to facilitate connectivity among the tree vole habitat clusters over time.

In general, habitat specialists with limited dispersal capabilities, such as the red tree vole, have a lower critical threshold for responding to fragmented habitats (Linnell and Lesmeister 2019, entire); 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). Reduced survival probability for animals moving through linear corridors of habitat may be offset by large numbers of dispersers, but for animals with relatively low reproductive rates and low mobility, such as the red tree vole, survival probability may be compromised under such conditions (Martin and McComb 2003, p. 578). Poor-quality habitat conditions for red tree voles in riparian management areas, such as from reduced canopy cover and a greater prevalence of hardwoods in smaller areas restricted to short distances from the streams, may reduce their probability of survival in moving through such a patch (Martin and McComb 2003, p. 577). For example, 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 (*e.g.*, 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 (Rosenberg *et al.* 1997, p. 683; Debinski and Holt 2000, p. 351) 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, entire; Rosenberg *et al.* 1997, entire).

In the case of the red tree vole, the longest documented dispersal distance (340 m (1,115 ft)) (see section 3.4.3 Home Range and Dispersal) is nearly an order of magnitude less than the mean distance between old-forest patches considered as tree vole habitat in the analysis area (3.1 km (1.9 mi)) (Linnell *et al.* 2017, p. 8). Hence, connectivity between patches of tree vole habitat is most likely achieved over multiple generations as individuals move and settle iteratively through suboptimal habitats of young forest matrix (Linnell and Lesmeister 2019, p. 1). 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, in general. 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 is no empirical evidence yet to indicate that gene flow is occurring across the matrix between contemporary clusters of tree voles (Linnell and Lesmeister 2019, p. 7). Therefore, while it may be possible for genetic exchange across these landscapes over multiple tree vole generations, we consider it a strong limitation to population resiliency.

We qualitatively assessed connectivity by assuming that clusters with no Federal or State lands between them and a neighboring cluster, or that were so far removed from the nearest cluster that likelihood of genetic exchange was limited, were classed as Low. This was based on the assumption that much of the management on private and other non-Federal or non-State land would result in limited development of red tree vole habitat; thus, connectivity is not expected to improve substantially in most areas, if at all. Clusters that did have intervening Federal or State lands were classed as moderate, based on the assumption that habitat development would occur in reserve or constrained land allocations, and that timber harvest land allocations may still provide brief periods of low-quality habitat given the longer rotation periods that occur on Federal and State lands compared to most private lands. Clusters that greatly exceeded an imputed population range of 1,000 were classed as high because it was assumed they did not need to rely on regular gene flow from other clusters to maintain their resilience.

6.3.3 Summary of Current Condition Categories

A total condition for each habitat cluster was derived based on combining the scores for the imputed population range and connectivity. Where the condition scores were different, the overall condition reflected the lower of the two values. Table 8 outlines the metrics used in combination to assess the resiliency of each cluster including imputed population range and level of connectivity. The level of representation with respect to vegetation zones is also included as a measure of representation, but is not factored into the overall population resiliency score.

Table 8. Population condition resiliency ranking factors and associated metric scores for each condition category. The imputed population size is described in section 6.3.1. Red tree vole capacity and imputed population range. Connectivity is described in section 6.3.2. Red tree vole connectivity.

Condition Category Score	Imputed Population Range	Connectivity	Representation	Overall Resiliency Condition
High	Range is above 1000	Imputed population range >>1,000	Both vegetation zones occur	Both imputed population range and connectivity are high
Moderate	Range is between 100 and 1000	Potential to develop connectivity, via habitat ingrowth, to nearest neighboring vole cluster given existing land management and ownership patterns	Only one vegetation zone occurs	Both imputed population range and connectivity are moderate; or one is moderate and the other is high
Low	Range falls below 100	Low likelihood for connection with nearest neighboring vole cluster, via habitat ingrowth, given existing land management and ownership patterns		Either imputed population range or connectivity are low

6.4 Current Condition Rankings

The results of the red tree vole condition model provide the basis for our analyses of the species' current status using the 3Rs. The condition scores allow us to directly assess and compare the resiliency of each red tree vole cluster (Table 9, Figure 13), which then support our analyses of the species' redundancy (within and among the 11 identified clusters) 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.

Compared to historical conditions, red tree vole habitat has been substantially reduced (Dunk and Hawley 2009, p. 632; Forsman *et al.* 2016, pp. 80-81), and is even more restricted within the analysis area (Dunk 2009, pp. 4-5; Forsman *et al.* 2016, pp. 80-82; Lesmeister *et al.* 2016, p. 28). 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 effort in the analysis area used LiDAR and satellite imagery (Lesmeister *et al.* 2016, entire; Linnell *et al.* 2017, entire). This model provides higher resolution and higher density sampling of the vegetation across the analysis area than the modeling used in previous DPS analyses (Dunk 2009, entire) wherein sampling was limited to 388 Forest Inventory Analysis plots (long-term vegetation sampling plots systematically placed across the landscape). Seventy-two percent of the analysis area does not contain red tree vole habitat, 3 percent is marginal, and the remaining 26 percent is considered habitat (combined categories of "suitable" and "highly suitable" in Linnell *et al.* (2017, p. 5)) (Lesmeister *et al.* 2016, p. 28). Furthermore, red tree vole habitat is disproportionately found on Federal lands, which comprise 22 percent of the analysis area, but contain 63 percent of tree vole habitat; 73 percent of the unsuitable or marginal habitat occurs on private lands (Lesmeister *et al.* 2016, p. 28; Linnell *et al.* 2017, p. 5). Similarly, an Oregon range-wide habitat model estimated that red tree vole habitat was restricted to 22 percent of forest-capable area (Forsman *et al.* 2016, p. 80). When broken down by subregion, this same model estimated that 12 and 16 percent of habitat capable lands in the north coast and central coast subregions, respectively, were suitable for red tree voles (Forsman *et al.* 2016, pp. 80-82).

Table 9. Current condition scores for each occupied red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Imputed Population Range and Associated Score	Connectivity Score	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	17-34 Low	Low	Sitka spruce zone	Low
2-Tillamook State Forest Nehalem	88 (34)	85-170 Moderate	Moderate	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	173-346 Moderate	Moderate	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	24-48 Low	Low	Sitka spruce zone	Low
5-Nestucca Block	1,480 (571)	2,283-4,565 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	227-455 Moderate	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	100-199 Moderate	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	17,211-34,422 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	175-350 Moderate	Low	Western hemlock zone	Low
10-Junction City	29 (11)	45-89 Low	Moderate	Western hemlock zone	Low
11-Spencer Butte	15 (6)	30-61 Low	Low	Western hemlock zone	Low

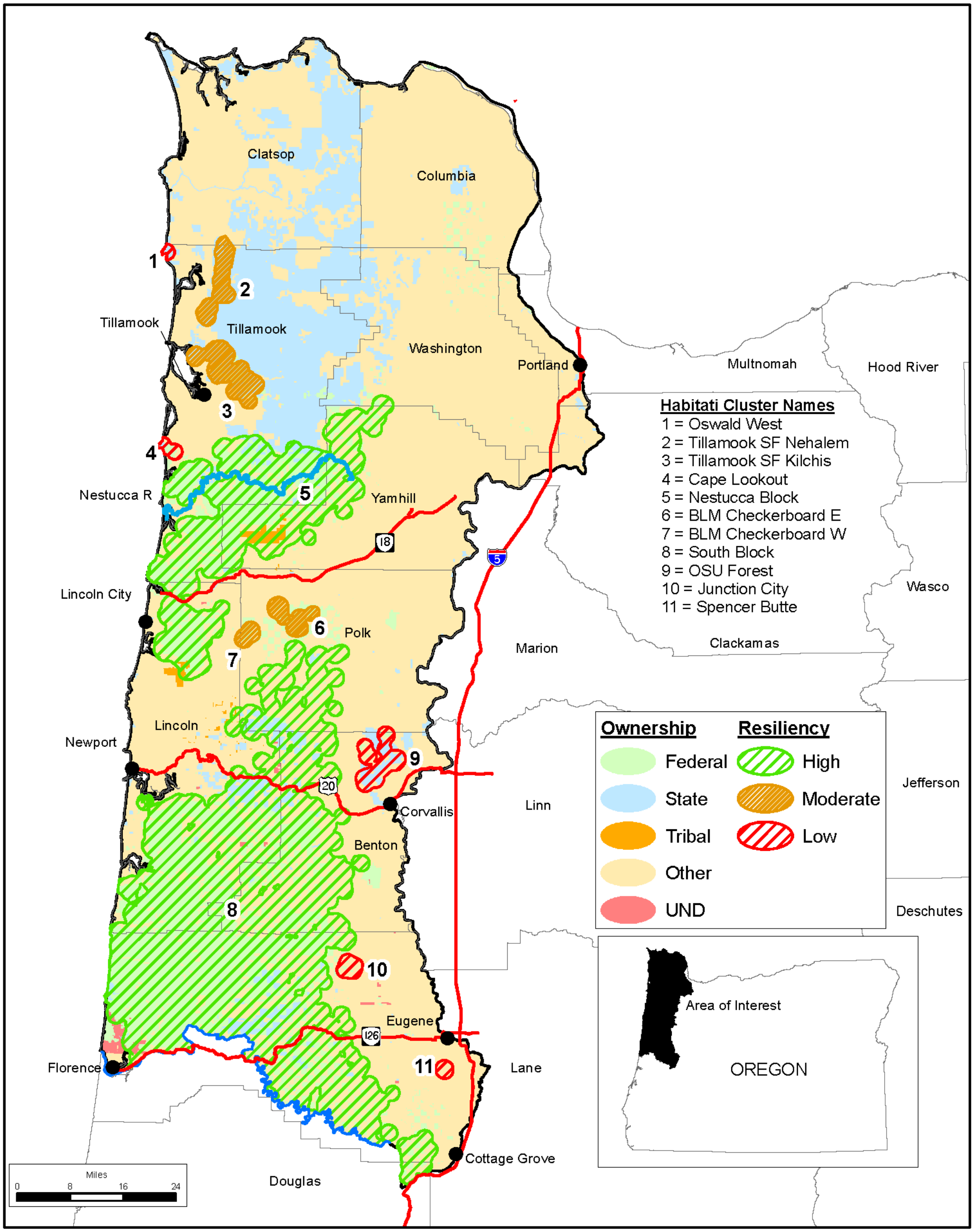

Figure 13. Red tree vole occupied habitat clusters depicted by their overall resiliency scores (see Table 9).

Another modeling effort paints a more optimistic picture of red tree vole habitat within the Coast Range physiographic province of Oregon (Spies *et al.* 2007b, entire). Their results 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 paragraph 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 Coast Range physiographic province, which includes the DPS and most of the analysis area, covers an additional 7,280 km^2 (2,810 mi^2) extending south of the DPS and analysis area (Figure 5). 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 paragraph were empirically developed based on the presence or absence of red tree vole nests.

6.5 Current Condition 3 Rs

6.5.1 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 clusters. As noted previously, our evaluation of the 3Rs here does not consider future trends or conditions, just the current status of the populations.

6.5.1.1 Current resiliency discussion per red tree vole occupied habitat cluster

1 Oswald West (7 km^2 (3 mi^2))
This cluster is the smallest in area of all habitat clusters and has the second least amount of available habitat of all. The cluster has a low score on both imputed population range and connectivity. Red tree vole habitat makes up 65 percent of the area, which is the greatest proportion among all the vole clusters. This is likely because the majority of the ownership is Oswald West State Park. This cluster is mostly restricted to this isolated patch of ownership, which limits its size and its ability to expand because the area is otherwise surrounded by private lands, which are not expected to develop additional tree vole habitat. Furthermore, the nearest neighboring vole cluster, Tillamook State Forest Nehalem, is 9.7 km (6 mi) away, with only a single, small block of State land in between and limited available habitat to facilitate movement between these clusters. Given the small size and limited connectivity to adjacent clusters of predicted habitat, the Oswald West cluster is given a Low resiliency condition score.

2 Tillamook State Forest Nehalem (88 km^2 (34 mi^2))
This cluster had moderate scores for both imputed population range and connectivity. Red tree vole habitat is patchily distributed across the unit and makes up 28 percent of the area, the 3rd lowest portion among all of the vole clusters. The nearest cluster is the Tillamook State Forest

Kilchis, located 4.3 km (2.7 mi) to the south. Tillamook State Forest comprises all of the ownership between these two units, giving it a moderate connectivity score because there is the opportunity for ODF to manage these lands for red tree vole connectivity. Although much of this intervening area is currently void of red tree vole habitat, the current implementation plan for the Tillamook State Forest's Tillamook District calls for a desired condition of older or layered forest structure in this intervening area, which would improve the connectivity between these two vole clusters over time (ODF 2009, p. 68, desired future condition map). Given the moderate imputed population score, and the potential for connection to the nearby Tillamook State Forest Kilchis cluster, this vole cluster scores a moderate overall resiliency condition score.

3 Tillamook State Forest Kilchis (138 km^2 (53 mi^2))
Similar to the Tillamook State Forest Nehalem habitat cluster, this cluster had moderate scores for both imputed population and connectivity. Relatively contiguous patches of red tree vole habitat are distributed across much of the unit, although they only make up 36 percent of the unit. Connectivity options include the Tillamook State Forest Nehalem 4.3 km (2.7 mi) to the north, and the Nestucca block, which is 14.5 km (9.0 mi) by way of contiguous State forest land where tree vole habitat would be more likely to develop. Habitat is currently absent from the landscape between this cluster and the neighboring vole clusters. Given the moderate imputed population score, and the potential for connection to either the nearby Tillamook State Forest Nehalem or the Nestucca Block clusters, this cluster scores a moderate overall resiliency condition score.

4 Cape Lookout (19 km^2 (7 mi^2))
This cluster is similar to Oswald West in that it is small (second smallest in area of all clusters, behind Oswald West) and restricted to the coastal headlands. It is fairly close to the Nestucca block, 2.6 km (1.6 mi) away, but in the intervening area there is no habitat or non-private lands with reserves on which to recruit habitat. Given the low imputed population score and the low likelihood of connection to the nearby Nestucca Block, this vole cluster scores a low overall resiliency condition score.

5 Nestucca Block (1,480 km^2 (571 mi^2))
This second-largest vole cluster in area ranked high on both imputed population and connectivity. Almost half of the unit is tree vole habitat (45 percent) and relatively contiguous patches are distributed throughout the unit. Tree vole habitat is primarily associated with Federal lands, with 81 percent of available habitat on Federal land, even though Federal land is only 56 percent of the landbase within this cluster. The imputed population range is considered to be large enough that limited connectivity to surrounding clusters isn't as crucial for resiliency. Neighboring vole habitat clusters are Tillamook State Forest Kilchis and Cape Lookout to the north and the two BLM checkerboard units to the south (see individual descriptions for these clusters to get distances to the Nestucca Block). The combined high condition scores for the large size and connectivity gives this vole cluster an overall condition score of high.

6 BLM Checkerboard East (60 km^2 (23 mi^2))
This is one of two blocks of BLM checkerboard ownership, located between the two largest vole clusters (Nestucca Block to the north and South Block to the south). It is the larger of the two BLM checkerboard units and has over twice as much habitat as BLM Checkerboard West, but

the proportion of area as habitat (46 percent) is similar between the two clusters. The nearest neighboring units are South Block 1.8 km (1.1 mi) to the south, and BLM Checkerboard West, 4.5 km (2.8 mi) to the west. There is a checkerboard landscape of Federal/private lands between these habitat clusters with very little tree vole habitat currently available. The moderate imputed population range along with a moderate potential for connectivity to a neighboring cluster results in an overall moderate condition score for this cluster.

7 BLM Checkerboard West (26 km^2 (10 mi^2))
This vole cluster is similar to BLM Checkerboard East in terms of its condition and location on the landscape between the two largest vole clusters. Tree vole habitat makes up 47 percent of the cluster area. Closest clusters are the Nestucca Block 3.5 km (2.2 mi) to the west and BLM Checkerboard East, 4.5 km (2.8 mi) east. There is effectively no tree vole habitat to connect these clusters currently. There is checkerboard BLM land between the two connectivity blocks, but there is no Federal or State land between this unit and the neighboring Nestucca Block. Thus, connectivity is most likely restricted to clusters to the south. Similar to BLM Checkerboard East, this cluster scored moderate for both imputed population range and connectivity, and thus, moderate overall.

8 South Block (4,425 km^2 (1,708 mi^2))
Red tree vole habitat makes up 47 percent of this cluster, and it mostly occurs in relatively contiguous patches where the Federal ownership is blocked up and not in a checkerboard pattern. However, the checkerboard portion of Federal ownership and its associated habitat (Figure 10) does seem to provide for some distribution of tree voles (Figure 11). Tree vole habitat is primarily on Federal lands, which contain 76 percent of the habitat, even though they make up only 49 percent of the ownership. The nearest neighboring vole habitat clusters are BLM Checkerboard East to the north, as well as OSU Forest and Junction City to the east (see individual descriptions for these clusters to get distances to the South Block). As noted in the description for this cluster above (see section 3.3 Analytical Units—Occupied Red Tree Vole Habitat Clusters), the portion north of U.S. Highway 20 probably functions more as a patchwork of connectivity habitat extending to the north given the scattered distribution of habitat and State and Federal lands. Habitat is much more fragmented in this section and, through time, this portion could fragment into more isolated clusters given current landscape management. As the largest habitat cluster identified, this unit ranked high in all condition metrics with an overall score of high. This cluster is likely connected to red tree vole populations outside of the DPS to the south, further contributing to its resiliency. The Siuslaw River, which makes up much of the southern boundary of the DPS is likely a strong filter to movement, though we cannot conclude it is impenetrable to tree voles. More connection opportunities to red tree vole populations to the south exist near the southern end of the Willamette Valley, at the southeastern portion of the DPS.

9 OSU Forest (103 km^2 (40 mi^2))
This habitat cluster has one of the lowest proportions of habitat at 21 percent of its area. The nearest neighboring habitat cluster is South Block, 4.5 km (2.8 mi) west. There is currently no habitat in this intervening area and ownership is private, limiting the ability to develop suitable connectivity under current regulatory practices. This cluster ranked moderate in imputed population range, but low in connectivity because the nearest neighboring cluster is nearly 3 mi

away over a landscape that is not likely to facilitate connectivity of tree voles in the future. Hence, the overall resiliency condition is low.

10 Junction City (29 km^2 (11 mi^2))
This habitat cluster has the lowest proportion of tree vole habitat of all clusters at 19 percent, likely because of the limited Federal ownership (17 percent of the unit). It is on the margin of the Willamette Valley and comprises mostly private forest land but is 1.4 km (0.9 mi) from the South Block cluster, with intervening Federal lands and some small patches of tree vole habitat in between. This cluster ranked low in imputed population range, but moderate in connectivity given the intervening checkerboard of Federal land, resulting in an overall condition of low.

11 Spencer Butte (15 km^2 (6 mi^2))
This is the second smallest habitat cluster in area, and has one of the lowest proportions of habitat at 24 percent. It is on the edge of the Willamette Valley and, compared to the other clusters, far removed from any neighboring clusters, in this case South Block. The shortest distance to the next cluster is 10.0 km (6.2 mi) and does not traverse any Federal or State lands. This habitat cluster scored low in both the imputed population range and connectivity categories, resulting in an overall resiliency condition of low.

6.5.1.2 Resiliency summary

Two relatively large vole clusters, South Block and Nestucca Block, both have relatively large imputed population ranges with large amounts of tree vole habitat distributed in relatively contiguous patches across much of their area, and their overall condition score was high. Furthermore, we assume the South Block cluster connects with tree voles outside of the DPS. Federal ownership makes up much of these blocks, and most of the tree vole habitat occurs on Federal land. In fact, almost all of the Federal ownership in the analysis area is encompassed in these two clusters, except for scattered or isolated patches of BLM checkerboard ownership. These two clusters can be thought of as the foundation of the red tree vole population in the analysis area. In fact, Forsman *et al.* (2016, p. 47) concluded that, “red tree voles will likely continue to thrive in the extensive areas of old forest on Federal lands that are currently protected under the Northwest Forest Plan.”

All the remaining habitat clusters are substantially smaller than the Nestucca Block or South Block, and several are far removed from any neighboring clusters. Four of these clusters (the two Tillamook State Forest units, and the two BLM checkerboard units) had an overall condition of moderate. They all have imputed population ranges above the threshold of 100, reducing the chance of inbreeding. They are all far removed from nearby clusters, far exceeding the longest documented dispersal distance of 1,115 ft (340 m) (see section 3.4.3 Home Range and Dispersal). The shortest distance between any two clusters (1,800 m (1.1 mi) between South Block and BLM Checkerboard East) is over five times the longest known dispersal distance of tree voles. Thus, with intervening forest lands likely consisting of transitory patches of marginal tree vole habitat, there is limited ability for demographic or genetic support to or from nearby clusters. However, despite the current lack of habitat surrounding these clusters, they have a moderate connectivity score given surrounding ownership/management and the potential to develop habitat that would support connectivity to neighboring clusters.

Five vole clusters had an overall low condition score (Oswald West, Cape Lookout, Spencer Butte, OSU Forest, and Junction City). The latter two had a low (mixed) rating because either the imputed population size or connectivity score was moderate, whereas the remaining clusters scored low on both population size and connectivity. These clusters are currently isolated, all by distances far surpassing tree vole dispersal distances. All but one (Junction City) scored low on connectivity, meaning there is little potential to develop tree vole habitat under existing management of intervening private lands. Forsman *et al.* (2016, p. 47) concluded that, where Federal lands are lacking, tree voles are highly likely to disappear without management for old-growth forests, particularly in areas with little Federal lands.

The three vole clusters occupying the smallest area (Oswald West, Cape Lookout, and Spencer Butte) also had the three lowest red tree vole imputed population ranges. This, combined with a low connectivity score, flags these clusters as being particularly vulnerable to extirpation by having a limited ability to persist and respond to stochastic events. In addition, two of these clusters (Oswald West and Spencer Butte) were the farthest removed from neighboring clusters (over 30 times the known tree vole dispersal distance) and are most likely completely isolated from tree voles in the rest of the analysis area. Their small population and isolation makes it unlikely that they will persist over the long term without intervening management.

There are also blocks of habitat, particularly on State forest land in the north coast subregion, that are not currently known to have tree voles but may be large enough to support tree voles at some point. However, even if occupied, these habitat blocks would continue to remain isolated without subsequent management of the intervening landscape. Riparian buffers are in place on all ownerships, though size and retention amounts vary between Federal and State management plans and the Oregon Forest Practices Act. However, their role in facilitating tree vole movement among clusters is suspect (see section 6.3.2. Red tree vole connectivity).

6.5.2 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.

Populations with adequate redundancy are able to withstand catastrophic events. While 11 tree vole clusters may sound like substantial redundancy, it must be considered within the context of the estimated resiliency of the individual clusters as well as the scale at which a catastrophic disturbance may occur and thus how many clusters, or how big a portion of individual clusters, are affected. Red tree voles are well distributed on most Federal lands throughout the analysis area, where most of the available habitat remains (Figures 10 and 11). There are two large blocks of Federal ownership corresponding with the two largest tree vole clusters, the Nestucca Block, and the South Block (Figure 9). Their large size ensures high resiliency. The remaining nine clusters in the analysis area are substantially smaller in area and population size, isolated from neighboring clusters, and are less resilient to stochastic events. The scale of catastrophic events in the coast range such as wildfire cause us to heavily weigh the largest clusters in their contribution to redundancy of red tree vole clusters in the analysis area.

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 Coast Range, creating localized patches of blowdown that are unlikely to severely affect a tree vole habitat cluster (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 clusters or further fragment or isolate them from neighboring clusters. For the smallest clusters, such an event may be enough to severely impede their resiliency and cause their extirpation. This is of special concern given the limited vagility of red tree voles.

Wildfires in the Oregon Coast Range are infrequent events (on the order of hundreds of years) and are most often stand replacing. They are often quite large, (*e.g.*, 1,000 km^2 (400 mi^2)) and as large as 3,240 km^2 (1,250 mi^2) (see section 5.1.1.1 Wildfire). The only tree vole cluster in the analysis area large enough to not be completely consumed by such a large fire is the South Block habitat cluster. Although this cluster area is larger than the largest reported wildfires in the Oregon Coast Range, it could still be substantially diminished by a fire, especially if the fire consumed all or most of the area between Highway 20 and Highway 126. This 3,237 km^2 (1,250 mi^2) area is where the Federal ownership and tree vole habitat is blocked up and fairly contiguous. This is just within the size range of historical wildfires, and a large fire in here would sever the cluster into two isolated clusters comprising fragmented areas of checkerboard ownership. The second-largest cluster, the Nestucca Block, is small enough that it could be completely consumed by a single fire event typical of historical wildfires. Wildfires in the Coast Range have historically been associated with drought conditions (Long *et al.* 2007, p. 924), making fires more damaging, more difficult to fight, and perhaps leading to multiple events, such as the large Nestucca and Yaquina fires that totaled nearly 4,500 km^2 (1,700 mi^2) and occurred within a decade of each other in the mid-1800s. Multiple wildfires of that size could dramatically reduce the largest of the tree vole clusters in the analysis area, leaving only smaller and further isolated clusters with limited habitat in which to persist until burned areas recover over the following 8 or so decades.

While there is a broad distribution of tree vole clusters across at least the southern and central portion of the analysis areas, most of them would not provide adequate redundancy in the event of a large wildfire. Many could be extirpated in a single event; if they were spared a fire event, they would be further isolated from other clusters, reducing their likelihood of persistence over the time necessary to develop habitat in the burned area to provide connectivity to other clusters. Under the current condition, vole clusters with a low resiliency score are not likely to effectively contribute redundancy to the overall population in the analysis area because of their limited population size and the inability to provide immigration support to adjoining clusters. The remaining clusters with a moderate condition score are questionable as to their contribution to redundancy as well. While they may be able to withstand an event such as a severe windstorm, by definition they are currently isolated from other clusters and have limited ability to provide individuals to or receive immigrants from adjoining clusters in response to a catastrophic disturbance. In the event of a stand-replacing wildfire, all of these units are vulnerable because they are considerably smaller than the typical size of historical Coast Range wildfires. And while a single fire event wouldn't be large enough to remove all of these smaller units at once, the units that remain unscathed post-fire would be further isolated if adjoining units were consumed in the fire, thus limiting their ability to support or be supported by the overall population in the assessment area.

As with resiliency, redundancy is best supported by the two largest clusters. However, in the event of a stand-replacing Coast Range wildfire, both are vulnerable to complete loss or substantial degradation. This would substantially reduce red tree voles in the analysis area and further isolate existing clusters, limiting refugia from which to recover as the burned areas regrow.

6.5.3 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 clusters of tree voles might be isolated from the remaining clusters, 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.* 2016, p. 52). The difference is necessary in order 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 3.4.2 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.* 2016, p. 52). Red tree voles found in the Sitka spruce vegetation zone generally feed on either Sitka spruce or western hemlock, which are the dominant tree species found in this zone. The Sitka spruce zone is restricted to the coastal portion of the analysis area (Figure 7), and most of the red tree vole population occurs outside of this zone. Retaining red tree vole clusters 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 analysis area, as well as the red tree vole range.

Only the two largest clusters occur in both vegetation zones and individually represent the spectrum of coniferous species and associated foraging behaviors. The remaining clusters comprise only a single vegetation zone. The northern coastal clusters (Oswald West, the two Tillamook State Forest units, and Cape Lookout) are found in the Sitka spruce zone, and the ones in the central coast portion (the two BLM checkerboard units, OSU Forest, Junction City, and Spencer Butte) occur in the western hemlock zone. The north coast clusters represent the Sitka spruce zone, but there is very little tree vole habitat left in this zone as much of it has been harvested, converted to Douglas-fir plantations, or grew into alder stands after wildfires. The presence of the Sitka spruce zone in the Nestucca Block and South Block makes up a small portion because it is restricted to the coastal portion of these clusters. The loss of the north coast subregion clusters would result in a decrease in ecological and behavioral representation of the red tree vole.

6.6 Summary of Current Condition

We evaluated 11 tree vole occupied habitat clusters in the north coast analysis area. In modeling current resiliency of individual clusters, we derived an imputed population range, and considered connectivity potential to neighboring clusters to derive an overall relative resiliency score. We also assessed representation and redundancy for each cluster. Two of the eleven clusters (Nestucca Block and South Block) have high resiliency scores under the current condition. They also contain representation of both vegetation zones and hence, the behavioral capacity of tree voles to forage on different coniferous species. In addition, they 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 severely limit their resiliency and redundancy, depending on the fire size and location. Hence, these two clusters are essential to the persistence of red tree voles in the analysis area. The remaining clusters are scattered across the analysis area, except for the northern portion of the north coast subregion, which is void of known occupied habitat. Four clusters have overall moderate resiliency scores (the two Tillamook State Forest units and the two BLM checkerboard units). These contain the only two clusters on State forest land, and two clusters located on BLM checkerboard ownership between the two largest clusters. The remaining five have overall low resiliency scores (Oswald West, Cape Lookout, OSU Forest, Junction City, and Spencer Butte), and are located near the edges of the analysis area, either along coastal headlands or the Willamette Valley margin.

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 clusters (with each other and under various future scenarios) and assess the species' viability under the 3Rs, we categorized the final condition scores under each future scenarios as "high" (cluster generally secure), "moderate" (cluster marginally secure), or "low" (cluster 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 assumptions to carry into future scenarios was timber harvest and its consequential effects on habitat fragmentation and habitat cluster 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 and wildfire. We were not able to project the extent of the likely expansion of Swiss needle cast or the probability of catastrophic events such as wildfire through time. However, we note they are events that will occur at some point in time. We also note that the longer 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 specific stressors and factors that may play into future trends. 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 also acknowledge the growth of barred owl populations in the DPS and how their relatively recent invasion may alter predator and prey communities and their subsequent effects on red tree vole populations. However, as noted earlier (see section 5.2 Predation), we do not have enough information to assess the level of impact on red tree vole clusters and to meaningfully inform future condition scenarios.

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 can 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 Coast Range Physiographic Province is projected to provide an increase (approximately 20 percent) in red tree vole habitat over a 100 year time span, primarily on Federal and State lands (Spies *et al.* 2007b, p. 53). Vegetation simulations indicate that private industrial timber lands will generally be dominated by open, small-, and medium-sized coniferous forests. Old-forest structure and habitat will strongly increase on Federal and State lands, and large, continuous blocks of forest will increase primarily on Forest Service and State lands (Johnson *et al.* 2007, pp. 41-42). This is consistent with the current distribution of red tree voles and their habitat (Figures 10 and 11). The estimate of older 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 Coast Range Province, 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). Although timber production in the Coast Range has shifted by ownership class, declining on Federal lands and increasing on private lands, overall production is projected to stay at recent harvest levels. Actual production may result in 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 in the 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 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

Observed changes in the global climate is unequivocal, with many changes observed since 1950 being unprecedented over the span of tens to thousands of years. Specifically, the atmosphere and oceans have warmed, amounts of snow and ice have decreased, and sea levels have risen. Human influence on the changes in global climate have been extensively documented and human–related emissions of greenhouse gases are the highest in history (IPCC 2014, p. 2). Multiple lines of evidence indicate a strong and consistent relationship between cumulative carbon dioxide emissions and projected global temperature change to the year 2100 (IPCC 2014, p. 8). Changes in precipitation, combined with melting snow and ice are affecting the quality and quantity of water resources, while many animal species have shifted their geographic ranges, seasonal activities, migration patterns, abundances, and interactions with other species in response to ongoing changes (IPCC 2014, p. 6).

Many species are subject to an increased risk of extinction as a consequence of climate change projected through this century and beyond, particularly as climate change interacts with other stressors. Most plant species cannot shift their geographical range fast enough to respond to current projected rates of climate change predicted in most landscapes. It is also predicted that most small mammal species will not be able to shift their ranges fast enough to keep up with changes in climate and vegetation predicted under moderate and high greenhouse gas emissions scenarios. In particular, 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 high future risk to plant and animal species is corroborated by observations of historical climate change rates, which are less than the current human–associated rates, causing significant ecosystem shifts and species extinctions over the past several millennia (IPCC 2014, pp. 13, 67).

Global mean surface temperature is projected to increase from 0.3 to 0.7 ºC (0.5 to 1.3 ºF) over the period 2016–2035. Beyond 2035, the projections diverge substantially depending on which emissions scenario is modeled (a range of greenhouse gas emissions are represented in the literature ranging from a stringent emissions mitigation scenario to very high emissions amounts) (IPCC 2014, pp. 58–59). Consequently, the level of confidence in the model projections drops substantially after 2035.

Climate change is projected to result in warmer temperatures for Oregon and the Pacific Northwest. Temperatures are projected to increase 1.6 to 3.9 ºC (3 to 7 ºF) by the mid–21st century, and from 2.8 to 6.1 ºC (5 to 11 ºF) by the late 21st century (Hayhoe *et al.* 2004, p. 12423; Mote and Salathé 2010, p. 41; Halofsky *et al.* 2011, p. 14; Cayan *et al.* 2012, p. 4; Pierce *et al.* 2013a, p. 844; Dalton *et al.* 2017, p. 4). Summer temperatures are projected to increase more than winter temperatures (Mote and Salathé 2010, pp. 41–42; Salathé *et al.* 2010, pp. 65–66; Cayan *et al.* 2012, p. 8; Pierce *et al.* 2013a, p. 845). 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.* 2010, p. 69; Cayan *et al.* 2012, p. 10; Pierce *et al.* 2013a, p. 848; Dalton *et al.* 2017, p. 8). 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 abating the effects in the Oregon Coast Range.

Future precipitation trends vary considerably (Pierce *et al.* 2013b, entire), but most simulations project slight increases for western Oregon (Hayhoe *et al.* 2004, p. 1242; Christensen *et al.* 2007, p. 890; Littell *et al.* 2011, p. 74; Dalton *et al.* 2017, p. 9). Nearly all simulations show a strong decrease in summer precipitation and many show an increase in winter precipitation (Mote and Salathé 2010, pp. 42–43; Halofsky *et al.* 2011, p. 15; Cayan *et al.* 2012, pp. 13–20; Pierce *et al.* 2013a, p. 849; Dalton *et al.* 2017, p. 9). Annual precipitation is projected to increase in Oregon (Cayan *et al.* 2012, pp. 14–17; Dalton *et al.* 2017, p. 9), however, model projections are variable and there is less confidence in projecting precipitation amounts than in projecting temperature (Dalton *et al.* 2017, p. 9). Overall, summers are expected to be warmer and drier, and extreme heat and precipitation events are projected to be more frequent.

Warmer and drier conditions are expected to affect vegetation, and ultimately red tree vole habitat, in several ways. First, the distribution and range of vegetation communities are predicted to shift in response to changing temperatures and precipitation and increased growing season. In Oregon, the range and area of temperate coniferous forest (*i.e.* coastal western hemlock forests associated with the Oregon Coast Range) is projected to contract and be replaced by mixed evergreen forests (Lenihan *et al.* 2008, p. S221; Shafer *et al.* 2010, pp. 180–181; Dalton *et al.* 2017, p. 54).

Globally, poleward and upward elevation shifts in the ranges of plant and animal species are being observed and evidence indicates recent warming is influencing this change in distribution (Parmesan 2006, pp. 648-649; Marris 2007, entire; Chen *et al.* 2011, entire; IPCC 2014, p. 51; Romero-Lankao *et al.* 2014, p. 1458). 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; OCCRI 2010, pp. 16-18; Shafer *et al.* 2010, pp. 183-185; Mote *et al.* 2014, p. 495; Romero-Lankao *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). Ecosystem resilience is expected to be exceeded by the unprecedented combination of climate change, its associated disturbances, and other ecosystem pressures such as land-use change and resource over-exploitation (IPCC 2007, p. 11). These projections discussed above indicate further reduction and isolation of red tree vole habitat over the next century.

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. Climate change assessments predict possible extirpations of local populations if they cannot shift their ranges in response to environmental change (Karl *et al.* 2009, p. 137).

Swiss needle cast, which is strongly affected by climate, is expected to increase its distribution in the Oregon Coast Range. Already, warmer winter temperatures and increasing spring precipitation has increased the distribution and severity of the disease. In the Oregon Coast Range between 1996 and 2015, the disease distribution increased from 530 km^2 (205 mi^2) to 2,387 km^2 (922 mi^2) (Ritokova et al. 2016, p. 5), although disease outbreaks have been widespread and synchronous since 1895 (Lee et al. 2017, p. 11179). Disease severity is expected to increase at higher elevations and at more inland sites where fungal growth is currently limited by cold winter temperatures (Stone *et al.* 2008, p. 175; Lee *et al.* 2017, p. 11184; Dalton *et al.* 2017, p. 51). The extent of this expansion, however, has not been estimated. Furthermore, the intensity and frequency 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). The effects of Swiss needle cast on tree vole habitat would likely reduce Douglas-fir needles, a food and cover source. Given that Swiss needle cast disease mostly occurs in younger Douglas-fir stands and substantially reduces their growth rate, the primary effect is likely a reduction in habitat ingrowth in infected areas, with limited loss of existing old-forest habitat. In that part of the tree vole range where their principle 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, the development of older stands containing these species will take decades as western hemlock and Sitka spruce return to these stands and develop the older forest characteristics conducive to red tree vole habitat.

In the western hemlock and Sitka spruce vegetation zone that dominates the Coast Range, wildfires tend to be rare events. When they occur, they are usually stand-replacing events associated with infrequent and extreme climate events, although low- and moderate-severity fires also occur (see section 5.1.1.1 Wildfire) (Teensma 1991, p. 3; Impara 1997, p. 92; Gedalof *et al.* 2005, p. 170; Meyn *et al.* 2007, pp. 294, 301-303). Climate change, combined with Euro-American settlement, may have influenced the onset of large-scale wildfires (Weisberg and Swanson 2003, p. 25). 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 older forest habitat suitable for red tree voles (Agee 1993, p. 213).

Forests in the Pacific Northwest face an increased risk of large-scale wildfires; under the conditions of projected climate change, the effects of forest pathogens and wildfire on forests are expected to increase. There are few predictions of how climate change will specifically affect wildfire activity in coastal rainforests because there has been little area burned in these forests over the past several decades with which to derive any probabilities. Studies summarized by Reilly *et al.* (2018, pp. 52-54), offer variable predictions for coastal rainforests in Oregon. All found some increase in wildfire suitability, potential, or area burned through this century, but estimates ranged from minor increases of <1 to 2 percent in fire suitability (Davis *et al.* 2017, p. 179), to increases in fire potential by 2.5 to 5 times (Liu *et al.* 2013, pp. 132-133; Reilly *et al.* 2018, p.52), and increases in area burned from 76-310 percent (Rogers *et al.* 2011, p. 11). Reilly *et al.* (2018, p. 54) point out that a projected increase of 76-310 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. Yet the historical data used by Rogers *et al.* (2011, p. 3) only captured wildfires from 1971-2000, completely missing the large fire events that are of concern in this assessment. 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 increase 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 Coast Range (Rogers *et al.* 2011, p. 6).

Wildfire suppression organization, tactics, and technology have improved since the large fires of the last two centuries (*e.g.*, increased road access, air tankers, and incident command teams), 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 the previous extensive wildfires in the 1800s. Regardless, the intense, large, high-severity wildfires that can occur in the Coast Range are driven by severe weather events (droughts or east wind patterns) (Teensma 1991, p. 3; Agee 1997, p. 154; Gedalof *et al.* 2005, p. 170; Meyn *et al.* 2007, pp. 294, 301-303), conditions under which wildfire suppression is severely hampered at best and ineffectual at worst (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), limiting our ability to keep fires small. Hence, given that most of the remaining tree vole habitat in the analysis area is restricted to two clusters (Nestucca Block and South Block), it is possible to lose much of the habitat in either of these blocks to a single stand-replacement wildfire, further limiting habitat and restricting the range of the tree vole.

Although large wildfires occurred within the analysis area historically, in the past there were many additional areas of older forest that were less isolated from other older 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 few such refugia available (Wimberly 2002, p. 1322; Wimberly *et al.* 2004, p. 152) (see section 5.1.2 Fragmentation and Isolation of Older Forest Patches). Though infrequent, past wildfires in the Coast Range have burned areas of up to 3,250 km^2 (1,250 mi^2), large enough to remove all or substantive portions of either of the large blocks of Federal land within the analysis area. Furthermore, projections of climate change point to the increased risk of drought and potential magnitude of wildfire in this region (*e.g*., OCCRI 2010, p. 16). Consequently, it is reasonably likely that a stand-replacing wildfire capable of eliminating large areas of remaining tree vole habitat could occur within the analysis area, although we have no probability analysis to predict the likelihood over a specific time period or location.

There is the potential for substantial vegetation shifts as a result of climate change, but there is considerable variability in those projections. For instance Peterson et al. (2014, p. 102) predicts 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. In addition, projections of vegetation distribution are usually based on modeling the climate that is suitable 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 Peterson et al. (2014, p. 112) suggest, 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, thus maintaining habitat for Sitka spruce forests in the Pacific Northwest. Consequently, in the absence of a stand-replacing disturbance, coastal temperate forests of the northern Oregon Coast Range may remain through the century.

7.2 Future Scenarios

7.2.1 Scenario Development and Methodology

We looked at time frames of 30 and 60 years in the future. We chose 30 years as an interim period to track any changes in cluster condition on the way to 60 years. Sixty years was chosen because it is the time at which all of the lands in the NWFP LSR land-use allocations 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 approximate conditions suitable for red tree voles. The NWFP went into effect in 1994, and young stands in LSRs at the time were meant to grow in to late-successional forest. Hence, the youngest stands at the time of LSR designation would be around 80 in another 60 years. Although BLM has since revised their plans and no longer operate under the NWFP, we expect that much of their reserve allocations will also be at or near 80 years old because many of them were designated LSR while they were under the NWFP. However, our assumption that all 80-year old stands are tree vole habitat overestimates projected habitat to some degree because it is generally a minimum habitat threshold, with most forests classified as tree vole habitat being much older (see section 3.4.4 Habitat).

Similar to our current condition analysis, our future scenarios were habitat based, wherein we revised our estimate of imputed population ranges based on assumed changes in red tree vole habitat condition consistent with harvest patterns by ownership and land-use allocation (described below). Our evaluation of overall resiliency condition scores remained the same as described for the current condition (see section 6.3 Condition Analysis Model, Table 8) with the following exceptions. Vole clusters that retained a low score for the imputed population range in the 60-year scenarios were considered extirpated. This is because these clusters are already at risk of inbreeding in their current condition given their low sizes. Consequently, we assume that after 60 years, a point at which most of the habitat ingrowth will have occurred (see below), especially on Federal lands in the HI-ingrowth scenario (see below), clusters continuing to have low imputed population scores would ultimately succumb to the effects of inbreeding and become extirpated.

The changes in habitat we modeled incorporated habitat loss associated with timber harvest and habitat increase associated with ingrowth. Rates of loss or ingrowth were specific to ownership and, for State and Federal lands, land-use allocation or management units. We used two different data sources to model habitat changes through time. The first scenario, which we call LO-ingrowth, uses timber harvest and ingrowth of old forest depicted in the most recent monitoring report on late-successional and old-growth forests in the NWFP area (Davis *et al.* 2015, pp. 30-31). This document reported trends in old forest on Federal and non-Federal lands within the NWFP area over the 20 year period of NWFP implementation, 1993-2012. This report defined late-successional and old-growth forests based on structural characteristics rather than age, and thus represents tree vole habitat, with its associated structures and stand complexity, better than age alone would.

While the NWFP monitoring scenario may fairly represent tree vole habitat, extrapolating the past ingrowth rate through the time span evaluated in our future scenarios isn't an accurate projection of ingrowth. This is because ingrowth amounts over time are a reflection of when previous disturbances happened. For example, much of the ingrowth depicted in Davis *et al.* (2015, pp. 30-31) is from forest stands that were regenerated from disturbances approximately 80 years prior (*i.e.* 1913-1932). Although, because the authors used structural characteristic for their old-forest definition, this could represent forests with earlier or later regeneration dates. Nevertheless, this period in the early 20th century was before the dramatic increase in timber harvest beginning in the 1940s (Andrews and Kutara 2005, pp. 3-7). Consequently, we would expect to see ingrowth rates increase in the next decade or two and remain at these higher levels as the increased number of stands harvested in the 1940s and beyond begin to attain the structural characteristics of old forests. Yet, applying the ingrowth rate from Davis *et al.* (2015, pp. 30-31) through all the decades of our future scenarios will not account for that expected change. To account for this, we present a second scenario, described next.

To account for the full ingrowth that is expected to happen through time in land-use allocations where timber harvest is not expected, we developed a second scenario, which we label HI-ingrowth. In 60 years, the reserve allocations on Federal lands should mostly comprise forest stands 80 years old or greater, which we assume will begin to represent red tree vole habitat. We make the same assumption for State lands as well, although there may be younger stands that are not yet 80 years old, having been harvested or subject to other disturbance over the past 2 decades. We also assume that 90 percent of all reserve or constrained land-use categories on Federal and State land, respectively, would be in a condition suitable for red tree voles within 60 years. This equates to a 15 percent ingrowth rate per decade.

The target of 90 percent of reserves containing tree vole habitat within 60 years is admittedly arbitrary. 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 reserve allocations. Hence, greater amounts of old-forest would be expected in wetter provinces such as the Oregon Coast Range, as well as in reserve allocations where old-forest habitat is expected to develop and be retained (Davis *et al.* 2015, pp. 7-8). We believe it is incorrect to assume that an entire allocation will ever become habitat for tree voles. This can be for several reasons, such as not all stands at 80 years old necessarily contain tree vole habitat either due to structural conditions or vegetation composition (*e.g.* large amounts of hardwoods). Another likelihood is that some portion of the area will be subject to minor disturbance events over a 60 year time span that will set back some stands (*e.g.* wind, landslides, forest insects, and pathogens). We believe this scenario likely approaches the maximum capacity of tree voles given current land management tendencies.

We discuss our future scenario assumptions for each of the four ownership categories separately. We then describe the resultant changes for each vole cluster and how they affect red tree vole resiliency, redundancy, and representation (see section 7.3 Red Tree Vole Occupied Habitat Cluster Conditions Under Future Scenarios).

7.2.1.1 Federal lands

We divided Federal lands into those that had reserve land-use allocations (*i.e.*, red tree vole habitat was likely to be retained over time) and non-reserve land-use allocations (*i.e.*, the timber harvest matrix and other areas where tree vole habitat was not likely to be maintained). For National Forest lands, the non-reserve 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 reserve allocation. Consequently, this overestimates the amount of non-reserves. Non-reserve allocations were almost always where programmed timber harvest was meant to occur. Allocations we classified as "reserve" include some for which tree vole habitat might be removed or altered (*e.g.* administrative withdrawals and riparian reserves); in addition, red tree vole surveys are not required in stands <80 years old where thinning is proposed (USDA and USDI 2011, entire), which could be a substantial activity in some reserve allocations where development of late-successional forest is an objective. Hence, this may somewhat overestimate future habitat. There were also some Federal lands that did not operate under the NWFP (*e.g.* FWS) and we did not make any projections for tree vole habitat development. However, they were such a small portion of the overall Federal ownership (see Table 1) as to not substantively affect our results. For the reserve lands, we assumed tree vole habitat would remain through time and that unsuitable habitat would gradually grow into habitat. For non-reserve lands we assumed that unsuitable habitat would remain unsuitable and that current habitat would be removed through time.

7.2.1.1.1 LO-ingrowth

Under the LO-ingrowth scenario, we obtained an ingrowth rate based on NWFP late-successional and old-growth monitoring data (Davis *et al.* 2015, p. 30). We looked at trends of stands with an old growth structure index of 80 (OGSI-80). These OGSI-80 stands represent forests that are in a structural condition at or older than the age at which forests generally begin to develop the structural features characteristic of mature, late-successional forest (Davis *et al.* 2015, pp. 16-18). We assumed this condition was consistent with red tree vole habitat. An estimate of the ingrowth of young forest into old (OGSI-80) forest on Federal land was derived from Table 6 in Davis *et al.* (2015, p. 30), where we added the net area change in OGSI-80 forest in the Coast Range physiographic province (2,550 ha (6,300 ac)) to the total loss to disturbance in the Coast Range (5,221 ha (12,900 ac)) to get the actual acres that grew into old-forest condition (7,730 ha (19,100 ac)). To get the area of young forest available for ingrowth, we subtracted the 1993 value of OGSI-80 forest area (256,377 ha (633,500 ac)) from the total Federal forest capable land in the coast range physiographic province area (563,423 ha (1,392,200 ac)), as displayed in Moeur *et al.* (2011, p. 8); we divided this value into the total ingrowth amount calculated above to get the proportion of young forest that grew into old forest over the two-decade time period in the report. Because the ingrowth was over a two-decade period, we divided it by 2 to get a decadal ingrowth amount of 1.3 percent.

To estimate loss of habitat in non-reserve allocations on Federal land, we again used Davis *et al.* (2015, p. 30). We divided the harvest acres lost in the Oregon Coast Range physiographic province (4,937 ha (12,200 ac)) by the 1993 value of OGSI-80 forest (256,377 ha (633,500 ac)) to obtain a decadal loss of 1 percent.

7.2.1.1.2 HI-ingrowth

In this scenario, we accounted for the fact that, in the absence of disturbance, all of the forest-capable lands in reserve allocations will be at or older than 80 years in the next 6 decades because the reserve land-use allocations have been in place for over 20 years and the stands will grow into the 80-year age class through time. This likely overestimates the ultimate amount of habitat available because some of these stands may not have the structural characteristics used by tree voles, as represented in the OGSI-80 index used by Davis *et al.* (2015, pp. 30-31). Conversely, compared to the LO-ingrowth scenario, this scenario accounts for the known increase in ingrowth that will occur over the next several decades as larger areas of younger forest reach the OGSI-80 condition through succession.

We assumed that 90 percent of the area in reserve allocations would reach an OGSI-80 condition by 60 years (see section 7.2.1 Scenario Development and Methodology). Dividing 90 percent by 6 decades gives a decadal ingrowth rate of 15 percent, which we applied in this scenario. For loss of habitat in non-reserve allocations, we continued to use the rates calculated for the LO-ingrowth scenario.

7.2.1.2 State lands

State lands were divided into 3 categories, based on what State entity managed the lands. We assumed lands that were not State forest or the OSU McDonald Dunn Forest were State Parks or managed by Oregon Department of Fish and Wildlife (ODFW). For ODFW and State Parks, we assumed that all habitat would be maintained and that unsuitable habitat would grow into tree vole habitat at the same rate as Federal lands for the two respective ingrowth scenarios. For the OSU McDonald Dunn Forest, we did not have land-use allocation layers to be able to spatially estimate loss or growth of tree vole habitat. In the absence of these data, we assume no change in tree vole habitat on the OSU forest because the OSU forest retains or manages for older, complex forest structure, and because older forest age classes are generally retained through time (Fletcher *et al.* 2005, p. 39, Figure 27).

For State forest lands, we obtained a map layer of “constrained” management areas. These are areas where timber harvest is not planned 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). Hence, 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 in the midst of unsuitable habitat); this may lead to overestimating red tree vole habitat on State lands compared to other ownerships. 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 grow into tree vole habitat. Conversely, we assumed that outside of the constrained areas, red tree vole habitat would be harvested and no new habitat would develop.

7.2.1.2.1 LO-ingrowth

We used the same methodology to determine ingrowth rates on State lands and State forest constrained lands as we did on Federal lands. The exception is for the OSU McDonald Dunn Experimental Forest, where we assumed no change in habitat. The source of the data is from Davis *et al.* (2015, pp. 30) and is for Federal lands. The authors also have done the same analysis for non-Federal lands, which we considered applying to the State lands in determining ingrowth rates. However, we chose to use the Federal ingrowth rates because management on these lands is more similar to Federal lands than to private lands. Also, the difference in ingrowth rates between Federal and non-Federal ownership, as calculated for our purposes, differs by only 0.1 percent.

We assumed no harvest on all State lands (*e.g.*, State Parks, OSU Forest) except for the non-constrained land-use category on State forest lands, wherein we used the projected acres of harvest from the Tillamook Implementation Plan. This is the State forest district that makes up the majority of ownership in the two Tillamook State Forest clusters. There are also State forest lands in other habitat clusters that are managed by different districts and likely have different harvest rates. However, these State forest lands make up such a small portion of their respective clusters that we chose to apply the Tillamook District harvest rates to all State forest lands in the analysis area. The Tillamook District implementation plan projected an annual harvest rate of 1,319 ha (3,258 ac) of combined regeneration and partial cuts (ODF 2009, p. 15 Table 4). Multiplying this by 10 and dividing by the district area of 101,418 ha (250,601 ac) gives a decadal harvest rate of 13 percent.

7.2.1.2.2 HI-ingrowth

The Tillamook District implementation plan estimates it will take 80 to 100 years to attain their structural complexity targets of old and layered forests (ODF 2009, p. 41). We take the mean of that range and subtract 10 years (because the plan is already 10 years old) to get 80 years as the span when enough time has elapsed so that ingrowth will create the target forest stand conditions. Because we are only looking out 60 years, that equates to 75 percent of the time span projected by ODF. If we divide this by 6, we get a decadal ingrowth of 12.5 percent per year. Similar to Federal lands, we assume only 90 percent of the ingrowth will be tree vole habitat, giving a final ingrowth of 11.25 percent.

The harvest rates remain the same as under the LO-ingrowth scenario for State lands (see section 7.2.1.1.1 LO-ingrowth).

7.2.1.3 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. Furthermore, tribal ownership within the analysis area is such a small proportion that its management will not be a driver of this analysis. Hence, we assume, for the purposes or our analysis, that current amounts of tree vole habitat will remain the same on tribal lands.

7.2.1.4 Private lands

We acknowledge that this category represents a diverse array of owners with equally diverse management objectives. This includes some county and municipal ownerships, which may range from protecting areas for municipal watersheds, to managing for timber receipts. For example, 10 percent of the area within the Spencer Butte vole cluster is managed as a municipal park. The vast array, however, is private ownership. Private ownership may range from industrial timberlands generally managed on short 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, wildlife, recreation, or other reasons. We do not have the data to tease apart these differences for our analysis. Hence, we assume that tree vole habitat will be harvested and that unsuitable tree vole habitat will not grow into habitat. However, we believe it unreasonable to assume that all the remaining tree vole habitat will be harvested during our future scenarios because some unknown amount in the private land category is already occurring in riparian and wildlife site protection buffers and would not be subject to timber harvest. We didn’t have the information to know how much remaining tree vole habitat is currently protected by buffers under the Oregon Forest Practices Act, but we assumed 50 percent. We calculated the private land harvest rate similar to what was done for Federal lands, only we used the non-Federal data in Davis *et al.* (2015, p. 31). We took the amount of timber harvest in the Coast Range province (115,380 ha (285,100 ac)), divided it by the 1993 area of OGSI-80 forest (329,952 ha (815,300 ac)), divided the result by 2 to meet our assumption that 50 percent is retained in retention buffers, and divided that result by 2 to get a decadal harvest rate of 8 percent. The exception to this application was for the Spencer Butte vole cluster, where we assumed the portion managed by Eugene as a city park would have a harvest and ingrowth rate the same as State parks (see 7.2.1.2 State lands).

7.3 Red Tree Vole Occupied Habitat Cluster Conditions Under Future Scenarios

We go into detail below characterizing individual habitat clusters with respect to the three Rs, resiliency, redundancy, and representation. As an introduction, however, we describe some overall observations of habitat cluster characteristics as a result of applying the future scenarios (Tables 10-13, Figures 14 and 15).

The overall resiliency condition scores, as well as the individual resiliency metrics (imputed population range and connectivity scores) did not change for any of the vole clusters in either of the two 30-year future scenarios (HI-ingrowth and LO-ingrowth) (Tables 10-11). For both of the 60-year scenarios (HI-ingrowth and LO-ingrowth), the four smallest clusters were predicted to become extirpated (Tables 12-13) because of continued low imputed population scores and the potential effects of inbreeding. We noted earlier that our assumption that 80-year old stands would be tree vole habitat overestimates the amount of habitat described in future scenarios (see section 3.4.4 Habitat). However, there was no improvement in the resiliency condition score of any individual tree vole cluster in any of the future scenarios that would require tempering based on this assumption. Furthermore, while a case could be made that the imputed population range scores for the lowest-scored moderate clusters (Tillamook State Forest Nehalem and BLM Checkerboard West) may be an overestimate as a result of our assumption and could actually be in the low range (*i.e.* overestimating habitat based on age resulted in masking a decline in a tree vole cluster resiliency score), we believe that is unlikely. To test this, for each of these clusters, we assumed no habitat ingrowth in Federal reserve land use allocations and State non-constrained management categories (where all ingrowth was assumed to occur and where our assumption factored into our model), while still assuming harvest of habitat on other lands; for each future scenario the imputed population range resiliency score remained in the moderate category for these two clusters.

For connectivity, the two vole clusters on the Tillamook State Forest (Tillamook State Forest Nehalem and Tillamook State Forest Kilchis) improved from moderate to high in the HI-ingrowth, 60-year scenario (Table 13). This was because the intervening land between these two clusters is in a desired future condition to be managed for layered and older forest structure (ODF 2009, map section-desired future condition map); because much of this area is currently in an understory condition (ODF 2009, map section, current condition map; ODF 2010, pp. C-8 to C-9), and as such, likely 20 years old or older, we assume much of it should approach habitat conditions that would facilitate connectivity among clusters in 60 years.

For the different future scenarios, overall changes in red tree vole habitat cluster capacity from current condition showed some general patterns (Figure 14). For individual habitat clusters, the HI-ingrowth scenarios always resulted in a higher tree vole capacity than their associated time span (*i.e.* 30 vs. 60 years) in the LO-ingrowth scenarios. LO-ingrowth scenarios mostly resulted in capacity declines or relatively little change from current condition, whereas HI-ingrowth scenarios resulted in relatively large proportional increases in tree vole capacity for several clusters although three of the clusters decreased in capacity even under the HI-ingrowth scenarios. This is largely driven by land management, as these are areas where there are limited reserve lands (*e.g.* Federal or State forest reserves and State or municipal parks) within which tree vole habitat is assumed to develop. In these instances, the ingrowth, even under a high scenario, could not keep up with harvest; this is also borne out by the fact that the declines for the clusters that decreased in capacity was greater in the 60- than the 30-year scenarios, as more habitat was removed through time. In scenarios where cluster capacity increased, they all occurred in the HI-ingrowth scenarios, and all had greater capacities as a result of the 60-year compared to the 30-year scenario (Figure 14), indicating ingrowth was outpacing habitat loss and longer time frames yielded more habitat.

Table 10. Future scenario (30 years, LO-ingrowth) scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Imputed Population Range and Associated Score	Connectivity Score	Representation	Overall Resiliency Condition Score
1-Oswald West	7 (3)	17-34 Low	Low	Sitka spruce zone	Low
2-Tillamook State Forest Nehalem	88 (34)	84-168 Moderate	Moderate	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	169-338 Moderate	Moderate	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	24-47 Low	Low	Sitka spruce zone	Low
5-Nestucca Block	1,480 (571)	2,219-4,438 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	211-423 Moderate	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	95-190 Moderate	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	16,440-32,880 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	164-328 Moderate	Low	Western hemlock zone	Low
10-Junction City	29 (11)	39-77 Low	Moderate	Western hemlock zone	Low
11-Spencer Butte	15 (6)	26-51 Low	Low	Western hemlock zone	Low

Table 11. Future scenario (30 years, HI-ingrowth) scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Imputed Population Range and Associated Score	Connectivity Score	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	18-36 Low	Low	Sitka spruce zone	Low
2-Tillamook State Forest Nehalem	88 (34)	117-234 Moderate	Moderate	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	218-436 Moderate	Moderate	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	27-54 Low	Low	Sitka spruce zone	Low
5-Nestucca Block	1,480 (571)	2,533-5,065 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	228-457 Moderate	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	106-213 Moderate	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	18,154-36,307 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	166-333 Moderate	Low	Western hemlock zone	Low
10-Junction City	29 (11)	41-81 Low	Moderate	Western hemlock zone	Low
11-Spencer Butte	15 (6)	26-52 Low	Low	Western hemlock zone	Low

Table 12. Future scenario (60 years, LO-ingrowth) scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Imputed Population Range and Associated Score	Connectivity Score	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	17-33 Low	Low	Sitka spruce zone	Extirpated
2-Tillamook State Forest Nehalem	88 (34)	83-166 Moderate	Moderate	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	165-331 Moderate	Moderate	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	23-47 Low	Low	Sitka spruce zone	Extirpated
5-Nestucca Block	1,480 (571)	2,155-4,310 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	196-391 Moderate	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	90-180 Moderate	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	15,669-31,337 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	153-306 Moderate	Low	Western hemlock zone	Low
10-Junction City	29 (11)	33-65 Low	Moderate	Western hemlock zone	Extirpated
11-Spencer Butte	15 (6)	21-42 Low	Low	Western hemlock zone	Extirpated

Table 13. Future scenario (60 years, HI-ingrowth) scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Imputed Population Range and Associated Score	Connectivity Score	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	20-39 Low	Low	Sitka spruce zone	Extirpated
2-Tillamook State Forest Nehalem	88 (34)	149-298 Moderate	High	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	264-527 Moderate	High	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	30-61 Low	Low	Sitka spruce zone	Extirpated
5-Nestucca Block	1,480 (571)	2,783-5,565 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	229-459 Moderate	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	113-227 Moderate	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	19,096-38,193 High	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	158-316 Moderate	Low	Western hemlock zone	Low
10-Junction City	29 (11)	37-73 Low	Moderate	Western hemlock zone	Extirpated
11-Spencer Butte	15 (6)	22-44 Low	Low	Western hemlock zone	Extirpated

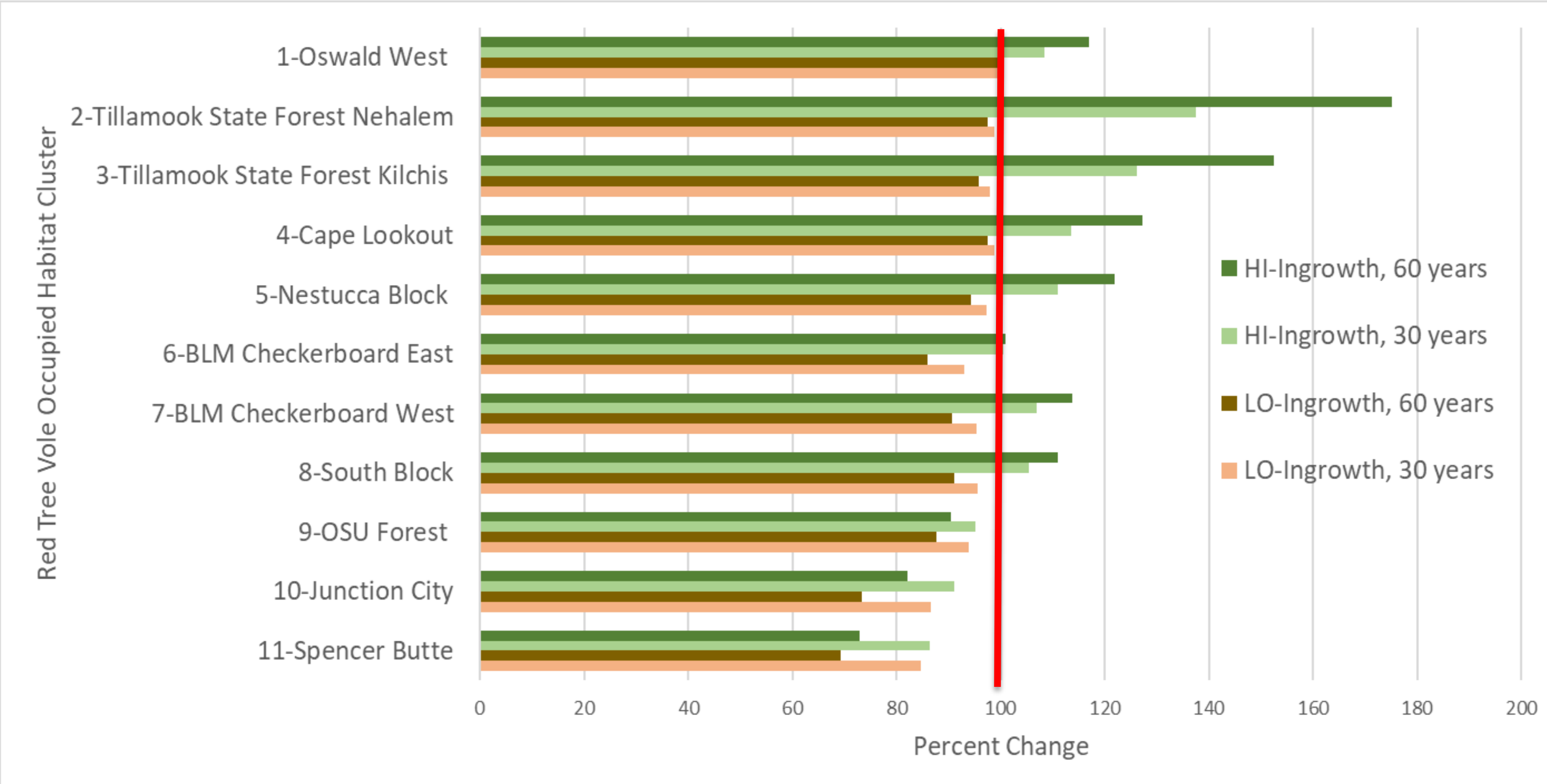

Figure 14. Future condition scenarios for each red tree vole habitat cluster displayed as a percentage of their current condition capacity (see Appendix B).The 100 percent line is outlined in red and indicates no change from current condition. Terminal points of bars to the right indicate scenarios where clusters have increased capacity compared to current condition; conversely, terminal points of bars to the left indicate cluster capacity declines from current condition. Legend is color-coded so that greens represent the Hi-Ingrowth scenarios and browns represents the LO-ingrowth scenarios; the lighter color shade in each ingrowth scenario represents the 30-year timeframe, whereas the darker shade represents the 60-year time frame.

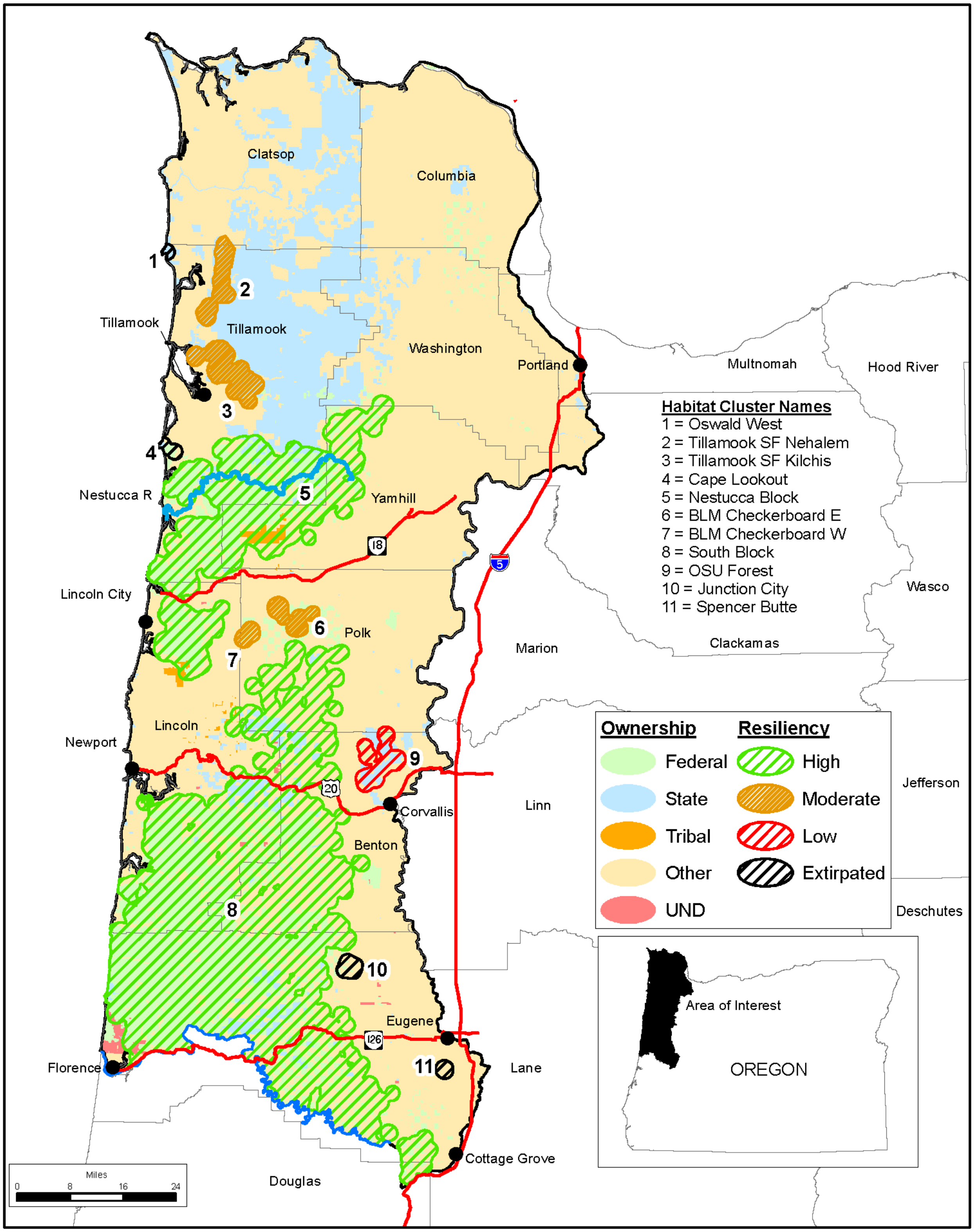

Figure 15. Red tree vole occupied habitat clusters and overall resiliency condition scores for the 60 year time step (both LO-ingrowth and HI-ingrowth scenarios).

7.3.1 Resiliency

Below we address the individual occupied habitat clusters and their resiliency condition under the future scenarios.

7.3.1.1 Future resiliency by red tree vole habitat clusters

1-Oswald West (7 km^2 (3 mi^2))
This cluster's imputed population range remained relatively unchanged under the LO-ingrowth scenarios but increased under the HI-ingrowth scenarios. However, the increase wasn't enough to move the cluster out of a low resiliency score. This cluster is 87 percent State ownership and benefited from ingrowth on the State Park land. However, even under the HI-ingrowth 60 year scenario, which assumes that 90 percent of the State land will be tree vole habitat, the imputed population estimate remains below the threshold of concern for inbreeding (see section 6.3.1. Red tree vole capacity and imputed population range). Given the isolation of this cluster at 9.7 km (6 mi) from the nearest cluster (Tillamook State Forest Nehalem), and a low likelihood of connectivity given existing ownership in the intervening land, this cluster does not improve from its current condition score of low in any of the 4 scenarios. Furthermore, the individual resiliency metrics (population and connectivity) do not improve either. Because the imputed population score remains in a low condition at the 60-year time step in both ingrowth scenarios, this occupied habitat cluster is assumed to be extirpated.

2-Tillamook State Forest Nehalem (88 km^2 (34 mi^2))
This cluster retained its overall resiliency score of moderate in all future scenarios. Imputed population ranges remained relatively unchanged from current conditions under the LO-ingrowth scenarios, but had the highest increase among all clusters under the HI-ingrowth scenarios. This is a reflection of the ownership (81 percent State, and most, if not all, is Tillamook State Forest) and the fact that only a small portion is currently tree vole habitat (28 percent of cluster area, 32 percent of State land). Hence, this occupied habitat cluster represents an opportunity for increasing red tree vole habitat and associated population size. The modeled increase in habitat may be overestimated somewhat because some of the areas with harvest constraints will likely never become tree vole habitat (see section 7.2.1.2 State lands). Furthermore, stands retained as layered or old-forest structure condition are not retained in perpetuity; they may only function as tree vole habitat for a few decades before being harvested as other stands across the landscape reach the layered and old-forest conditions. Consequently, these forests are on the younger end of the old-forest spectrum of suitable tree vole habitat, and may not contribute as much to tree vole capacity over the long term as they would if they were older. Even with these conditions, we still expect a substantial improvement in tree vole capacity in this cluster. However, the imputed population score still remains in the moderate category in all future scenarios, even with the relatively substantial growth.

The connectivity score for this cluster improved to high under the HI-ingrowth 60-year scenario because the intervening State forest land between it and the Tillamook State Forest Kilchis cluster is expected to mostly be in a habitat condition more suitable for red tree voles. This is based on the desired future condition for the intervening lands, as described in the Tillamook District implementation plan (ODF 2009, map section, desired future condition map). Most of the area between these two clusters are planned for either a layered or older forest structure condition, two structural categories that should be suitable for red tree voles. Much of the area is currently in an understory condition (ODF 2009, map section, desired future condition map), where average tree size is often 15-25 cm (6-10 in) DBH (diameter at breast height) with a developing understory that may create layered forest canopies (ODF 2010, p. C-8 to C-9). Such stands will likely approach or become tree vole habitat in another 60 years.

3-Tillamook State Forest Kilchis (138 km^2 (53 mi^2))
This habitat cluster retained its overall resiliency score of moderate in all future scenarios. It responded to all future scenarios in a manner similar to the Tillamook State Forest Nehalem habitat cluster for similar reasons. This cluster is 48 percent State and 21 percent Federal land. Red tree vole habitat makes up 43 percent of the State and Federal ownership, combined, providing an opportunity for substantial habitat ingrowth under the HI-ingrowth scenarios. As described in the Tillamook State Forest Nehalem habitat cluster description, the habitat ingrowth and associated tree vole capacity may be overestimated, but we still expect to see an increase in tree vole capacity even without the overestimate. The population score still remained in a moderate condition, even with an estimated increase in the imputed population range under future scenarios. However, the connectivity score increased to a high condition for the same reasons described above for the Tillamook State Forest Nehalem cluster.

4- Cape Lookout (19 km^2 (7 mi^2))
Similar to the Oswald West habitat cluster, Cape Lookout showed an increase in the imputed population size in the HI-ingrowth scenarios. However, the size was so small to begin with that the increase does not change the population score. The connectivity score remains low because the nearest cluster, Nestucca Block, is 2.4 km (1.5 mi) away with intervening habitat or land ownership continuing to restrict tree vole connectivity. Similar to Oswald West, barring any change in management on the intervening land between it and the nearest tree vole cluster, there is no opportunity for further increases in this cluster's condition score given that ingrowth of tree vole habitat has been effectively maximized in the 60-year, HI-ingrowth scenario. Because the imputed population size remains low at the 60-year time step in both ingrowth scenarios, we assume this tree vole cluster becomes extirpated.

5-Nestucca Block (1,480 km^2 (571 mi^2))
This cluster retained its overall resiliency score of high, despite slight declines in imputed population size associated with the LO-ingrowth scenarios. In the HI-ingrowth scenarios, however, population size increased. Given the substantial amount of Federal reserve allocations where red tree vole habitat can be retained over time, even with low rates of ingrowth, this occupied habitat cluster is sufficiently large enough to remain in an overall high resiliency condition in all scenarios.

6-BLM Checkerboard East (60 km^2 (23 mi^2))
This cluster retained its overall resiliency score of moderate. This cluster sits in a mix of BLM and private checkerboard ownership. Under the HI-ingrowth scenarios, an increase in habitat and associated tree vole capacity may provide connectivity to the nearby South Block and BLM Checkerboard West clusters in the future. Voluntary habitat development in the private ownership portion of the checkerboard to facilitate this connectivity may be a conservation priority. However, much of the BLM land in this cluster is currently in a harvest landbase

designation, where long-term development and retention of tree vole habitat is not expected to occur.

7 BLM Checkerboard West (26 km^2 (10 mi^2))
This cluster retained its overall resiliency score of moderate. As with the BLM Checkerboard East cluster, the intervening checkerboard ownership creates an opportunity for connectivity with neighboring habitat clusters, but the opportunity may be diminished given that much of the BLM ownership in this habitat cluster is in a harvest land-use allocation where long-term development and retention of tree vole habitat is not expected to occur (see discussion under BLM Checkerboard East).

8-South Block (4,425 km^2 (1,708 mi^2))
This habitat cluster remained the largest in terms of imputed population size, and retained its overall resiliency score of high under all future scenarios. Red tree vole habitat and associated imputed population size decreased slightly under the LO-ingrowth scenarios and increased under the HI-ingrowth scenarios (Figure 14). Federal and State lands contain 81 percent of the tree vole habitat in this cluster, and 71 percent of their combined ownership is already tree vole habitat. Thus, much of the Federal and State ownership already provides habitat for tree voles. In addition, 46 percent of the cluster area is private land, particularly those portions north of Highway 20 and south of Highway 126 where ownership and habitat is much more fragmented in these regions of the habitat cluster. Although our model couldn't capture this, current management over time may fragment these two areas of the South Block habitat cluster, effectively reducing the size of South Block and splintering it into smaller clusters. Nevertheless, this cluster continues to remain a stronghold for red tree voles in the analysis area with its overall high resiliency score. It is also the only habitat cluster with likely connectivity to tree vole populations to the south outside of the DPS, further improving its resiliency.

9-OSU Forest (103 km^2 (40 mi^2))
This cluster retained its overall resiliency score of low in all future scenarios. As for individual resiliency metrics, it also remained unchanged. That is, the imputed population score remained moderate in spite of population declines under all future scenarios, and the connectivity score remained low. This cluster didn't respond very differently to the different ingrowth scenarios (Figure 14) because only 5 percent of the area is in Federal ownership where we assumed ingrowth to occur. Given that we assumed no change in tree vole populations on State lands in this cluster, which was mostly the OSU experimental forest, and given that there was very little Federal land in the cluster area, the change in the imputed population size was driven by the loss of tree vole habitat on private land. This cluster, in spite of its moderate size, remains isolated from the nearest neighboring cluster, South Block.

10-Junction City (29 km^2 (11 mi^2))
This habitat cluster declined under all four future scenarios. Individual resiliency scores (imputed population size and connectivity) remained unchanged in all four future scenarios, retaining a low imputed population score but a moderate connectivity score. Although connectivity remains moderate, there are just a few scattered sections of Federal ownership between this block and the nearby South Block, 1.4 km (0.9 mi) away, and they are mainly in a harvest landbase allocation.

Because the imputed population score remained low at the 60-year time step in both ingrowth scenarios, this vole cluster is assumed extirpated.

11-Spencer Butte (15 km^2 (6 mi^2))
This vole cluster decreased under all future scenarios. Individual resiliency scores (imputed population size and connectivity) remained unchanged in all four future scenarios, retaining a low imputed population score and connectivity score. In addition, this cluster continues to be far removed from the nearest vole cluster at 10.0 km (6.2 mi). Hence, it is unlikely to ever connect to other tree vole clusters, even ones outside of the analysis area given its isolated location at the southern end of the Willamette Valley. Given the low imputed population condition score in both of the 60-year scenarios, we assume this vole cluster to be extirpated.

7.3.1.2 General future resiliency

The Nestucca Block and South Block continue to retain high imputed population range sizes and high overall resiliency scores under all future scenarios. They remain the foundation vole clusters for the analysis area with high resiliency given their capacity to absorb loss of individuals because of their relatively large area and population size. The remaining clusters also continue to remain in their low or moderate condition in the 30-year scenarios, and 4 become extirpated in the 60-year scenarios due to the long-term low imputed population range sizes.

It seems clear that, under existing Federal and State land management and barring large-scale catastrophic disturbances, red tree vole habitat can be developed and maintained in the analysis area sufficient to support some of the clusters. Forsman *et al.* (2016, p. 85) concluded that, as long as old-forest harvest restrictions remain in effect on Federal lands, red tree voles will likely continue to occupy extensive areas of Federal lands. Hence, the clusters with the largest Federal ownership, Nestucca Block and South Block, are likely to remain resilient over time, as predicted in our future scenarios. This is also consistent with modeling indicating that implementing current land management policies in the 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).

While tree voles appear to have been largely eliminated from the Tillamook and Clatsop State Forests (Forsman *et al.* 2016, p. 39), they still occur on the western edge of the Tillamook State Forests (Tillamook State Forest Nehalem and Tillamook State Forest Kilchis clusters). Forsman *et al.* (2016, p. 39) concluded that tree voles may eventually recolonize areas where ODF actively manages to produce tree vole habitat. Indeed, our HI-ingrowth scenarios project just such an increase in habitat given the desired future condition of managing for layered and old-forest structure in these clusters. The intervening State forest land between these two clusters is also likely to develop into tree vole habitat under the existing management plan, possibly resulting in these two clusters becoming a single cluster (see the description for the Tillamook State Forest Nehalem cluster, section 7.3.1.1 Future resiliency by red tree vole habitat clusters). However, this combined cluster may continue to remain isolated from the nearby Nestucca Block because intervening State forest lands are not currently being managed in a fashion to produce connecting blocks of tree vole habitat.

We predict that the clusters with a low imputed population score (Oswald West, Cape Lookout, Junction City, and Spencer Butte) will ultimately become extirpated because they all have imputed population size ranges that indicate a high probability for inbreeding. In spite of the fact that there may have been sufficient habitat to retain these clusters under our future scenario modeling, their small population size makes them vulnerable to other events unrelated to habitat, including loss of genetic variability, inbreeding depression, demographic stochasticity, environmental stochasticity, and natural catastrophes (Franklin 1980, entire; Shaffer 1981, p. 131; Gilpin and Soulé 1986, pp. 25-33; Soulé and Simberloff 1986, pp. 28-32; Lehmkuhl and Ruggiero 1991, p. 37; Lande 1994, entire). Furthermore, all but Junction City retain a low connectivity score, making it unlikely there will be demographic or genetic support to retain them on the landscape.

The OSU Forest cluster retains a moderate imputed population score under all future scenarios, but remains isolated from nearby clusters (low connectivity score), as do the Oswald West, Cape Lookout, and Spencer Butte clusters. Isolated populations are more likely to decline than those that are not isolated (*e.g*., Davies *et al.* 2000, p. 1456). Combining this with the low imputed population scores for Oswald West, Cape Lookout, and Spencer Butte make it highly likely that these latter 3 clusters will become extirpated without providing demographic and genetic support or a change in land management.

The vole clusters with a moderate imputed population score (the two Tillamook State Forest clusters, the two BLM checkerboard clusters, and OSU Forest) indicate clusters that are not at a high risk of inbreeding. However, it is suggested that isolated populations of this size are at risk to loss of genetic diversity, which can diminish the long-term capacity of the species to evolve by adapting to changes in the environment (*e.g*., Franklin 1980, pp. 140-144; Soulé and Simberloff 1986, pp. 28-29; Nunney and Campbell 1993, pp. 236-237; Reed and Frankham 2003, pp. 233-234; Blomqvist *et al.* 2010, entire).

7.3.2 Redundancy

In future scenarios, redundancy remains similar to current conditions in the sense that the two largest vole clusters continue to likely withstand catastrophic windstorm events, but remain vulnerable to large, stand-replacing wildfires. The clusters with low imputed population scores remain vulnerable to all catastrophic events, and are even more vulnerable as their population numbers decline over time. Redundancy, however, is diminished given that the four smallest clusters with low overall resiliency scores will likely become extirpated in 60 years, and their contribution to redundancy will be lost. With any catastrophic disturbance event, there would likely be individual clusters retained post disturbance. However, they would be extremely fragmented and isolated, particularly in the event of a large wildfire; their ability to persist in small fragmented patches long enough to recolonize recovered areas is questionable given the already fragmented nature of red tree vole distribution in the analysis area.

A large-scale, stand-replacing wildfire consistent with historical fire regimes in the coast range remains the stressor with the greatest implications to red tree vole clusters in the analysis area. It is not a question of if, but when it occurs and was not a factor that could be incorporated into our analysis. There is no way to predict whether a catastrophic wildfire will or will not occur within the 30- or 60-year timeframe we have chosen 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 such an event will occur because of increased droughts projected with climate change, and simply because more time has passed within which an episodic event like a stand-replacing wildfire can occur.

7.3.3 Representation

In our future scenarios, representation of the western hemlock zone is fairly secure, barring stand-replacing wildfires. Retaining representation in the Sitka spruce zone is more tenuous because much of it occurs in the smaller clusters along the north coast, which have only moderate or low resiliency. These habitat clusters continue to remain small, and two are assumed to become extirpated in the 60-year scenarios, reducing representation in the north coast region of the analysis area. Increasing vole cluster sizes on the two Tillamook State Forest are likely an overestimate, but these areas, given their moderate condition, remain the most likely place to retain voles over the long term in the Sitka spruce zone in the northern portion of the analysis area.

7.4 Summary of Future Condition

The best available data indicate that, of the 11 identified red tree vole clusters, 5 are currently in a low resiliency condition and remain that way through the two 30-year future scenarios. In the two 60-year future scenarios, the four smallest clusters become extirpated because they remain vulnerable to inbreeding with imputed population ranges below 100. The remaining vole cluster with a low overall resiliency score at 60 years, OSU Forest, has an imputed population score of moderate but is far removed from any adjacent clusters. In addition, we assumed no change in tree vole management on the forest, but given that the forest currently does not manage for red tree voles, loss of habitat or occupied stands can still occur, further reducing numbers in this unit.

Four vole clusters have an overall moderate resiliency score and may remain at that level over time, but they are at risk for loss of genetic diversity and the evolutionary capacity to adapt to changing environments. Knowing the potential for climate change to alter forest ecosystems to become more of a mixed forest and less of a temperate rainforest, retaining adaptive capability becomes more important, putting these moderate clusters at more risk to extirpation.

The two clusters that have retained a high overall resiliency score are the strongholds for red tree vole populations within the analysis area. Their high resiliency is attributed to the land ownership and associated management of retaining and developing old-forest habitat. In addition, the ownership is fairly contiguous, with large patches of habitat that allow for the connectivity of red tree voles across the landscape.

We limited our analysis to currently identified red tree vole occupied habitat clusters and did not attempt to predict new development of future clusters based on habitat ingrowth outside of the known clusters. Hence, we do not factor in the possibility for new clusters to develop over time or for additional clusters to be discovered. There are blocks of habitat on the Tillamook and Clatsop State Forest (Figure 10) that appear large enough to support red tree voles but where surveys indicate tree voles no longer occur (Forsman *et al.* 2016, pp. 30, 72). It is possible that occupied stands have been missed in the survey effort (false negative), although tree vole surveyors and researchers believe that likelihood is small (Swingle 2019, pers. comm.). Nevertheless, if we were to assume that some of these areas were occupied habitat clusters, they would be subject to the same concerns as our moderate and low resiliency clusters in terms of their isolation and low ability to provide or receive genetic and demographic support from neighboring clusters. However, conservation measures that facilitate tree vole occupancy in these areas may improve tree vole redundancy and representation in the analysis area.

We also do not account for the possibility that some clusters might increase and expand their area based on habitat development in the adjoining landscape. We believe this is most relevant to the two State forest clusters (Tillamook State Forest Nehalem and Tillamook State Forest Kilchis). Some of the State forest land adjoining these two clusters will likely develop into red tree vole habitat over the coming years, likely increasing the footprint of these two clusters, and even connecting them (see section 7.3.1.1 Future resiliency by red tree vole habitat clusters). This may also be a possibility for the two BLM checkerboard clusters, although we think it a low probability given that the intervening Federal land is mostly in a harvest landbase allocation where red tree vole habitat is not expected to grow. For the remaining clusters, the surrounding land is primarily private land which we believe holds little prospect for developing red tree vole habitat under existing forest management regulations and practices.

The two largest vole clusters, Nestucca Block and South Block, are the best sources for redundancy in the analysis area because they are large enough to withstand most events, with the exception of large-scale wildfires. The clusters with low resiliency scores will likely not contribute to long-term redundancy because we expect them to become extirpated, with a possible exception for the OSU Forest, which retains a moderate population of voles though it has a low connectivity score. The clusters with an overall moderate resiliency score may contribute to redundancy, but given their isolation from other clusters, they will contribute little to other clusters without additional management support.

The western hemlock vegetation zone continues to remain well represented through all future scenarios. However, we expect that two of the tree vole clusters in the Sitka spruce zone will become extirpated, reducing the representation of this zone and associated foraging behavior from the analysis area-wide population.

8 SYNTHESIS

The North Coast DPS of the red tree vole has lost viability over the past 100 years due to the loss of habitat that has not been restored or regrown, combined with an associated decline or extirpation of voles 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 clusters primarily restricted to Federal and State lands. Multiple features of tree vole biology, including their low reproductive capacity and limited vagility, limit the ability of the population to rebound from the level of habitat loss and fragmentation that has occurred. Serious stressors will continue to affect species viability; these include continued timber harvest that removes or precludes habitat development, as well as the contribution of climate change to the increased spread of Swiss needle cast and the increased threat of wildfires.

Smaller, isolated vole clusters are expected to become extirpated over time under existing management. The two largest tree vole clusters that encompass the large blocks of Federal land in the analysis area are expected to maintain resiliency through time and remain the foundation of the red tree vole population in the analysis area; this assumes that current Federal management persists and there is no or limited habitat loss to wildfires. Catastrophic wildfires in the Oregon Coast Range are difficult, if not impossible, stressors to manage for and are the principle threat to the two large clusters of tree voles (Nestucca Block and South Block).

Opportunities exist to increase the resiliency of existing vole clusters through habitat development, particularly on State lands. Increasing cluster connectivity will be necessary to improve the evolutionary capacity of those clusters ranked as having moderate resiliency. Facilitating connectivity among clusters will require cooperative and collaborative planning among multiple stakeholders and land managers.

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10 APPENDICES

Appendix A Lesmeister and Linnell 2019 occupied habitat cluster analysis report

This appendix includes the final version of the analysis that derived the habitat clusters used in the red tree vole species status assessment (SSA) (see section 3.3 Analytical Units—Occupied Red Tree Vole Habitat Clusters). A draft version of this report (Lesmeister and Linnell 2018, entire) was used to develop the SSA; minor revisions were made to this draft based on peer review, but the final version is not substantively different from the draft version, and the revisions do not change the analysis done in the red tree vole SSA.

US Department of Agriculture
Forest Service Pacific Northwest
Research Station

Red Tree Vole
Habitat Clusters
September 18, 2019

1. Title

Habitat Clusters for Red Tree Voles in the Coast Range

of Oregon Research Team

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2. Introduction and objectives

Small populations are vulnerable to extirpation due to stochastic events, such as large disturbances, or loss of fitness due to reduction of genetic diversity (Frankham et al. 2014). Estimating the minimum area required to support a viable population through time is often the first step in assessing resiliency of wildlife populations to stochastic events or inbreeding depression (Pe'er et al. 2014). Herein we identified clusters of presumed occupied old-forest patches (henceforth, clusters) with at least 1 detection of a red tree vole (*Arborimus longicuadus;* henceforth: tree vole) or their sign in the previous 20 years and of sufficient extent to potentially support a small, viable population of red tree voles within the distinct population segment in the northern Oregon Coast Range (USFWS 2011, Forsman et al. 2016).

Forsman et al. (2016) and Linnell et al. (2017) identified old Douglas-fir dominated forests (≥80 years old) as the forest cover type most likely to support tree vole populations through time as 80 years is the age at which structural complexity begins to develop (Spies and Franklin 1991), including abundant nest supports required by tree voles, and that old forests are projected to be more stable (lower likelihood of disturbance) than young forests (<80 years old). Based on foresttype relationships, area requirements, and population densities (Marks-Fife 2016, Linnell et al. 2017), we identified clusters of old-forest patches (>20 ha.) of sufficient extent and adjacency that was assumed to support >100 individuals or >1000 individuals (Pe'er et al. 2014). We assumed that old-forest patches were occupied at a density of 1.5 tree voles per ha, which was the average density of two studies (Maser 1966, Marks-Fife 2016). We used extent of old-forest patches and presence of tree voles (or their sign) within identified clusters as we lacked data on tree vole abundances and distribution within clusters. We followed the estimates by Maser (1966) and suggestions by Linnell et al. (2017) that patches of old forests need to be of sufficient size (>20 ha) to support a small number of breeding tree voles. We then used general recommendations (i.e., not specific to tree voles) from Frankham et al. (2014) that minimum effective population size (N_e) of 100 individuals required to limit inbreeding depression to <10% over five generations in the wild and N_e of 1000 to retain the evolutionary potential for fitness in perpetuity. These recommendations were for minimum effective population size needed to achieve genetic benchmarks with limited inbreeding. The actual number of individuals in the population is always higher than the effective population size, with an average ratio of 0.1–0.2 (N_e/N) (Frankham 1995, Frankham et al. 2014).

3. Study Area

The study area occurred in the distinct population segment within the historical range of the tree vole in the northern half of the Oregon Coast Range (Fig. 1; USFWS 2011). The area contained approximately 16,000 km^2 of forested land (Forsman et al. 2016, Linnell et al. 2017). Most coniferous forests in the study area were dominated by Douglas-fir (*Pseudotsuga menziesii*) with a narrow zone along the coast dominated by western hemlock (*Tsuga heterophylla*) and Sitka spruce (*Picea sitchensis*). Stands of red alder (*Alnus rubra*) and bigleaf maple (*Acer macrophyllum*) occurred throughout the study area. Tree vole habitat within the study area occurred mostly in small patches especially in the northern portion (north of the Nestucca River, Fig. 1) with a relatively extensive area of continuous habitat occurring in the southern portion (Linnell et al. 2017).

The climate was characterized by cool wet winters and warm dry summers with areas of summer fog near the coast, and natural disturbance consisted of infrequent but large, high-severity wildfires (Long et al. 1998). Large wildfires (1931–1951 Tillamook Burn) and subsequent timber harvesting in the early 20th century almost completely eliminated old forests in the northern portion of the study area (Highsmith and Beh 1952, Kennedy and Spies 2004), including areas now managed by the state of Oregon north of the Nestucca River (ODF, 2010).

Forests were primarily managed by private timberland owners (60%) and federal agencies (23%; Forest Service and Bureau of Land Management) with state and local government (15%) and Native American tribes (2%) managing the remainder. Most state forest lands occurred north of the Nestucca River and most federal lands to the south (Fig. 1). Most reserves in the study area constituted late successional reserves on federal lands set aside for the northern spotted owl and assumed to provide habitat for broad range of organisms (USDA Forest Service and USDI Bureau of Land Management 1994). Some forests on state lands were managed for old forest conditions within a shifting-mosaic over time with few set-aside reserves (ODF, 2010).

4. Methods

We used a habitat-based approach and calculated a minimum area required to maintain occupancy of clusters of old-forest patches through time. Extensive surveys for tree voles have occurred within the study area and we used recent detections: >1 detection in surveys conducted 2001–2014 (n = 1558 detections) to determine whether a cluster was likely to be occupied. We used the guidelines outlined by Frankham et al. (2014) and used the mean of the average density (1.5 tree voles per ha) from two studies: 1.0 adult per ha (Maser 1966) and 1.9 tree voles per ha (Marks-Fife 2016). We assumed that tree voles would occur in old-forest patches at this density. Therefore, following Frankham et al. (2014), a minimum of 67 ha of old-forest patches would be required for >100 individuals (67 ha = 100 individuals / 1.5 individuals/ha) and 667 ha for >1000 individuals (667 ha = 1000 individuals / 1.5 individuals/ha). This assumes actual population size, not the effective population size.

We used a moving window approach to identify clusters of old-forest patches that when aggregated would be of greater extent than our thresholds of 67 ha or 670 ha. Each cluster was defined as an aggregation of old-forest patches located < 2 km from the nearest adjacent old-forest patch. The two km threshold was based on the modeled distance from patches of old forest of >2 km (Linnell et al. 2017) at which the model predicted young forest would become unsuitable based on tree vole occurrence data.

Our rule set was as follows:

1. ≥1 tree vole detection within the cluster
2. Two km moving window comprised of a total of >667 ha of old-forest patches (1000 individuals) or >67 ha (100 individuals)
3. Old-forest patches were assigned to only one cluster

We used two km for our moving window radius and assumed that old-forest patches within two km of each other would be functionally connected by at least occasional gene flow (Linnell et al. 2017, Linnell and Lesmeister 2019). We assumed that young forest would function to provide for occasional connectivity between patches of old forest but because more frequent disturbances there (i.e. timber harvesting) would not provide stable habitat. We then set thresholds of 67 ha (subpopulation of >100 individuals) and 667 ha (subpopulation >1000 individuals).

Results

We identified 11 discrete habitat clusters based on our rule set, six were estimated to contain sufficient old-forest patches to support >100 individuals (small population) and four to contain a large cluster of old-forest patches estimated to be of sufficient extent to support >1000 individuals (Fig. 1). Large clusters were primarily located in where federal lands predominated and small clusters were primarily where state lands predominated and federal lands were relatively scarce. Three clusters in the northern portion of the study area were small and highly isolated.

4. Discussion

Our analysis provides a basis for evaluating the likelihood that the tree vole population within the distinct population segment comprises several potentially isolated clusters rather than a single inter-breeding population. We identified four large clusters (>667 ha) and six smaller clusters (>67 ha) of old-forest patches. Our estimate should be interpreted as an attempt at identifying potential discontinuities within the distinct population segment based on old-forest patch clustering analysis. Assuming an effective population size to population size ratio of 0.1–0.2 (N_e/N), clusters of <1000 individuals should be interpreted cautiously as <1000 individuals may not represent a viable population.

Our results are similar to Forsman et al. (2016) in that they demonstrate that tree voles occur in two main blocks of forest on federal lands south of the Nestucca River, but our results provide higher resolution as to where distinct clusters occur. For example, the three most northerly tree vole detections (2006–2008) are located outside of clusters in that they occur in areas where tree voles, per our cluster analysis would be unlikely to persist as the population would be predicted to consist of fewer than 100 individuals (Fig. 1), and where tree voles are likely to remain isolated. Further, the discontinuity between the two most extensive clusters, located near the Nestucca and Yaquina Rivers, will likely persist because little old forests remains there and timber harvesting is likely to continue on non-federal lands. Alternatively, this discontinuity may represent an opportunity to prioritize an area for restoration to connect clusters (Linnell and Lesmeister 2019).

We emphasize several assumptions that require further validation: 1) that no barriers to genetic and demographic flow occur within habitat clusters such that each cluster could be assumed to be continuously occupied by tree voles, and 2) that old-forest patches will support tree vole populations at scales relevant to genetic and demographic flow into the future, 3) the analysis does not account for intermittent major disturbances of habitat such as large wildfires, nor (4) effects of predators and other organisms (e.g. pathogens and disease) on local populations occurring in clusters. For (1), the lack of tree vole detections near the eastern reaches of the Yaquina River and north of the Nestucca River may indicate discontinuities within the two largest clusters. Near the Yaquina River, the distance between the most adjacent north-south detections is >20 km. Given the sparsity of old-forest patches there and that tree voles have not been located there during surveys (Forsman et al. 2016), we caution that this area may represent a discontinuity within this cluster.

For (2), based on the assumptions of Linnell et al. 2017, we assumed that >80 years old was a relevant minimum threshold for forests that provide copious amounts of branch and bole structures that are lacking in young forests. We emphasize that 80 years is assumed to be a minimum and that older forests (e.g. old-growth >195 years old; Spies and Franklin (1991)) are likely optimal habitat for tree voles (Dunk and Hawley 2009, Forsman et al. 2016, Linnell et al. 2017) . Moreover, younger forests, including those at or near 80 years old, may not resemble extant old-growth in the future due to shifts in climate and disturbance regimes. Therefore, we clarify that our analysis represents current conditions and that shifts in disturbance or climate may alter the trajectories of habitat and disturbances in the area of our cluster analysis.

At this stage we were unable to perform a population viability assessment to estimate the number of tree voles needed to minimize extinction risk probability to below 0.05 over 100 years, a common benchmark for estimating minimum viable population size (Pe'er et al. 2014). Next steps to further understand the potential for long-term persistence of this tree vole population may be to perform a population viability assessment and directly examine the result of isolation on genetic structure within and between clusters. Important to also include these analyses will be sensitivity tests to better understand the effect of key parameters affecting tree vole populations. For example, tree voles may experience relatively rapid loss of genetic diversity because of limited dispersal capability and short generation times. Limited dispersal between and within habitat clusters may further limit transfer of genes, further limiting genetic diversity and capacity of the population to adapt to shifts in habitat and disturbances.

5. Acknowledgments

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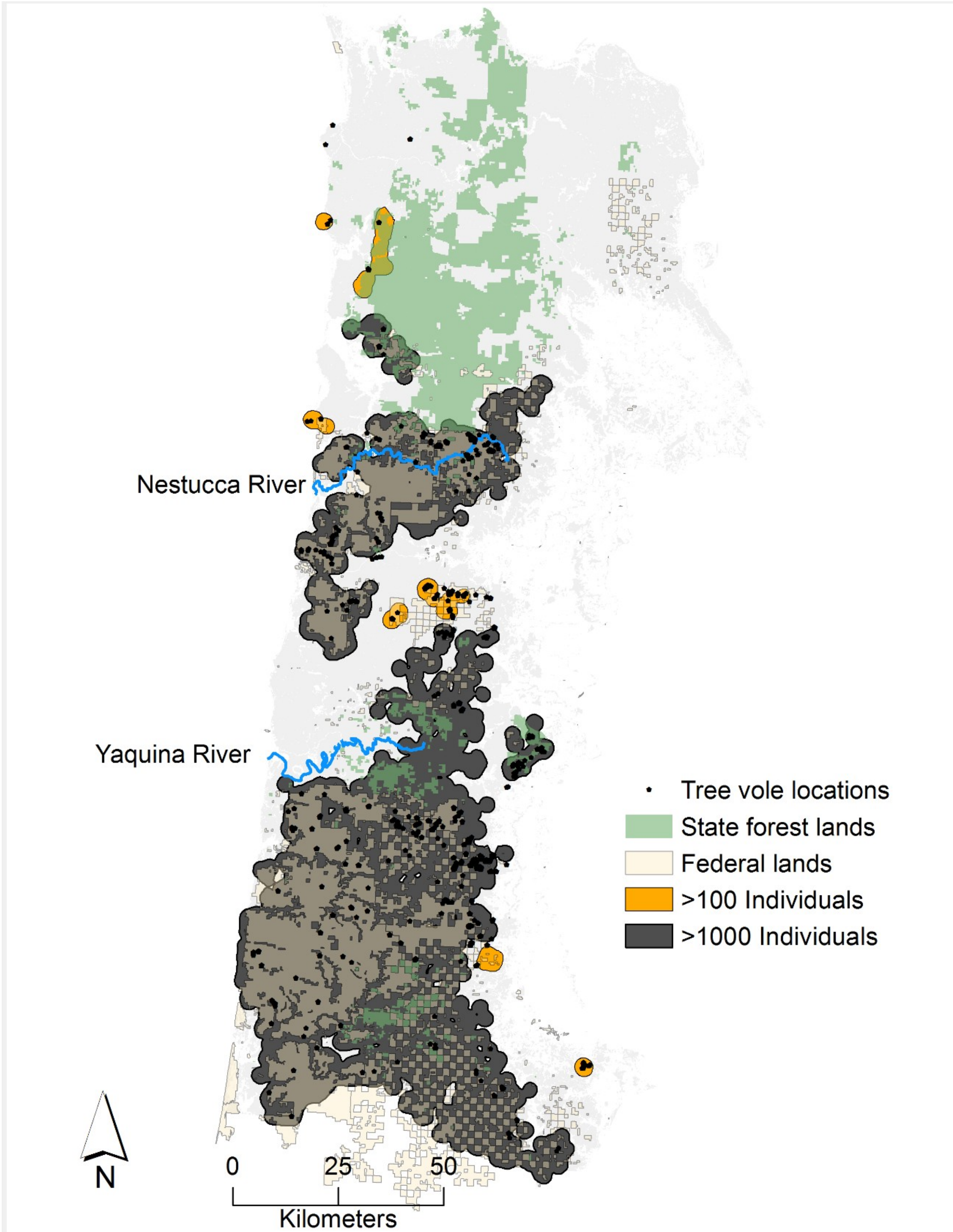

Figure 1. Discrete habitat clusters within the distinct population segment of red tree voles in the northern Oregon Coast Range. Habitat clusters were identified based on the assumption that >100 or >1000 individuals could be supported by clusters of old-forest patches >67 ha

or >670 ha located <2 km apart.

Appendix B Intermediate tables used for deriving red tree vole habitat cluster resiliency conditions

This appendix includes intermediate tables containing red tree vole habitat cluster vole capacities and effective population size ranges that were used to derive imputed population range scores for each habitat clusters, as described in section 6.3.1. Red tree vole capacity and imputed population range.

For future revisions, it is recommended that vole capacity be expressed not as a point estimate, but as a range to incorporate the variability in such things as habitat suitability, density estimates, and the ratio of observed nests to observed voles.

Table B-1. Current condition scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat cluster	Area	Vole Capacity[a]	Vole N_e Range[b]	Connectivity	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	168	17-34	Low	Sitka spruce zone	Low
2-Tillamook State Forest Nehalem	88 (34)	851	85-170	Moderate	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	1,728	173-346	Moderate	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	239	24-48	Low	Sitka spruce zone	Low
5-Nestucca Block	1,480 (571)	22,826	2,283-4,565	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	2,273	227-455	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	995	100-199	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	172,111	17,211-34,422	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	1,748	175-350	Low	Western hemlock zone	Low
10-Junction City	29 (11)	445	45-89	Moderate	Western hemlock zone	Low
11-Spencer Butte	15 (6)	303	30-61	Low	Western hemlock zone	Low

[a] Capacity is based on combined suitable and highly suitable habitat categories (Linnell *et al.* 2017, pp. 5-6), adjusted for occupancy rates of red tree vole protocol surveys specific to subregions within the analysis area (see section 6.3.1. Red tree vole capacity and imputed population range). It represents an overall carrying capacity of the habitat cluster.

[b] N_e range is an estimated effective population size ranging from 10 to 20 percent of the vole capacity.

Table.B-2 Future scenario (30 years, LO-ingrowth) scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Vole Capacity[a]	Vole N_e Range[b]	Connectivity	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	168	17-34	Low	Sitka spruce zone	Low
2-Tillamook State Forest Nehalem	88 (34)	840	84-168	Moderate	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	1,692	169-338	Moderate	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	236	24-47	Low	Sitka spruce zone	Low
5-Nestucca Block	1,480 (571)	22,188	2,219-4,438	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	2,115	211-423	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	949	95-190	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	164,399	16,440-32,880	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	1,639	164-328	Low	Western hemlock zone	Low
10-Junction City	29 (11)	386	39-77	Moderate	Western hemlock zone	Low
11-Spencer Butte	15 (6)	256	26-51	Low	Western hemlock zone	Low

[a] Capacity is based on combined suitable and highly suitable habitat categories (Linnell *et al.* 2017, pp. 5-6), adjusted for occupancy rates of red tree vole protocol surveys specific to subregions within the analysis area (see section 6.3.1. Red tree vole capacity and imputed population range). It represents an overall carrying capacity of the habitat cluster.

[b] N_e range is an estimated effective population size ranging from 10 to 20 percent of the vole capacity.

Table.B-3 Future scenario (30 years, HI-ingrowth) scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Vole Capacity[a]	Vole N_e Range[b]	Connectivity	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	182	18-36	Low	Sitka spruce zone	Low
2-Tillamook State Forest Nehalem	88 (34)	1,170	117-234	Moderate	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	2,182	218-436	Moderate	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	272	27-54	Low	Sitka spruce zone	Low
5-Nestucca Block	1,480 (571)	25,326	2,533-5,065	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	2,284	228-457	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	1,064	106-213	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	181,537	18,154-36,307	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	1,665	166-333	Low	Western hemlock zone	Low
10-Junction City	29 (11)	405	41-81	Moderate	Western hemlock zone	Low
11-Spencer Butte	15 (6)	262	26-52	Low	Western hemlock zone	Low

[a] Capacity is based on combined suitable and highly suitable habitat categories (Linnell *et al.* 2017, pp. 5-6), adjusted for occupancy rates of red tree vole protocol surveys specific to subregions within the analysis area (see section 6.3.1. Red tree vole capacity and imputed population range). It represents an overall carrying capacity of the habitat cluster.

[b] N_e range is an estimated effective population size ranging from 10 to 20 percent of the vole capacity.

Table.B-4 Future scenario (60 years, LO-ingrowth) scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Vole Capacity[a]	Vole N_e Range[b]	Connectivity	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	167	17-33	Low	Sitka spruce zone	Extirpated
2-Tillamook State Forest Nehalem	88 (34)	829	83-166	Moderate	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	1,655	165-331	Moderate	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	233	23-47	Low	Sitka spruce zone	Extirpated
5-Nestucca Block	1,480 (571)	21,549	2,155-4,310	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	1,956	196-391	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	902	90-180	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	156,687	15,669-31,337	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	1,531	153-306	Low	Western hemlock zone	Low
10-Junction City	29 (11)	327	33-65	Moderate	Western hemlock zone	Extirpated
11-Spencer Butte	15 (6)	210	21-42	Low	Western hemlock zone	Extirpated

[a] Capacity is based on combined suitable and highly suitable habitat categories (Linnell *et al.* 2017, pp. 5-6), adjusted for occupancy rates of red tree vole protocol surveys specific to subregions within the analysis area (see section 6.3.1. Red tree vole capacity and imputed population range). It represents an overall carrying capacity of the habitat cluster.

[b] N_e range is an estimated effective population size ranging from 10 to 20 percent of the vole capacity.

Table.B-5 Future scenario (60 years, HI-ingrowth) scores for each red tree vole habitat cluster. Area is in km^2 (mi^2).

Habitat Cluster	Area	Vole Capacity[a]	Vole N_e Range[b]	Connectivity	Representation	Overall Resiliency Condition
1-Oswald West	7 (3)	196	20-39	Low	Sitka spruce zone	Extirpated
2-Tillamook State Forest Nehalem	88 (34)	1,489	149-298	High	Sitka spruce zone	Moderate
3-Tillamook State Forest Kilchis	138 (53)	2,635	264-527	High	Sitka spruce zone	Moderate
4-Cape Lookout	19 (7)	304	30-61	Low	Sitka spruce zone	Extirpated
5-Nestucca Block	1,480 (571)	27,827	2,783-5,565	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
6-BLM Checkerboard East	60 (23)	2,295	229-459	Moderate	Western hemlock zone	Moderate
7-BLM Checkerboard West	26 (10)	1,133	113-227	Moderate	Western hemlock zone	Moderate
8-South Block	4,425 (1,708)	190,963	19,096-38,193	High	Mostly western hemlock zone, Sitka spruce strip mainly along coast	High
9-OSU Forest	103 (40)	1,582	158-316	Low	Western hemlock zone	Low
10-Junction City	29 (11)	366	37-73	Moderate	Western hemlock zone	Extirpated
11-Spencer Butte	15 (6)	221	22-44	Low	Western hemlock zone	Extirpated

[a] Capacity is based on combined suitable and highly suitable habitat categories (Linnell *et al.* 2017, pp. 5-6), adjusted for occupancy rates of red tree vole protocol surveys specific to subregions within the analysis area (see section 6.3.1. Red tree vole capacity and imputed population range). It represents an overall carrying capacity of the habitat cluster.

[b] N_e range is an estimated effective population size ranging from 10 to 20 percent of the vole capacity.