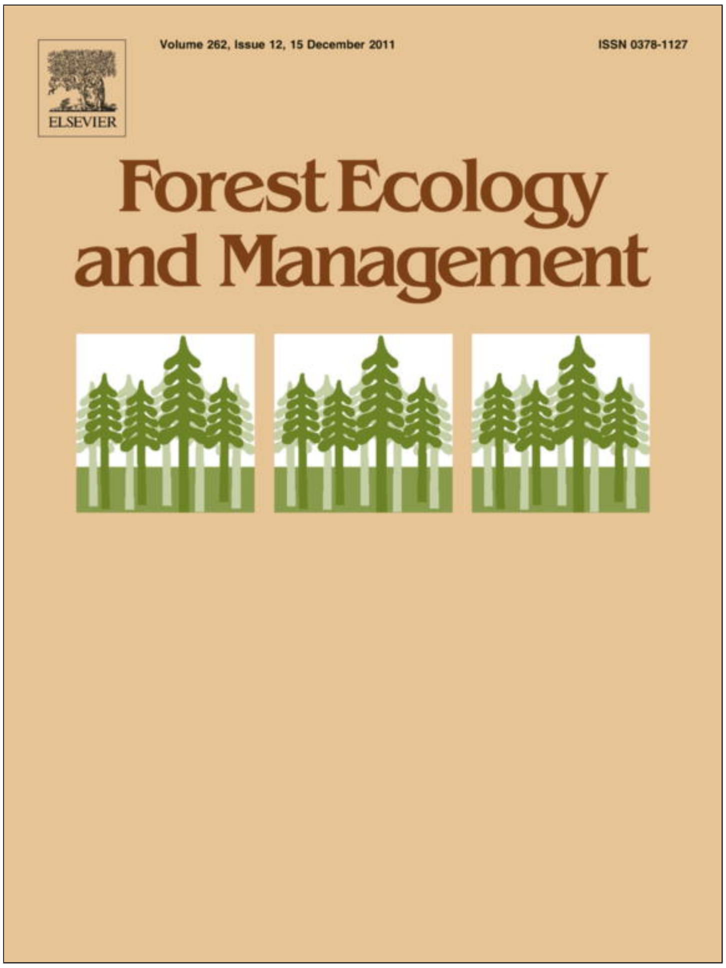
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Annual allowable cut for merchantable woody species in a community managed forest in western Kenya

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ABSTRACT

Changes in stand density, basal area, off-take and annual increment were determined from 18 permanent sample plots established in 1997 in Got Ramogi Forest in western Kenya. The plots were assessed in 2003 and 2008. A total of 824 stems $\geqslant$1.5 m in height were recorded from 43 woody species. Key merchantable woody species comprised 20% of the woody species and 67% of the overall stem density. There was a significant reduction in the overall stand density and in the stem density of key merchantable woody species, but not among other woody species between 1997 and 2008. The basal area decreased significantly among key merchantable woody species, but not for the overall forest. The basal area decreased from 22.6 to 9.7 $m^2\ ha^{-1}$ for key merchantable woody species. The stand volume of key merchantable woody species decreased from 156 $m^3\ ha^{-1}$ in 1997 to 61.7 $m^3\ ha^{-1}$ in 2008. The mean annual off-take declined from 10.3 $m^3\ ha^{-1}\ year^{-1}$ between 1997 and 2003 to 9.1 $m^3\ ha^{-1}\ year^{-1}$ between 2003 and 2008, while the mean annual increment increased from 2.9 to 3.3 $m^3\ ha^{-1}\ year^{-1}$. It was predicted that forest recovery would surpass the 1997 stand volume of 156 $m^3\ ha^{-1}$ if off-take levels between 10% and 90% of the mean annual increment were adopted. We settled on an annual allowable cut of 80% of the mean annual increment as a compromise between consumptive and conservation interests. We identified over-harvesting as the main cause of the reduction in stem density among key merchantable woody species. A management plan with compartment registers indicating the diversity, abundance and distribution of each woody species was recommended to guide their utilization and monitor their population dynamics.

1. Introduction

Although the global rate of deforestation is reported to have decreased over the past decade, it continued at a steady rate in many countries in Africa and South America during the same period (FAO, 2010). Unplanned logging, over-harvesting and poor forest management practices were reported as some of the major causes of rapid decline in forest cover in these regions (Dykstra and Heinrich, 1996). Managing forests in such a way that utilization of woody resources does not compromise their ability to provide non-wood products and environmental services has been identified as one of the solutions to deforestation (Bawa and Seidler, 1998; Sist et al., 1998). However, the concept of sustained-yield utilization of woody forest resources is still met with reluctance by conservation authorities in Africa, particularly for community-managed forests (Gaugris et al., 2007). The reluctance is based perhaps on past experience, where management of such resources by local communities may have resulted in their deterioration (Bucher and Huszar, 1999). Amid the reluctance, many forests have continued to come under uncontrolled use by adjoining rural communities causing deforestation, negative impacts on biodiversity and loss of livelihood.

Unplanned logging and over-exploitation have been recognized as important causes of deforestation in many tropical forests (FAO, 2007). The situation is common in dry tropical forests, which have received little attention because of the perception that they are able to recover to mature state relatively fast when disturbed (Levesque et al., 2011). Resolving unplanned logging and over-exploitation of forest resources requires a good understanding of the dynamics of forest exploitation, degradation and recovery by forest users (Isango, 2007; Backeus et al., 2006). According to Taylor et al. (2008), Africa is more vulnerable to deforestation because of a limited number of long-term studies on stand population dynamics, the difficulties of protecting such study sites and the resources required to maintain these studies. Thus, forest degradation is often realized when it has already occurred. The challenge is even greater for community-managed forests where felling is done on a walk in – walk out basis. The situation is worse in Kenya where

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excisions and clear-felling in government forests and over-harvesting in community forests have reduced the closed canopy forest cover from about 3% to 1.7% of the country's land area over the past three decades (Matiru, 1999; Mau Forest Interim Coordinating Secretariat, 2009).

In this paper, we present findings of a study on stand dynamics carried out between 1997 and 2008 in Got Ramogi Forest in western Kenya. The forest is presently managed by a community trust under the supervision of a local council of elders. Until the late 1960s, the forest was managed primarily for biodiversity conservation and preservation of historical sacred sites (Otuoma and Odera, 2009). The local community believed that the sacred sites, which are located within the forest, were the homesteads of their ancestors. Thus, strong cultural taboos protected the forest from tree felling. Over the past three decades, however, increases in human population, economic drivers and change in religious beliefs have eroded some of the cultural taboos. Over time, the local community began to harvest trees from the forest, albeit stealthily, but this has since become a common livelihood activity. The realization that over-exploitation of woody forest resources is becoming widespread has presented the community trust with the challenge of identifying an appropriate management approach to guide sustainable use of these resources. The aim of this study was to assess changes in stand density, basal area and growth increment between 1997 and 2008, use the incremental rates of various diameter size-classes to predict a possible stand recovery pattern for the next two decades and recommend a sustainable annual allowable cut.

2. Materials and methods

2.1. Study area

An assessment of the sustainability of harvesting was carried out in Got Ramogi Forest in western Kenya in March 2008 in permanent sample plots that were established in 1997. The forest vegetation has been described as dry semi-deciduous woodland with a closed multilayered canopy (Otuoma and Odera, 2009). It lies between 00° 06′ 23″ S and 34° 04′ 10″ E near the northeastern shores of Lake Victoria in Bondo District. It ranges from an elevation of 1160–1320 m above sea level and covers an area of 374 ha. The area receives bimodal rainfall with an annual mean of 800 mm and a mean annual temperature of 28 °C. The area has shallow, dark red to brown sandy-clay loam soils, with rock outcrops in many places. The forest is registered as a trust land and belongs to Bondo County Council. The county council assigned it to the Kenya Forest Service to manage it as a trust land. However, since the forest is not gazetted as a forest reserve, the role of the Kenya Forest Service has remained minimal, effectively leaving it under the control of the local community.

2.2. Sampling design

In 1997, a total of 18 permanent sample plots were established in the forest using randomized block design to monitor trends in stand structure, basal area and stand volume. Each sample plot measured one ha. Three subplots measuring 30 m by 20 m were randomly delineated within each one-ha sample plot giving a total sample area of 0.18 ha. All woody life-forms $\geqslant$1.5 m in height were identified by species, and their heights and diameter at breast height (DBH) measured. The trees were marked with paint to make it easy to identify them during subsequent assessment. The same parameters were measured in 2003 and 2008 from the same subplots. DBH was measured at a height of 1.3 m (or just above the buttress if present) using a metric diameter tape. Tree height was measured using ranging rods (the height of majority of trees ranged between 3.5 and 7 m, emergent trees ranged between 10 and 12 m). Mortality was recorded by counts of trees that died from non-anthropogenic causes, while recruitment was recorded by counts of new stems.

The datasets were used to compare the species diversity, evenness and stand population structure for the forest in general and for key merchantable woody species. Key merchantable woody species are tree species that were often felled from the forest. They were used for firewood, charcoal, construction poles, carving wood and timber. We estimated the mean annual increment and current off-take for the key merchantable woody species (FAO, 1998). Using the annual incremental rates of different DBH size-classes of each key merchantable wood species for the past ten years, we extrapolated the likely recovery scenarios under different annual off-take rates for the next two decades. We used the recovery scenarios to derive allowable off-take targets and their likely impact on the basal area and residual stand volume. Species diversity was determined using the Simpson diversity index (He and Hu, 2005; Mani and Parthasarathy, 2009). Stand volume was calculated using Huber's formula (Plank and Cahill, 1984; Waddell, 1989).

2.3. Mean annual increment

The mean annual increment between 1997 and 2008 was derived using equations by Shackleton (1993), FAO (1998) and Luoga et al. (2002), and expressed as follows:

$$G = \{(I_{\text{trees}} * n) - M + R\}/n$$

where, G = the mean annual increment (m^3/ha/year), I_{trees} = the sum of increments of stems that survived during the period of measurement (m^3/ha/year), M = the volume of stems that died during the period of measurement and hence no longer contributed to net forest growth (m^3/ha), R = the volume of in-growth or recruitment, during the same period (m^3/ha), n = the period of measurement in years.

2.4. Estimating current off-take and permissible off-take rates

Current off-take was estimated by accounting for the number of stems that existed in 1997, but were missing either in 2003 or 2008. Their respective basal area and heights were used to calculate the off-take volume. Permissible off-take rates were estimated by calculating off-take as a fraction of the mean annual increment on a scale of 10–90%. These off-take levels were considered permissible in the sense that they were lower than the mean annual increment of the stand volume. Each permissible off-take rate was used to extrapolate the likely residual stand volume for the next 20 years on the basis of net gains in the mean annual increment. Calculations were done at the level of DBH size-class based on DBH increments between 1997 and 2008. The intention was to illustrate the duration it would take to attain various residual stand volumes for different permissible off-take targets.

2.5. Estimating annual allowable cut

The most complex part of the study was how to arrive at an acceptable annual allowable cut. Conservation interests preferred an allowable cut that was well below the mean annual increment, while consumptive interests were not keen to see a big variation between current off-take level and the allowable off-take. We settled on a hypothetical allowable cut of 80% of the mean annual increment as a compromise between conservation and consumptive interests, but made sure that we presented all the allowable off-take scenarios and their implications for the residual stand volume.

2.6. Data analysis

DBH measurements were organized into diameter size-class intervals of 10 cm for each tree species; starting with <10 cm and ending with >50 cm DBH size-classes. Since the data comprised counts of tree species and their measures, we used generalized linear mixed models to analyse it (Bolker et al., 2008; Levesque et al., 2011). Variations in stand density, basal area, mortality, recruitment and off-take rates between 1997 and 2008 were determined using the Poisson distribution with a logarithmic link function as part of the generalized linear mixed model. Significant differences were declared at 5% significance level. General statistics package version 13 (VSN International, 2009) was used for data analysis.

3. Results

3.1. Stand population structure

A total of 824 stems ⩾1.5 m in height were recorded from 18 sample plots covering an area of 3.24 ha in 1997. The stems were of 43 woody species from 25 families. The same woody species were recorded in 2008, but with changes in stand density, basal area and stand volume. Key merchantable woody species comprised 20% of the stand population by species and 67% by stem density. These species included *Craibia brownii*, *Drypetes gerardii*, *Haplocoelum foliosum*, *Lannea schweinfurthii*, *Ochna ovata*, *Psydrax schimperiana*, *Strychnos henningsii* and *Teclea trichocarpa*. There was no significant variation in woody species diversity and evenness ($F_{(1,387)} = 1.37$; $P = 0.248$) between 1997 and 2008. The overall stand population structure of the forest showed an inverse J-shaped DBH size-class distribution pattern ($y = -55.77\text{Ln}(x) + 120.56$; $R^2 = 0.86$). All the key merchantable woody species had a similar DBH size-class distribution pattern with R^2 values ranging from 0.70 to 0.93, except *Lannea schweinfurthii* ($R^2 = 0.10$) (Fig. 1).

There was a significant reduction in the overall stand density of the forest between 1997 and 2008 ($F_{(1,387)} = 12.8$; $P < 0.001$). During the same period, a significant reduction was observed in the stand density of key merchantable species ($F_{(1,190)} = 23.9$; $P < 0.001$), but not among other woody species ($F_{(1,195)} = 0.2$; $P < 0.653$). The decline in stand density reduced the proportion of key merchantable woody species within the forest to 58% of the overall stand density in 2008 (Fig. 2).

We found a significant reduction in the basal area of key merchantable woody species between 1997 and 2008 ($F_{(1,861)} = 4.1$; $P = 0.043$), but not for the overall forest ($F_{(1,1348)} = 2.8$; $P = 0.092$) or other woody species ($F_{(1,484)} = 2.2$; $P = 0.14$). The basal area of key merchantable woody species reduced from 22.6 to 9.7 m^2 ha^{-1} between 1997 and 2008 (Fig. 2). Tree height declined significantly between 1997 and 2008 among key merchantable woody species ($F_{(1,861)} = 8.7$; $P = 0.003$), but not for the overall forest ($F_{(1,1348)} = 2.7$; $P = 0.101$). The mean tree height was 6.8 m in 1997 and 4.5 m in 2008. The stand volume of key merchantable woody species reduced from 156 m^3 ha^{-1} in 1997 to 61.7 m^3 ha^{-1} in 2008, while that of other woody species reduced marginally from 44.2 to 39.8 m^3 ha^{-1} during the same period.

3.2. Mortality and recruitment

The mortality of key merchantable woody species from non-anthropogenic causes was not significant ($F_{(1,93)} = 0.18$; $P = 0.674$). In the 18 sample plots covering 3.24 ha, a total of 19 and 22 dead stems were recorded in 1997 and 2008, respectively. Tree recruitment, however, increased significantly between 1997 and 2003 ($F_{(1,93)} = 74.6$; $P < 0.001$), but reduced significantly between 2003

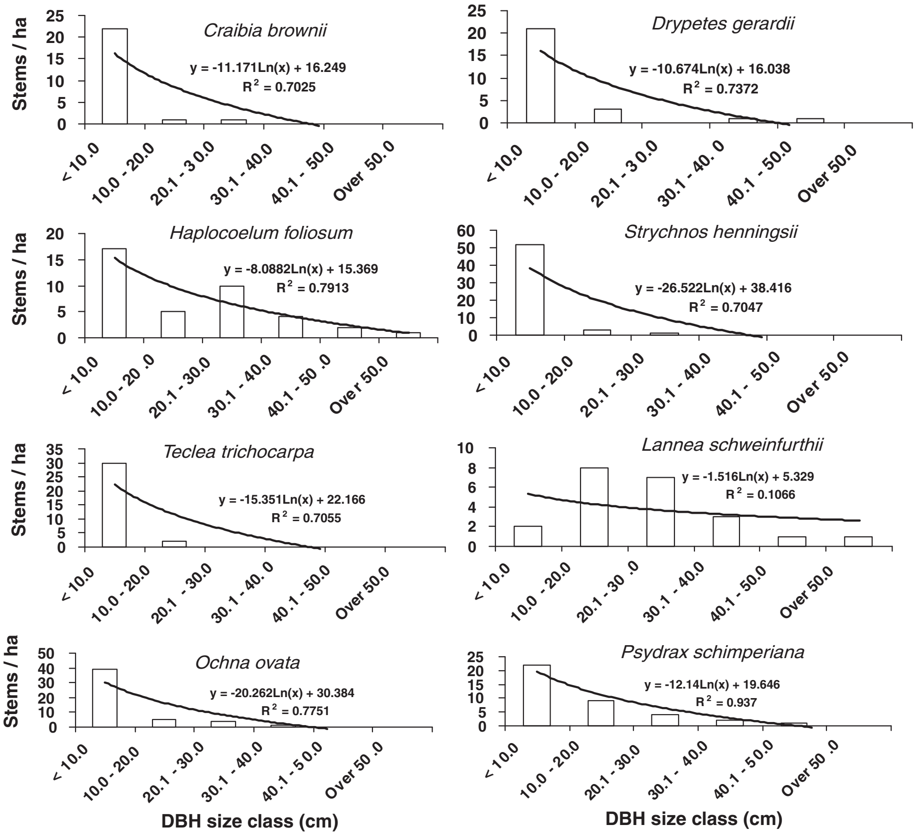

Fig. 1. DBH size-class distribution among key merchantable woody species in Got Ramogi Forest in western Kenya in 2008.

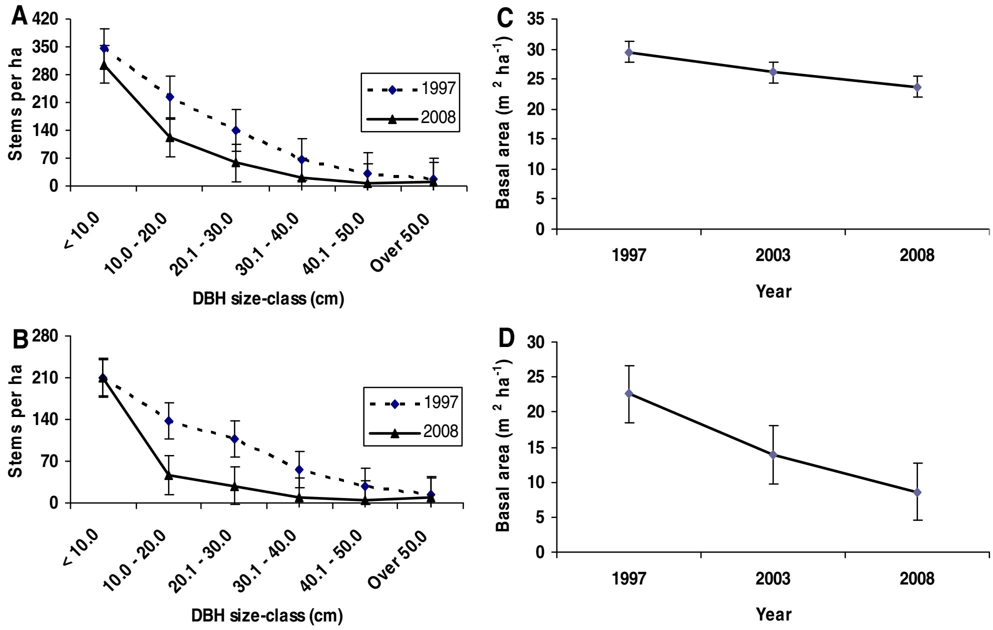

Fig. 2. A comparison of changes in stand density of the overall forest (A) and stand density of key merchantable woody species (B), and the basal area of the overall forest (C) and the basal area of key merchantable woody species (D) in Got Ramogi Forest in western Kenya between 1997 and 2008.

and 2008 ($F_{(1,93)} = 34.9$; $P < 0.001$). There were 168 new stems between 1997 and 2003 compared to 77 between 2003 and 2008. About 89% of the recruits were stump sprouts, 7% were from root suckers, while the rest developed from seed.

3.3. Current off-take and annual increment

We found a significant increase in mean annual off-take between 1997 and 2003 ($F_{(1,89)} = 64.5$; $P < 0.001$), and also between 2003 and 2008 ($F_{(1,89)} = 29.4$; $P < 0.001$). Although fewer stems were removed between 1997 and 2003 than between 2003 and 2008, the mean annual off-take declined from 10.3 $m^3\ ha^{-1}\ year^{-1}$ between 1997 and 2003 to 9.1 $m^3\ ha^{-1}\ year^{-1}$ between 2003 and 2008. The reduction may have been caused by the occurrence of relatively more stems in lower diameter size-classes after the year 2003. The mean annual increment increased from 2.9 $m^3\ ha^{-1}\ year^{-1}$ during the period 1997 to 2003 to 3.3 $m^3\ ha^{-1}\ year^{-1}$ from 2003 to 2008.

3.4. Annual allowable cut

All off-take targets below the mean annual increment were predicted to lead to an increase in the basal area and residual stand volume. For instance, 10% and 90% off-take targets of the mean annual increment, were predicted to surpass the stand volume of 1997 of 156 $m^3\ ha^{-1}$ by 80 and 20 $m^3\ ha^{-1}$, respectively in 20 years (Table 1). However, the challenge was determining which specific off-take target to select for the local community because 10% off-take was only 3.6% of current off-take, and would most likely be rejected by majority of forest users because of the huge variation between the proposed rate and the prevailing scenario. On the other hand, 90% off-take was considered rather high from a conservation viewpoint. The 80% annual allowable cut that we settled on translated to 29% of current off-take rate.

An annual allowable cut of 80% of the mean annual increment would enhance forest resilience and help recover the basal area and stand volume of key merchantable woody species within a period of 20 years. The basal area would increase from 9.7 to 26.0 $m^2\ ha^{-1}$during the same period. The stand density was, however, predicted to oscillate between 286 and 340 stems ha^{-1}

Table 1
Projected recovery scenarios in stand volume over the next two decades for various annual off-take levels in Got Ramogi Forest in western Kenya.

Off-take rate as a % of mean annual increment	Projected recovery scenarios in stand volume ($m^3\ ha^{-1}$)			
	Year 0	Year 5	Year 10	Year 20
0	62.8	78.6	120.4	244.3
10	62.7	77.1	119.8	236.7
20	62.6	76.3	116.8	229.2
30	62.5	75.6	113.8	221.6
40	62.4	74.8	110.8	214.0
50	62.3	74.0	107.9	206.5
60	62.2	73.3	104.9	198.9
70	62.1	72.5	101.9	191.3
80	61.9	71.7	98.9	183.8
90	61.8	70.9	95.9	176.2

because a substantial proportion of the increment was expected to be distributed within various diameter classes unlike the scenario in 2008 where most stems were between <10 and 20 cm DBH size-classes. These figures were converted into a felling schedule to guide logging operations by the local community and forest managers (Fig. 3).

4. Discussion

Our results indicate that changes occurred in Got Ramogi Forest in stand density, basal area and stand volume between 1997 and 2008. It can be argued that these changes were largely attributed to the exploitation of key merchantable woody species on two fronts. First, key merchantable woody species constituted 67% of the stand density hence their exploitation was bound to alter the stand population structure. Second, the results indicate that the local community did not harvest a large proportion of other woody species during that period. Both observations point to the fact that key merchantable woody species are important indicators of forest resilience to anthropogenic disturbance, at least for now, in Got Ramogi Forest. The inverse J-shaped DBH size-class distribution

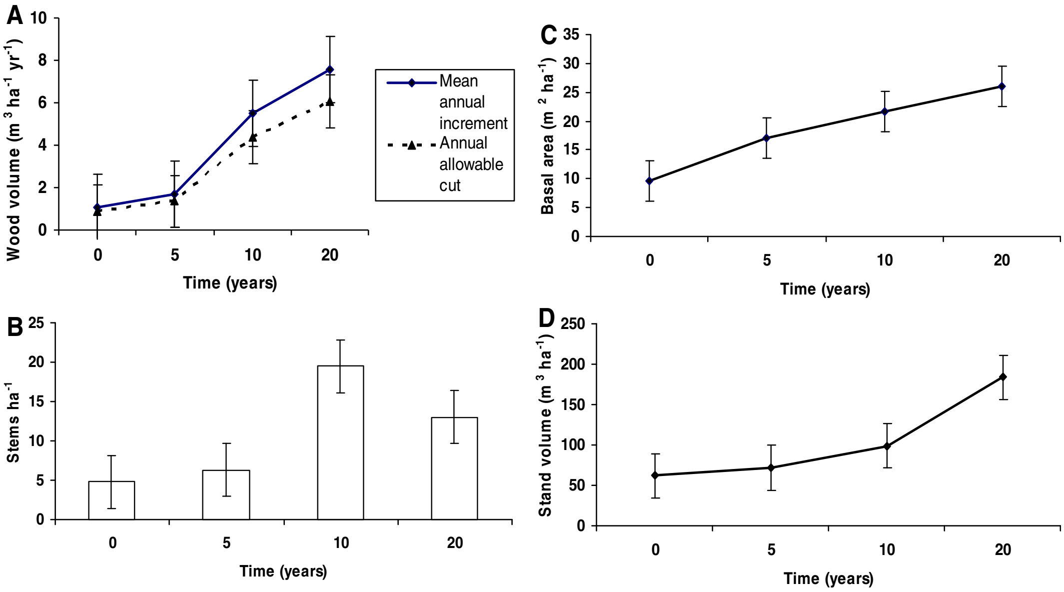

Fig. 3. Projected changes for key merchantable woody species in mean annual increment and annual allowable cut (A), felling intensity (B), basal area (C), and stand volume (D) over the next two decades in Got Ramogi Forest in western Kenya.

pattern among these species indicates that they are still highly resilient to disturbance even after the reduction of their stand density by about 45% between 1997 and 2008. This observation is consistent with findings of Isango (2007) in community managed Miombo woodlands in Tanzania, which also illustrated a high resilience to disturbance. The increase in mean annual increment in 2008, after the reduction in stand density, suggested a more rapid growth rate among smaller diameter stems than relatively larger ones. Backeus et al. (2006) attributed the quick recovery of dry land forests in eastern Africa to regrowth from tree stumps and root suckers, which this study identified as the main sources of recruitment in Got Ramogi Forest.

The significant reduction in stand density and basal area among key merchantable woody species points to high rate of exploitation. We attribute it to the present unplanned logging scenario where individuals walk in and out of the forest with logs. Although it did not impact species diversity and evenness between 1997 and 2008, the ability of the forest to recover from disturbance under this logging approach cannot be guaranteed. There is need for a comprehensive logging plan that comprises forest stand maps detailing the location of harvestable trees, the location of haul roads, skid trails and a framework for monitoring the recovery of harvested species. Thus, as demonstrated elsewhere by Mbwambo et al. (2008), we suggest that the management of Got Ramogi Forest would do better with an improved knowledge base to enable the local community harness its ecological, social and economic potential in a sustainable way. The application of clearly defined permissible off-take targets, that this study proposes, is one of the silvicultural operations necessary to balance the competing needs of resource utilization, biodiversity conservation and preservation of socio-cultural value. As illustrated by our results, setting targets for annual allowable cut is applicable in Got Ramogi, but it remains a complex decision that requires the input of different stakeholders promoting diverse interests in the forest. The annual allowable cut that we have presented in our results is a hypothetical scenario that is intended to balance consumptive and conservation needs. Fortunately, the study has presented the gains that are likely to be made in residual stand volume from various off-take levels. This provides a basis for negotiations among various interest groups in deciding on an applicable off-take target.

Applying the allowable off-take targets is expected to raise the stand density, basal area and stand volume (Bawa and Seidler, 1998; Isango, 2007; Backeus et al., 2006) and eventually create a closed canopy multilayered forest as is presently the case in relatively intact sections (Otuoma and Odera, 2009). However, the application of any of these allowable off-take targets in the absence of appropriate silvicultural operations would not guarantee the regeneration and sustainable yield of merchantable species. As demonstrated elsewhere by Bawa and Seidler (1998), Fredericksen and Putz (2003) and Valle et al. (2007), silvicultural operations would entail management of the stand dynamics to guard against the emergence of stands dominated by pioneer tree species, protect forest undergrowth during logging operations and prevent the conversion of the forest to other land uses. The study has not provided permissible off-take levels for each merchantable woody species, but it will be necessary to monitor the uses, demand and population dynamics of each species. For instance, the stand structure of *Lannea schweinfurthii* indicated that the number of stems in the less than 20 cm DBH size-class does not correspond to the rate at which its stems have been exploited over the past decade. It is suspected that this species may be having a low resilience to disturbance. As illustrated by Obiri et al. (2002), Lawes and Obiri (2003), off-take thresholds for such a species should be set at rates that do not alter the natural abundance and capacity to regenerate after disturbance.

5. Conclusion

The stand density, basal area and stand volume reduced significantly among key merchantable woody species in Got Ramogi Forest between 1997 and 2008. We sought to find out if the stand volume of 1997 was recoverable in two decades through the application of off-take levels that are less than the mean annual increment. The study has demonstrated that it is possible to surpass it even at 90% off-take level. On the basis of this finding, we propose an annual allowable cut of 80% of the mean annual increment. Unplanned logging and over-harvesting were identified as challenges to sustainable forest management. We recommend that a management plan be put in place with compartment registers indicating the diversity, abundance and distribution of each woody species to guide their utilization and monitor the stand population dynamics.

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