Forest Ecology and Management 314 (2014) 26–37

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Can harvesting for timber in tropical forest enhance timber tree regeneration?

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ARTICLE INFO

Article history:
Received 2 September 2013
Received in revised form 10 November 2013
Accepted 19 November 2013
Available online 18 December 2013

Keywords:
Functional groups
Ghana
Logging disturbance
Mortality
Recruitment
Soil seed bank

ABSTRACT

It has been suggested that the disturbance caused by logging of tropical forests impairs timber tree regeneration, whilst foresters view logging as a means to stimulate both the growth of the residual trees and the germination and establishment of new recruits. Whilst substantial increases in tree seedlings after logging have been shown, there have been no direct tests of whether this initial enhancement is maintained. We tested if the initial response to logging in a tropical forest in Ghana resulted in increases in seedling recruitment relative to unlogged parts of the same forest and whether subsequent seedling mortality was greater in areas disturbed by logging. We also compared seedling composition, density, species diversity and height 7 y after logging to see if disturbed areas differed from unlogged areas. Timber tree species seedling recruits were assessed after logging in 160 sample plots randomly located on skid trails, felling gaps and in unlogged parts of the same forest. Recruits were named, tagged, mapped, counted and heights measured on five occasions spanning 7 y after logging had ceased. Seedling recruitment was initially enhanced by logging disturbance, principally by Pioneer species, but after 1 y Non-Pioneers dominated the recruits. Mortality of recruits was initially greater in unlogged areas but declined over the 7 y of the study converging on that of disturbed areas to an annualised rate of 0.2. The resultant densities of surviving recruits declined after the initial increase, especially amongst Pioneers. After 7 y, Pioneers were least abundant. Species diversity was initially enhanced by logging disturbance but declined on skid trails after 3 y. In unlogged forest, diversity of recruits increased steadily, and converged on disturbed samples by 7 y. Species composition of recruits initially differed between unlogged and logged samples, but showed convergence after 3 y. The initial effects of disturbance were, however, still detectable at 7 y. The results confirm the initial enhancement of timber tree recruitment after logging disturbance which suffered no greater mortality than unlogged areas. Within 7 y of logging, however, most measures of seedling dynamics were similar in logged and unlogged forest presumably due to canopy closure. Whilst most of the tallest trees at 7 y were Pioneer timber species, Non-Pioneers were numerically dominant. We conclude that appropriately controlled logging does not impair timber tree regeneration. The benefits appear to be securing the establishment and fast growth of Pioneer timber species whose regeneration might be less successful in unlogged forest.

1. Introduction

An important expectation of the Selection System of natural forest management in the tropics is that harvesting operations will stimulate the growth of residual trees (Maitre, 1987) and enhance the regeneration of tree species, particularly those of commerce (Kuusipalo et al., 1996; Magnusson et al., 1999). These effects are argued to be due to reduced competition caused by gap formation in the canopy and soil, increasing light for growth of the residuals and stimulating the germination and establishment of new recruits from seeds.

There is good evidence for increased growth of residuals (e.g. Maitre, 1987; Gourlet-Fleury et al., 2013a,b), but this is accompanied by a period of higher mortality rates, largely due to damage to residual trees during extraction (Johns et al., 1996; Sist and Nguyen-The, 2002). There is also evidence for the stimulation of new seedling recruits in those parts of the forest disturbed by logging operations, (especially skid trails and felling gaps), compared with unlogged parts (Kuusipalo et al., 1996; Magnusson et al., 1999; Fredericksen and Mostacedo, 2000; Swaine and Agyeman, 2008).

The potential benefits for regeneration are tempered, however, by various negative effects. The relaxation of competition offers benefits for all plants, not just timber tree species, but short-lived, non-commercial Pioneer tree species are the most numerous tree beneficiaries in studies where they have been included (Dickinson

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http://dx.doi.org/10.1016/j.foreco.2013.11.025

et al., 2000; Fredericksen and Mostacedo, 2000; Arets, 2005; Park et al., 2005; Felton et al., 2006; Swaine and Agyeman, 2008; Ouédraogo et al., 2011; Gourlet-Fleury et al., 2013a). The effect is stronger in larger canopy openings where the soil is disturbed because these conditions break dormancy of seeds in the soil seed bank and because such tree species demand high irradiance for establishment and continued growth. Other non-tree Pioneers also benefit and may compete strongly with newly recruited commercial species. These include invasive exotics such as *Chromolaena odorata* (L.) King & Robinson in West Africa which is known to suppress the growth of tree seedlings in the field (Honu and Dang, 2000) and in a pot experiment with *Ceiba pentandra* and *Pycnanthus angolensis* (Gough, 2004) (Nomenclature follows Hawthorne, 1995, unless stated). In Bolivia, native species of *Heliconia* may also dominate in logging gaps (Felton et al., 2006) and liana proliferation is widely reported to follow logging (Schnitzer et al., 2004). These effects of competitors may be equivocal as germination and seedling growth of many tree species are maximal in less than full irradiance (Agyeman et al., 1999; Kyereh et al., 1999) so that a light canopy of Pioneers may 'nurse' tender seedlings of such species.

These uncertainties are reflected in a lack of agreement amongst studies. In felling gaps, where soil disturbance is generally less than on skid trails, germination may be less and competition from residual vegetation greater than on skid trails (Fredericksen and Pariona, 2002). However, soil compaction due to skidding may prevent the establishment of seedlings from seeds whose dormancy was broken by the gap microclimate. Removal of topsoil during skidding will also displace the seeds contained within it (Pinard et al., 1996).

Timber tree regeneration following logging may also be affected by the way in which the logging is done (Pena-Claros et al., 2008; Putz et al., 2008). The length and distribution of skid trails will affect the area of disturbance in addition to the number of trees felled. Different operators of extraction vehicles may have different impacts on the forest in terms of total area disturbed and the number of relict trees which are damaged. The type of extraction vehicle (tracked or wheeled) and the season of operations (wet or dry season) will affect the impacts on soil conditions (e.g. compaction, topsoil removal, etc.). In Sabah, Pinard et al. (2000) found that skid trails were still impoverished of woody stems 18 years after logging and in Ghana, Hawthorne et al. (1999) reported reduced stocking on skid trails up to 30 years after logging. Gourlet-Fleury et al. (2013b), in central Africa, concluded that disturbance caused by logging and subsequent thinning of non-commercial species and lianes was followed by rapid recovery of above-ground biomass but slow recovery of timber stocking which was not expected to be complete within the 25–30 years felling cycle. In contrast, Dekker and de Graaf (2003) suggested that forests logged under the CELOS management system recover the stocking of commercial species within 20 years whilst Okuda et al. (2003) found similar basal area and stem density in unlogged forest and forest regenerated with the Malayan Uniform System over 41 years after harvest. These management systems, unlike the Selection System, involve considerable intervention to achieve their results. The differential effects of logging practice on forest have been shown, for example, in comparisons of Reduced Impact Logging with traditional logging (Pinard et al., 2000; Sist et al., 2003; Mac Donagh et al., 2010), and we may expect similar contrasts between carefully controlled and uncontrolled traditional logging.

In studies which showed poor stocking of trees on old skid trails, the presumed initial enhancement of tree recruitment would have been negated by greater mortality on skids trails in subsequent years. The outcome of the diverse possible effects of logging on tree regeneration should therefore be evident by examining logged forest over the years succeeding the harvest by comparing sites of logging disturbance with the undisturbed parts of the same forest.

The Selection System as operated in Ghana is controlled by the Resource Management Services Centre of the Ghana Forestry Commission which calculates the allowable harvest from 100% stock surveys, identifying individuals to be felled and those to be retained as 'seed trees' and completes pre- and post-harvest inspections. Logging operations in the forest follow the advice of the Forestry Commission (Ghana Forest Service, 1998) and are monitored by the relevant Regional Forest Office.

Conservationists have claimed that sustainable management of tropical forests for timber is problematic (e.g. Rice et al., 1977) arguing that economic and political drivers cause overexploitation and permanent damage to the forest. In contrast, others argue that sustainable management is possible, if not often achieved (e.g. Dawkins, 1988). A first requirement of sustainable use is that the regeneration of timber tree species after logging is adequate to replace the extracted and damaged trees. In this study, we tested if controlled logging at two different intensities benefits timber tree regeneration in one Forest Reserve in Ghana. We tested three hypotheses: (1) the initial seedling recruits of timber tree species after logging are more numerous in parts of the forest disturbed by logging; (2) recruited seedlings suffer higher mortality in parts of the forest disturbed by logging than in areas unaffected by logging; and (3) within 7 years, the density of timber tree recruits is no greater in disturbed areas than in areas unaffected by logging.

2. Materials and methods

The rationale for our methods was as follows. We established permanent sample plots on skid trails, in felling gaps and in unlogged parts of the forest in order to monitor the density, growth and mortality of tree seedling recruits for 7 y after logging. Recruits were identified to species so that the effects of logging on species diversity and composition could be monitored. We measured initial post-logging canopy openness and scored soil conditions in order to distinguish these two influences on seedling dynamics. We measured soil seed bank densities in order to assess its contribution to the recruits relative to the seed rain from current adults.

2.1. Study site

The research was conducted in Compartment 4 (c. 134 ha) of Pra Anum Forest Reserve (123 km^2, 6°11′ to 6°20′N, 1°07′ to 1°16′W; Fig. 1) in Ghana, which was reserved and gazetted in 1925. The reserve has been logged several times since 1954 under the control of the Ghana Forestry Commission (formerly the Forest Department).

The forest falls within the moist semi-deciduous forest type (SE sub-type) of Hall and Swaine (1981) and is mostly of gentle topography at about 120 m asl rising to about 160 m (Fig. 1). The tallest trees are about 50 m. Mean annual rainfall at Amantia over a 5 y period prior to 1963 was 1620 mm, slightly higher than longer-term means at two other stations within 15 km (Ntronang, 1538 (25 y); Akokoase, 1543 mm (25 y)). The 45 y mean for Akim Oda (40 km S) was 1580 mm prior to 1963 but the mean at Akim Oda for 2000–2005 was less at 1377 mm. It is not clear if this is a reflection of the general decline (Nicholson et al., 2000) in West African forest rainfall. There are 4 months each year with rainfall < 100 mm, with peaks in June and October.

Soil conditions, as judged from a nearby single bulked sample (No. A65 in Hall and Swaine (1976)) are: pH 5.1, total exchangeable bases 4.2 m-equiv/100 g, total nitrogen 0.22% (Kjeldhal), available phosphorus 6.6 ppm (fluoride extraction), 33% sand and 21% clay (Boyoucos particle size analysis).