To plant or protect: Evaluating forest recovery dynamics under natural and aided regeneration in western Kenya

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Abstract

Forest degradation remains a serious problem in Kenya, but opinion is divided on whether to protect degraded forests in order to facilitate natural regeneration or plant them to accelerate forest recovery. In situations where tree planting has been adopted, appropriate spacing has also been identified as a challenge. We used a replicated randomized block experiment to compare forest recovery under site protection and aided regeneration at 0.3 m, 1 m and 5 m spacing in order to identify the most appropriate forest rehabilitation technique in the Nandi Forest Ecosystem. Data was collected on tree species type, tree height and diameter at breast height (DBH). The data was analyzed using two-way analysis of variance in Genstat procedures. Under aided forest recovery, tree height and DBH were significantly higher at 0.3 m spacing than 1 m and 5 m, which gave fairly comparable results. There was no significant difference in tree height and DBH between natural regeneration and aided forest recovery at 0.3 m spacing. Findings of the study suggest that site protection and dense planting give fairly similar results, but the former is more appropriate in degraded forest sites with adequate sources of natural regeneration, such as a viable soil seed bank, remnant trees and stump sprouts. Aided forest recovery, particularly dense planting, is suitable in sites with insufficient sources of natural regeneration.

Key words: Forest degradation, natural regeneration, aided recovery

1. Introduction

Over the past century, Kenya's natural forests have been subjected to varying levels of degradation. The latest state of forests report indicates that the country's closed canopy forest cover decreased from about 12 % in 1960s to 1.9 % in 2010 as a result of over-exploitation of woody forest resources, forest fires and land use conversion to pasture and farmland (FAO, 2010; KFS, 2010). Areas that previously comprised pristine primary forest have been converted to disturbed primary forest, secondary forest, forest plantations and man-made glades (Tsingalia & Kassily, 2009). The situation has compromised the ability of these forests to sustain some of their key functions, such as biodiversity conservation, carbon sequestration and provision of timber and non-timber forest products (Blanc et al., 2000). Ordinarily, degraded tropical forests recover naturally after a disturbance event (Smidt & Blinn, 1995; Turner et al., 1998). However, in Kenya and many other developing countries, the recovery of a majority of degraded natural forests has been observed to delay by well over two decades after initial disturbance (Duncan & Chapman, 2003; Sajise, 2003; Otuoma et al., 2010). The delay is characterized by the invasion of degraded forest sites with non-wood plants such as ferns, vines, grasses and shrubs at the expense of woody species (Capers et al., 2005).

The traditional view of secondary forest succession (Clements, 1916) suggests that the delay in forest recovery may be due to poor habitat quality caused by forest degradation. Studies supporting this view suggest that habitat quality improves as the age of a degraded forest increases to the extent that the pH and base saturation of the topsoil decrease (Bossuyt et al., 1999), while shading, litter accumulation and topsoil organic matter content increase, which are useful for the recruitment and growth of woody species (Bawa & Ng, 1990; Muys et al., 1992; Verheyen et al., 1999). Other studies identify habitat quality as a minor factor regulating woody species regeneration in degraded forests and argue that seed dispersal limitations arising from site disturbance is the main impediment to post-disturbance forest recovery (Debussche & Lepart, 1992; Matlack, 1994; Brunet & Von Oheimb, 1998). They argue that forest disturbance, such as logging, affects tree fruiting pattern in forests by altering the microhabitat and distribution of trees species, consequently altering seed production and dispersal pattern. Recent studies on natural forest rehabilitation indicate that deterioration in habitat quality and seed dispersal limitations are important constraints to post-disturbance forest regeneration, but repeat site disturbance through grazing and trampling by herbivores and forest fires is perhaps the most important factor that delays post-disturbance forest recovery after initial disturbance (Otuoma et al., 2010).

In recognition of the delay in post-disturbance natural forest regeneration, attempts have been made to rehabilitate these forests, but these too have had little success (Catterall et al., 2008). Their failure has been attributed to inadequate understanding of suitable rehabilitation approaches to address the various constraints to natural forest regeneration (Smidt & Blinn, 1995; Turner et al., 1998). For instance, one of the greatest challenges to forest rehabilitation presently is the conflict of opinion on whether to protect degraded forests in order to facilitate natural regeneration or plant them to accelerate forest recovery (Lung, 2009). In situations where tree planting has been adopted, appropriate spacing has also been identified as a challenge. It is therefore important to identify techniques suitable for rehabilitating different levels of forest degradation, and also the procedures for implementing these techniques (Catterall & Kanowski, 2010).

The present delay in post-disturbance recovery of most degraded forests implies that Kenya will continue to receive sub-optimal levels of key forest goods and services for the foreseeable future. Moreover, in the event of further forest degradation, which is highly likely, the situation would not only worsen, but also make the country extremely vulnerable to climate change, weather-related disasters and food insecurity (Gregory & Ingram, 2000; Ludi, 2009; Sonwa et al., 2009). Kenya's South Nandi Forest Ecosystem is one of the degraded forest blocks where post-disturbance forest recovery has not only delayed, but rehabilitation interventions have also failed (Otuoma et al., 2010). Given the forest's unique attribute as one of the few forests with rainforest and afro-montane species, its degradation is likely to lead to loss of critical biodiversity and ecosystem services (Tsingalia & Kassily, 2009). The forest was gazetted in 1936 as a forest reserve with an area of about 20,200 ha. Over the past five decades, approximately 3,260 ha of its original primary forest have been clear-felled; 1,400 ha have been placed under exotic forest plantations; 2,200 ha have been excised for human settlement; while 340 ha have been converted to tea plantation. The present closed canopy forest cover is only 13,000 ha (BirdLife International, 2013). For the past two decades, efforts have been made by the Kenya Forest Service and non-governmental agencies, such as Nature Kenya to rehabilitate the degraded 3,260 ha, which presently comprises scrubby grassland, with very little success. In 2009, the Kenya Forestry Research Institute (KEFRI) initiated a study to evaluate forest recovery dynamics under natural and aided forest regeneration. Thus, the objective of this paper was to assess woody species growth performance under natural and aided forest recovery in research plots that were established by KEFRI. Findings of the study are expected to assist in identifying the most appropriate forest rehabilitation techniques to accelerate the recovery of degraded natural forests in Kenya.

2. Materials and methods

2.1 Study area

The study was carried out in Kobujoi Block of South Nandi Forest between March 2009 and April 2013. The forest is located west of Kapsabet Town and east of Kakamega Forest at $0^{o}.00'$ & $0^{o}.15'$N and $34^{o}.45'$& $35^{o}.07'$E (Njunge & Mugo, 2011). It falls within a transition zone between a tropical rainforest and tropical afro-montane forest. The transition is caused by the fact that the western part of the forest is an extension of the Kakamega rainforest at 1,700 m above sea level, while the eastern part extends into the Rift Valley at an elevation of about 2,000 m above sea level (Tsingalia & Kassily, 2009). The increase in altitude causes a gradual change in species characteristics from tropical rainforest to tropical afro-montane forest (BirdLife International, 2013). The area's mean annual rainfall ranges from 1,600 to 2,000 mm, while the mean temperature is 19^{o} C (Jaetzold & Schmidt, 1983). The area has a gently undulating terrain underlain by granitic and basement rocks, which weather to give deep, well-drained soils (BirdLife International, 2013). The forest is the upper catchment of Kimondi and Sirua rivers, which merge downstream to form River Yala that drains into Lake Victoria (Mitchell et al., 2006). It has over 86 indigenous woody species. The most dominant of these species are *Croton megalocarpus*, *Tabernaemontana stapfiana*, *Strombosia scheffleri*, *Macaranga kilimandscharicum* and *Celtis africana* (Njunge & Mugo, 2011). The Forest is classified as an Important Bird Area with over 60 species of birds (BirdLife International, 2013). According to the 1999 human population census, approximately 371 people per km^2 reside within 3 km from the forest boundary and depend on it for firewood, honey, pasture, construction materials, herbal medicine and indigenous fruits and vegetables (Kenya National Bureau of Statistics, 2011).

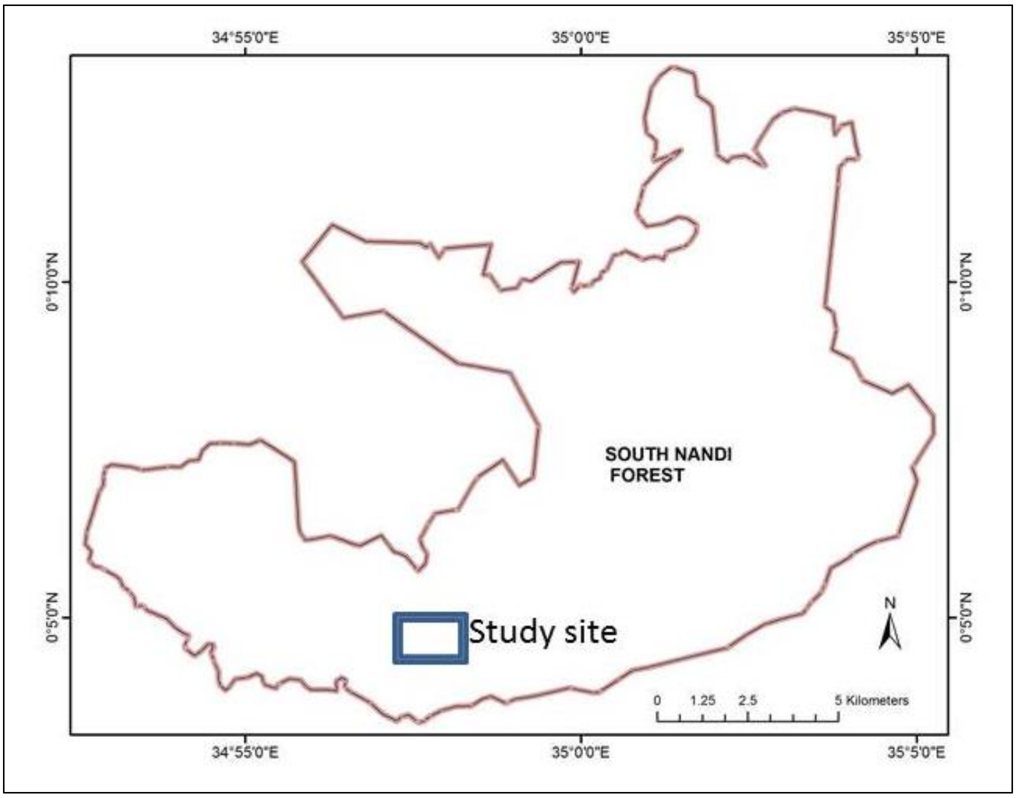

Figure 1: An illustration of the study site in South Nandi Forest. Map developed from topographic maps using geographic information techniques.

2.2 Study design

The study employed a randomized block design with three replicates to assess the recruitment and growth performance of woody species under natural and aided forest regeneration. The replicates comprised three sample plots of approximately 100 m by 120 m located about 0.5 to 1 km away from each other. A sample plot was sub-divided into two equal parts: one part was protected from repeat site disturbance using an enclosure, while the other part was exposed to disturbance and served as the control. The enclosed plot was further sub-divided into four equal parts of 50 m by 30 m. One of the four sub-plots was placed under natural regeneration, while the other three were placed under aided regeneration with mixed indigenous species planted at 5 m by 5 m, 1 m by 1 m and 0.3 m by 0.3 m spacing. Simple random sampling was employed to collect data in the three sample plots. Data were collected using three randomly located 10 m by 5 m sampling plots in each of the 50 m by 30 m sub-plots and the control plot.

2.3 Data collection

Data were collected on tree species, tree height and tree diameter at breast height (DBH) or root collar diameter (RCD) for saplings shorter than 1.5 m in height. Tree species were identified by their botanic names. Data on tree DBH were obtained by measuring tree diameter in centimeters at 1.3 m above the ground using a diameter tape. Tree height was measured in meters using a ranging rod. Data collection was carried out once every year over a period of three years.

2.4 Data analysis

The data set on tree species was used to analyze changes in woody species richness over time under site protection and aided forest regeneration using two-way analysis of variance

(ANOVA) in Genstat at 95% confidence level (VSN International, 2009; Sokal & Rohlf, 2012). The data set on tree height was used to determine variation in mean tree height under site protection and aided forest regeneration. The data on tree stem diameter were used to analyze variation in mean stem DBH under site protection and aided forest regeneration.

3. Results

3.1 Natural regeneration

There was a significant variation in the number of woody species, stem density, tree height and stem diameter between protected and unprotected sites that were placed under natural forest regeneration. The protected site had more woody recruits, greater tree height and stem DBH than the unprotected area.

3.1.1 Number of woody species. In the protected site, the number of woody species increased from four at the point of erection of enclosures to 23 three years later. During the same period, the number of woody species decreased from four to one in the unprotected area.

3.1.2 Stem density. The number of woody stems increased significantly in the protected site compared to the unprotected area ($F_{(1,1)} = 11.81$; $p < 0.001$). The variation became more pronounced over time with the number of recruits increasing from 40 stems ha^{-1} during the erection of enclosures to 107 stems ha^{-1} after one year, 167 stems ha^{-1} in the second year and 653 stems ha^{-1} by the third year (Figure 2). In the unprotected site, the number of recruits increased from 34 stems ha^{-1} to 47 stems ha^{-1} over the three year period.

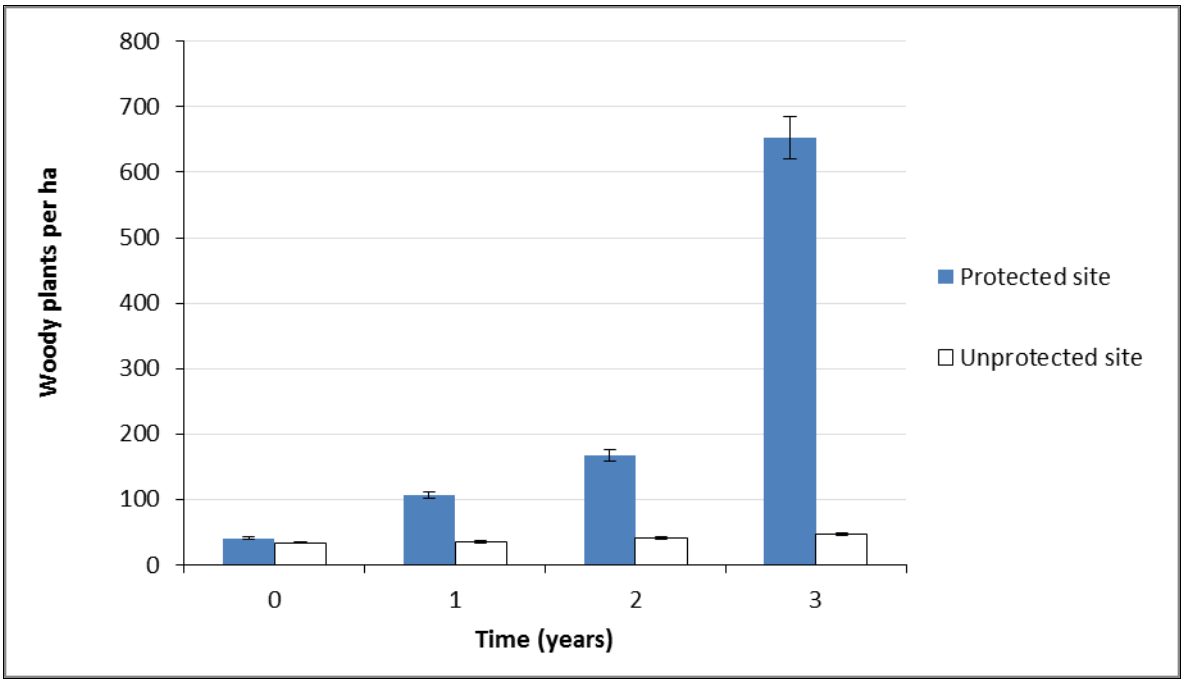

Figure 2: Changes in stand density over a three year period in protected and unprotected sites under natural forest regeneration in South Nandi Forest

3.1.3 Tree height. Tree height increased in both protected and unprotected sites, but the rate of increase was significantly higher in the former than in the latter ($F_{(1,1)} = 51.47$; $p < 0.001$).

The highest rate of increase in tree height within the protected site was recorded in the first year of natural forest regeneration (Table 1).

Table 1: Changes in tree height over a three year period in protected and unprotected sites under natural forest regeneration in South Nandi Forest

Site status	**Mean tree height (m)**			
	Year 0	**Year 1**	**Year 2**	**Year 3**
Protected	0.364 ± 0.30	2.137 ± 0.41	2.800 ± 0.77	3.738 ± 1.09
Unprotected	0.396 ± 0.39	0.614 ± 0.18	0.925 ± 0.19	1.150 ± 0.22

3.1.4 Tree DBH. The rate of increase in stem diameter was significantly higher in the protected area than in the unprotected site ($F_{(1,1)} = 21.06$; $p < 0.001$). The greatest increase in tree DBH within the protected site was recorded in the first year (Figure 3).

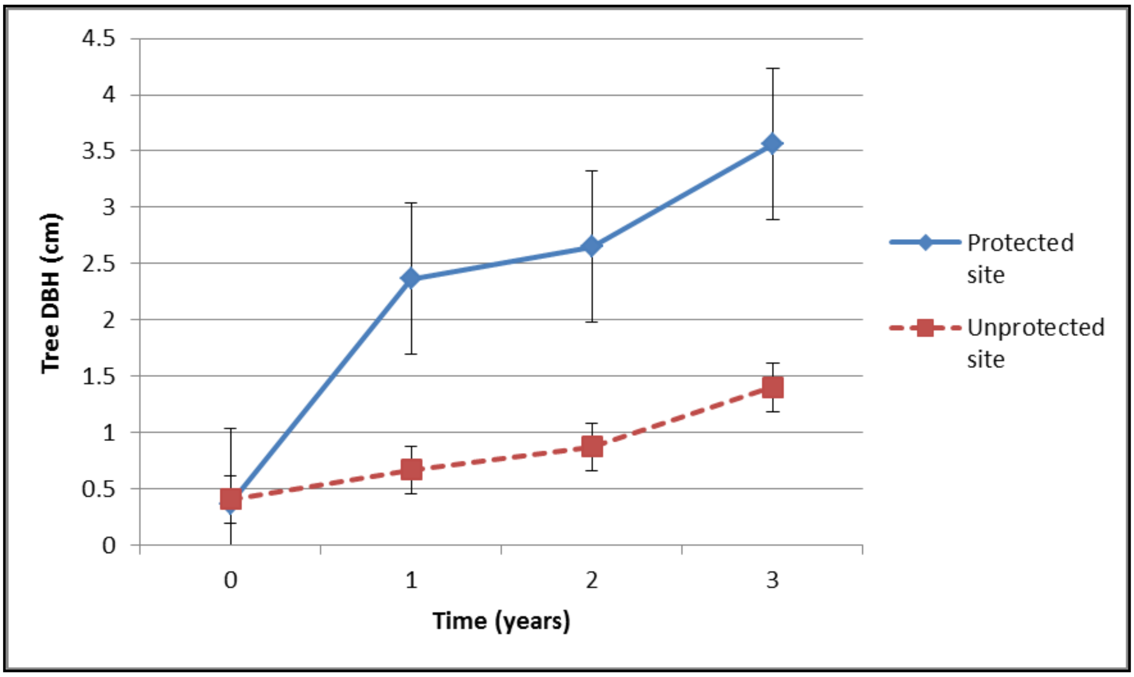

Figure 3: Changes in tree DBH over a three year period between protected and unprotected sites under natural forest regeneration in South Nandi Forest.

3.1.5 Key natural forest regeneration species. A comparison of the growth performance of the 23 tree species that recruited through natural regeneration indicated that *Albizia gummifera*, *Croton megalocarpus*, *Harungana madagascariensis* and *Psidium guajava* were the fastest growing (Figure 4).

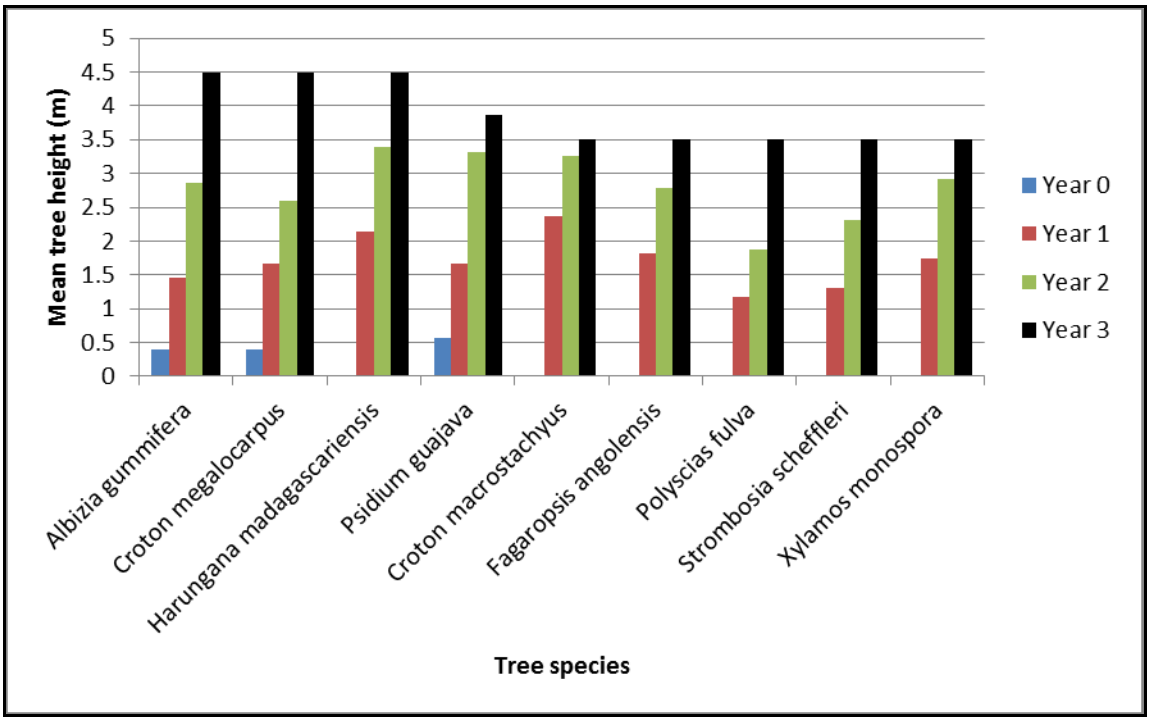

Figure 4: A comparison of tree growth rates among key natural forest regeneration species over a three year period in South Nandi Forest

3.2 Aided forest regeneration

There was a highly significant difference in tree growth performance between 0.3 m spacing on the one hand, and 1 m and 5 m spacing on the other hand. There was an observed difference in tree growth performance between 1 m and 5 m spacing, but it was not statistically significant.

3.2.1 Tree height. The rate of increase in tree height was much faster under 0.3 m spacing than 1 m and 5 m spacing, both of which were not significantly different from each other ($F_{(1,2)} = 22.57$; $p < 0.001$) (Table 2).

Table 2: Variation in mean tree height over a three year period under different aided forest regeneration spacing regimes in South Nandi Forest

Spacing (m)	Mean tree height (m)			
	Year 0	**Year 1**	**Year 2**	**Year 3**
0.3	0.351 ± 0.06	1.459 ± 0.09	2.528 ± 0.16	3.604 ± 0.25
1	0.349 ± 0.08	0.587 ± 0.10	1.246 ± 0.23	1.641 ± 0.05
5	0.356 ± 0.06	0.648 ± 0.13	1.279 ± 0.21	2.037 ± 0.08

3.2.2 Stem DBH. The rate of increase in mean tree DBH was significantly higher at 0.3 m spacing than 1 m and 5 m spacing ($F_{(1,3)} = 6.6$; $p = 0.002$). The observed difference in stem diameter between 1 m and 5 m spacing was not statistically significant (Figure 5).

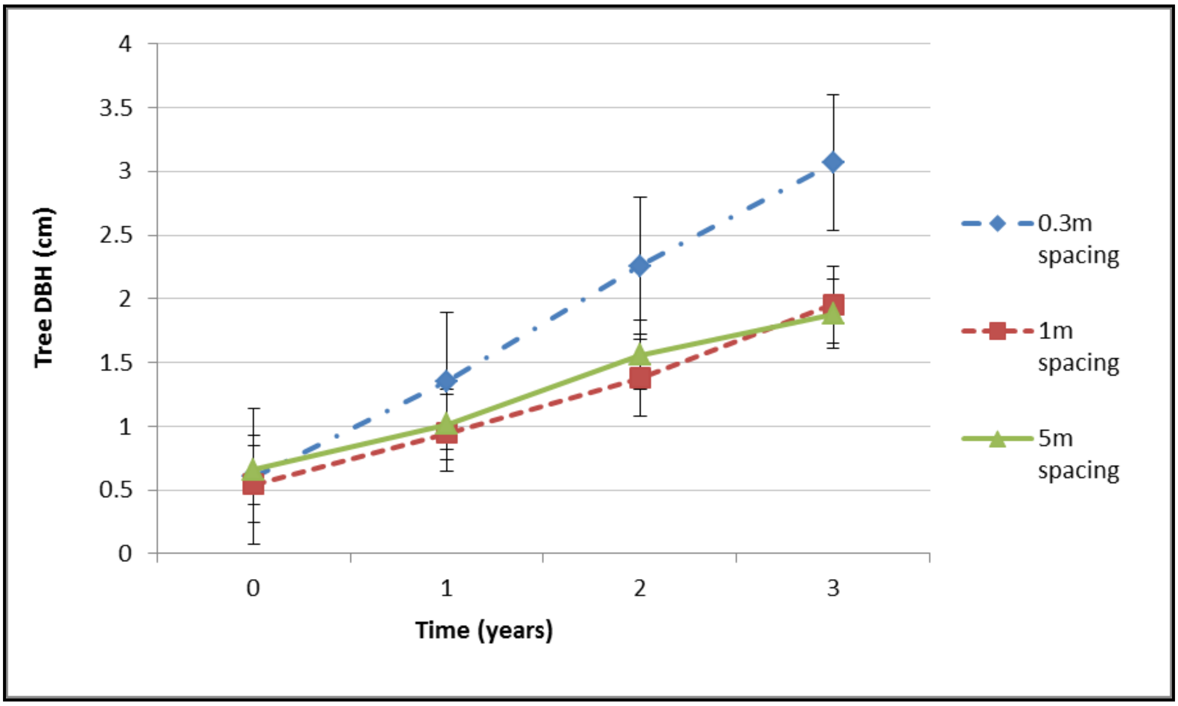

Figure 5: Variation in mean tree DBH over a three year period under different spacing regimes in aided forest regeneration in South Nandi Forest

3.2.3 Growth performance of key aided regeneration species. A comparison of the growth performance of the eleven tree species used for aided forest regeneration indicated that *Harungana madagascariensis*, *Croton megalocarpus*, *Spathodea campanulata* and *Croton macrostachyus* were the fastest growing species (Figure 6).

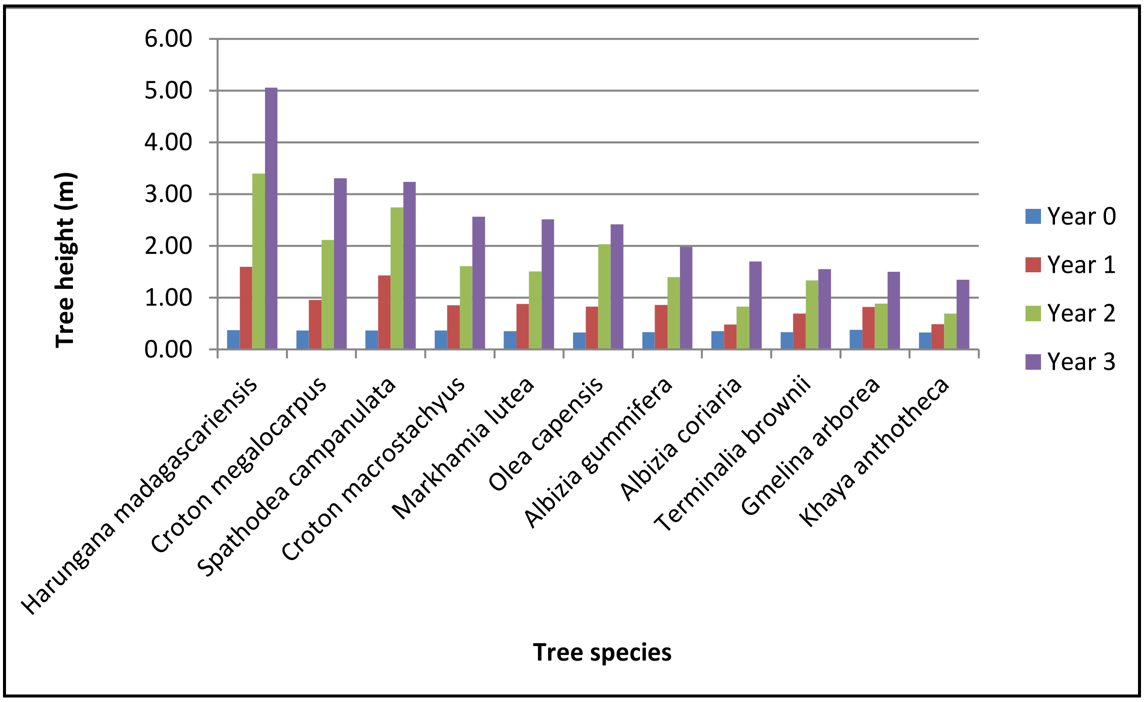

Figure 6: Variation in mean tree height over a three year period under aided forest regeneration in South Nandi Forest

3.3 Comparing tree growth under natural and aided forest regeneration

3.3.1 Tree height. The rate of increase in tree height under natural forest regeneration was slightly higher, but not significantly different from that under 0.3 m spacing. It was, however, significantly higher than that under 1 m and 5 m spacing ($F_{(1,3)} = 23.45$; $p < 0.001$) (Table 3).

Table 3: A comparison of tree growth rates over a three year period under natural and aided forest regeneration in South Nandi Forest

Rehabilitation technique	Mean tree height (m)			
	Year 0	**Year 1**	**Year 2**	**Year 3**
0.3 m spacing	0.351 ± 0.06	1.459 ± 0.09	2.528 ± 0.16	3.604 ± 0.25
1.0 m spacing	0.349 ± 0.08	0.587 ± 0.10	1.246 ± 0.23	1.641 ± 0.05
5.0 m spacing	0.356 ± 0.06	0.648 ± 0.30	1.279 ± 0.30	2.037 ± 0.08
Natural regeneration	0.380 ± 0.25	1.889 ± 0.13	2.689 ± 0.21	3.634 ± 0.20

3.3.2 Stem DBH. The rate of increase in tree DBH was slightly higher under natural forest regeneration, but it was not significantly different from that under aided regeneration at 0.3 m spacing. It was, however, significantly higher than that under 1 m and 5 m spacing ($F_{(1,3)} = 8.03$; $p < 0.001$) (Figure 7).

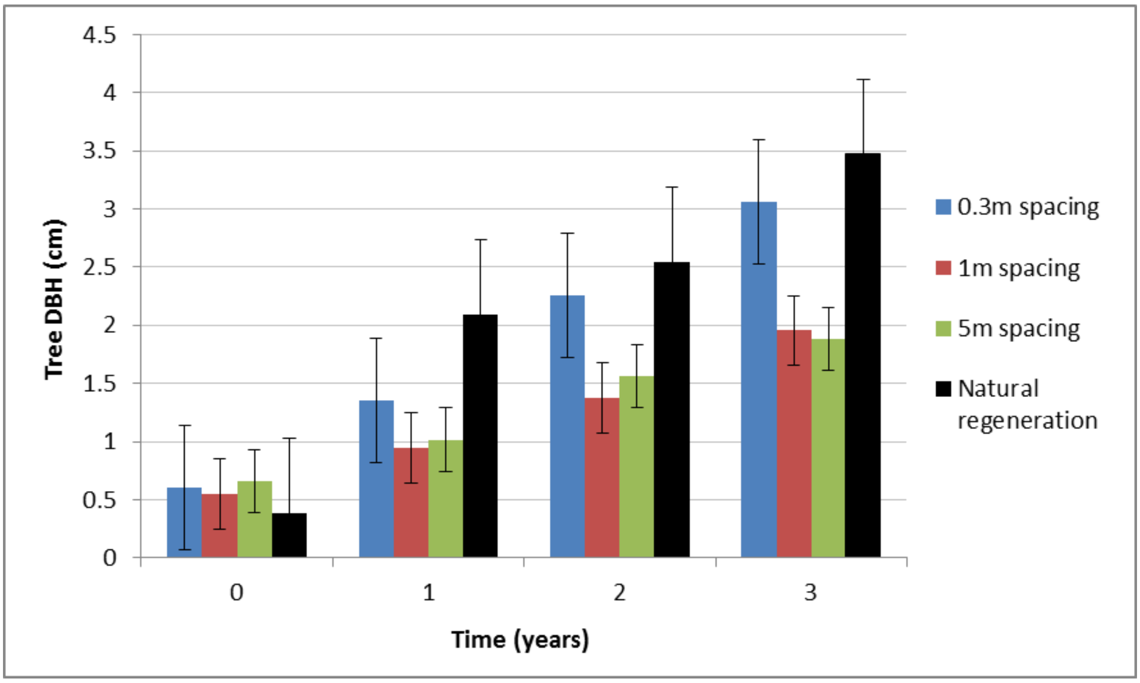

Figure 7: Variation in mean tree DBH over a three year period under both natural and aided forest regeneration in South Nandi Forest

4. Discussion

4.1 Role of site protection in forest regeneration

The results of this study indicate that site protection is a critical factor for both natural and aided forest recovery. They also explain the long standing controversy on whether delay in post-disturbance forest regeneration is caused by site quality limitations arising from initial site disturbance or repeat incidences of disturbance (Muys et al., 1992; Bossuyt et al., 1999; Honnay et al., 1999; Verheyen et al., 1999; Baeten et al., 2009). The spontaneous increase in woody recruits, tree height and stem diameter upon the erection of enclosures is a clear indication that the delay in post-disturbance forest recovery is caused mainly by repeat incidences of disturbance, such as grazing, logging, crop cultivation and forest fires. If the delay was caused by initial site disturbance, then site protection would not have an immediate effect on natural forest regeneration. However, it is important to note that site protection may not lead to immediate natural forest recovery in sites that have lost sources of regeneration, such as remnant trees, stump sprouts and a viable soil seed bank (Debussche & Lepart, 1992; Brunet & Von Oheimb, 1998; Singleton et al., 2001; De Keersmaeker et al., 2011). Nonetheless, unless the initial disturbance constitutes clear-felling of a forest stand, most sources of regeneration are normally lost through repeat incidences of disturbance (Sajise, 2003).

Despite showing the merits of site protection in forest recovery, one of the limitations of the study is its failure to provide a practical and affordable remedy against repeat forest disturbance. The erection of enclosures that was applied in the study is both economically and ecologically unviable, particularly over large degraded forest areas. It is not only too costly, but it is also likely to hinder the free movement of animal biodiversity within a forest ecosystem. In an effort to protect disturbed forest sites in the future to facilitate natural forest recovery, forest managers may be compelled to identify forest protection strategies that are both affordable and ecologically sound. One such strategy is regulated resource use (Costanza & Neuman, 1997; Kissinger et al., 2012). For instance, grazing permits that are presently issued by the Kenya Forest Service to livestock owners may have to indicate clearly areas where such grazing is prohibited, as opposed to the current scenario where permit holders can graze their livestock in any part of the forest. Moreover, livestock carrying capacity should be a key consideration in the issuance of permits to ensure that grazing does not convert designated grazing sites into degraded forest lands.

4.2 Natural or aided forest regeneration?

Although opinion tends to favour aided forest recovery over natural forest regeneration, the results of this study indicate that both forest rehabilitation techniques give fairly comparable outcome with regard to tree growth performance. Thus, in a situation where either of the two techniques is applicable, it would be advisable to employ natural forest regeneration. Nonetheless, the preference for any of the two techniques should be guided by the rehabilitation needs of a given degraded forest site because the two forest rehabilitation techniques work best under different site conditions (Lamb & Gilmour, 2003; Shono et al., 2007). For instance, natural forest regeneration works better in degraded forest sites with sources of regeneration, such as remnant trees, a viable soil seed bank and / or stump sprouts (9). It is often less successful in degraded sites where regeneration sources have been removed through prolonged cultivation or repeat forest fires. Aided regeneration, on the other hand, is ideal for degraded forest sites where seed sources have been removed by repeat disturbance events. It can also be applied to enhance woody species diversity in sites where forest degradation has reduced tree species richness (ITTO, 2002; Kigomo et al., 2010). Thus, aided forest recovery works best in sites that have been exposed to severe levels of forest degradation. However, it often presents the challenge of high cost of establishment and maintenance of planted seedlings. The challenge becomes more serious if planting is carried out in a site with high potential for natural regeneration because planted seedlings end up being swamped by natural growth (9).

4.3 Optimal spacing under aided forest regeneration

This study does not provide a conclusive finding on a spacing regime that can be considered most suitable under aided forest recovery. However, it provides important insight regarding spacing regimes that range between 1 m and 5 m, indicating that they do not provide impressive outcome in the short term with regard to tree growth performance. The 0.3 m spacing, however, raises questions regarding its costs and whether its results can be achieved at a spacing that is less than 1 m but greater than 0.3 m. On this basis, it would be interesting to find out in a future study if tree growth performance is likely to vary significantly under 0.5 m and 0.3 m spacing.

Conclusion

The delay in post-disturbance forest recovery is caused mainly by repeat disturbance events, such as grazing, cultivation, logging and forest fires, which inhibit the recruitment and growth of woody species. The absence of woody recruits gives shrubs, ferns, vines and grasses an opportunity to colonize degraded forest sites. In such a situation, it is advisable to employ either natural or aided forest rehabilitation techniques to accelerate forest recovery. The two techniques are suitable for different levels of forest degradation, but they give a fairly similar outcome in terms of tree growth performance in degraded forest sites. Natural regeneration is suitable for degraded sites with sources of regeneration, such as remnant trees, stump sprouts and a viable soil seed bank. Aided forest recovery is suitable for degraded sites where repeat incidences of disturbance have destroyed sources of natural regeneration. It is also appropriate for enrichment planting in sites where forest degradation has severely reduced woody species diversity making it essential to introduce other species through planting. It is important to note that site protection is extremely important for a successful outcome in both natural and aided forest regeneration interventions.

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