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Conservation and relative habitat suitability for an arboreal mammal associated with old forest

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ABSTRACT

Contraction of native old forest can limit occurrence of old forest associated species, especially species with limited vagility. Patterns of size and distribution of remaining patches of old forest along with forest disturbance and what replaces old forest can influence whether species adapt or perish after forest loss. The arboreal red tree vole (*Arborimus longicaudus*) is a small arvicoline rodent that is associated with old coniferous forest and typically emigrates short distances. Since 1911, old forest (≥80 years old) in the northern half of the Oregon Coast Range has been reduced by >80%, primarily due to large stand replacing wildfires, timber harvest, and subsequent conversion to young forest (<80 years old). In 2011, the tree vole population in the northern half of the Oregon Coast Range was listed as a candidate species as a distinct population segment under the United States Endangered Species Act, primarily due to habitat loss. We examined the contribution of current and historical (early 20th century) old forest cover, and recent disturbances (1984–2012) on relative habitat suitability for tree voles using light detecting and ranging (LiDAR) data, Landsat imagery, and machine learning. We used a step-wise variable removal procedure to build a parsimonious model and to rank contribution of variables in our final model. We further described the configuration of large patches of old forest using metrics of amount and distance from patch for historical, current, two forest loss scenarios, and two forest restoration scenarios within our study area. Red tree vole relative habitat suitability was positively correlated with current old forest cover at the local-scale and negatively correlated with distance from large patches of current old forest. Landscape context, specifically proximity to old forest and absence of recent disturbance contributed most to relative habitat suitability of young forest matrix. If old forest contracted to only reserves on federal lands, amount would decrease from 10.9% to 9.5% and be spatially clumped with an increase in average distance to nearest patch from 3.1 km to 11.1 km. Alternatively, a random addition of patches equivalent to a 1.4% increase in amount, would reduce distance to nearest patch to 1.8 km. Given the history of large historical wildfires in the Oregon Coast Range, restoration of even a small amount of old forest throughout the study area would likely enhance connectivity and resiliency of red tree vole populations in the event of large-scale loss of old forest.

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1. Introduction

Globally, native old forest ecosystems have contracted in area and have been highly altered by human actions, and this is the case of old forest in the Pacific Northwest (Hansen et al., 1991; Noble and Dirzo, 1997). For old forest associated species, the amount and configuration of remaining old forest, what replaces old forest, and the species' life history traits are the main drivers of whether species adapt or perish in altered forest ecosystems (Fahrig, 2001; Franklin, 1993; Kupfer et al., 2006; Ruffell et al., 2017; Selonen and Hanski, 2003). Matrix, or background cover types in which old forest resides, can influence species' dispersal, movement, and population-level processes by either enhancing or limiting species persistence, often depending on its resemblance or contrast to pre-existing old forest (Franklin, 1993; Greene and McCleery, 2017; Prevedello and Vieira, 2010; Ritchie et al., 2009; Ruffell et al., 2017).

Arboreal mammals may be particularly sensitive to contraction of native old forest because they often depend on structural or ecological characteristics of old trees that take decades or centuries to develop (Banks et al., 2013; Forsman et al., 2016). Where young forest replaces old forest, young forest can complement remaining old forest (Andrén, 1994; Franklin, 1993; Kupfer et al., 2006). If

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young forest can facilitate emigration, survival, and reproduction for old forest associated species, albeit at potentially lower rates than old forest, young forest may function as low-contrast matrix and increase the footprint of dispersed patches of old forest.

The arboreal red tree vole (*Arborimus longicaudus*, hereafter tree vole) is a small arvicoline rodent endemic to western Oregon and northwest California that depends entirely on coniferous forests for life history requirements. Tree voles build nests on complex branch and bole structures consisting of broken tops, cavities, palmate branch whorls, large limbs, forked trunks, and dense limb whorls that are near fresh conifer needles that they feed on (Benson and Borell, 1931; Howell, 1926; Maser, 1966; Swingle, 2005). Tree vole habitat models have shown a strong association with old forest (≥80 years old) characteristics where complex branch and bole structures are most prevalent (Dunk and Hawley, 2009; Forsman et al., 2016; Johnston and Moskal, 2017; Spies and Franklin, 1991). Some have suggested that young forest (<80 years old) is non-habitat or marginal habitat for tree voles (Aubry et al., 1991; Carey, 1991; Huff et al., 1992). However, many have found populations of tree voles in young forest (20–80 years old; Clifton, 1960; Maser, 1966; Swingle and Forsman, 2009; Thompson and Diller, 2002). Fragmentation models that delineate hard boundaries between habitat and non-habitat do not account for the potential contribution of low-contrast matrix as habitat (Fischer and Lindenmayer, 2006). Proximity to old forest may constrain occurrence of tree voles in young forests because, on average, tree voles do not move or disperse far (<60 m; Swingle, 2005; Swingle and Forsman, 2009).

In the Oregon Coast Range, the amount of old forest consisting of mature (80–200 years old) and old-growth (>200 years old) forest (Spies and Franklin, 1991) was reduced from 36% to 13% in the period from 1936 to 1993, and is currently estimated to be outside the lower limits of natural variability (Kennedy and Spies, 2004; Wimberly et al., 2000). Old forest currently occurs as smaller and more isolated patches within a matrix primarily composed of young forest, compared to larger blocks that historically occured (Forsman et al., 2016). Forest age largely differs across ownership boundaries (Stanfield et al., 2002) with most old forest occurring on federal lands managed by the USDI Bureau of Land Management and the USDA Forest Service, most of which is protected as old forest reserves as habitat for the threatened northern spotted owl (*Strix occidentalis*) and other old forest associated species (Davis et al., 2015; USDA and USDI, 1994). Primarily because of habitat loss (i.e., old forest), the tree vole population in the Oregon Coast Range north of the Siuslaw River was recognized as a distinct population segment and listed as a candidate species for protection under the United States Endangered Species Act in 2011 (USDI, 2011).

We examine the contribution of current old forest, young forest, and historical forest cover patterns on relative habitat suitability for tree voles in the entirety of the area containing the distinct population segment. We began with the premise that old forest was likely to be primary habitat at the local- and landscape-scale (120 m and 1 km radius, respectively) for tree voles (Dunk and Hawley, 2009; Forsman et al., 2016). We also predicted that: (1) if tree vole occurrence in young forest was due to emigrants originating from patches of old forest (>20 ha) estimated to support a small population of 1.0–1.9 tree voles per ha (Maser, 1966; Marks-Fife, 2016), then relative habitat suitability would diminish with distance from these patches, (2) recent removal or alteration of forest cover would decrease relative habitat suitability because site-level occurrence of tree voles is dependent on intact forest cover; and (3) if large historical disturbances from the early 20th century where old forest was removed limited recolonization by tree voles, then current tree vole occurrence would decrease with distance from historical 1911 and 1936 old forest cover (Harrington, 2003; Oregon State Board of Forestry, 1914). Finally, we described landscape configuration using amount, mean size, and minimum distance from patches of old forest (Prugh et al., 2008) to compare configuration of old forest cover in historical (1911, 1936, and 2015), two forest loss scenarios (if old forest contracted to old forest management areas on state and federal vs. only federal lands), and two restoration scenarios.

2. Data and methods

2.1. Study area

The study area contained the distinct population segment within the historical range of the tree vole in the northern half of the Oregon Coast Range (Fig. 1). The area contained approximately 16,000 km^2 of forested land (Forsman et al., 2016). Most coniferous forest in the study area was 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. The climate was characterized by cool wet winters and warm dry summers with areas of summer fog (Franklin and Dyrness, 1973). Natural disturbance consisted of infrequent but large, high-severity wildfires (Wimberly et al., 2000). In the early 20th century, the four large wildfires of the 1931–1951 Tillamook Burn (Highsmith, 1952) and clear-cut harvesting denuded old forest in the northern portion of the study area, including areas now managed by the state of Oregon north of the Nestucca River (ODF, 2010). Forests were primarily managed by private 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 background cover types (matrix) consisted of intensively managed young forests of Douglas-fir of varying age originating after clear-cut timber harvest (Lorensen et al., 1994). Private forests were typically managed with short harvest rotations (40–60 years) and state forests were managed with longer rotations up to 80 years (Adams et al., 2002; Oregon Deparment of Forestry, 2006). Some state forest lands were managed as anchor habitat for site-specific protection for species of concern to maintain some old forest structure within a shifting mosaic design over time (Oregon Department of Forestry, 2010). Federal land management within the study area followed the Northwest Forest Plan from 1994 to 2015 (USDA and USDI, 1994). The Northwest Forest Plan created reserves to enhance and maintain old forest conditions as habitat for the northern spotted owl, marbled murrelet (*Brachyramphus marmoratus*), and other old forest associated species. Areas of old forest outside of federal reserves have been subject to timber harvesting if Survey and Manage species, including the tree vole, were not detected (Huff et al., 2012; Huff, 2016; USDA and USDI, 1994). Much of the most recent harvesting on federal lands has focused on young forest and typically consisted of commercial thinning.

2.2. Tree vole data

Our data consisted of tree vole nests located during 2000–2015. We used data collected during research surveys conducted on state, federal, and private lands (Forsman et al., 2016) by the Forest Service's Pacific Northwest Research Station and data collected on federal lands as part of "pre-disturbance," "purposive," and "strategic" surveys conducted by the Bureau of Land Management and Forest Service as part of the Northwest Forest Plan Survey and