Initial Effects of Clearcutting and Partial Retention Forest Harvesting Methods on Some Small Mammals in Northern British Columbia

Research Report

Alexia Constantinou, Cole Burton, Suzanne Simard, & Dexter Hodder

Abstract

British Columbia's interior forests have been heavily subjected to logging, burning, and beetle outbreaks for decades. Partial retention forest harvesting may be a method that could mitigate some of the negative effects of clearcut harvesting on wildlife. We conducted live trapping for small mammals at John Prince Research Forest in north-central BC to estimate species diversity, population density, and habitat use across a gradient of overstory tree retention. We detected 7 species, with diversity highest in the uncut forest (control) relative to the clearcut (control mean Shannon Index = 1.01, SE = 0.14) and partial retention treatments (30% and 60% retention, mean Shannon Indices = 0.99, 0.98; SE = 0.17, 0.17), and significantly lower in the seed tree treatment (mean = 0.63, SE = 0.17, $p = 0.02$). Greater population densities of North American deer mouse (*Peromyscus sonoriensis*) and southern red-backed vole (*Myodes gapperi*) in partially harvested stands, as estimated with spatially explicit capture-recapture models, support these practices for supporting populations of forest specialists. More experimental approaches to forest operations are needed across larger spatial scales, such as adaptive management of forest harvest methods with rigorous wildlife monitoring to ensure ecological objectives are met.

Keywords: small mammals, forest harvesting, partial harvesting, live trapping, spatial capture re-capture

Introduction

Small mammals make up just 4% of vertebrate biomass in boreal forests but they have disproportionately large effects on ecosystems (Villette et al. 2016; Krebs et al. 2018a, 2018b; Boonstra et al. 2016). They are prey for a wide variety of species, are crucial spore dispersers, encompass a wide range of diet types, can be ecological indicators of changes to forest structure and function, and include both diurnal and nocturnal species; a healthy forest ecosystem depends on small mammals (Fuller et al. 2004; Sullivan et al., 1990; Maser et al. 1978; Klenner & Sullivan 2009). Small mammals alter plant communities through

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processes such as seed predation and dispersal, and their population dynamics are affected by forest management (Klenner & Sullivan 2009). While clearcutting is considered disruptive to small mammals, whether partial retention of overstory trees can mitigate its impacts is not well known. Further, despite their ecological importance, very few small mammals are included among the 85 species listed as Identified Wildlife in the *Forest and Range Practices Act* (included are the water shrew species, *Sorex bendirii* and *Sorex palustris brooksi*, under the federal *Species at Risk Act*; Ministry of Forests, Lands, Natural Resource Operations and Rural Development 2002). This means that, broadly, natural resources harvesting it is not required to directly consider other small mammal species at any point in the planning phases or execution of forest management in the province. Small mammals (in this work, considered to be species <1 kg, in the Orders Rodentia and Insectivora) are the most diverse group of mammals globally, as well as in British Columbia (Nowak & Walker 1999). Forest harvesting operations rarely are required to directly consider small mammal species at any point in the planning or execution of forest management in the province (Province of British Columbia 2002; Hoberg & Malkinson 2013). Research indicates that partial harvesting methods could promote small mammal habitat use within harvested areas (Ransome et al. 2009). Partial harvesting could help create a heterogeneous landscape that supports small mammal species and their predators that use and inhabit mature forest, as well as more meadow-dependent species, similar to patterns of natural disturbances (Steventon et Al. 1998; Fuller et al. 2004).

This article tests the overarching hypothesis that partial retention forest harvesting methods create heterogeneous open- and closed-canopy conditions that support a more diverse small mammal community than clearcut harvesting. Based on documented variation in habitat preferences, the authors hypothesized that: 1) red squirrels (*Tamiasciurus hudsonicus*), as a tree-dependent species, would be present almost entirely within closed-canopy treatments; 2) deer mouse (*Peromyscus sonoriensis*) and common shrew (*Sorex cinereus*) would occur more frequently in the clearcuts or open canopy treatments based on previous literature about positive or neutral response to disturbance (Sullivan et al. 1999); and 3) southern red-backed vole (*Myodes gapperi*) would be most dense in the partial harvesting treatments, as there has been much disparity in the literature—both initial positive response to harvesting and unharvested forest cover supporting more voles (Kirkland 1990; Sullivan 1999).

Materials and methods

This study took place in the John Prince Research Forest (JPRF; n.d.), encompassing an area of 16,500 hectares of sub-boreal forest between 54°35’–54°45’ N latitude and 124°10’–124°36’ W longitude. The JPRF is comanaged by Tl’azt’en Nation, Binche Whut’en, and the University of Northern British Columbia. This area is in the Stuart variant of the Dry Warm Sub-boreal Spruce biogeoclimatic unit (SBSdw3). The forests in JPRF are naturally biodiverse and are characterized by stand-replacing wildfires occurring roughly every 100–200 years if not influenced by fire suppression (Delong 1999). The climate is characterized by warm summers (average 17°C) and cold winters (average -10°C), with average winter snow depths between 0.80 m and 1.2 m. Specifically, this field work was conducted within the Mother Tree Project (MTP), which is investigating forest renewal practices that aim to protect biodiversity, carbon storage, and forest regeneration as climate changes (Simard et al. 2020; Mother Tree Project, 2020). The MTP at JPRF was located in a 129-year-old post-fire second growth forest dominated by interior spruce, subalpine fir, lodgepole pine, paper birch, and trembling aspen. The study used a randomized complete block design consisting of five forest harvesting treatments (clearcut (0% retention), seed tree (10% dispersed retention), 30% patch retention, 60% patch retention (strip-style harvest with thinning from below), and uncut control (see Figure 1) replicated three times. The patches in the 30% retention treatment had an understorey that was not disturbed by the logging machinery. Each treatment unit was three to five hectares in size. Blocks of all five experimental units are referred to as "replicates." For the purposes of this study, volume of coarse woody debris was measured using systematic transects with calipers as part of MTP sampling.

Figure 1. Examples of the forest harvesting gradient. A is control forest, where 100% of natural canopy cover is maintained. B is 30% patch retention where the patches are untouched by machinery and the understory is intact. In the middle row, C shows 60% partial retention, which is harvested in strips, and D is seed tree retention with the largest Douglas-fir every 25 metres maintained. The last photo, E, is the clearcut treatment where all canopy is removed. Photos taken at JPRF in 2018 upon completion of forest harvesting.

Small mammal live trapping

Live trapping was used to evaluate small mammal species diversity, composition, and population density (De Bondi et al. 2010; Kelt 1996; Sullivan et al. 2001). Researchers set up Longworth (35 x 17 x 22 cm) and Tomahawk (15 x 15 x 48 cm) live traps (Longworth Small Mammal Trap, Oxford, UK; Tomahawk Live Trap, Hazelhurst, WI) on a one-hectare 7 x 7 trap grid (14.29 m spacing) in each forest harvesting treatment (lines of traps alternating between Tomahawks and Longworths). The experimental grid was set up following the methods of Sullivan et al. (1999) and Steventon et al. (1998). For each trapping grid, there were two days of pre-baiting (using carrots, apples, and oats), followed by five trapping sessions (three mornings, two afternoons). In total, there were 4,410 active trap nights across 245 traps (# traps x 5 treatments x 3 replicates) in June and August of 2019. Each captured animal was weighed and evaluated for its sex and age class (juvenile or adult; following standards and considerations outlined by Jewell & Fullagar 1966; Seddon et al. 2014). Mice and voles were tagged on the right ear with a unique numbered tag to track capture histories for mark-recapture analysis before being released. Shrews and squirrels were not tagged in this study—individual stress was perceived as too high to sustain consistent, safe, and ethical tagging. All methods were approved by the UBC Animal Care Committee (protocol A19-0012), and a permit was obtained from the Ministry of Forests, Lands and Natural Resources Operations (Wildlife Act: Permit PG19-492155).

Analyses

Researchers compared species diversity across treatments, as well as habitat use as index by population density for two species (deer mice and southern red-backed vole) and as capture rate (relative abundance) for two species (red squirrel and common shrew).

Diversity analysis

The *vegan* package in R statistical software (v4.4.1; R Core Team 2021; Oksanen 2019) was used to calculate the Shannon diversity index, a mathematical measure that combines species richness and relative abundance of each species sampled. It assumes that all species have an equal chance of being captured and does not weight species by dominance (Krebs 1999). Researchers calculated the mean and standard error of diversity estimates across replicates within each treatment and compared treatments using a one-way analysis of variance (ANOVA). Additionally, a generalized linear mixed model was used to test the effects of treatment on Shannon diversity, while accounting for coarse woody debris. The model included harvesting treatment and volume of coarse woody debris as fixed effects, with replicate as a random effect to account for the non-independence of treatments within replicates. Researchers tested a post-hoc hypothesis that this difference in diversity could be related to variation in coarse woody debris by adding this variable to a model at the sampling unit level (n = 15). Coarse woody debris is known to be an important habitat feature for small mammals (Sullivan & Sullivan 2019) and was observed in the field to vary across treatments and replicates.

Small mammal density estimates

Researchers used spatially explicit capture-recapture (SECR) analysis in the secr package in R to estimate densities of mice and vole populations—the two species with sufficient captures to support SECR models. Spatially explicit capture-recapture is an approach to estimate population density using detection histories (captures and re-captures) of marked individuals, including spatial locations of traps (Efford 2020; Efford & Fewster, 2012). Density was estimated for each species in the five treatments and both sampling months (June, August). Researchers considered differences between density estimates to be statistically significant when the 95 percent confidence intervals did not overlap. Null SECR models (i.e., no covariates) were run on each data set, since researchers did not hypothesize that any variable other than harvest treatment would have a significant effect on small mammal densities.

Small mammal habitat usage

For red squirrel and common shrew, no individual tags were administered and there were also insufficient captures to estimate densities using the R package secr. To assess variation across treatments, capture rates were analyzed as an index of habitat use, recognizing that without individual identity, this measure confounds abundance and movement (e.g., can double-count the same individuals or not account for detectability; Hopkins & Kennedy 2004). Generalized linear models (GLM, function *glm()* in R) were used to compare habitat use (via number of captures) across treatments and modelled the total number of captures in each month and replicate as a Poisson random variable with harvest treatment as a categorical independent (predictor) variable, with clearcut as the reference level (intercept).

Results

Summary of small mammal trapping efforts and detections

Seven small mammal species were captured a total of 826 times, with a total of 449 captures and recaptures of deer mice, 283 captures and recaptures of southern red-backed voles, 29 captures of red squirrel, and 58 captures of common shrew (Table 1).

Table 1. Summary table of small mammal captures by treatment. First is number of captures (includes captures, recaptures, escapees and mortalities), followed by the number of individuals in parentheses for deer mice and southern red-backed voles.

Treatment species	Clearcut	Seed tree	60% Retention	30% Retention	Control	Total
North American Deer mouse (*P. sonoriensis*)	131 (53)	104 (46)	67 (35)	75 (37)	72 (36)	449 (183)
Southern Redbacked Vole (*M. gapperi*)	26 (12)	57 (28)	100 (42)	57 (35)	43 (23)	283 (138)
Common Shrew (*Sorex cinereus*Kerr)	19	11	8	11	9	N/A
Red Squirrel (*Tamiasciurus hudsonicus*)	4	-	9	7	9	N/A
Total					**820**	

Note: There are individual species that appeared in two different treatments (e.g., for voles, two individuals appeared in two different treatments, though number of total individuals is 138, not 140).

Density estimates

Density estimates across treatments ranged from one (SE = 0.5) to 26 (SE = 12.4) deer mice per hectare (Figure 2) and one (SE = 0.9) to 6 (SE = 1.8) southern red-backed voles per hectare (Figure 3). Deer mouse densities were generally higher in August, ranging from one mouse/hectare (60% treatment, SE = 0.48) to six mice/hectare (clearcut, SE = 1.31) in June, and from five (30% treatment, SE = 1.47) to 26 individuals (control, SE = 12.91) per hectare in August (Figure 2). In June, the findings were consistent with the hypothesis that deer mice, as generalist, meadow-dependent species, would appear more in the clearcut than any other treatments. By contrast, in August there was a significantly higher density of deer mice in the control plot than in the 30% partial harvest, and deer mouse density was similar in the other harvest treatments (Figure 2). The control had 24 captures of 20 unique animals, and thus the low number of recaptures resulted in high uncertainty in the estimate.

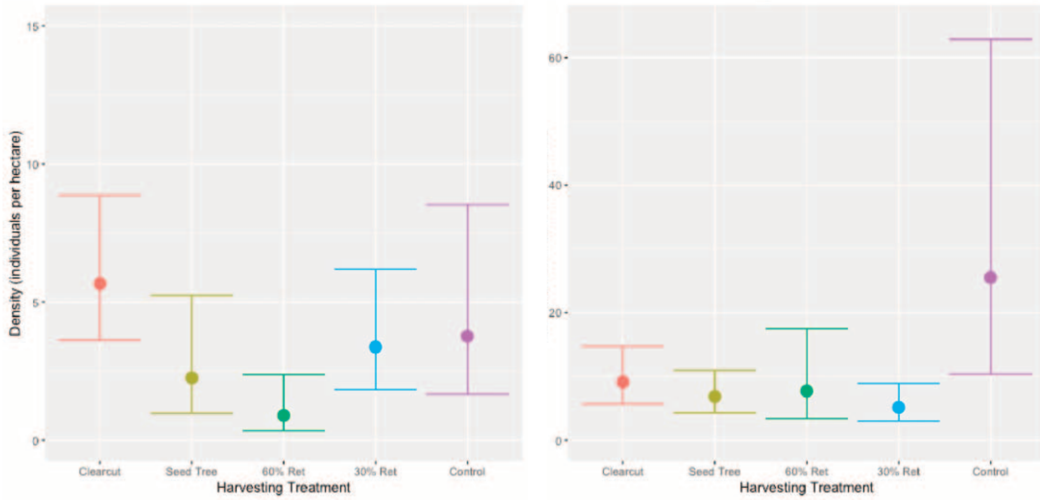

Figure 2. Spatially explicit capture-recapture density estimates of deer mice across forest harvesting treatments in June (left) and August (right), with 95% confidence intervals.

For southern red-backed vole, the highest density in both June and August was in the 30% partial harvesting treatment (June density = 6 voles/hectare, SE = 1.79; August density = 5 voles/hectare, SE = 2.52; Figure 3). However, there were no statistically significant differences in density estimates between harvesting treatments. In June, density estimates for the partial harvesting treatments were similar (five, five, and six voles per hectare, for seed tree, 60% retention, and 30% retention, respectively), and were all higher than for the control (two voles per hectare), which is consistent with the hypothesis that southern red-backed voles would appear most in the partial harvesting treatments. There were not enough vole captures (and no recaptures) in the clearcut in June (six individuals) and the control in August (four individuals) to allow density estimation with a secr model.

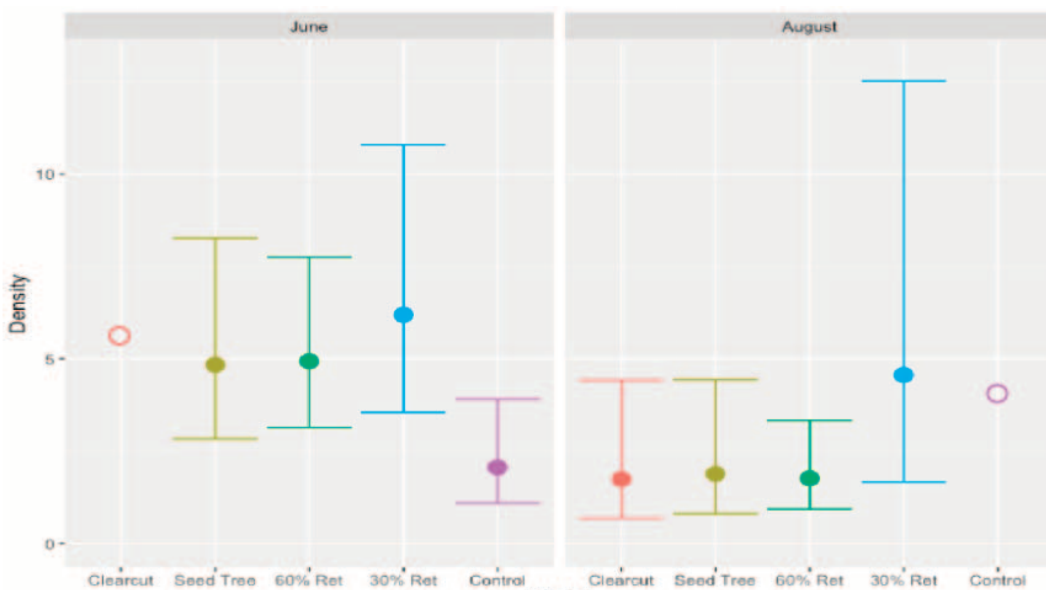

Figure 3. SECR density estimates of southern red-backed voles across forest harvesting treatments in June (left) and August (right), with 95% confidence intervals. The order of the harvesting treatments in this figure is: clearcut, seed tree, 60% retention, 30% retention, and control. The two dots without error bars represent the number of individuals that were live-trapped (minimum number of southern red-backed voles alive) but were insufficient to calculate a density estimate.

Common shrews and red squirrel relative abundance

Common shrews were captured 58 times over the two trapping months, with more captures in clearcut than other treatments. Parameter estimates from the Poisson count GLM indicated that shrews were captured significantly less frequently in the 60% partial retention than the clearcut (Table 2).

Table 2. Poisson generalized linear model results for common shrew captures across the gradient of forest harvesting treatments. Raw capture count is the number of captures of shrews, not unique individuals. The significant *p*-value for the 60% partial retention treatment is bolded.

	Raw capture count (# of captures of shrews)	Estimate	Std error	z-value	*p*-value
Clearcut (Intercept)	19	1.15	0.23	5.02	5.05*10^-7
Control	9	-0.75	0.40	-1.85	0.06
30% retention	11	-0.55	0.38	-1.44	0.15
60% retention	8	-0.87	0.42	-2.05	**0.04**
SEED	11	-0.55	0.38	-1.44	0.15

Red squirrels were the least captured of the four main species, with 27 live captures and two mortalities (29 total captures) across all replicates and both months. There were insufficient captures to statistically model differences across treatments, but the majority of red squirrel captures (25 of 29 = 86%) were in treatments with greater canopy cover (i.e., 60% retention, 30% retention, and control; Table 3).

Table 3. Generalized linear mixed model results for small mammal diversity with treatment and coarse woody debris as predictor variables. Significant *p*-values are bolded.

	Estimate	Std. error	Z value	*p*-value
Intercept (Control)	1.232	0.162	7.617	**2.6*10^-14***
30% Retention	-0.056	0.137	-0.409	0.682
60% Retention	-0.034	0.135	-0.248	0.804
Seed tree	-0.423	0.137	-3.095	**0.002***
Clearcut	-0.338	0.139	-2.425	**0.015***
Coarse woody debris	-0.001	0.0003	-2.415	**0.016***

Small mammal community diversity

Across all small mammals captured, the Shannon diversity index tended to be greater in the control and two partial harvesting methods than the clearcut or seed tree treatments (Fig. 4). This diversity measure included the four focal species analyzed above, as well as meadow vole (*Microtus pennsylvanicus*; four detections), short-tailed weasel (*Mustela erminea*; one capture), and least weasel (*Mustela nivalis*; one capture). Diversity was highest in control forest (mean Shannon Index = 1.007, estimate = 1.01, SE = 0.14), closely followed by the partial harvesting treatments (30% mean SI = 0.999, 30% SE = 0.17, 60% mean

SI = 0.976, 60% SE = 0.17). Mean diversity values for seed tree and clearcut were considerably lower, at 0.63 and 0.75, respectively (significantly lower for seed tree: estimate = -0.38, SE = 0.17, *p*-value = 0.02).

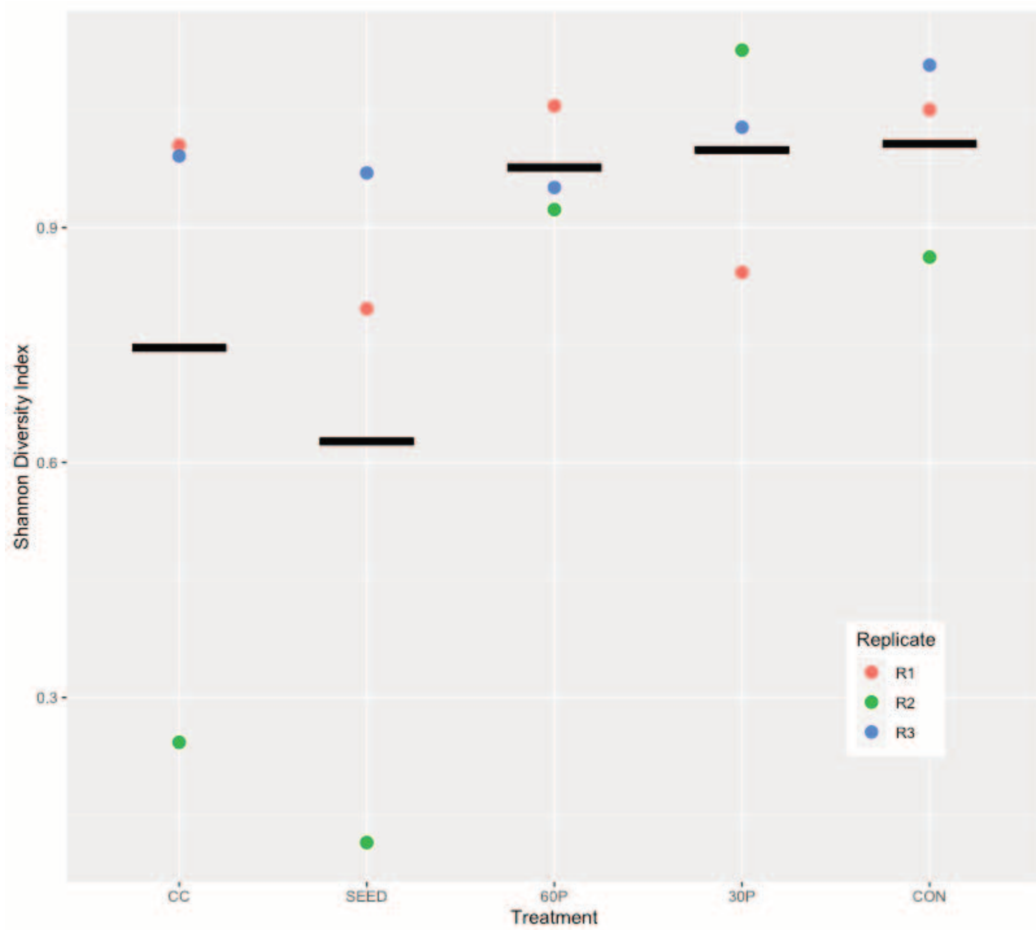

Figure 4. Mean and replicate-specific Shannon diversity index value for each treatment. Each dot represents a replicate diversity value for that treatment, and the black lines represent the mean for that treatment (n = 3).

Clearcut and seed tree treatments in replicate two had much lower diversity values, compared with the other treatments and replicates (Figure 4). Coarse woody debris ranged from 41.7–538.2 m^3 across sampling units (mean = 215.6 m^3, standard error = 33.6 m^3), and coarse woody debris volumes in clearcut and seed tree treatments in replicate 2 were 166 and 290.7 m^3, respectively. The significant effect of coarse woody debris in the model results (Table 3) suggest that it has a negative effect on the community diversity index, which is contrary to the researchers' expectations.

Discussion

Small mammal diversity

Small mammal diversity trended higher in the control plots and partial harvesting treatments and trended much lower in the seed tree and clearcut treatments. This is consistent with the hypothesis that a heterogeneous canopy created by partial harvesting will support both forest- and meadow-dependent species in the small mammal community, but was evident only when coarse woody debris was included in the model. Coarse woody debris functions as habitat for small mammals, as well as for their mustelid predators (Sullivan & Sullivan 2019). Roach et al. (2024) found that harvesting resulted in an increase in small, fresh coarse woody debris, which may have provided greater habitat for small mammals in the decade following logging (see also Sullivan & Sullivan 2019). This may indicate that small mammals are selecting coarse woody debris elements at finer spatial scales than the scale of this study's harvest treatments. Despite the trend toward lower diversity in the more open treatments, the differences for clearcut were not statistically significant due to the small sample size and variation among replicates within treatments (Fig. 4; estimate = -0.26, SE = 0.17, p = 0.12).

Mouse and vole densities across the harvesting gradient

Other studies generally demonstrate that deer mice are habitat generalists that favour low coniferous cover, with populations increasing 5–10 years following clearcutting (Zwolak 2009). This study's results contrast with Fuller et al. (2004), where deer mice were most abundant in partially harvested stands (and mature deciduous forest, not part of this study's experimental design) and absent from most clearcuts. The authors suggest that deer mice were more abundant in clearcuts in the present study because of their ability to survive in an early-successional stage ecosystem as a generalist.

The 30% and 60% partial harvesting treatments were best at supporting southern red-backed voles. Southern red-backed voles had marginally higher estimated densities in the partial retention treatments than the clearcut or control, supporting the hypothesis that the voles would prefer the mix of open and closed canopy cover in proximity. Sullivan and Sullivan (2001) found that the southern red-backed vole was most abundant in group seed tree, patch cut, and uncut forests, which is similar to this study's findings. Vole preference for partial retention could be explained by the fact that harvest machinery moves through the cut block, disturbing the undergrowth and coarse woody debris, exposing roots and debris, and thereby creating conditions that are ideal for one of southern red-backed vole's favourite foods: hypogeous ectomycorrhizal fungi (Sullivan & Sullivan 2001).

Squirrel and shrew habitat use

Spatial variation in captures indicated that habitat use of shrews and red squirrels also varied with harvest treatments. In agreement with this article's hypothesis, researchers found greater numbers of shrews in clearcuts than any of the other harvesting treatments or control plots. Recently harvested blocks have ripped up course woody debris, which insects and invertebrates break down, providing a food source for shrews (Fisher & Wilkinson 2005). In the long term, Sullivan, Lautenschlager, and Wagner (1999) found shrew species to appear in relatively similar numbers across forested and clearcut sites.

Red squirrels were captured most frequently in the unharvested control plots, followed by partial retention, then clearcut and seed tree retention treatments. Trapping was conducted roughly one and a half years after harvesting, and researchers observed a decline in number of captures from the full canopy cover in the control to none in the clearcut. This was expected as red squirrels are conifer seed specialists and nest in trees, with fewer recorded observations in clearcuts. Red squirrels have been found to use cut blocks as an occasional summer forage area; however, these could be juveniles in sub-optimal habitat or dispersing individuals in the summer (Fisher & Wilkinson 2005; Larsen 2009). As field work was conducted in the summer, it is possible that researchers began to live trap early dispersers but cannot conclusively state if individuals were seeking home territories, passing through, or inhabiting clearcuts. In contrast to our results, Herbers and Klenner (2007) found little difference in red squirrel density between harvesting treatments one year after logging. After two to four years, however, they found that density declined with increased tree removal, congruent with this study's results.

Policy and large-scale implications

This work documented the use of forest patches by a diversity of small mammals and supports the application of forest practices that retain patches of overstory trees as important components of biodiversity. One major limitation of this small mammal analysis was the small sample sizes for many species and accordingly low statistical power to detect differences among harvest treatments. Further research is needed to test the functional linkages between small mammals and forest diversity (such as tree species richness, understory plant diversity, heterogeneity of surrounding habitat) and health (e.g., herbivory, seed predation, or dispersal). Additionally, longer-term research is needed to determine if these harvesting treatments have a lasting effect on the populations of small mammals. Forest harvest in BC is still broadly dominated by clearcutting; the authors thus recommend a shift to partial harvesting to maintain small mammal diversity. In BC, partial harvesting is not applied frequently (clearcutting and variations of clearcutting make up 92% of harvesting; Beese et al. 2019), but these methods can be used to mitigate negative impacts to biodiversity, and they combine ecological and economic goals in managed landscapes (Fuller et al. 2004; McComb et al. 1993). In BC, clearcut logging is one of the most widespread and prolific anthropogenic effects on forest environments, altering wildlife habitat and biodiversity, habitat selection, and inter-species dynamics of the entire mammal community (Shackelford et al. 2018; Thorn et al. 2017; Schleuning et al. 2011; Lochhead et al. 2022). Mitigation of logging impacts on habitat are crucial in the face of multiple pressures on forest ecosystems (Daniels et al. 2011). Collaborative actions have been taken by First Nations land stewards with industry, researchers, and government managers to improve sustainability of forestry in BC and to inform best harvesting practices that increase the wildlife habitat, biodiversity, and resilience of BC's forests.

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