Biological Conservation 167 (2013) 194–202

Contents lists available at ScienceDirect

Biological Conservation

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

Comparison of silvicultural and natural disturbance effects on terrestrial salamanders in northern hardwood forests

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ARTICLE INFO

Article history:
Received 30 April 2013
Received in revised form 30 July 2013
Accepted 4 August 2013

Keywords:
Forest management
Red-backed salamander
Plethodon cinereus
Disturbance
Ice-storm
Timber harvest

ABSTRACT

In forested ecosystems timber harvesting has the potential to emulate natural disturbances, thereby maintaining the natural communities adapted to particular disturbances. We compared the effects of even-aged (clearcut and patch cut) and uneven-aged (group cut, single-tree selection) timber management techniques with natural ice-storm damage and unmanipulated reference forest sites on red-backed salamanders. We used cover boards and litter searches to survey for salamanders in northern hardwood forests in New Hampshire, USA. We estimated abundance while accounting for detection probability using the Dail–Madsen open population model. We found significant reduction in salamander abundance in recent group cuts, patch cuts, and clearcuts compared to reference forest sites, and significant but less effect of single-tree selection and ice-storm damage. Our results contribute to the evidence of detrimental effects of even-aged harvests on salamander abundance, but in contrast to most previous research, we also found lower abundance in sites following uneven-aged harvest practices when we accounted for detection probability. To more accurately reflect the total effect of harvests on salamanders, we also employed a parametric, nonlinear hierarchical model to estimate edge effects while accounting for imperfect detection. We found that group cut, patch cut, and clearcut logging reduced salamander abundance 34 m into the surrounding forest. These edge effects can greatly expand the total area affected by logging, especially in the northeastern US where cuts tend to be relatively small. This novel method for estimating edge effects will allow managers to directly calculate the total effects on populations for various size and shape harvesting plans.

1. Introduction

Disturbance is one of the primary factors that regulate natural populations, structure communities, and maintain biodiversity. Because local communities are thought to be adapted to natural disturbance regimes, a common goal of ecosystem management is to replicate natural disturbances (e.g. Buddle et al., 2006; Perry, 1998). Nevertheless, emulating natural disturbances with management practices can be difficult because effects on populations and communities can vary by habitat or the type, frequency, and severity of the disturbance (Runkle, 1985). Therefore, to properly inform forest management it is important to quantify the effects of various disturbances, such as from severe winds, insect outbreaks, wildfire, landslides, and ice-storms and compare them to silvicultural practices.

Much of the research directly comparing natural and anthropogenic disturbances has focused on wildfire (e.g. Buddle et al., 2006; Simon et al., 2002) and wind (e.g. Greenberg, 2001; Lain et al., 2008) in relation to prescribed burns and timber harvests. However, wind and ice storms are the major causes of natural disturbance in northern hardwood forests (Lorimer and White, 2003). Ice storms, which generally result in small canopy gaps, are a frequent disturbance agent occurring every 1–25 years in northern hardwood forests (Irland, 2000). The frequency of severe storms including snow and ice storms in New England are expected to increase given climate change predictions (Frumhoff et al., 2007). In contrast to ice storms, stand-replacing natural disturbances, such as major fires and hurricanes, which create large gaps, occur relatively infrequently (return times of 100–1000 years) in the temperate forests of northeastern North America (Runkle, 1985). Correspondingly, clearcutting is an intensive silvicultural practice which involves the removal of the entire canopy at longer harvest rotations, whereas single-tree selection and group selection cuts result in small gaps in the canopy, more similar to most natural disturbance in the region, and require logging a greater area of forested land, and shorter time between re-entry to stands (Walker, 1999).

Disturbance that opens gaps in the canopy increases light penetration (Minckler et al., 1973) and rain throughfall (Heatwole, 1962), and can have direct consequences on other abiotic factors

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0006-3207/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biocon.2013.08.006

such as soil moisture, leaf litter depth, and soil temperature (Johnson et al., 1985; Minckler et al., 1973). Relative changes in abiotic factors are likely dependent on gap size with larger gaps having greater reductions in soil moisture (Troendle, 1970) and leaf litter depth (Johnson et al., 1985), and increases in soil temperature (Marquis, 1967) compared to smaller gaps (Phillips and Shure, 1990). Additionally, the resulting amount of course-woody debris is a function of natural disturbance type and silviculture practices. The differential impacts on microhabitat characteristics due to differences in forest disturbance area and intensity may result in varying effects on wildlife populations.

Plethodontid salamanders are particularly sensitive to changes in forest conditions (Peterman et al., 2013; Welsh and Droege, 2001) and may be differentially affected by various forest disturbances. Salamanders are influenced by several habitat characteristics that can be altered immediately following a forest disturbance (Ash, 1997; Crawford and Semlitsch, 2008a; Tilghman et al., 2012), including temperature (Feder and Pough, 1975), soil moisture (Heatwole and Lim, 1961), density of understory vegetation (Brooks, 1999), the number, area, or volume of coarse woody debris (CWD; Brooks, 1999; Mathis, 1990), and leaf-litter depth (Crawford and Semlitsch, 2008a; Pough et al., 1987).

In addition to the general effects of large-scale disturbance such as clearcutting, these disturbances create an environmental gradient from the interior of the disturbed area extending out into the surround undisturbed forest. This edge gradient varies in light, temperature, moisture, vapor pressure deficit, humidity, and shrub cover (Matlack, 1993) and can extend 50 m or farther from the edge (Chen et al., 1999; Matlack, 1993; Murcia, 1995). The width of these edge effects has important conservation implications because the effects of disturbance can extend beyond the area directly disturbed. Among wildlife, amphibians are especially sensitive to increased light, temperature, and reduced moisture associated with forest edges around recent timber harvests (Crawford and Semlitsch, 2008a; deMaynadier and Hunter, 1998). The effect of forest edges on amphibian abundance varies by location and season (Baker and Lauck, 2006; deMaynadier and Hunter, 1998; Schlaepfer and Gavin, 2001) and by species (deMaynadier and Hunter, 1998; Urbina-Cardona et al., 2006). In the northeastern United States, amphibian abundance, especially of forest dependent species, is reduced 20 – 35 m into the forest surround timber harvests (DeGraaf and Yamasaki, 2002; deMaynadier and Hunter, 1998). Amphibians are also known to change their movement patterns in response to forest-open-canopy edges (Graeter et al., 2008; Popescu and Hunter, 2011; Rothermel and Semlitsch, 2002), potentially contributing to observed abundance distributions along edge gradients.

Although declines of amphibian abundance following timber harvest are documented throughout the United States (e.g. deMaynadier and Hunter, 1995; Petranka et al., 1993; Tilghman et al., 2012), few studies have directly compared the effects of natural forest disturbances with different forest management practices on amphibians (but see Greenberg, 2001; Strojny and Hunter, 2010). Our objectives were to (1) compare the short-term impacts of various forest harvesting practices and natural ice-storm damage on the red-backed salamander (*Plethodon cinereus*) in northern hardwood forests, and (2) examine how salamander abundance varies along the edge gradient from cut interior to surrounding forest, while accounting for imperfect detection.

2. Methods

2.1. Study design

We established study sites in northern hardwood forest within the White Mountain National Forest (WMNF), New Hampshire. The forest canopy was dominated by American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), and sugar maple (*Acer saccharum*). These mature hardwood forests developed from woods selectively harvested between 1887 and 1916 (Belcher, 1980). Our sites were located in undisturbed forest, recently harvested forest, and mature forest recently damaged from ice storms and ranged in elevation from 226 to 573 m and varied in slope and aspect. All harvests were conducted in the winter of 1998–1999. Undisturbed forest sites ($n = 8$) consisted of stands not harvested in the past 60 years and without recent ice damage. Previous research has demonstrated no difference in salamander populations between old growth forests and 60 year-old secondary forests (Petranka et al., 1993; Pough et al., 1987). Harvested sites consisted of clearcuts ($n = 2$), patch cuts ($n = 5$), group selection ($n = 2$), and single-tree selection harvests ($n = 4$). Harvests were located low to moderately steep slopes to minimize runoff. Primary orientation of harvests varied within treatments. Most treatments had replicate sites with aspects that ranged in all cardinal directions, with the exception that group selection cuts and clearcuts were predominately in south- and east-facing orientations because there were only 2 replicated of each.

Silvicultural treatments were classified according to White Mountain National Forest management definitions (USDA Forest Service, 1986). Clearcuts and patch cuts (even-aged management practices) resulted in the removal of all merchantable trees down to 5 cm, with clearcuts ranging in size from 4 to 12 ha and patch cuts ranging from 1 to 4 ha. Uneven-aged management includes single-tree selection and group selection. Single-tree selection involves removal of individual trees based on characteristics such as quality and size, whereas group selection removes trees in small groups resulting in gaps 0.1–0.8 ha in size. Specifically at our study locations, the reference stands and pre-harvest areas had a mean basal area of 30.3 $m^2\ ha^{-1}$, which was reduced by approximately 25% to a mean of 22.8 $m^2\ ha^{-1}$ in the single-tree selection harvested stands.

In January 1998, a 100-year ice-storm hit the northeast United States and parts of eastern Canada, affecting principally mature northern hardwood forests at elevations between 300 and 800 m. More than 6.9 million ha of northern hardwood and spruce-hardwood forest were affected in New England and New York (Lorimer and White, 2003). Of the 430,000 ha of forest in New Hampshire, approximately 27% of the trees received light or moderate damage and 23% were seriously damaged. In New Hampshire, the average crown loss within damaged areas was 64% per individual tree (Miller-Weeks and Eagar, 1999). Ice-storm damage maps obtained from the USFS were used to identify areas of severe storm damage. Ice-storm damaged sites ($n = 9$) were chosen based on both proximity to harvest sites and accessibility (total $N = 30$ sites) and occurred on sites with aspects in all cardinal directions except west.

In each clearcut, patch cut, and group cut, we centered a transect at the harvest edge , which extended 80 m into harvest and 80 m into surrounding forest perpendicular to the harvest edge. We established sampling plots at the harvest-forest edge (0 m) and at 20 m intervals in both directions. An additional plot was located 10 m into the forest to help estimate a more precise edge effect. Group cuts and one patch cut were too small for plots to be located 80 m from a forest edge; therefore, these transects were truncated 40 or 60 m into the cut. At undisturbed, ice-storm damage, and single-tree selection sites, we randomly located the first plot and established three additional plots 20 m apart in random directions.

2.2. Salamander sampling

At each plot, we sampled red-backed salamander abundance using artificial cover objects (ACOs) and 1 m^2 area constrained