Small mammal and Bird Responses to Restoration Thinning in Young Post-Logging Stands of Redwood National Park and California Redwood State Parks

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Abstract

The restoration of old forest characteristics where they have been significantly degraded is a conservation objective on public lands in the coastal forests of the Pacific States. The Redwood National Park and California Redwoods State Parks complex in coastal northwestern California contains approximately 30,000 hectares of dense young forest that have regenerated after intensive timber harvesting. Restoration thinning has emerged as an important tool to use to actively manage these un-naturally dense stands to restore natural species dominance patterns and hasten the development of old forest characteristics. I evaluated the responses of small vertebrates to restoration thinning using a blocked treatment (thinned)-control (not thinned)-reference (old growth) study design. Three blocks were selected representing restoration thinning that had occurred 5, 15, and 30 years prior. Passerine birds and diurnal Sciurids were sampled using modified area searches along fixed transects in each study stand. Forest floor small mammals were sampled using Sherman live traps in 10x10 trapping grids with 10m between each trap location on the grid. Area searches and live trapping occurred between 5 September to 25 October 2012. Overall abundances of Passerine birds, small mammals, and Sciurids were significantly higher in restoratively thinned versus not thinned stands. Diversity of Passerine birds was significantly higher in thinned versus not thinned stands and was largely due to the presence of species representing sub-canopy, shrub, and ground foraging guilds using thinned stands and not using not thinned stands. Responses by small vertebrates were rapid (<5 years) and the overall magnitude of differences between thinned and not thinned stands was consistent up to 30 years after thinning occurred. Small vertebrate communities were more similar to old growth reference communities than those found in not thinned stands. Restoration thinning provides a valuable tool for managers seeking to hasten the restoration of old forest conditions by increasing the vegetative complexity that supports small vertebrate bird and mammal communities that are similar to those in old growth stands many decades before they will develop in dense young stands not thinned.

1.0 Introduction

The management of previously intensively harvested forests to meet objectives other than primarily for timber production continues to receive increasing interest worldwide. The rise in the importance of producing timber products in balance with the objectives such as maintaining water quality, healthy fisheries, and wildlife populations, continues to influence forest management across public and private lands. To meet these shifting objectives, managers must design stand scale prescriptions that when aggregated at larger spatial scales, will meet the desired objectives. One of the most dramatic shifts in forest management is that with the objective of intensive timber production to that with the objective of restoration. In the Redwood National and State Park complex in northwestern California, approximately 50% of the approximately 60,000 hectares of forest in these reserves was previously intensively harvested. To restore the pre-harvest conditions that existed in the extensive second growth forests of these reserves will require decades of carefully planned forest management and an experimental approach to identify and evaluate the types of management prescriptions that will achieve the overall restoration objectives (Porter et al. 2007).

In the Pacific coastal forests of the United States, large-scale intensive timber harvesting has resulted in two problems: 1. The overall loss of old forest characteristics, in most cases, outside their historical range of variability at the landscape scale (e.g., Whimberly et al. 2000) 2. The initiation of stand regeneration post-harvest has occurred under conditions uncharacteristic of the natural disturbance and regeneration dynamics of their systems (e.g., Porter et al. 2007). The net result of the first problem is the decline of species most reliant on old forest characteristics at large spatial scales, typically led by upper level trophic species such as predators like the Northern spotted owl (*Strix occidentalis*; see review in Thomas et al. 1990) and Humboldt marten (*Martes caurina humboldtensis*; Slauson et al. 2007) or species requiring specific old forest elements to complete key life history needs such as nesting on large diameter limbs for the marbled murrelet (*Brachyramphus marmoratus*; Hamer and Nelson 1995). To reverse these trends, restoration objectives seek to hasten the restoration of old forest characteristics to benefit the conservation of the species most at risk as soon as possible. The second problem requires managers to reconcile the post-harvest regeneration conditions, including altered species compositions and overall stem densities, with the characteristics of naturally regenerating stands or to understand how the developmental trajectories will result in future stand conditions. Stands regenerating after harvest, including post-harvest site preparation which may include burning and /or herbicides, and aerial reseeding or planting typically lead to live tree densities far beyond those observed under natural regeneration conditions (Veirs 1986, Thornburg et al 2000, Porter et al. 2007).

Density management involving the thinning of trees has emerged as a valuable tool for directing the developmental trajectory to meet restoration or management goals in young stands (e.g., Carey 2003, O'hara et al. 2010). The principal is straight-forward and has been used by silviculturalists for some time to achieve production goals, provide more growing space for individual trees and their vigor, measured in both live crown ratio and diameter growth, will increase. Numerous studies in Pacific coastal forests have confirmed this (e.g., Chan et al. 2006, Chittick and Keyes 2007). In most forests, the presence of sunlight as a resource supports the presence and vigor of sub-canopy trees, shrubs, and herbs. In the coastal forests of the Pacific states, old growth forests typically have a rich assemblage of understory vegetation, supported by the presence of light and moisture (Pelt and Franklin 2000, Sawyer et al. 2000) that forms the base of the food web for the understory and forest floor species. Many of the dominant understory woody plants produce mast crops that provide important food for a large number of species that occur there, such as hard mast from species like tanoak (*Lithocapus densiflora*), and soft mast from species like evergreen huckleberry (*Vaccinium ovatum*) and salal (*Gaultheria shallon*). The understory vegetation provides a host of ecological niches for vertebrate wildlife species by providing resources directly such as vegetation and mast and indirectly such as invertebrate prey. The efficacy of thinning to achieve restoration goals should be evaluated using multiple criteria, including responses of over and understory vegetation, responses of wildlife species in general, and over time responses of wildlife species that require old forest characteristics.

Despite the abundance of young coastal forest in the Pacific states, few studies have measured wildlife responses to thinning, done either for production or restoration objectives, of young previously harvested stands. While the types of thinning done for production typically produce homogenous stands with uniform spacing between trees that are not seen in natural stands. Thinning prescriptions to achieve restoration objectives will produce heterogeneity closer to that observed in natural stands if approaches such as variable-density thinning is used (Carey 2003). Despite the differences in tree spacing that results from the two types of thinning approaches, considering the results of plant and animal responses to all types of thinning in young stands can be valuable to assess the short term responses that may be likely. Most of the studies measuring wildlife responses to thinning have focused on the responses by small vertebrates, including largely mammalian rodents and insectivores <250 grams and passerine birds. The diversity present in these small vertebrate communities provides a means to assess their responses to particular resources, such as soft mast, understory structure, and how key prey species may influence the eventual responses of their predators, such as the Northern spotted owl and Pacific marten.

Two studies of forest floor small mammals showed increased total abundances over short (<5 years) and long (>10 years) periods, with the highest increases in insectivorous (shrews [*Sorex* sp.]), generalists (e.g., Deermouse [*Peromyscus sp.*]) and herbivorous (e.g., Creeping vole [*Microtus oregoni*]) species following thinning (Carey 2003, Suzuki and Hayes 2003). The only forest floor small mammal showing a short-term (<5 years) negative response was the red-backed vole (*Clethrionomys californicus*), but this species appears to recover and have increased reproductive output over time in thinned versus not thinned stands (Suzuki and Hayes 2003). Sciurids have shown mixed responses to thinning, with Townsend's chipmunks (*Tamias townsendii*) showing immediate increases in abundance (Carey 2003), northern flying squirrels showing both no short-term declines (Gomez et al. 2005) and short-term declines followed by recovery within 5 years (Carey 2003) and no response by Douglas' squirrels (*Tamaisciurus douglasii*; Carey 2003). Importantly, the only two species showing any negative responses were mycophagists that specialize in hypogeous fungus and are likely responding to the short-term negative effect thinning can have on this resource (Gomez et al. 2003). Other than the short term decline in hypogeous fungi specialists, the rest of the species responded positively, in terms of abundance, to thinning.

Several studies have measured the responses of birds during the breeding season to thinning and they collectively found that thinning increased species richness and the overall abundance of breeding birds and that the species that declined were never completely lost in thinned stands and were composed largely of canopy-gleaning insectivores (Hagar et al.1996, Hayes et al. 2003, Hagar et al. 2004). Haveri and Carey (2000) reported that resident bird species richness and overall abundances, measured in the winter, increased following thinning. Similar to the small mammal responses, overall both breeding birds and resident birds responded with an increase in overall abundance. In addition, the diversity of birds was greater in thinned versus not thinned stands, suggesting that thinning also increased the structural complexity present and additional bird species responded by occupying these new niches.

Collectively, these studies suggest that thinning young stands increases the overall abundances of both small mammals and breeding and resident Passerine birds compared to not thinning young stands. In addition, thinning stands increased the structural complexity and increased bird species richness during the breeding season. Negative effects were either short term on hypogeous fungi specialist mammals or only slightly reduced abundances of common canopy foraging birds. The objectives of this study were to evaluate whether small mammals and Passerine birds respond to restoration thinning similarly in young coastal forests of Redwood National and California State Parks. I used a retrospective blocked treatment-control-reference experimental design to measure responses in areas that included stands that were previously thinned 5, 15 , and 30 years prior, paired control stands that were not thinned, and nearby old growth reference stands. For small vertebrates, abundance, diversity, and guild structure for birds only were compared. Beyond the breeding season and resident species of birds, coastal forests supply mast crops that are seasonally important to both partial migrant and complete migrant species of birds. Accordingly birds and their use of soft mast were sampled during the fall migration season.

2.0 Methods

2.1 Experimental Design

I used a blocked treatment-control-reference experimental design, where each block consisted of 1 restoratively thinned (treatment) stand, an adjacent not thinned (control) stand, and an old growth (reference) stand. In each block, paired thinned and not thinned stands were clearcut harvested during the same year and used the same stand regeneration methods following harvest. Adjacent old growth stands provided a reference for both local conditions, between block variation, and a means to evaluate the trajectory of species responses in thinned versus not thinned stands. Three blocks were selected to represent a temporal gradient of 5, 15, and 30 years since restoration thinning. The blocked design allowed for variation within blocks to be distinguished from that among blocks, such that the overall effect of restoration thinning could be distinguished from spatial variation between blocks or temporal variation due to the time since thinning had occurred.

2.2 Study Area and Stand Characteristics

Three areas in Redwood National and California Redwood State Parks were selected where restoration thinning had been conducted previously. The earliest two restoration thinning experiments occurred in Redwood National Park and were conducted between 1978-1995 in the upper Lost Man Creek watershed. The first of these sites, known locally as the Holter Ridge thinning study, was thinned in 1978 and consists of a 80.9 hectare, ~55 year old stand of second growth dominated by coastal redwood (*Sequoia sempervierns*), Douglas fir (*Psuedotsuga menzesii*), and tanoak. This stand was harvested in 1954 using the seed tree method, with an average of 1 redwood seed tree per acre left, resulting in stand regeneration through natural seeding (Veirs 1986). The second restoration thinning site, known locally as the Whiskey Forty Forest Restoration Study, was thinned in 1995 and consists of a 16.2 hectare, ~50 year old second-growth stand (Teraoka and Keyes 2011). This stand was clearcut in 1962, was burned post-harvest, and regenerated by aerially reseeding of Douglas-fir redwood, Sitka spruce (*Picea sitchensis*), and Port Orford cedar (*Chamaecyparis lawsoniana)*. Natural regeneration included western hemlock (*Tsuga heterophylla*), grand fir (*Abies grandis*), and tanoak. The third area was located in the Mill Creek watershed of Del Norte Coast Redwood State Park where numerous stands throughout the watershed have been restoratively thinned within the last 10 years (Porter et al. 2007, O'hara et al. 2011). A 11.3 hectare ~20 year old stand, known locally as the North by Northwest stand, thinned in 2007, was selected. This stand was established in ~1990 following clearcut harvesting and was regenerated using planting of Douglas-fir on regular spacing and natural regeneration of redwood from stump sprouts and natural reseeding primarily of Douglas fir.

In each thinning area, one or more thinning treatments had been implemented and one or more control stands were not thinned. For the present study only a single thinning treatment stand and a paired control stand were selected from each thinning area. To provide a local reference old growth stand, the most proximal old growth stand, sharing the same topographic and macro-aspect characteristics as thinned and control stands was selected. In the Holter ridge study area, the thinning treatment was a 4.8-5.4 m spacing density thin with hardwoods cut, with an adjacent control stand adjacent (Veirs 1986). Both thinned and control stands occupied ridge top slope positions and west macro-aspects. The old growth reference stand was located 6.5 km southwest on the same ridge line and was the nearest old growth stand occupying the same slope position and macro-aspect as the thinned and control stands.

In the Whiskey Forty area, a low thinning prescription was applied where all trees <11.4 cm were removed (Teraoka and Keyes 2011). The control and old growth stands were adjacent and all occupied ridge top slope positions and north facing macro-aspects. In the Mill Creek area, the Northwestern thinning treatment was a high-density thin with 4.8 x 4.8 m density thin. The control and old growth reference stands were adjacent to the thinned stand. At the time thinning treatments were implemented pre-thinning stem densities exceed 5000 stems/ha in both the Holter Ridge and Whiskey Forty areas and >3000 stems/ha in the Northwestern area. Post-thinning, stem densities were reduced to <500 stems/ha in the Holter Ridge (Veirs 1986) and Northwestern areas (e.g., O'Hara et al. 2010) and <1500/ha in the Whiskey Forty area (Teroka and Keyes 2011).

2.3 Characterizing Bird Abundance and Use of Berries

Modified area searches (Ralph et al. 1993) within each selected stand were conducted on 3 occasions spaced at minimum of 2-week intervals during the peak fall land bird migration period from 1-Sept to 31 Oct. Treatment and control stands were not uniform in size, thus to standardize effort and area surveyed, modified area searches consisted of a 20-min survey period, conducted along a 200 m transect in each stand. All surveys were conducted within 5 hours after sunrise. All birds detected were recorded, however only birds within 50m of the transect line were included in the analysis, equaling an area of 2 ha surveyed in each stand. All 3 stands within each block were surveyed on each survey occasion. On each survey occasion a different stand within the block was surveyed first, such that each stand was surveyed during the first, second, and third survey periods across all survey occasions to equally distribute any within-day temporal variation on survey results between all stands. All avian species were identified by sight and sound and to identify foraging behavior, especially direct fruit consumption or indirect evidence of fruit consumption such as bills stained by berries. Each detection was identified as occurring in or out of the stand and within 3 distance categories, 0-50, 50-100, and >100m. Fly overs were recorded but considered out of stands and not included in the analysis. All avian surveys were conducted by the same individual to control for observer variation.

The results of avian area searches were used to calculate 4 types of bird response variables: index of overall species diversity, index of overall bird abundance, abundance indexes for all resident and migratory species, and abundance indexes by foraging guilds. Resident species were defined as those that can be found in the study stand locations year-round. Migratory species included both complete and partial migrants. Complete migrants are defined as those species that could only be found in the study area during part of the year, such as breeding season or migration season. Partial migrants included species that may be present year-round but whose numbers substantially increase during the migration or winter seasons due to the influx of individuals from other portions of their ranges. Foraging guilds were defined at the scale of the primary structural layer in forests that the species utilizes for foraging during the season of the year during which surveys were conducted (De Graaf et al. 1985).

2.4 Characterizing Small Mammal Communities

In each selected stand, forest floor mammals were sampled using a 10 x 10 grid with 10 m spacing between grid points and a single Sherman live trap placed at each grid point. Small mammal sampling occurred on a single occasion in each selected stand between September and October. Each trapping occasion consisted of 8 consecutive trap nights where traps were checked each morning and in the afternoon. Live traps were baited with a combination of cobb (combination of rolled oats and molasses) and peanut butter. Cotton bedding material was provided in each trap. Each small mammal captured was identified to species, sex, weighed, and given a PIT tag for future identification prior to release.

Indexes of abundance were estimated using the standardized index of the number of individuals of each species captured / 100 trap nights, where trap night effort was calculated following the methods of Nelson and Clark (1973):

Trapping effort = [(total # of traps * total # traps nights) – (1/2 * total # of traps with either closed doors or when traps were inoperable)

Animal trapping and handling adhered to the animal care and use guidelines advocated by the American Society of Mammalogists and was approved by the National Park Service Institutional Animal Care and Use Committee (project approval number: PWR_REDW_Slauson_Rodents_2012).

Diurnal Sciurids, including Douglas squirrel and 2 species of chipmunks (*Tamias senex* and *T. siskiyou*), were sampled using the same area searches used for sampling birds. The two chipmunk species occurred allopatrically, with the Siskyou chipmunk (*T. Siskiyou*) at the 5-year thin area and Shadow chipmunk (*T. senex*) at the 15- and 30-year thin areas (Ganon and Lawlor 1989). Both Douglas squirrels and chipmunks are highly territorial and can be detected sight and sound (Carey et al. 1991). During each area search the total number of individual Sciurids of each species detected were recorded and, as with birds, particular care was taken to not count the same individual twice by noting the location relative to the transect line. To evaluate the overall probability of detecting diurnal Sciurids using the area search protocol, the following equation was used:

$$\text{Probability of detection} = 1 - (v_1 * v_2 * v_3)$$

where v_i is the single visit probability of detecting the species on the $_i$th survey, given presence. To provide a relative index of abundance, the average number of individuals detect per area search was calculated across the 3 visits for each stand surveyed. Relative indexes of abundance were compared using blocked ANOVA without replication, to evaluate the effect of thinning treatments and to account for between block variation.

2.5 Analysis

Two-factor blocked ANOVAs were used to evaluate whether stand type, old growth, thinned , and not thinned, and block, 5-, 15-, and 30-year old thinning areas, affected indexes of bird and mammal abundances. Because between block variation and variation due to time since thinning had occurred were confounded, the effect of time since thinning could not be evaluated using the blocked ANOVA tests.

For abundance indexes representing number of birds or mammals per unit effort, blocked ANOVAs *without replication* were used because repeat surveys to individual stands were used to calculate a single index estimate for each stand. In the case where migratory bird species were used to calculate either overall bird abundance or migratory bird abundance, repeat surveys were considered independent due to the substantial turnover in species composition and in the numbers of migratory bird present between surveys. In these cases, blocked ANOVAs *with replication* were used for the analysis. To evaluate whether thinning significantly affected indexes of bird and mammal abundances, pairwise comparisons were made between thinned and not thinned stands only. For each of these comparisons, 1-tailed paired t-tests were used to evaluate the hypothesis that indexes of each abundance were higher in thinned versus not thinned stands.

3.0 Results

3.1 Avian Area Searches

Each stand was surveyed on 3 occasions, with subsequent survey occasions separated by ≥14 days, between 06 Sept and 25 Oct 2012. A total of 473 individual bird detections consisted of 31 species of birds across all stands (Table 1). Two commonly detected species, Chestnut-backed chickadee (*Poecile rufescens*) and Golden-crowned kinglet (*Regulus satrapa*), always occurred in groups. Because accurate identification of group size for these species was not always possible I standardized the detection of these species to represent 5 individuals, the mean number from all flocks where total number of individuals could be determined. Bird detections peaked in late September and early October, with the overall pattern of change in abundance due to migration consistent across stand types (Figure 1). As expected species diversity was highest in old growth stands (25 species, 17 residents, 8 migrants). However diversity in thinned stands (20 species, 14 residents and 6 migrants) was not much lower than in old growth stands, but was approximately twice as high as not thinned stands (9 species, 7 residents, 2 migrants). Bird species diversity was significantly greater in thinned versus not thinned stands ($df = 2$, $t = 4.0$, 1-tailed $p = 0.03$).

The 2-factor blocked ANOVA with replication, where each area search in a stand was considered a replicate within each block-stand type category to account for the observed temporal changes in abundance, had a significant effect of stand type ($df = 2$, $F = 12.6$, $p < 0.001$) and block ($df = 2$, $F = 6.03$, $p = 0.01$) on the total abundance of birds per area search. Overall bird abundance was highest in old growth stands, followed by thinned stands and lowest in not thinned stands (Figure 2). Thinned stands had significantly larger total abundance of birds than not thinned stands ($df = 2$, $t = 3.64$, 1-tailed $p = 0.03$).

The 2-factor blocked ANOVA, without replication, for the *mean* abundance of residents per area search did not have a significant effect of stand type ($df = 2$, $F = 5.50$, $p = 0.07$) or block ($df = 2$, $F = 1.80$, $p = 0.27$). The mean numbers of resident birds per area search in old growth (mean = 18.7, SE = 1.6) and thinned (mean = 15.3, SE = 3.9) stands were similar, but were on average double that of not thinned stands (mean = 7.0, SE = 2.6). Thinned stands had marginal statistical support for greater mean abundances of residents compared to not thinned stands ($df = 2$, $t = 2.42$, 1-tailed $p = 0.07$).

The 2-factor blocked ANOVA, with replication, for *cumulative* abundance of migrant birds had both a significant effect of stand type (df = 2, F = 3.53, p = 0.05) and block (df = 2, F = 3.75, p = 0.04) on migrant abundance. The cumulative number of migrant birds detected in old growth (n = 81) and thinned stands (n = 54) were 9-13 times higher than in not thinned stands (n = 6). The cumulative number of migrant bird detections in thinned stands was significantly greater than in not thinned stands (df = 2, t = 4.6, 1-tailed p = 0.02). Sixty-three percent of all migrants were detected in old growth stands, followed by 34% in restoratively thinned, and 3% in not thinned stands.

Of the overall 31 species of birds detected, only 19 species were detected ≥5 time and these species represented 86% of all detections. For the foraging guild analysis only the 19 species detected ≥5 times were used and these species fell into 5 foraging guilds: canopy (3), sub-canopy (3), bark (2), shrub (4), and ground (7) foragers (Table 1). Blocked ANOVAs conducted for each guild showed significant stand type effects on the cumulative abundance of sub-canopy, shrub, and ground foraging species per area search (Table 2). Foraging guilds representing sub-canopy, shrub, and ground foragers were nearly absent from un-thinned stands despite representing 14 (74%) of the species and 55% of the total number of bird detections in the guild analysis (Figure 3).

3.2 Use of Berries by Birds

A total of 5 bird species, Golden-crowned sparrow (11), Fox sparrow (2), Hermit thrush (1), Varied thrush (1), and White-crowned sparrow(1), were seen directly and indirectly consuming berries on 17 occasions. Birds were observed consuming berries on 12 occasions in thinned, 5 occasions in old growth, and on 0 occasions in not thinned stands.

3.3 Small Mammals

At total of 411 individual small mammals, representing 13 species, were captured in Sherman traps across all stands (Table 3). Overall species diversity was not significantly different between stand type (df = 2, F = 1, p = 0.44) but did differ significantly between blocks (df = 2, F = 7, p = 0.05). Of the 13 total species captured, 5 species: Trowbridge shrew (*Sorex trowbridgii*), Fog shrew (*S. sonomae*), Red-backed vole, North American deermouse (*P. maiculatus*), and Northern flying squirrel, were used for additional analysis because they represented 90% of all captures and were captured at nearly all blocks (Table 3). Using the index of abundances for the top 5 species combined (Table 4), there was a significant effect of stand type on small mammal abundance (df = 2, F = 29.3, p = 0.004) and a marginally significant effect of block (df = 2, F = 5.6, p = 0.068). Thinning significantly increased the index of abundance for the top 5 small mammal species compared to not thinned stands (df = 2, t = 3.46, 1-tailed p = 0.04). Overall, the combined small mammal abundances in thinned stands (mean = 4.32 captures / 100 trap nights) were double those in not thinned stands (mean = 2.14 captures per trap night). The overall magnitude of differences between indexes of abundances for the top

5 small mammal species did not significantly change by stand type across the blocks, suggesting that the effect of thinning was consistent over the 5-30 year period that the blocks represented (Figure 4).

For the top 5 small mammal species, all but red-backed voles showed increased indexes of abundances in thinned versus not thinned stands (Table 4). However, only Trowbridge shrew had a statistically significant ($p < 0.05$) pairwise difference ($df = 2$, $t = 4.52$, 1-tailed $p = 0.02$). Northern flying squirrels were only captured in old growth and thinned stands (Table 4).

A total of 38 diurnal Sciurids, 24 chipmunks and 14 Douglas squirrels, were detected during area searches. The 3-visit area search protocol had a 98.6% probability of detecting overall chipmunk presence in stands and 96.8% probability of detecting overall Douglas squirrel presence in stands. No Douglas squirrel detections occurred in not thinned stands. There was a significant effect of stand type on the average number of Douglas squirrels detected per area search ($df = 2$, $f = 7.6$, $p = 0.04$). The average number of Douglas squirrels detected per area search between old growth (0.78 individuals/area search) and thinned stands (0.89 individuals/area search) were similar but detections in thinned stands were significantly higher than not thinned stands (0 individuals/area search; $df =2$, $t = 3.01$, 1-tailed $p = 0.05$).

There was not a statistically significant effect of stand type on chipmunk indices of abundance ($df =2$, $f = 1.89$, $p = 0.26$). However the average number of chipmunks detected per area search was higher in both old growth (0.89 individuals/area search) and thinned (1.55 individuals/area search) stands compared to control stands (0.11 individuals/area search). Despite the index of chipmunk abundance being >10 times greater in thinned versus not thinned stands, this difference was not statistically significant ($df = 2$, $t = 1.46$, 1-tailed $p = 0.14$).

4.0 Discussion

Restoratively thinned stands had increased overall abundances of forest floor small mammals and Passerine birds compared to not thinned stands. Diversity did not differ for forest floor small mammals but did significantly differ for Passerine birds. These two responses by these taxa are the same as reported from studies evaluating the effects of pre-commercial (Hagar et al. 1996, Suzuki and Hayes 2003, Hagar et al. 2004) and restorative (Haveri and Carey 2000, Carey 2003) thinning in young Pacific coastal forests on small vertebrates. The characteristics of the responses by these two small vertebrate communities, both rapid (<5 years) and sustained across multiple decades post-thinning was also consistent with prior studies (Suzuki and Hayes 2003).

While an increase in species diversity may not always be an ecologically beneficial response (Noss 1991), in this study the increased diversity of Passerine birds in thinned stands represented the presence of multiple species representing foraging guilds that depend on the sub-canopy habitat structure and productivity that are also found in old growth reference stands. As with the abundance response, the diversity of Passerine birds during the fall was much closer to that of old growth stands than not thinned stands. The increased species diversity response of Passerine birds to restorative thinning is consistent with studies that measured responses to pre-commercial thinning during the breeding season (Hagar et al.1996, Hayes et al. 2003, Hagar et al. 2004) and restorative thinning during the winter (Haveri and Carey 2000) in Pacific coastal forests. Collectively these studies support that thinning dense young stands increases Passerine species diversity by increasing the breadth of ecological niches available.

The majority of migrant bird species detected in this study were detected utilizing understory habitat features and foraging resources, which included insects, berries, and seeds. Nearly all of the bird species observed consuming berries were migrants. Berries were only observed on shrubs in old growth and thinned stands, while shrubs in not thinned stands were scarce and those present had growth characteristics consistent with declining vigor. Migratory species in all sub-canopy foraging guilds were nearly absent from not thinned stands suggesting that these stands provide little or no value to migratory species seeking sub-canopy resources. More importantly, the developmental trajectory in not thinned stands will likely require re-establishment of shrub layers from seed due to the declines in shrub layers that has already occurred and the decades necessary for canopies develop more open conditions from the processes of mortality and natural disturbances such as windthrow. Pacific coastal forests occur along a major migration route, the Pacific flyway, and provide for many species of birds during the fall who rely on stop-over (e.g, Tietz and Johnson 2007) habitat providing foraging resources necessary to support migration.

Douglas and Northern flying squirrels were not detected in not thinned stands and the 2 species of chipmunks were more abundant in thinned stands compared to not thinned stands. Two of the 3 species utilize conifer cone crops as major portions of their diets (Smith et al. 2003), especially in winter. This suggests that thinning increased the resources residual trees could put toward cone production, thus providing greater seed crops for these two species than not thinned stands. Production of cone crops is related to size and age of trees and thinning releases the residual trees from competition, increases diameter growth, and thus shortens the time to cone production (Schopmeyer 1974, Johnstone 1981). Some caution should be taken in magnitude of these results due to the small size of study stands relative to home range sizes of these Sciurids, ~1 ha in young forests for Douglas and Northern flying squirrels (reviewed in Smith et al. 2003). However, given the importance of these species as key prey for predators of conservation concern such as the Northern spotted owl (reviewed in Thomas et al. 1990) and Humboldt marten (Zielinski et al. 1983, K. Slauson unpubl. data) suggests that restorative thinning may hasten the restoration of key prey populations by decades compared to not thinned stands.

The restorative thinning of unnaturally dense stands of young trees that are the result of previous intensive logging practices in coastal forests of Redwood National and State Parks have multiple benefits including: 1. Increasing tree growth rates and canopy depth of residual trees (Chittick and Keyes 2007, O’hara et al. 2010, Teraoka and Keyes 2011) 2. Stratification of tree canopy into multiple layers and development of a dense shrub layer (Chittick and Keyes 2007).

This study complements the vegetative responses with small vertebrate wildlife responses including: 1. Increased abundance of forest floor small mammals and Passerine birds during the fall. 2. Increased diversity of resident and migrant birds, particularly due to the development and increased productivity of the understory tree, shrub, and ground layers. 3. Increased abundances of Sciurids that represent key prey species of predators of conservation concern. At a minimum, restorative thinning of young coastal forests that have developed under unnatural conditions results in vegetative developmental and ecological trajectories that are several decades, if not substantially longer, ahead of stands that were not thinned. The overall result is that restoratively thinned stands have begun to develop the understory vegetative complexity and productivity to support small vertebrate communities that much more closely resemble old growth reference stands than not thinned stands.

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Literature Cited

California State Parks. 2010. Del Norte Coast Redwood State Park. Preliminary General Plan Amendment / Final Environmental Impact Report : Mill Creek Acquisition. 384 p.

Carey, Andrew B. 1991. The biology of arboreal rodents in Douglas-fir forests Gen.Tech. Rep. PNW-GTR-276. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 46 p. (Huff, Mark H.; Holthausen, Richard S.; Aubry, Keith B., tech. coords.; Biology and management of old-growth forests).

Carey, A. B., Biswell, B. L., & Witt, J. W. 1991. Methods for measuring populations of arboreal rodents. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, GTR-273.

Carey, A. B. 2003. Biocomplexity and restoration of biodiversity in temperate coniferous forest: inducing spatial heterogeneity with variable-density thinning. Forestry, 76(2), 127-136.

Chan, S. S., Larson, D. J., Maas-Hebner, K. G., Emmingham, W. H., Johnston, S. R., & Mikowski, D. A. 2006. Overstory and understory development in thinned and underplanted Oregon Coast Range Douglas-fir stands. Canadian journal of forest research, 36(10), 2696-2711.

Chittick, A. J., & Keyes, C. R. 2007. Holter Ridge thinning study, Redwood National Park: preliminary results of a 25-year retrospective. In Proceedings of the Redwood Science Symposium: What Does The Future Hold (pp. 271-280).

De Graaf, R. M., Tilghman, N. G., & Anderson, S. H. (1985). Foraging guilds of North American birds. Environmental Management, 9(6), 493-536.

Gannon, W. L., & Lawlor, T. E. (1989). Variation of the chip vocalization of three species of Townsend chipmunks (genus Eutamias). Journal of Mammalogy, 740-753.

Gomez, D. M., Anthony, R. G., & Trappe, J. M. 2003. The influence of thinning on production of hypogeous fungus sporocarps in Douglas-fir forests in the northern Oregon Coast Range. Northwest Science 77: 308-319.

Gomez, D. M., Anthony, R. G., & Hayes, J. P. 2005. Influence of thinning of Douglas-fir forests on population parameters and diet of northern flying squirrels. Journal of Wildlife Management, 69(4), 1670-1682.

Hagar, J. C., McComb, W. C., & Emmingham, W. H. 1996. Bird communities in commercially thinned and unthinned Douglas-fir stands of western Oregon. Wildlife Society Bulletin, 353-366.

Hagar, J., Howlin, S., & Ganio, L. 2004. Short-term response of songbirds to experimental thinning of young Douglas-fir forests in the Oregon Cascades. Forest Ecology and Management, 199(2), 333-347.

Hamer, T. E., & Nelson, S. K. 1995. Characteristics of marbled murrelet nest trees and nesting stands. Ecology and Conservation of the Marbled Murrelet. USDA Forest Service General Technical Report PSW-GTR-152. Pacific Southwest Research Station, Albany, CA, 69-82.

Haveri, B. A., & Carey, A. B. 2000. Forest management strategy, spatial heterogeneity, and winter birds in Washington. *Wildlife Society Bulletin*, 643-652.

Hayes, J. P., E. G. Horvath, and P. Hounihan. 1995. Townsend's chipmunk populations in Douglas-fir plantations and mature forests in the Oregon Coast Range. Canadian Journal of Zoology 73:67-73.

Johnstone, W. D. 1981. Pre-commercial thinning speeds growth and development of lodgepole pine: 25 year results. Northern Forest Research Center of Canada Information Report NOR-X-236. Edmonton, Alberta.

Keyes, C. R. 2005. Ecological basis for old growth redwood forest restoration: 25 year assessment of redwood ecosystem response to restorative thinning. A report to Save-the-Redwoods League. Humboldt State University, Arcata, CA.

Nabhan, G. P. 2004. Conserving Migratory Pollinators and Nectar Corridors in Western North America. Tucson Univ. of Arizona Press.

Nelson, L., & Clark, F. W. 1973. Correction for sprung traps in catch/effort calculations of trapping results. *Journal of mammalogy*, *54*(1), 295-298.

Noss, R. F. 1991. Do We Really Want Diversity?. In Willers (Ed.). Learning to Listen to the Land. Island Press.

O'Hara, K. L., Nesmith, J. C., Leonard, L., & Porter, D. J. (2010). Restoration of Old Forest Features in Coast Redwood Forests Using Early-stage Variable-density Thinning. Restoration Ecology, 18(s1), 125-135.

Pelt, R. V., & Franklin, J. F. 2000. Influence of canopy structure on the understory environment in tall, old-growth, conifer forests. Canadian Journal of Forest Research, 30(8), 1231-1245.

Porter, D., Gizinski, V., Hartley, R., & Kramer, S. H. (2007). Restoring complexity to industrially managed timberlands: The Mill Creek Interim Management Recommendations and early restoration thinning treatments. In Proceedings of the Redwood Science Symposium: What Does The Future Hold (pp. 283-294).

Ralph, C. J., G. R. Geupel, P. Pyle, T. E. Martin, and D. F. DeSante. 1993. Handbook of field methods for monitoring landbirds. General Technical Report PSW-GTR-144.

Sawyer, J. O., Sillett, S. C., Popenoe, J. H., LaBanca, A., Sholars, T., Largent, D. L., ... & Van Pelt, R. 2000. Characteristics of redwood forests. The Redwood Forest: History, Ecology, and Conservation of the Coast Redwoods. RF Noss (ed.) Island Press, Covelo, California, 39-80.

Schopmeyer, C. S. 1974. Seeds of woody plants in the United States. Agriculture Handbook, US Department of Agriculture, 450 p.

Slauson, K. M., W. J. Zielinski, and J. P. Hayes. 2007. Habitat selection by American martens in coastal California. Journal of Wildlife Management 71: 458-468.

Slauson, K. M. and W. J. Zielinski. 2009. Status and estimated size of the only remnant population of the Humboldt subspecies of the American marten (*Martes Americana humboldtensis*) in northwestern California. USDAFS, Pacific Southwest Research Station, Arcata, CA. 28 p.

Slauson, K. M., W. J. Zielinski, and T. A. Kirk. 2010. Effects of forest restoration on mesocarnivores in the northern redwood region of northwestern California. Final Report. Pacific Southwest Research Station, Arcata, CA. 29 p.

Slauson, K. M. In press. Mesocarnivores as focal species for the restoration of post-logging second growth in the northern redwoods. Proceedings of the Redwood Region Forest Science Symposium, Santa Cruz, CA, USA. General Technical Report PSW-GTR-19x.

Smith, W. P., Anthony, R. G., Waters, J. R., Dodd, N. L., & Zabel, C. J. 2003. Ecology and conservation of arboreal rodents of western coniferous forests. Mammal community dynamics: management and conservation in coniferous forests of western North America (CJ Zabel and RG Anthony, eds.). Cambridge University Press, Cambridge, United Kingdom, 157-206.

Suzuki, N., & Hayes, J. P. 2003. Effects of thinning on small mammals in Oregon coastal forests. The Journal of wildlife management, 352-371.

Teraoka, J. R., & Keyes, C. R. 2011. Field note: low thinning as a forest restoration tool at Redwood National Park. Western Journal of Applied Forestry, 26(2), 91-93.

Thomas, J. W., E. D. Forsman, J. B. Lint, E. C. Meslow, B. R. Noon, and J. Verner. 1990. A conservation strategy for the Northern Spotted Owl. Interagency Committee to Ad- dress the Conservation of the Northern Spotted Owl. U.S. Department of Interior, Portland, Oregon, USA.

Thornburgh, D. A., Noss, R. F., Angelides, D. P., Olson, C. M., Euphrat, F., & Welsh, H. J. 2000. Managing redwoods. The redwood forest: history, ecology, and conservation of the Coast Redwoods. Island Press, Washington, DC, 229-261.

Tietz, J. R. and M. D. Johnson. 2007. Stopover Ecology and Habitat Selection of Juvenile Swainson's Thrushes during Fall Migration along the Northern California Coast. The Condor 109: 795-807.

Veirs, S.D. 1986. Redwood second-growth forest stand rehabilitation study, Redwood National Park: Evaluation of 1978-79 thinning experiments. Redwood National Park, Arcata, CA.

Wimberly, M. C., Spies, T. A., Long, C. J., & Whitlock, C. 2000. Simulating historical variability in the amount of old forests in the Oregon Coast Range. Conservation Biology, 14(1), 167-180.

Zielinski, W. J., Spencer, W. D., and Barrett, R. H. 1983. Relationship between food habits and activity patterns of pine martens. Journal of Mammalogy, 387-396.

Table 1. Bird species detected on modified area searches 5-September to 25 October 2012 in old growth refence (n = 3), restoratively thinned (n = 3), and not thinned control (n = 3) stnads in Redwood National Park and California Redwoods State Parks.

		5-yr Thin			15-yr Thin			30-yr Thin			
Foraging Guild	**Species**	**Old Gr.**	**Thin**	**Unthin.**	**Old Gr.**	**Thinned**	**Unthin.**	**Old Gr.**	**Thinned**	**Unthin.**	**Status**
Canopy Foragers											
	Chestnut-backed chickadee	5	15	5	15	5	0	15	10	5	Resident
	Golden-crowned kinglet	15	5	20	15	15	0	20	10	15	Resident
	Townsend's warbler	2	4	2	2	3	0	1	0	0	Migrant
	Purple finch	5	1	0	0	1	0	0	0	0	Resident
Sub-canopy Foragers											
	Ruby-crowned kinglet	2	4	3	0	1	0	3	0	0	Migrant
	Hutton's vireo	3	4	3	2	3	0	4	2	0	Resident
	Pacific-slope flycatcher	1	0	0	0	2	0	1	0	0	Migrant
	Wilson's warbler	6	8	2	4	5	1	4	2	0	Migrant
Bark Foragers											
	Red-breasted nuthatch	1	3	0	1	0	0	3	2	1	Resident
	Brown creeper	0	1	0	4	2	0	5	0	1	Resident
Shrub Foragers											
	Wrentit	6	2	0	0	0	0	0	0	0	Resident
	Song sparrow	0	5	0	0	0	0	0	0	0	Resident
	Spotted towhee	5	0	0	0	0	0	0	0	0	Resident
Ground Foragers											
	Pacific wren	6	12	4	8	7	0	8	3	1	Resident
	Hermit thrush	6	3	0	1	6	0	2	1	0	Part. Migrant
	Varied thrush	34	15	0	7	1	0	12	10	0	Part. Migrant
	American robin	0	4	0	7	1	0	2	0	0	Resident
	Sooty fox sparrow	12	1	0	0	0	0	0	1	0	Migrant
	White-crowned sparrow	0	4	0	0	0	0	0	0	0	Resident
	Dark-eyed junco	0	2	0	0	0	0	3	0	0	Resident

Table 2. Avian foraging guild 2-factor blocked ANOVA analysis comparing mean bird abundance per area search 5-September to 25 October 2012 in old growth refence (n = 3), restoratively thinned (n = 3), and not thinned control (n = 3) stnads in Redwood National Park and California Redwoods State Parks.

				ANOVA Results				Thinned vs Not Thinned	
Foraging Guild	**Stand**	**Mean Count / Area Search**	**SE**	**df**	**Factor**	**F**	**p-value**	**T-stat**	**1-tailed p-value**
Canopy	Old Growth	8.11	(2.02)	2	Stand Type	0.7	0.56		
	Thinned	7.11	(2.12)		**Block**	**14.5**	**0.01**		
	Not Thinned	6.67	(2.67)					1.64	0.12
Sub-canopy*	Old Growth	3.33	(0.67)	2	**Stand Type**	**4.6**	**0.02**		
	Thinned	3.56	(0.94)		**Block**	**3.6**	**0.04**		
	Not Thinned	1.33	(0.47)					**3.78**	**0.03**
Bark	Old Growth	1.56	(0.67)	2	Stand Type	2.3	0.22		
	Thinned	0.89	(0.22)		Block	0.8	0.50		
	Not Thinned	0.22	(0.22)					1.73	0.11
Shrub*	Old Growth	5.11	(1.41)	2	**Stand Type**	**18.0**	**<0.001**		
	Thinned	3.55	(0.94)		**Block**	**23.3**	**<0.001**		
	Not Thinned	0.55	(0.24)					2.16	0.08
Ground*	Old Growth	7.67	(2.99)	2	**Stand Type**	**4.2**	**0.03**		
	Thinned	5.22	(1.76)		Block	2.6	0.09		
	Not Thinned	0	0					2.56	0.06

Table 3. Complete list of all small mammals captured in Sherman live trap grids 5-September to 25 October 2012 in old growth refence (n = 3), restoratively thinned (n = 3), and not thinned control (n = 3) stnads in Redwood National Park and California Redwoods State Parks.

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		5-yr Thin			15-yr Thin			30-yr Thin		
Species		**Old Growth**	**Thinned**	**Not Thinned**	**Old Growth**	**Thinned**	**Not Thinned**	**Old Growth**	**Thinned**	**Not Thinned**
Trowbridge shrew	*Sorex trowbridgii*	5	3	3	18	8	7	3	6	7
Fog shrew	*Sorex sonomae*	2	8	2	4	0	0	3	1	1
Unk shrew species	*Sorex spp.*	1	2	0	6	0	0	2	4	1
American shrew-mole	*Neurotrichus gibbsii*	0	0	0	0	0	0	0	0	1
Dusky-footed woodrat	*Neotoma fuscipes*	0	5	2	0	0	0	0	0	0
Bushy-tailed woodrat	*Neotoma cinerae*	0	0	0	0	0	0	0	0	0
Sonoma tree vole	*Arborimus pomo*	0	0	0	0	1	0	0	0	0
Brush rabbit	*Silvilagus bachmani*	0	1	0	0	0	0	0	0	0
Red-backed vole	*Clethrionomys californicus*	2	6	9	15	5	6	8	7	9
Northern flying squirrel	*Glaucomys sabrinus*	0	0	0	3	4	2	0	2	0
Pacific jumping mouse	*Zapus trinotatus*	0	0	1	0	0	0	0	0	0
North American deer mouse	*Peromyscus maniculatus*	36	28	9	1	7	6	11	1	0
Pinon deermouse	*Peromyscus truei*	1	1	0	0	0	0	0	0	0

Table 4. Index of abundance (number of captures / 100 trap nights) for the 4 most frequently captured small mammals and the Northern flying squirrel from Sherman live trap grids from 5-September to 25 October 2012 in old growth refence (n = 3), restoratively thinned (n = 3), and not thinned control (n = 3) stnads in Redwood National Park and California Redwoods State Parks. .

	5-yr Thin			15-yr Thin			30-yr Thin		
Species	**Old Growth**	**Thinned**	**Not Thinned**	**Old Growth**	**Thinned**	**Not Thinned**	**Old Growth**	**Thinned**	**Not Thinned**
Trowbridge shrew	0.88	0.61	0.31	3.14	1.10	0.62	0.58	1.14	0.91
Fog shrew	0.29	0.97	0.21	0.52	0.00	0.00	0.35	0.11	0.11
Northern flying squirrel	0.00	0.00	0.00	0.39	0.14	0.00	0.00	0.34	0.00
North American deermouse	5.84	3.76	1.14	0.13	1.10	0.77	1.38	0.11	0.00
Red-backed vole	0.29	0.73	0.94	1.96	0.69	0.31	0.92	0.80	1.02

Figure 1. Variation in the average number of individual bird detections on area searches conducted from 5-September to 25 October 2012 in old growth refence (n = 3), restoratively thinned (n = 3), and not thinned control (n = 3) stnads in Redwood National Park and California Redwoods State Parks.

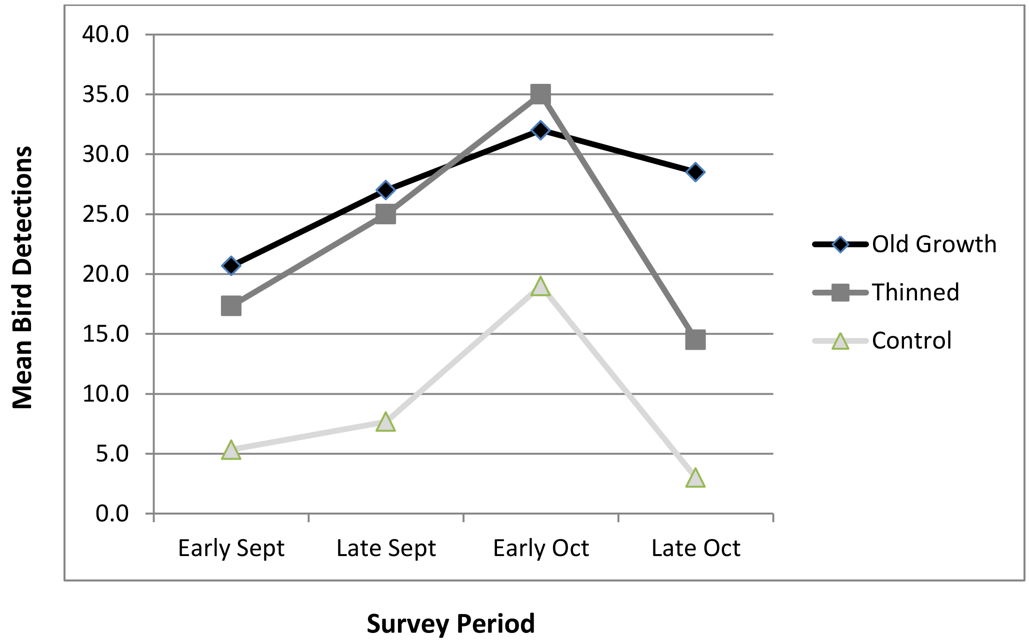

Figure 2. Box and whisker plots for bird abundance during areas searches conducted from 5-September to 25 October 2012 in each of the 9 study stands, 3 old growth reference stands, 3 restoratively thinned stands thinned from 5-30 years prior, and 3 not thinned control stands in Redwood National and California Redwoods State Parks.

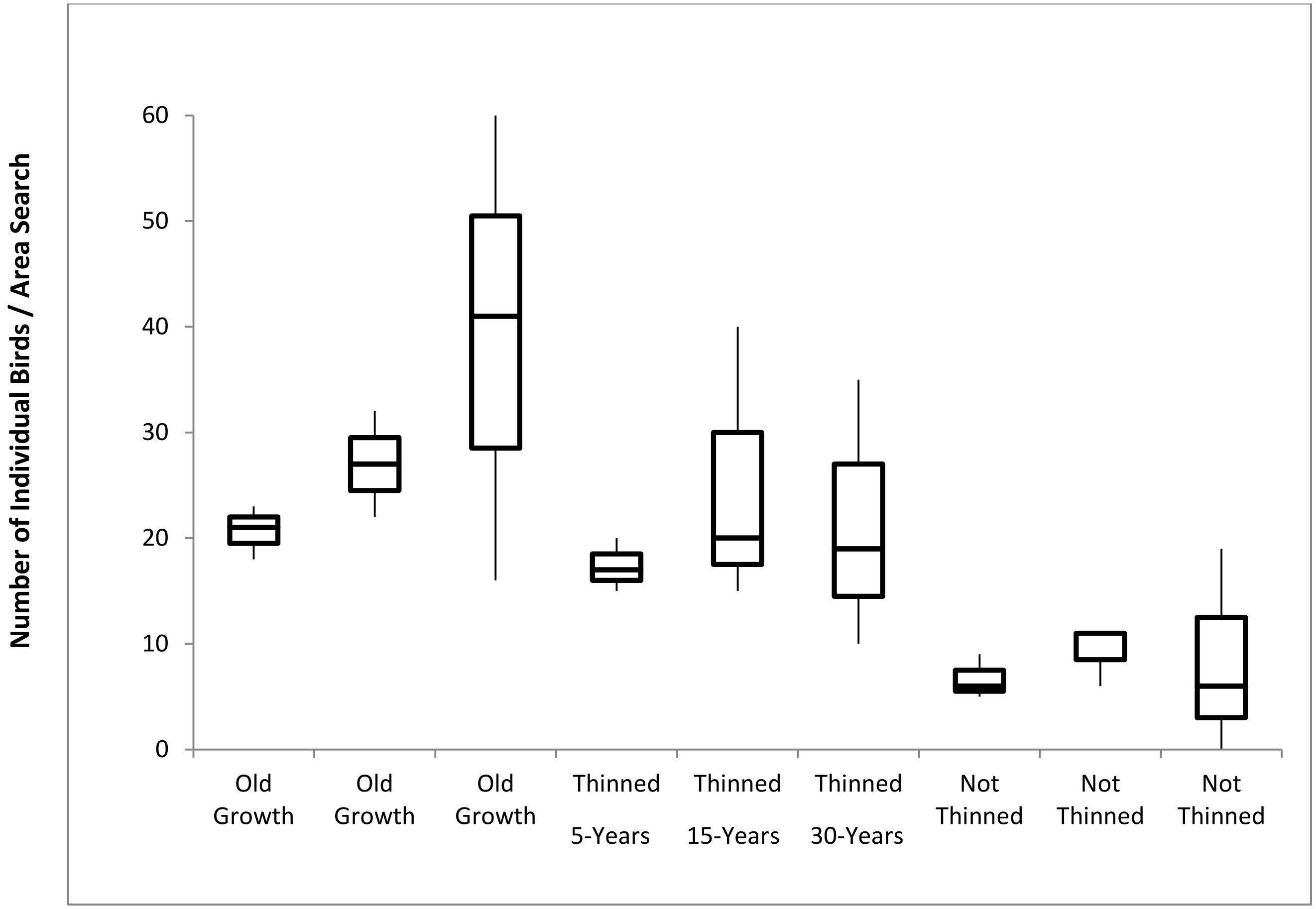

Figure 3. Mean bird abundance by forgaing guild on area searches conducted from 5-September to 25 October 2012 in old growth refence (n = 3), restoratively thinned (n = 3), and not thinned control (n = 3) stnads in Redwood National Park and California Redwoods State Parks.

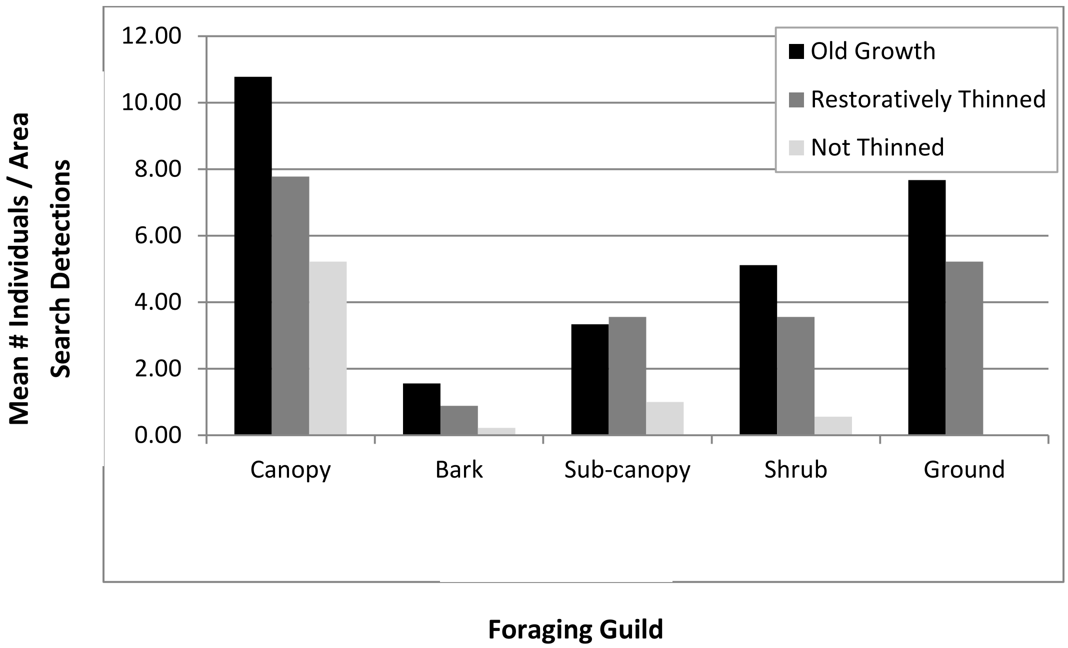

Figure 4. Index of abundance for the 5 most commonly captured small mammal species, Trowbridge shrew, fog shrew, North American deermouse, Northern flying squirrel, and red-backed vole, during the fall (September-October) of 2012 across old growth refence (n = 3), restoratively thinned (n = 3), and not thinned control (n = 3) stands in Redwood National Park and California Redwoods State Parks.