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Natural establishment of indigenous trees under planted nuclei: A study from a clear-felled pine plantation in an afrotropical rain forest

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ABSTRACT

Applied nucleation has been proposed as a cost-effective reforestation alternative to large-scale re-planting or establishing plantations with exotic tree species. We tested applied nucleation in a regenerating clear-cut pine plantation in Kibale National Park, Uganda, where natural succession had been slow. We planted *Neoboutonia macrocalyx*, a relatively common indigenous pioneer tree species with animal dispersed seeds and a wide crown, in the pine plantation clear-cuts as seeds and transplanted seedlings. After six years of monitoring the growth of the nucleus trees we identified all naturally recruited seedlings under the nuclei and adjacent control sites without planted nuclei. We monitored the growth and turnover of the recruited seedlings for one year and examined the ground vegetation structure under the nuclei and control sites. We found that the *N. macrocalyx* nucleus trees had survived equally well if planted as seeds or transplanted seedlings and had attained heights up to ten meters tall. Understory vegetation structure under the established nuclei was less dense ($P = 0.001$) and shorter ($P = 0.039$) compared to control sites. We also found that natural recruitment of indigenous tree species under the nuclei was higher compared to control sites. The seedling density under the nuclei was significantly higher ($P = 0.035$), and there was a significant difference in the composition of seedling communities ($P = 0.0001$) with a larger number of different tree species found under the nuclei. We found that a viable seedling community had been established with a good potential to take over when planted nucleus trees eventually die. Our results show that planting nucleus trees can increase recruitment of indigenous tree species in locations where natural succession is otherwise slow.

1. Introduction

There is an urgent need to develop cost-effective and ecologically sound forest restoration strategies in the tropics in order to curb the loss of ecosystem services (Lamb et al., 2005), conserve biodiversity (Laurance and Useche, 2009), reduce carbon emissions (van der Werf et al., 2009) and reverse altered hydrological cycles (Sheil and Murdiyarso, 2009). More than half of the tropical moist forest cover has been reduced to less than 50% of tree cover (Asner et al., 2009). Achard et al. (2014) estimated forest cover changes in the tropics in 1990–2000 and 2000–2010 and recorded a net forest loss in humid tropical forests to be 4.0 million ha per year in the 1990s and 3.2 million ha per year in the 2000s, whilst the total cover of humid tropical forests in 2010 was 972 million ha. Rightly, restoration of degraded ecosystems has been recognized as an increasingly important global environmental policy target (Aronson and Alexander, 2013).

The most economic reforestation strategy is to leave logged or otherwise degraded areas to regenerate naturally (Lamb et al., 2005). However, this strategy is sometimes inefficient. Degradation may have resulted in topsoil loss and reduced soil fertility impairing reforestation potential. Woody shrubs and herbaceous plants can also encroach upon the recovering stands, thereby suppressing tree recruitment and resulting in arrested succession (Paul et al., 2004). Moreover, a considerable factor impeding forest recovery is lack of seed dispersal (Holl, 1999; Holl et al., 2000). Most tropical rainforest seeds remain viable only for a short time in the soil, even if they form part of the soil seed bank (Vázquez-Yanes and Orozco-Segovia, 1993). Therefore, succession in degraded lands depends on recently dispersed seeds (Holl, 1999). The majority of tropical tree species depend on animals for dispersal (Howe, 1984); however, most animals avoid open areas since they offer few resources for frugivores, limited shelter from predators and no trees for birds to perch or bats to fly (Schupp et al., 1989).

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Active reforestation in the tropics is often carried out by establishing industrial monocultures with a limited number of species belonging to a small number of genera (particularly *Pinus*, *Eucalyptus* and *Acacia*) (Lamb et al., 2005). However, according to Lamb et al. (2005), even though these monocultures may be economically profitable, they fail to provide the same level of goods and services once provided by the indigenous forest. Restoration planting offers an alternative approach and is carried out particularly when attempting to re-establish indigenous forest ecosystems and the services they provide. This can be done by re-planting an entire area either with small number of pioneer tree species or by densely planting a greater number of species representing later successional stages (e.g. Parrotta et al., 1997; Lamb, 1998; Lamb et al., 2005; Rodrigues et al., 2009; Holl, 2012). However, application of these approaches is often limited by their high cost (Holl et al., 2011).

The restoration approach referred to as applied nucleation can offer a cost-effective alternative to extensive re-planting, but despite some promising results it has been relatively little studied (Corbin and Holl, 2012). This technique builds on the nucleation hypothesis (Robinson and Handel, 2000; Zahawi and Augspurger, 2006) by promoting the natural recovery process using a small number of pioneer tree species established in patches to create canopy cover and facilitate recruitment of other tree species (Yarranton and Morrison, 1974). The established tree islands or "nuclei" can also trap wind-dispersed seeds (Franks, 2003; Zahawi et al., 2013) as well as attract animal seed dispersers that would otherwise avoid open areas, allowing natural recruitment and the forested area to expand (Schlawin and Zahawi, 2008). The nuclei then shade out grasses and other competing plants, which favors germination, natural establishment of tree seedlings and increases the rate of forest expansion over time (Elliot et al., 2003). Examples of recent research on applied nucleation include a study by Albornoz et al. (2013) who examined the nucleation process in a burned area of an evergreen temperate rainforest in Chile. The study recorded higher tree regeneration under remnant tree patches compared to open areas and found that whereas open areas were waterlogged, the areas under patches were not and the patches also attracted bird seed-dispersers. Peterson et al. (2014) tested nucleation hypothesis in abandoned pastureland in Costa Rica and found indications that only larger (>40–50 cm DBH and taller than 20 m) isolated trees enhanced recruitment whereas smaller trees did not. The same study also found that in addition to larger trees, patches of other microsites, such as nurse logs and steep slopes promoted tree recruitment to a similar degree compared to larger isolated trees. Similarly, natural tree recruitment was examined on former pasture sites in a tropical premontane forest zone in Costa Rica by applying two restoration strategies, planting trees throughout and planting different sized tree islands and comparing the active restoration sites to control sites undergoing passive restoration (Holl et al., 2011, 2013; Zahawi et al., 2013). The studies found that both active restoration methods increased the abundance and diversity of tree recruitment and the active restoration sites had a higher level of animal-dispersed tree species compared to passive restoration sites. The studies found that the level of tree recruitment in the island treatment was similar to the more intensive plantations, concluding that applied nucleation has good potential as a restoration strategy since it yields similar results to larger scale planting but is less expensive to implement.

Our study examined experimentally if planting patches of an indigenous, early successional tree species in clear-cut pine plantation gaps can facilitate natural forest regeneration by forming recruitment nuclei for other tree species. We asked (i) Do planted *N. macrocalyx* Pax tree seeds and seedlings survive and grow to form patches of canopy cover in clear-cut plantation gaps where natural succession has been found to be slow? (ii) Is natural establishment of indigenous tree seedlings under the nuclei higher compared to adjacent open areas and hence (iii) Is applied nucleation an effective restoration technique in areas where natural regeneration is slow? According to nucleation hypothesis (Zahawi and Augspurger, 2006), under established nuclei we expected to see less dense and shorter understory vegetation cover, higher density of naturally recruited seedlings and differences in seedling communities when compared to control sites.

2. Methods

2.1. Study area

This study was carried out in Kibale National Park (KNP), Uganda (Fig. 1) (0°13′ to 0°41′N and 30°19′ to 30°32′E, 795 km^2). The altitude ranges between 1110 and 1590 m above sea level and the area has two distinct rainy seasons from March to April and from September to November (Struhsaker, 1997). The annual rainfall monitored between 1990 and 2011 at the Makerere University Biological Field Station was 1696 mm (Chapman and Chapman unpublished data after Chapman et al., 2013). The soil has been characterized as dark gray to red sandy loams or sandy clays with a soil fertility ranging from fair or favorable to good (McKey et al., 1978). The KNP comprises different habitats including swamps, grasslands, mature forest and colonizing forest patches (Struhsaker, 1997).

The forest also contained exotic softwood plantations (mainly *Pinus and Cupressus*) that were established in grasslands in the late 1960s and early 1970s (Fimbel and Fimbel, 1996). The grasslands themselves were presumably a result of former agricultural activities in the forest (Kingston, 1967 after Fimbel and Fimbel, 1996). The forest was granted a national park status in 1993 (Struhsaker, 1997) after which the softwood plantations have gradually been logged in order to allow natural forest recovery. The KNP also contains a variety of canopy gaps resulting from logging of the plantations (Chapman et al., 2010) and selective logging of mature forest (Paul et al., 2004). The management strategy was to leave these cleared areas to regenerate naturally, but succession in the gaps has been slow or even arrested, and the gaps are commonly dominated by grasses, shrubs and herbs, such as *Pennisetum purpurea* and *Acanthus pubescens* (e.g. Paul et al., 2004; Lawes and Chapman, 2006) and *Lantana camara* (authors' personal observation).

Our study was established at the vicinity of the Makerere University Biological Field Station, in the former Nyakatojo plantation that was logged during 1995–1999. The study was established in gaps where trees had not recruited naturally.

2.2. Study species

We used *Neoboutonia macrocalyx* Pax (Euphorbiaceae) since it is a relatively common early successional tree species across East Africa and therefore a tree that one could expect to find in the plantation clear-cuts. The distribution of *N. macrocalyx* ranges across the montane forests of central and eastern Africa (Lovett et al., 2006), such as Kibale forest in Uganda and Mt. Kenya forest in Kenya where it has been found to colonize post-logging gaps (author's personal observation). It is also found in some lowland rainforests like Kakamega in Kenya and Semuliki National Park in Uganda (Roininen personal observation). It usually grows in open areas, especially along valley bottoms and swamps (Chapman et al., 1999) and in secondary and partially logged forests (Kasenene and Roininen, 1999), but it is uncommon in low-light environments (Chapman et al., 2008). It is a medium sized tree