Forest Ecology and Management 353 (2015) 187–195

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Short- and long-term benefits for forest biodiversity of retaining unlogged patches in harvested areas

Susan C. Baker[a,b,c,*], Charles B. Halpern[c], Timothy J. Wardlaw[a,b], Rodney L. Crawford[d], Richard E. Bigley[e], Graham J. Edgar[f], Shelley A. Evans[a,c], Jerry F. Franklin[c], Gregory J. Jordan[a], Yuliya Karpievitch[g], Thomas A. Spies[h], Russell J. Thomson[f]

[a] School of Biological Sciences, University of Tasmania, Private Bag 55, Hobart, Tasmania 7001, Australia
[b] Forestry Tasmania, GPO Box 207, Hobart, Tasmania 7001, Australia
[c] School of Environmental and Forest Sciences, University of Washington, Box 352100, Seattle, WA 98195, USA
[d] Burke Museum, University of Washington, Box 353010, Seattle, WA 98195, USA
[e] Forest Resources Division, Washington State Department of Natural Resources, PO Box 47016, Olympia, WA 98505, USA
[f] Institute for Marine and Antarctic Studies, University of Tasmania, GPO Box 252-49, Hobart, Tasmania 7001, Australia
[g] School of Mathematics and Physics, University of Tasmania, Private Bag 50, Hobart, Tasmania 7001, Australia
[h] US Department of Agriculture Forest Service, PNW Research Station, 3200 SW Jefferson Way, Corvallis, OR 97331, USA

ARTICLE INFO

Article history:
Received 12 March 2015
Received in revised form 12 May 2015
Accepted 15 May 2015
Available online 4 June 2015

Keywords:
Edge effects
Forest influence
Retention forestry
Variable retention
Plants
Invertebrates

ABSTRACT

Aggregated retention, in which patches of trees (aggregates) remain unlogged within larger harvested units, was first applied commercially in 1986. A primary goal was to maintain greater diversity of forest-dependent species through harvest, relative to conventional clearcutting. Despite its global application, the long-term benefits for biodiversity and the comparative responses of disparate taxonomic groups to aggregated retention are largely unknown. A critical knowledge gap relates to the role of 'forest influence' – whether and to what extent aggregates affect biodiversity in neighboring harvested areas. We sampled plants, beetles, and spiders/harvestmen in the world's three oldest aggregated-retention sites (21–26 years old), matched with three recently harvested sites (5–8 years old). For each taxonomic group, we compared species composition between undisturbed aggregates and regenerating forests to assess the 'lifeboating' function of aggregates. For each group, we also modeled changes in species composition, and in the numbers of aggregate- and regeneration-affiliated species, with distance from the aggregate edge into the regenerating forest along transects at north-facing edges. For all three taxa, species composition differed between aggregates and regenerating forests in both older and recent sites, confirming the long-term effectiveness of aggregates for lifeboating. The compositional difference between habitats was significantly greater at recent than at older sites for plants, but not for invertebrates. Plants and spiders/harvestmen responded to forest influence, with a marginal response for beetles. Responses for plants and spiders generally manifested as increased numbers of aggregate-affiliated species and decreased numbers of regeneration-affiliated species in regenerating areas closer to edges. Our results indicate that aggregated retention has short- and long-term benefits for biodiversity reflecting both the lifeboating and forest-influence functions of aggregates. However, variation in the responses of plants, beetles and spiders suggests that these benefits cannot be generalized among taxa. We advocate broader application of aggregated retention in forests managed for timber production and encourage managers to incorporate the benefits of forest influence in harvest designs by arranging aggregates to reduce average distances from harvested areas to unlogged habitats.

1. Introduction

Aggregated retention, the practice of leaving unlogged patches within logged areas is a form of retention forestry that has gained increasing use globally as an alternative to clearcut logging (Gustafsson et al., 2012; Lindenmayer et al., 2012; Mori and

* Corresponding author at: Forestry Tasmania GPO Box 207, Hobart, Tasmania 7001, Australia. Tel.: +61 3 6235 8306; fax: +61 6 6235 8292.
E-mail address: sue.baker@forestrytas.com.au (S.C. Baker).

http://dx.doi.org/10.1016/j.foreco.2015.05.021
0378-1127/

Kitagawa, 2014). In contrast to clearcutting, retention forestry maintains habitat for species affiliated with closed forest—thus mitigating the negative effects of timber harvest—while also providing habitat for early-seral species (Fedrowitz et al., 2014). Developed in the late 1980s, retention forestry incorporates the benefits of retained forest elements for ecosystem recovery and habitat connectivity after disturbance. Nevertheless, widespread adoption of retention forestry is relatively recent, and much broader application is desirable since clearcutting is still prevalent in many regions (Lindenmayer et al., 2012).

Retention of undisturbed patches within harvest units is intended to sustain some forest-dependent species through disturbance—the 'lifeboating' function of aggregates (Franklin et al., 1997). In addition, aggregates may facilitate species' re-establishment within adjacent harvest areas through effects of 'forest influence'—a type of edge effect (Baker et al., 2013). Two edge-related mechanisms may contribute to re-establishment: microclimatic amelioration (shading) near the edge and greater proximity to source populations (Keenan and Kimmins, 1993; Heithecker and Halpern, 2007; Baker et al., 2013). Few studies have assessed the timing and or extent to which forest edges influence re-establishment in the harvest area (but see Helle and Muona, 1985; Tabor et al., 2007; Larrivée et al., 2008), particularly in the context of retention forestry. Small aggregates may be susceptible to edge and area effects, thus compromising both their lifeboating and forest-influence functions (Aubry et al., 2009; Baker et al., 2013).

Biotic responses to retention forestry have rarely been investigated in the long-term (e.g., Lõhmus and Lõhmus, 2010; Halpern et al., 2012). However, it is likely that habitat changes and ecological succession alter the importance of retained structure over time (Halpern et al., 2012). For example, the structural contrast between harvested and retained forest, and the strength of edge influence on microclimate in the harvested area, change with regrowth of the regenerating forest (Baker et al., 2014)—particularly the pace at which the canopy closes. As a consequence, the relative importance of aggregates as refuges for forest-dependent species or as structures that influence ecological processes in the harvested area may change with time since disturbance.

Studies of biological responses to forest management rarely consider multiple taxonomic groups. In the absence of empirical data, natural resource or conservation managers may thus assume that responses of forest-dependent or early-seral species in one taxonomic group apply to other taxa. For example, if responses of invertebrates are keyed to changes in vegetation (de Andrade et al., 2014), then surveying plants may be sufficient. Whether plants serve as surrogates for other taxa remains unresolved: some studies show partial surrogacy (Panzer and Schwartz, 1998; Catterall et al., 2004; Kati et al., 2004; de Andrade et al., 2014) and others, no clear relationship (e.g., Oliver et al., 1998; Wolters et al., 2006). Few studies of invertebrates consider more than one major group, regardless of evidence suggesting varying responses to management (Buddle et al., 2006; Lovell et al., 2007; de Andrade et al., 2014). Even when multiple taxa are considered, rarely is a common methodology used to facilitate direct comparison. Where comparable methodology has been used, taxa have shown varying responses to retention harvests. For example, Halaj et al. (2008) found that spiders and carabid beetles showed contrasting responses to edge within forest aggregates. Coincidental sampling of taxa in time and space makes it possible to evaluate more fully the ecological consequences of forest management.

Our research was designed to address these gaps in knowledge. We sampled plants, and ground-active beetles and spiders/harvestmen in the oldest known sites subjected to aggregated retention, and in more recently harvested sites contemporaneous with the use of aggregated retention in most regions of the world. Our objectives were to elucidate the importance of lifeboating and forest-influence within these contexts:

(1) Lifeboating: To characterize (a) the differences in species composition between mature (aggregate) and adjacent regenerating forests, and whether these differences vary (b) with time since harvest and (c) among taxonomic groups.
(2) Forest influence: To assess (a) the strength of forest influence on species composition in the harvested area and whether it varies (b) with time since harvest or (c) among taxonomic groups. (d) To assess whether compositional gradients are driven by species associated with mature and/or regenerating forest, which we expected to decline or increase in number, respectively, with distance from edge.

Our results provide some of the first empirical evidence of the longevity and relative effectiveness of these dual ecological functions for a taxonomically diverse set of forest organisms. They provide strong support for aggregated retention as a strategy for balancing conservation of biological diversity with timber production in managed forest landscapes.

2. Materials and methods

2.1. Study sites

We studied aggregated-retention sites in Douglas-fir (*Pseudotsuga menziesii* (Mirb.)) dominated forests on federal, state and private forestlands in Washington State, USA. We utilized the only three available early operational sites (i.e., "older" sites, harvested 21–26 years previously) and three more recently harvested sites (i.e., "younger" sites, harvested 5–8 years previously) (Fig. 1). The harvested areas of the older sites were in the stem-exclusion (closed-canopy) phase of forest development; those in the younger sites were in the stand-initiation (pre-closure) phase (Franklin et al., 2002). Details of the management history, dominant plant species, and general ecological settings of the sites are provided in Tables A1 and A2 in Appendix A, Supplementary material.

2.2. Sampling design

Within each site, we established a transect originating from the center of each of two unlogged aggregates, extending along an approximately northern bearing across the aggregate-harvest area boundary (20–40 m away) to a distance of 50 m into the harvested area ("regenerating forest"; Fig. 2). We chose a northerly bearing to maximize shading; effects of forest influence are likely to be weaker along south-facing (warmer, brighter) edges.

Aggregates varied in size from 0.4 to 1.3 ha and all but one were 0.4 to 0.8 ha. Because the largest aggregate was long and thin and the sampling transect was located at its far end, edge effects were probably similar to those of smaller aggregates. We established vegetation plots every 5 m along each transect in both directions from the aggregate edge. We established pitfall traps for ground-active invertebrates (beetles and spiders/harvestmen) every 10 m in the regenerating forest, but usually every 5 m in the aggregates to ensure at least four traps per transect in this more restricted habitat.

2.3. Data collection

Data were collected in summer 2012. We sampled vascular plants in two 1×1 m subplots per plot. Within each subplot, we visually estimated the percentage cover of each vascular plant