Forest Ecology and Management 381 (2016) 209–216

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Accelerating tropical forest restoration through the selective removal of pioneer species

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ARTICLE INFO

Article history:
Received 22 July 2016
Received in revised form 14 September 2016
Accepted 16 September 2016
Available online 28 September 2016

Keywords:
Selective thinning
Silviculture
Forest restoration
Sustainable forest management
Assisted natural regeneration

ABSTRACT

Demand for tropical forest restoration has grown rapidly as the potential role of recovering secondary forests in sequestering carbon and enhancing biodiversity has been recognised. Active forest management is often prescribed to accelerate natural regeneration, but evidence for the efficacy of interventions is scarce for tropical forests. In this study we examine the hypothesis that the selective removal of abundant pioneers in the understory of recovering selectively logged forests can improve the composition of forest stands and accelerate succession. Four selective thinning treatments of increasing intensity were implemented in 8.75 ha compartments and replicated six times. Within each compartment, three monitoring plots were established and measured immediately after thinning and one year later to assess implementation of thinning treatments, growth and survival of stems, and changes in stand composition. Canopy openness was measured using hemispherical photography. Thinning treatments substantially reduced the abundance of pioneers, but there was only a slight increase in canopy openness (3.7–4.3%) relative to the control (1.8%) 8 months after implementation. Canopy openness increased dramatically across all treatments in the follow year due to the 2015–16 El Niño event and increased more in thinning treatments. Large (>10 cm dbh) and small (2–10 cm dbh) late-successional stems showed enhanced growth only in the low intensity thinning treatment, whereas the growth of small pioneer stems increased across the thinning intensity gradient. The cost of implementing thinning treatments was $US80 per ha or approximately 10% of the cost of planting treatments in the same forest. Our findings suggest that selective thinning of understory pioneer stems is a practical option for manipulating stand composition and potentially accelerating natural regeneration. Continued monitoring of the experiment should reveal the long-term impact and cost-effectiveness of treatments.

1. Introduction

Tropical forests support essential ecosystem services, including sequestering large amounts of carbon (Lal, 2005; Stephens et al., 2007; Chazdon et al., 2016) and providing habitat for a disproportionate share of terrestrial biodiversity (Gaston, 2000). The restoration of 300–400 million ha of degraded tropical forests around the world is considered essential if a global temperature increase of >2 °C is to be avoided (Bonn Challenge), and limiting global temperature increase to well below 2 °C, as agreed on in Paris (COP, 2015), suggests even more ambitious restoration targets may need to be met. With respect to biodiversity conservation, Aichi Target 15 stipulates that 15% of degraded ecosystems, including tropical forests, should be restored by 2020 (www.cbd.int/sp/targets/). Meeting this global restoration agenda will necessitate a step change in the scale and cost-efficiency with which tropical forest restoration is currently implemented.

Most degraded tropical forests are found in rapidly developing countries, where large, growing populations., poverty and weak governance combine to create huge pressures for their conversion (Wright et al., 2007; Laurance et al., 2014). If forests are to be retained and restored it is essential that management options are available that enable the economic value of natural forests to be realised, without sacrificing other goals such as biodiversity conservation (Putz et al., 2001) and carbon sequestration (Pearce et al., 2003; Noormets et al., 2015). This includes realizing and enhancing revenues from sources such as payments for ecosystem services (e.g. REDD+; Edwards et al., 2010) or sustainable timber

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http://dx.doi.org/10.1016/j.foreco.2016.09.020
0378-1127/

harvests. Carbon stocks have been shown to recover at far higher rates in recovering selectively logged forests compared with equivalent old-growth forests (Gourlet-Fleury et al., 2013; Poorter et al., 2016) and plantations (Harmon et al., 1990; Noormets et al., 2015). The recovery of tree diversity and forest structure is largely a property of the degree of forest degradation and the relative isolation of stands (Arroyo-Rodríguez et al., 2015) and therefore selectively logged forests in large contiguous blocks should have sufficient influx of propagules to recover rapidly following disturbance. The critical question facing restoration practitioners is, can cost effective, silvicultural interventions be implemented that speed up the process of succession so that timber, carbon and biodiversity values can simultaneously restored be more rapidly?

Enrichment planting is often used to enhance forest restoration, but returns on investment for such an expensive intervention may be marginal. The purpose of enrichment planting is to increase the density of desirable seedlings which in theory accede to the canopy, enhancing the forest's future utility. Several hundred seedlings are typically planted per hectare in areas where the density of desirable stems is low (e.g. Moura Costa, 1996; Wheeler et al., 2016). However, in practice competition with established and naturally recruiting seedlings may be intense, particularly in selectively logged forests (Ådjers et al., 1995). Additional management of competing vegetation may be required for several years (Moura Costa, 1996; Wheeler et al., 2016), leading to relatively modest levels of success (Sampaio et al., 2007) at substantial financial expense (Palma and Laurance, 2015).

A potentially far more meaningful intervention is the selective removal of competing vegetation at sites where sufficient stocks of desirable seedlings and young trees are present. Forest managers have implemented commercial thinning of trees as a technique to enhance forest composition and merchantable yields for centuries (Zeide, 2001; Cameron, 2002). The technique focuses on harvesting a proportion of stems, usually of a given size class or species, so that these can be sold while accelerating the growth of the most desirable stems. It is usually straightforward in monospecific stands, such as in temperate production forests. Although, even in such a simple setting thinning can have undesirable consequences, for example: the residual stand is often damaged during harvesting (Han and Kellogg, 2000; Hartsough, 2003) or becomes vulnerable to wind damage as a result of greater distances between trees (Gardiner et al., 1997) and invasive or undesirable species may establish in response to elevated light levels (Thomas et al., 1999; Dalling and Hubbell, 2002; Powell and Bork, 2006).

Despite the widespread use of thinning as a silvicultural technique (Zeide, 2001; Cameron, 2002; Porté and Bartelink, 2002) comparatively little research has been conducted to assess its impact on productivity, species composition and the responses of non-target taxa outside of species-poor temperate forests and plantations. Thinning of non-arboreal vegetation such as smothering lianas, grasses, bamboos and dense shrubs, has received more attention, and generally demonstrated increases in habitat complexity and quality (Moura Costa, 1996; Thomas et al., 1999; Carey, 2003; De la Montaña et al., 2006; Edwards et al., 2009, 2012; Ansell et al., 2011), and elevated carbon sequestration (Wheeler et al., 2016). However, few studies have been conducted within selectively logged tropical forests to assess the effect of removing dominant low value tree species. Those that have, found that silvicultural interventions typically speed up the recovery of biomass, but rarely merchantable timber (Finegan and Camacho, 1999; de Graaf et al., 1999; Gourlet-Fleury et al., 2013).

Tropical forests are composed of many tree species, with widely differing regeneration niches, wood densities and commercial values, thus requiring nuanced management (Silvertown, 2004; Chave et al., 2006; Poorter, 2007). The removal of any vegetation through thinning will increase understory light intensity and may favour fast-growing light-demanding species (ter Steege and Hammond, 2001; Park et al., 2005), which are of low commercial value and contain less carbon. This has been demonstrated throughout the tropics by the wholesale replacement commercial species by a proliferation of disturbance responsive species as a result of logging (Slik et al., 2002).

Following disturbance, late successional species are suppressed by the more rapid growth of light demanding pioneer species (Guariguata, 1999). Under natural succession, the transition from a pioneer dominated to diverse late-successional forest takes decades while understory shade increases and pioneer species are replaced by a new crop of less light-demanding species from the sub-canopy. Centuries may be required until stocks are fully recovered (Chazdon, 2003; Cole et al., 2014). However, if the density of low-value, light-demanding species in the sub-canopy and understory can be reduced through selective thinning, it may be possible to asymmetrically enhance the growth and accession to the canopy of high value species from the understory (Guariguata, 1999). However, if the canopy is disturbed too much there may be a substantial increase in pioneer recruitment (Slik et al., 2002; Slik, 2004) and dry season mortality of desirable species (Gerhardt, 1996). This is particularly true under severe droughts, such as those occurring during El Niño Southern Oscillation events in South East Asia, which are predicted to as much as double in frequency under some climate models (Cai et al., 2014).

In this study, we present the initial findings (after 1–2 years) of a well replicated, large-scale experiment to assess the implementation and efficacy of selective pioneer removal on the recovery of a selectively logged Sumatran tropical forest. We implemented thinning at three different intensities, alongside a no management control. Treatments were replicated within randomised management compartments to control for variation in forest quality and environmental heterogeneity. Our objectives were to: (1) assess the effectiveness of the different thinning intensities for modifying species composition and canopy openness; and (2) measure the growth of pioneers and late successional stems within the different thinning treatments. Permanent plot sampling was used as an unbiased method to measure the efficacy of the treatments and follow tree growth and survival through time. Our hypotheses were:

1. The removal of pioneers through selective thinning will produce stands with a greater proportional basal area of late-successional species, which will increase with thinning intensity.
2. Canopy openness will increase with thinning intensity.
3. The growth rates of small trees will increase with thinning intensity and pioneer stems will exhibit more growth than late-successional stems, especially in the most intense thinning treatments.

Due to limited time elapsing since the implementation of silvicultural management compared with that required to measure the growth response of larger trees, this study presents only initial findings focusing on plot level responses and the growth of understory stems. However, as the light environment should be altered most dramatically immediately following thinning, the results present a good indication of the initial effect on these stems and the potential of this method for restoration. It is our intention to continue monitoring this experiment for at least 30 years.

2. Materials and methods

2.1. Study site

Harapan Rainforest is a 98,000 ha forest area comprised of two contiguous Ecosystem Restoration Concessions (ERCs) in Jambi and