Biological Conservation 175 (2014) 65–73

Contents lists available at ScienceDirect

Biological Conservation

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

Retention forestry as a major paradigm for safeguarding forest biodiversity in productive landscapes: A global meta-analysis

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ARTICLE INFO

Article history:
Received 3 February 2014
Received in revised form 14 April 2014
Accepted 17 April 2014
Available online 14 May 2014

Keywords:
Biological legacy
Ecologically sustainable forest management
Forest certification
Retention logging
Selective logging
Species richness
Variable retention

ABSTRACT

Currently, there is an increasing need for sustainable forest management to meet multiple beneficial social and ecological goals. This has spurred the emergence of retention forestry, which aims to maintain key elements of the stand during harvesting to ameliorate the post-logging structure over forest generations. Despite the global expansion of this approach as a conservation tool in production forests, quantitative evaluations of its effectiveness are still lacking, particularly for comparisons across different biomes, different levels of economic development, and different taxa. We conducted a meta-analysis to identify the general responses of forest species to the set-aside actions (i.e., retaining the important biotic and abiotic features during logging to conserve biodiversity). We found that retention forestry can preserve a degree of species richness equivalent to that of primary forests, at least at the stand level. This potential does not differ among regions or economic development levels, supporting the ecological meaning of retaining "biological legacies" over forest generations irrespective of forest biomes. Despite their common focus on biodiversity conservation, retention forestry is different from the reduced-impact forestry that is implemented with selective logging. The reason for this difference is that the former and the latter approach focus on what is retained and what is logged during harvesting operations, respectively. Thus, our meta-analysis also focused on comparisons between these two logging methods based on different viewpoints, i.e., from the species perspective vs. the perspective of human needs. We found that although selective logging was not detrimental to forest taxa, retention forestry was more effective in conserving biodiversity. We thus argue that the principles underpinned by retention approach, such as the consideration of natural disturbance regimes, and the provision of important habitats for species, will be essential overall for biodiversity-oriented forestry. Retention forestry will continue to play a fundamental role in encouraging further development of management schemes that have multiple goals.

1. Introduction

Currently, there is an increasing need for sustainable forest management, which aims to protect natural and semi-natural forests from undesirable deforestation; maintain and enhance the social, economic, and ecological value of forests; and secure forest ecosystem services for future generations (CPF, 2012; Paquette and Messier, 2010; Quine et al., 2013). This set of goals includes the preservation of the biodiversity benefits of forests (CPF, 2012). Forests are estimated to harbor up to three-quarters of all terrestrial taxa (CPF, 2008). Forest biodiversity underpins fundamental ecosystem services such as primary production, carbon sequestration, and food provision (Gamfeldt et al., 2013; Thompson et al., 2011), and bolsters the resilience that enables society to respond to various environmental changes and surprises (CBD, 2009; Mori et al., 2013). In terrestrial areas, the net decline in primary forests is estimated to have slowed down on a global scale during the first decade of the 21st century (FAO, 2010); however, forest conversion, fragmentation and degradation are still the principle causes of land-use change, threatening many forest-dependent taxa (Laurance et al., 2014; Meyfroidt and Lambin, 2011; Wilcove et al., 2013). Thus, the further development of a framework that ensures the long-term integrity of forested lands is desirable for conserving the biodiversity that forests support and humanity needs.

Along with sustainable forest management, protected areas play a critical role in conserving forest biodiversity and other ecosystem processes (Brooks et al., 2009; Butchart et al., 2010). However, protected areas, which cover only 13% of the world's

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http://dx.doi.org/10.1016/j.biocon.2014.04.016
0006-3207/

forest areas (FAO, 2010), are not necessarily designated to support the multi-functionality of forests that human society needs (Thompson et al., 2011). This situation has resulted in the emergence of another complementary approach, retention forestry, which aims to maintain key biological and physical elements of the stand (e.g., patches of live trees, the scattered distribution of old trees, and dead trees such as stumps, logs, and snags) during harvesting to ameliorate the post-logging structure over forest generations (Lindenmayer and Franklin, 2002). These structures retained in logged sites are ecologically important because they emulate "biological legacies" that are generally found in stands following natural disturbances (Franklin et al., 1997). This silvicultural system could be effective in satisfying socio-economic needs (i.e., timber production) without greatly compromising biological conservation, offering a profound potential to help realize ecologically sustainable forest management.

Retention forestry is fundamentally analogous to the idea of land sharing (Lindenmayer et al., 2012), which integrates different (and often conflicting) objectives of both biodiversity conservation and commodity demands on the same land (Fischer et al., 2008). As observed in the debate between land sharing and the alternative idea of land sparing, in which specific lands are allocated to high-yield production while other natural habitats are protected from land conversion (Phalan et al., 2011), several issues are still uncertain. One issue involves the contribution of the retention approach to the successful conservation of forest-dependent species. Since the adoption of this forestry practice in the early 1990s, a substantial number of studies have evaluated biodiversity responses in post-harvest sites. Based on these findings, several reviews have concluded that the approach is effective in safeguarding certain components of biological organization (Gustafsson et al., 2012, 2010; Lindenmayer et al., 2012). However, despite the global expansion of this silvicultural approach as a conservation tool in the production forest landscapes, quantitative, multidimensional evaluations of its effectiveness are still lacking, particularly for comparisons across different biomes, different levels of economic development, and different taxa. Such a global synthesis is urgently needed because the principle of set-aside forestry is now being incorporated into the major frameworks of forest certification that are rapidly expanding worldwide (Baker, 2011; Gustafsson et al., 2012). We thus conducted a meta-analysis to identify the general responses of forest species to retention actions.

Note that the retention approach is based on the following idea: "*more emphasis on what is retained as opposed to what is removed during harvesting*" (Franklin et al., 1997). To test whether this notion has been successfully conserved during forestry operations, we aimed to compare the responses of forest species to retention actions with those to another modern forestry method. This alternative method is selective logging, used as a strategy to reduce the impact of logging (so-called reduced-impact or low-impact logging). Selective logging is also a major management scheme used to reduce or minimize detrimental impacts of forestry operations on biodiversity, especially in the tropics (Putz et al., 2012). Biodiversity considerations receive an increasing emphasis in both approaches (Gustafsson et al., 2012). However, selective logging primarily aims to harvest the resources that people need. Accordingly, the two logging methods are based on somewhat different viewpoints, i.e., the species perspective vs. the perspective of human needs. We focused on this inherent difference, so that our meta-analysis evaluated biodiversity responses to retention and selective logging across the globe. Based on this evaluation, we aim to provide fundamental information that will help the forest sectors to ensure both the production of commodities and biological conservation.

2. Methods

2.1. Data collection

To allow the meta-analyses to quantify the effects of the practice of retention on forest biodiversity, we searched the literature using the ISI Web of Science database (up to and including December 2012). We used a combination of "retention" AND "forest*". These keywords matched 3044 publications. We then further searched the literature with the keywords of "log*" OR "cut*" OR "harvest*", resulting in 531 publications. We read through these articles carefully to select literature whose focus was forest biodiversity conservation. This selection process yielded 145 publications. Within this set of publications, we focused on studies that compared species diversity between productive and primary forests. We then extracted information necessary for our meta-analysis (see below), resulting in 146 comparisons from 23 case studies. For the meta-analyses whose goal was to evaluate the effects of selective logging on forest biodiversity, we again searched the literature with the ISI Web of Science database (up to and including December 2012). Here, we used a combination of "forest" AND "selective log*" OR "selective cut*" OR "selective harvest*". These keywords matched 795 publications. We then read through the literature to find publications that focused on forest biodiversity conservation with an element of low-impact forestry, resulting in 211 publications. From this set of publications, we further selected publications that included information available for our meta-analyses (see below), yielding 75 comparisons from 27 case studies.

For the selected publications, we focused on species richness for the control (primary forest) and experimental groups (logged forest). We retrieved sample size (n), mean and standard deviation (SD) from the main text, table(s), figure(s) and supplemental materials of the selected publications. If standard error (SE) values or 95% confidence intervals (CI) were given, we transformed them to SD values. If only figures were given, the software DataThief III version 1.6 (Tummers, 2006) was used to extract these parameters from the graphs. We also recorded the study location, biome (boreal, temperate, temperate (*Nothofagus*), subtropical, or tropical), and type of the focal taxonomic group (amphibian, arthropod, bird, epiphyte, mammal, vascular plant, or others). For the retention practices, we classified the retention type (aggregated retention, dispersed retention, or aggregated + dispersed retention combined), and, if available, we recorded the retention level (the area, the number of trees or the aboveground timber volume retained after logging). If the retention level was specified in the form of categorical data (e.g., 60–80% of trees were logged), we used median values. We did not record the logging type and intensity for selective logging because such information was rarely available.

2.2. Data analysis

For the analyses based on retention and those based on selective logging, we calculated the unbiased standardized mean difference (Hedges' d) between the mean values in primary and logged forest. The Hedges' d effect size (d) is calculated as follows:

$$d = (M_e - M_c)J/S$$

$$J = 1 - 3/(4df - 1)$$

where M_e and M_c are the mean values of the experimental and control groups, respectively, S is the pooled standard deviation, and J is a correction factor based on the sample size. The Hedges' d is a unit-free index that expresses the magnitude of the deviation from no difference in the response variable between comparisons. The size