Forest Ecology and Management 399 (2017) 143–154

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Mammalian responses to windrows of woody debris on clearcuts: Abundance and diversity of forest-floor small mammals and presence of small mustelids

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ARTICLE INFO

Article history:
Received 16 March 2017
Accepted 15 May 2017

Keywords:
Abundance
Habitat structure
Small mammals
Mustelids
Populations
Windrows
Woody debris

ABSTRACT

Forest harvesting often leaves excess woody debris on the forest floor that could provide habitat for small mammals and mustelid predators. A windrow or series of piles constructed from woody debris may connect patches of mature forest and riparian areas to allow small mammals and some of their predators to use clearcut openings. We tested two hypotheses (H) that woody debris arranged in windrows connecting reserves of uncut forest, on newly clearcut sites, would increase (H_1) abundance of the major vole species and total abundance, species richness, and species diversity of the forest-floor small mammal community, and (H_2) presence of small mustelids in response to abundance of small mammal prey; compared with sites of dispersed woody debris or uncut forest. We measured abundance and diversity of small mammals and the presence of small mustelids (American marten, *Martes americana*; short-tailed weasel, *Mustela erminea*; long-tailed weasel, *M. frenata*) from 2012 to 2016 in replicated treatments of woody debris in windrow and dispersed sites compared with uncut forest sites at two study areas near Elkhart and Golden in south-central British Columbia, Canada.

At Elkhart, mean abundance of total voles and total small mammals per index-line were higher in the windrow than dispersed sites, and higher or similar to forest sites. At Golden, mean abundance of total voles was similar, but the dispersed and windrow sites had higher numbers of total small mammals than the forest sites. Mean species richness and diversity were highest in the windrow sites at both study areas. Thus, the predictions of H_1 were supported, except for total voles at Golden. Mean abundance of the southern red-backed vole (*Myodes gapperi*), a principal prey species for mustelids, was higher in windrow than dispersed sites, and similar or lower than forest sites. *M. gapperi*, along with the long-tailed vole (*Microtus longicaudus*) dominated the overall vole population in windrows at Elkhart. *M. longicaudus* dominated the windrows and dispersed sites at Golden. Deer mice (*Peromyscus maniculatus*) and northwestern chipmunks (*Neotamias amoenus*) were at similar numbers in dispersed and windrow sites, but shrews (*Sorex* spp.) showed a positive response to windrows. Overall mean presence by marten and small weasels were, on average, 3.3–4.8 times higher in windrow than dispersed sites, and higher or similar to forest sites, which supported H_2. Our study is the first to connect windrows to patches and larger units of uncut forest and to cover a 5-year period since harvest. Responses in mean total abundance, species richness, and diversity of small mammals in windrows were maintained throughout the 5-year period. This consistent result was likely related to the connectivity between windrows and uncut forests. Strategic management of post-harvest woody debris in a network of windrows or piles will help to maintain abundance and diversity of forest mammals, both predator and prey species, on clearcuts.

1. Introduction

Harvesting of forests in temperate and boreal ecological zones of North America and Europe continues to be dominated by clearcutting, with and without some form of green-tree retention for conservation of biodiversity (Lindenmayer and Franklin, 2002; Rosenvald and Lohmus, 2008). Coarse woody debris (dead or down wood) on the forest floor also contributes to biodiversity by providing many important functions that are essential for long-term ecosystem productivity such as nutrient cycling, contribution of organic matter to soil structure, and modification of micro-

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http://dx.doi.org/10.1016/j.foreco.2017.05.028
0378-1127/

climate (Harmon et al., 1986; McComb and Lindenmayer, 1999; Laiho and Prescott, 2004). Retention of some post-harvest woody debris on newly harvested forest sites may provide critical habitat for wildlife (McComb, 2003; Bunnell and Houde, 2010; Fauteux et al., 2012; Sullivan et al., 2012). Although management of woody debris in forest ecosystems is crucial to conservation of biodiversity, it suffers from a dearth of experimental studies in both Europe and North America (Seibold et al., 2015). Woody debris structures (e.g., piles and windrows) may be built at the time of forest harvesting and log processing, and are composed of tops, branches, and bole ends of harvested trees, as well as trees knocked down during harvest, low-quality commercial trees, dead wood, and non-commercial trees left at the harvest site. A windrow or series of piles may connect patches of mature forest and riparian areas to allow small mammals and some of their predators to access and traverse clearcut openings. This practice is particularly relevant on large openings (e.g., >10 ha) in standard, but also larger (e.g., >100 ha) salvage harvesting operations (Lindenmayer et al., 2008), where many mammal species have declined in abundance (Fisher and Wilkinson, 2005).

Piles and windrows, not connected to uncut forest reserves, have consistently provided habitat on new clearcuts for southern red-backed voles (*Myodes gapperi*) and *Microtus* voles, as well as a host of other forest-floor small mammal species, at least up to three years post-construction (Sullivan et al., 2012; Sullivan and Sullivan, 2014). However, relative abundance levels of voles have declined in the third year in all studies, to date. In addition, the variable sizes and locations of constructed piles and windrows has been a confounding factor and at least partly responsible for the variable results with respect to abundance, species richness, and diversity of small mammal populations (Sullivan et al., 2012).

M. gapperi is a closed canopy specialist in old-growth and mature coniferous forests of western North America (Merritt, 1981) and may be considered an indicator species of "old-forest conditions" (Nordyke and Buskirk, 1991; Pearce and Venier, 2005; Boonstra and Krebs, 2012), but may also occur in younger managed forests (Gitzen et al., 2007). In addition, *M. gapperi* is a major mycophagist consuming hypogeous ectomycorrhizal fungi and disseminating their spores in the forest environment (Maser et al., 2008). This microtine may also be considered a "keystone species" (Thompson and Angelstam, 1999) because of its linkages in the various food webs found in old forests. When comparing habitats in managed forests, the presence of *M. gapperi* populations at mature or old-growth forest levels of abundance suggests that networks of food sources and predators may also be present as components of biodiversity. As is the case with mammalian carnivores, *M. gapperi* disappears from clearcuts within a year of harvest, presumably because of a loss of food, cover (both thermal and security), and other attributes of forest stand structure (Fisher and Wilkinson, 2005; Zwolak, 2009). Responses of other small mammal species to clearcutting in North America are species-specific with generalists that occupy a variety of habitats such as the deer mouse (*Peromyscus maniculatus*), northwestern chipmunk (*Neotamias amoenus*), and *Microtus* voles and *Sorex* shrews persisting on clearcuts, although some for variable periods (Fisher and Wilkinson, 2005).

The linear configuration of constructed windrows of woody debris may provide connectivity across forest openings and assist small- and medium-sized mustelids in using and crossing these sites in both summer and winter (Buskirk et al., 1989; Buskirk and Zielinski, 2003; Moriarty et al., 2015). American marten (*Martes americana*), short-tailed (*Mustela erminea*) and long-tailed weasels (*Mustela frenata*) may seek out such corridors since these mustelids may be prey species for other carnivores (Buskirk and Zielinski, 2003). This particular group of three mustelids readily used culverts (i.e., tunnels) as travel corridors to pass under roadways (Clevenger et al., 2001). Marten and weasels forage and select paths near or in downed wood (Buskirk and Zielinski, 2003; Andruskiw et al., 2008; Bunnell and Houde, 2010). Marten prefer habitats with dense canopy cover and complex understory conditions provided by coniferous trees and downed wood on the forest floor (Buskirk and Powell, 1994; Thompson et al., 2012). The small weasels (*Mustela* spp.) rely on a hunting strategy that takes them through the burrows and runway systems of various small mammal prey species and through all types of cover into which the prey could escape (King, 1989). Thus, the small mammal prey base available within woody debris structures is likely a critical source of food for mammalian carnivores on forest openings (Sullivan et al., 2012). Voles (*Myodes* and *Microtus* spp.) are major prey species for several mammalian carnivores such as marten (Martin, 1994), short-tailed weasels, and long-tailed weasels (Simms, 1979; Buskirk and Zielinski, 2003).

To date, large-scale field experiments have assessed various arrays and scales of piles and windrows of debris as habitat for mammals on clearcuts (Sullivan et al., 2012; Sullivan and Sullivan, 2014), but an evaluation of strategic management of windrows connecting forest reserves and patches has not been done. Thus, we tested two hypotheses (H) that woody debris arranged in windrows connecting patches and reserves of uncut forest, on newly clearcut sites, would increase the (H_1) abundance of the major vole species and total abundance, species richness, and species diversity of the forest-floor small mammal community, and (H_2) presence of small mustelids in response to abundance of small mammal prey; compared with sites of dispersed woody debris or uncut forest.

2. Methods

2.1. Study areas

Two study areas were located in south-central British Columbia (BC), Canada: (i) Elkhart (49°51′15″N; 120°18′23″W) 65 km west of Peachland; and (ii) Golden (51°14′39″N; 116°41′27″W) 30 km east of Golden. The Elkhart area is in the Montane Spruce (MS_{dm}) biogeoclimatic subzone with topography of rolling hills at 1558–1638 m elevation on the Okanagan plateau. The MS landscape has extensive young and maturing seral stages of lodgepole pine, which have regenerated after wildfire. Hybrid interior spruce (*Picea glauca* × *P. engelmannii*) and subalpine fir (*Abies lasiocarpa*) are the dominant shade-tolerant climax trees. Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) is an important seral species in zonal ecosystems and is a climax species on warm south-facing slopes in the driest ecosystems (Meidinger and Pojar, 1991).

The Golden area is in the Interior Cedar-Hemlock (ICH_{mk}) biogeoclimatic subzone with topography ranging from hilly to steep terrain at 1090–1280 m elevation in the lower ranges of the Rocky Mountains. Upland coniferous forests dominate the ICH landscape and comprise the highest diversity of tree species of any zone in BC. Western red cedar (*Thuja plicata*) and western hemlock (*Tsuga heterophylla*) dominate mature climax forests with Douglas-fir, lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*), Engelmann spruce (*Picea engelmannii*), their hybrids, and subalpine fir common in these stands (Meidinger and Pojar, 1991).

Study stands, prior to harvesting, at Elkhart had a mixture of lodgepole pine with variable amounts of subalpine fir and interior spruce, and at Golden were composed of a mixture of Douglas-fir, spruce, subalpine fir, western red-cedar, and western hemlock. Average ages of lodgepole pine ranged from 80 to 120 years and for Douglas-fir and other conifers ranged from 120 to 220 years. Overstory mean tree heights ranged from 22 to 26 m at Elkhart and from 25 to 32 m at Golden over all conifer species. There were