Ethiop. J. Biol. Sci., 4(1): 59-73, 2005

THE INFLUENCE OF LOGGING ON NATURAL REGENERATION OF WOODY SPECIES IN HARENNA MONTANE FOREST, ETHIOPIA

Getachew Tesfaye[1,]* and Demel Teketay[2]

ABSTRACT: The influence of selective logging on natural regeneration of woody species at logged areas in Harenna forest, southeast Ethiopia was investigated. The survey was done systematically at three different logged areas within the forest having variable size and age. Felling gaps at each over-logged area were enumerated to assess logging intensity. At every 5 m interval on each transect, quadrats of 2 m X 2 m (4 m^2) were laid for seedling regeneration survey, while for saplings and trees the size of quadrats was increased to 20 m x 20 m (400 m^2). All regenerated woody species found in each quadrat were identified, height and diameter measured and recorded. Composition, density and diversity of regenerated species were found variable among the over-logged areas. Eleven tree species were found regenerated in all the three over logged areas. Overall, mean densities of natural regeneration on logged fields varied between 267-273 individuals/ha for trees, 133-1409 individuals/ha for seedlings, and 35 individuals/ha for saplings. Logging intensities ranged between 18 and 48 trees per hectare. Species richness and diversity also varied between logged areas. *Croton macrostachyus* showed higher probabilities of felling gaps replacement. The change in composition from *Podocarpus falcatus* forest to *Croton macrostachyus* forest at logged fields will become a problem for sustained timber production in the area. Thus, application of silvicultural treatments that foster regeneration of desirable species at logged fields, and reducing the intensity of selective removal of *Podocarpus falcatus* for timber are among the recommended management options to protect and conserve the Harenna forest.

Key words/phrases: Logged areas; Natural regeneration; Selective logging.

INTRODUCTION

Sustainable management of the remaining natural forest in Ethiopia has become a priority and a matter of urgency in recent years. Every year about 250,000 hectares of natural forests are cleared and converted to other land use (EFAP, 1994). Most of the forest areas that are degraded or cleared have

[1] Institute of Biodiversity Conservation, P.O. Box 25680-1000, Addis Abeba, Ethiopia. E-mail: getachewtesfaye@yahoo.com
[2] Forest Stewardship Council, African Regional Office, P.O. Box UP 805, Kumasi, Ghana. E-mail: d.teketay@fsc.org
* Author to whom all correspondence should be addressed.

no management plan for regeneration. The future of many of the remaining natural forests in Ethiopia is uncertain, since the efforts to address the issue and proper guidance and management even for the selected high Forest Priority Areas (FPAs) are lacking (Tamrat Bekele, 1993; EFAP, 1994; Demel Teketay, 1997).

Disturbances on tropical forests are due to commercial logging, forest clearance for slash and burn agriculture, wind throw and wildfire (Whitmore, 1993; Getachew Tesfaye *et al.,* 2004). Canopy disturbance creates a highly heterogeneous habitat that recruits different species and play out different growth scenarios (Bazzaz, 1991; Ashton *et al.*, 2001). The response of tree species to the variation in environmental conditions, created due to gap formation under forest canopies, is different among the tropical species (Gomez-Pompa, 1991). Tree felling and log removal creates canopy gaps that influence regeneration depending on the disturbance effect, intensity of logging and silvicultural characteristics of tree species. Seedling damage and removal of soil seed banks are among the major problems encountered during logging operations (Saueli and Lamp, 1991; Whitmore, 1993; 1996).

Knowledge on the complex processes that exist in a forest ecosystem and the ecological requirement of a species are important for understanding the suite of regeneration pathways followed by trees. Knowledge of regeneration ecology and environmental requirements of desirable species can lead to better forest management and silvicultural practices. Such information contributes significantly to the options of sustainable forest management and restoration of degraded forests.

Because of the considerable exploitation of the Harenna forest for commercial logging, the vast majority of forested areas have been fragmented. Over the last decade, more than 30,000 hectares of natural forest were depleted due to selective logging (BZADD, 2001). However, no studies have yet investigated the influence of selective logging on natural regeneration of tree species in the Harenna forest. The objectives of the study were to assess the composition, structure and density of regenerated woody species at the logged fields in Harenna forest, and to assess the canopy replacement patterns and forest succession at logged fields.

MATERIALS AND METHODS

The Study Site

Harenna Forest, located at the southern slopes of Bale Mountains, southeastern Ethiopia (39° to 40°E and 6° to 7°N), covers an area of 7000 km^2. It is one of the largest tracts of remaining natural forest in Ethiopia and Northeast tropical Africa (Friis, 1986; Miehe and Miehe, 1994). It is characterized by wet and dry season from March to October and November to April, respectively. The prevalent soils are red and red browns to black silty loam originating from volcanic materials (Weinert and Mazurek, 1984).

Previous studies in the Harenna forest focused mainly on floristic composition and physiognomy of the forest vegetation (Mooney, 1963; Friis, 1986; Hillman, 1988; Uhlig, 1988; Lisanework Nigatu and Mesfin Tadesse, 1989) and natural regeneration (Getachew Tesfaye *et al.*, 2002; 2004). The Harenna plateau was assumed originally to have been covered by extensive evergreen forests interspersed by grassland and bamboo vegetation. It is occupied by mixed broad-leaved forest containing several broad-leaved species (Mooney, 1963; Chaffey, 1979; Friis, 1986; Uhlig, 1988; Lisanework Nigatu and Mesfin Tadesse, 1989). The forest shows a marked transition in species composition, structure and morphology of plants along gradient in altitude. The present study was conducted in forest zone between 1500 and 1800 m.a.s.l, where commercial logging has been practiced.

Sampling

Composition, density and structure of regenerated forest at logged fields

The regeneration study was conducted systematically at three different over-logged fields, which have variation in their sizes of gaps and age. The first logged site, logged about 14 years ago, was found to have two felling gaps with total size of 1600 m^2 area. In this logged site, three parallel transects of 160 m long were established for regeneration survey. The second logged site was logged about 8 years ago, and had two felling gaps with total size of 2000 m^2 area. In this logged site, four parallel transects of 200 m long were established for regeneration survey. The third logged site was logged 2 years ago and had two felling gaps with total size of 600 m^2. In this logged site, two parallel transects of 140 m long were established for regeneration survey.

At every 5 m interval on each transects, quadrats of 2 m x 2 m (4 m^2) were laid for seedling regeneration survey following the methods of Muller-Dombois and Ellenberg (1974). All regenerated seedlings of woody species encountered in each quadrat were identified, counted, height and diameter measured and recorded. To determine the density and population structure of saplings and trees, the same procedures described for seedlings were employed, except that the size of quadrats was increased to 20 x 20 m (400 m^2) and the distance between each plot to 50 m. Thus, a total area of 2800 m^2 was used to assess densities and population structure of saplings and trees regenerated at logged sites. In the present study, seedling refers to plants with 0-1.5 m, saplings 1.5-3m and trees ≥3m in height (Demel Teketay, 1997; Getachew Tesfaye *et al.*, 2002).

Information about selectively logged species and location of the logged fields (within the forest) and their respective years of logging was obtained from the BZADD (2001), and cross-checked by field observations together with forest technicians of the District Office. Enumeration of felling gaps was done at the logged fields to assess the logging intensity. Collected plant specimens were identified at the National Herbarium, Addis Ababa University, Ethiopia. The nomenclature of plant species in this paper follows Hedberg and Edwards (1989), Friis (1992) and Edwards *et al.* (1995).

Data Analysis

One-way ANOVA was conducted to test the significance of the density of regeneration between logged areas. Density, frequency and relative density of regeneration was analyzed according to Muller-Dombois and Ellenberg (1974). Species replacement probabilities in felling gaps were estimated for the three most logged species (gap-maker species). We assumed that the replacement probability depended only on the abundance of recruits (> 1cm DBH) of a species in felling gaps created by the same or another species. Replacement probabilities were estimated by counting the number of gap-fillers of a given species and expressing it as a proportion of the total number of gap-fillers per gap-maker (Runkle, 1981). For analysis of species diversity at logged fields, Shannon's diversity index (H') was calculated (Magurran, 1988). Similarity among the logged areas was computed using Sörensen similarity index.

Similarity Index = 2C/A + B

where, C= number of species common to the logged areas; A= total number of species in logged site A; and B= total number of species in logged site B.

RESULTS

Characteristics and Structure of Regenerated Forest

Characteristics and structure of the regenerated forest in each logged site at Harenna forest showed considerable variation. Accordingly, the height of the regenerated forest in the three logged sites varied between 25 $\pm$ 2.5, 19 $\pm$ 1.8, and 3.2 $\pm$ 0.6 m at logged sites I, II, and III, respectively. Similarly, the diameter at breast height varied between 60 $\pm$ 0.5, 51 $\pm$ 0.3, and 0.27 $\pm$ 0.01 cm at the logged sites I, II and III, respectively.

The logging intensity at the study sites were 48, 30 and 18 individuals per hectare at sites I, II and III, respectively. Twenty-two tree species were identified to be exploited for commercial logging from Harenna forest. The five most logged species were *Podocarpus falcatus* (80%), *Pouteria adolfi-friederici* (5%), *Warburgia ugandensis* (3%), *Croton macrostachyus* (3%) and *Olea capensis* (2%).

Regeneration Density and Composition

The composition and relative density of the regenerated woody species in the three logged sites were found to be highly variable (Fig. 1a-c). Similarly, species richness and diversity in these over-logged areas were also variable (Table 1).

In site I, a total of 15 woody plants belonging to 4 species were regenerated (Fig. 1a). The regenerated tree species comprised trees of *Croton macrostachyus* (66%) and, seedlings of *Podocarpus falcatus* (20%), *Celtis africana* (7%) and *Ocotea kenyensis* (7%). The density of regeneration at this stand was about 267 per hectare for trees, and 133 per hectare for seedlings.

In site II, a total of 37 woody plants belonging to 7 species were regenerated (Fig. 1b). Regenerated tree species comprised trees of *Croton macrostachyus* (16%) and seedlings of *Celtis africana* (30%), *Strychnos mitis* (24%), *Podocarpus falcatus* (16%), *Filicium decipiens* (6%), *Mimusops kummel* (5%) and *Warburgia ugandensis* (3%). Density of regeneration at this stand was estimated at 273 per hectare for trees, and 1409 per hectare for seedlings.

In site III, a total of 13 woody plants belonging to 5 species were regenerated (Fig. 1c). Regenerated species comprised saplings of *Podocarpus falcatus* (23%), *Ocotea kenyensis* (46%) and *Ekebergia capensis* (15%) and seedlings of *Polyscias fulva* (8%) and *Trema orientalis*

(8%). Density of regeneration at this stand was estimated at 191 per hectare for seedlings, and 35 saplings per hectare.

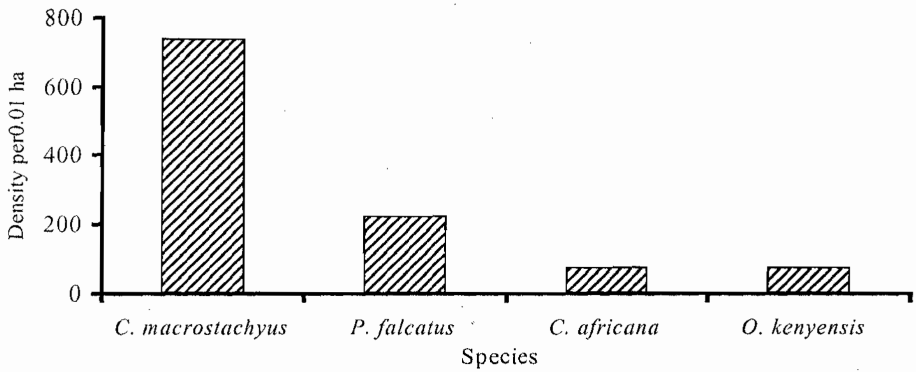

Fig. 1a. Mean densities (individuals per 0.01 ha) of regeneration in site I.

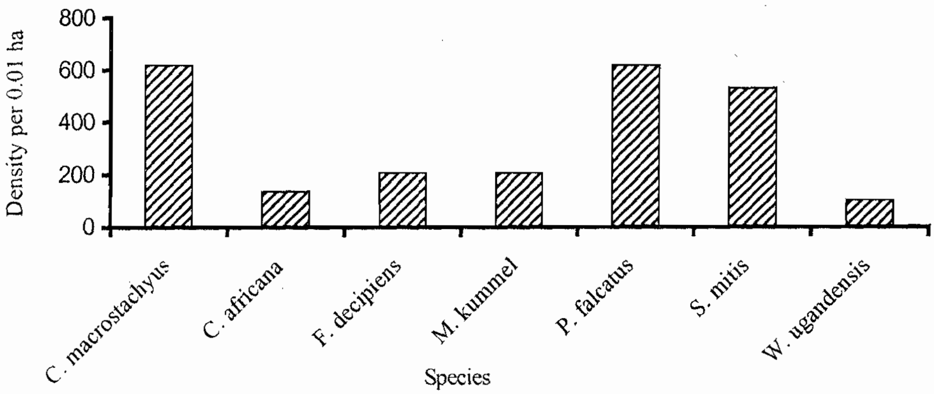

Fig. 1b. Mean densities (individuals per 0.01 ha) of regeneration in site II.

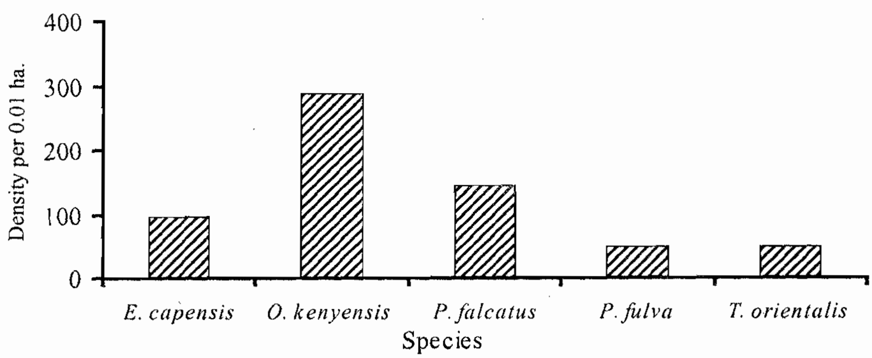

Fig. 1c. Mean densities (individuals per 0.01 ha) of regeneration in site III.

Over all, 11 woody species (*Podocarpus falcatus, Celtis africana, Croton macrostachyus, Ekebergia capensis, Filicium decipiens, Mimusops kummel, Ocotea kenyensis, Polyscias fulva, Trema orientalis, Strychnos mitis* and *Warburgia ugandensis*) were regenerated in the three logged sites at Harenna forest. Species diversity was found higher for site II, and the trend followed that of species richness indicted in Table 1.

Table 1 Species richness and Shannon diversity (H') in each logged site at Harenna forest.

Logged fields	Species richness	Shannon diversity (H')
Site I	4	0.83
Site II	7	2.23
Site III	5	1.52

Canopy Regeneration of Gap-filler Species in Over-logged Areas

The results of probabilities of gap-maker being replaced by gap-filler species are shown in Table 2.

Table 2 The probability of gap maker being replaced by all gap-filler species at logged fields at Harenna forest.

Gap-filler	Gap-makers		
	Podocarpus falcatus	*Pouteria adolfi-friederici*	*Diospyros abyssinica*
Ekebergia capensis	-	0.2	
Polyscias fulva	-	0.1	
Ocotea kenyensis	0.07	0.3	
Trema orientalis	-	0.1	
Filicium decipiens	0.04	-	
Croton macrostachyus	0.7	0.3	0.5
Warburgia ugandensis	0.02	-	-
Podocarpus falcatus	0.14	-	0.5
Mimusops kummel	0.04	-	
Strychnos mitis	0.04	-	
Celtis africana	0.24	-	

Gap-maker species at the logged fields include *Podocarpus falcatus* (75% of the total gaps encountered), *Pouteria adolfi-friederici* (16%) and *Diospyros abyssinica* (9%). It was shown that there was a low probability of self-replacement for *Podocarpus falcatus* (0.14) at the logged fields. On the other hand, the highest probability for gap replacement was shown by *Croton macrostachyus* which accounted for probability values of 0.7 under the *Podocarpus falcatus* gap, and 0.5 under the *Diospyros abyssinica* gap. Under the gaps of *Pouteria adolfi-friederici, Croton macrostachyus* and

Ocotea kenyensis had equal chances of canopy replacement probabilities. *Croton macrostachyus* and *Podocarpus falcatus* had also equal chances of canopy replacement probabilities under the gaps of *Diospyros abyssinica* gap (Table 2). On the whole, there was low likelihood for self-replacement and, high probability was shown by the species of *Croton macrostachyus* to replace the canopy gaps at the logged fields.

Variation in Vertical Structure

In site I, the regenerated trees (species of *Croton macrostachyus*) attained average height of 25 $\pm$ 2.5 m and diameter of 60 $\pm$ 0.5 cm, while the seedlings (about 3 species) were 0.43 $\pm$ 0.02 m in height and 0.02 $\pm$ 0.01 cm in diameter. Thus, the vertical structure of the regenerated stand showed two distinct growth phases as trees and seedlings. The trees were all mature population of species of *Croton macrostachyus* (Fig. 2a and b).

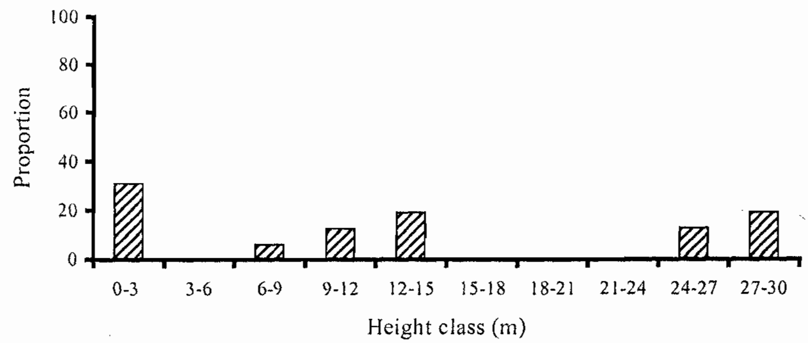

Fig. 2a. Height class distribution of regenerated forest in site I.

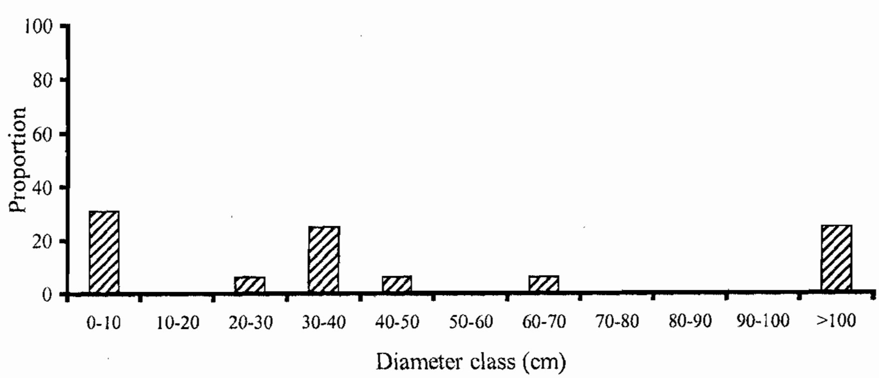

Fig. 2b. Diameter class distribution of regenerated forest in site I.

Croton macrostachyus was the early succesional species that colonized the logged field. *Podocarpus falcatus, Celtis africana* and *Ocotea kenyensis* seedlings emerged under the canopy of *Croton* trees and, were recognized as late successional species.

In site II, the regenerated trees (species *Croton macrostachyus*) attained average height of 19 ± 1.8 m and diameter of 50.6 ± 0.3 cm, while the seedlings were 0.37 ± 0.1 in height and 0.08 ± 0.009 cm in diameter. Thus, the vertical structure of the regenerating forest showed two distinct growth phases as trees and seedlings. The trees were all mature populations of species of *Croton macrostachyus* (Fig. 3a and b).

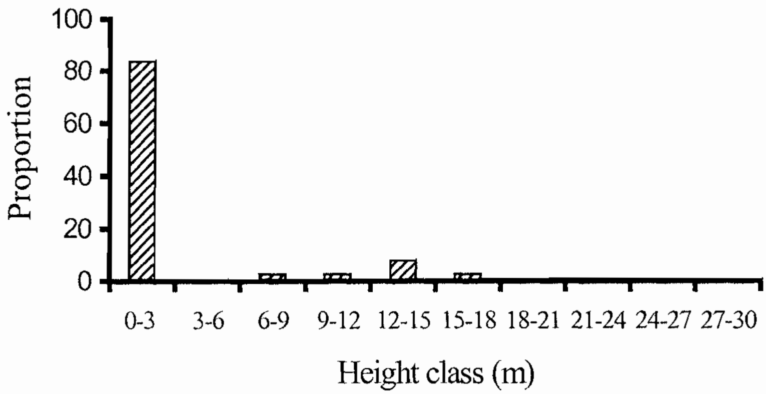

Fig. 3a. Height class distribution of regenerated forest in site II.

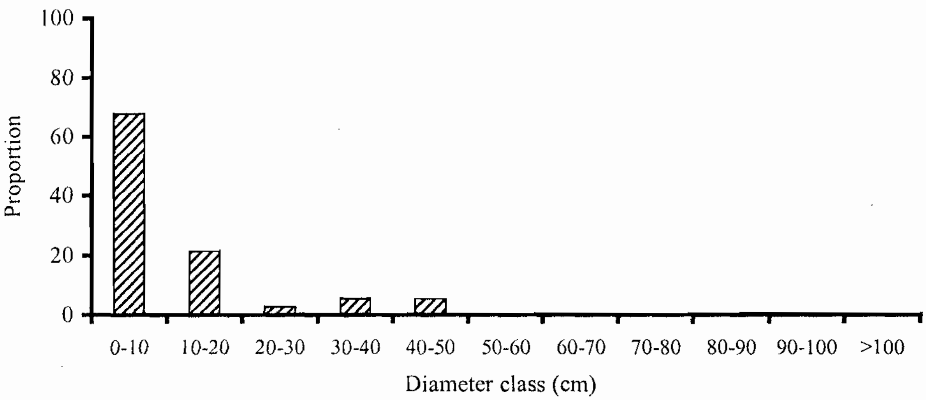

Fig. 3b. Diameter class distribution of regenerated forest in site II.

Many of the *Croton macrostachyus* trees at this stand were found closer to the height of the canopy of the surrounding forest. *Croton macrostachyus* has been recognized as the pioneer species which colonized the logged field, whereas seedlings of species of *Celtis africana, Filicium decipiens, Mimusops kummel, Podocarpus falcatus, Strychnos mitis* and *Warburgia ugandensis* were found regenerated under the canopy of *Croton macrostachyus* and were recognized as late successional species.

In site III, the regenerated saplings attained average height of 2.75 ± 0.3 m and diameter 0.27 ± 0.014 cm, while the seedlings were 1.4 ± 0.11 cm in height and 0.17 ± 0.016 cm in diameter (Fig. 4a and b). The vertical structure of the regenerating forest showed two growth phases as saplings and seedlings.

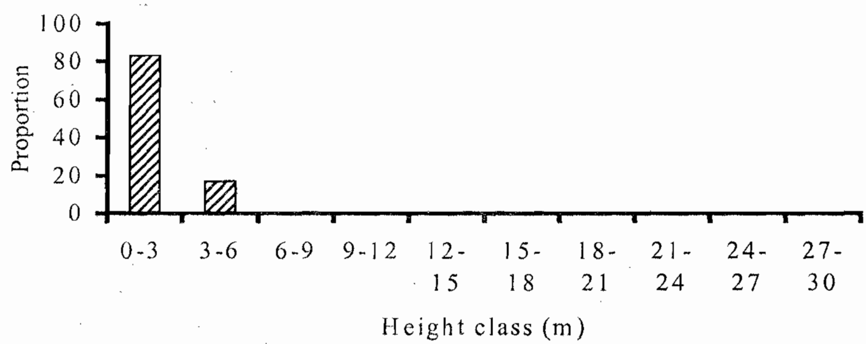

Fig. 4a. Height class distribution of regenerated forest in site III.

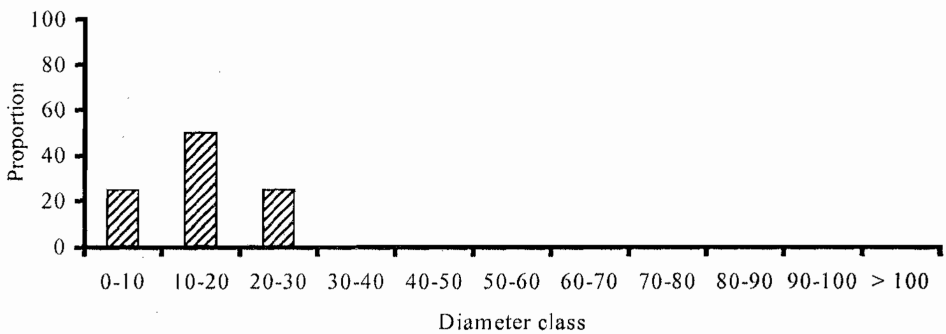

Fig. 4b. Diameter class distribution of regenerated forest in site III.

Similarity between Over-logged Areas

Results of Sørenson similarity index among the three sites were given in Table 3. Accordingly, highest similarity was found between sites I and II, while lowest was found between sites II and III.

Table 3 Sorensen similarity index in the logged sites at Harenna forest.

	Site I	Site II	Site III
Site I	-		
Site II	0.54	-	
Site III	0.44	0.16	-

DISCUSSION

In the present study, a total of 11 tree species were found regenerated at the logged fields of the Harenna forest. A study from the Southwest forests reported that about 22 tree species were found regenerated on logged fields (Tarekegn Abebe, 2003). The total number of regenerated species on the logged fields at Harenna forest was lower than what had been reported from the Southwest forests. This could be attributed probably to the variation in intensity of disturbance on the logged fields during the logging operation, sample size, and also in response to the variation of microenvironment in these forest ecosystems (Friis, 1992; Tesfaye Awas *et al.,* 2003). *Podocarpus falcatus* regenerated in the three logged sites at Harenna forest, while *Croton macrostachyus* and *Celtis africana* regenerated in site I and II. The remaining eight species regenerated at all of the three logged fields. On the other hand, only three species, namely, *Croton macrostachyus*, *Ekebergia capensis* and *Polyscias fulva* were identified as common regenerated species on the logged fields of both Harenna and Southwest forests.

The density of regenerated species was higher in site II followed by site I, while species diversity was higher in site II, followed by site III. The higher seedling density and species diversity in site II may be attributed to low disturbance effect on the established seedlings during logging operation. Generally, in areas of little topsoil disturbance, species composition would be higher, but the composition would decline where substantial disturbance occur (Saueli and Lamp, 1996). Creating big canopy gaps has an effect on microclimate in forest understorey (Vazquez-Yanez and Orzeco-Segovia, 1990) allowing the forest floor to desiccate more strongly and thereby affecting the composition of the regenerating species (Whitmore, 1993). In site I and II regenerated forests were dominated by species of *Croton macrostachyus*. The logging operation created big canopy holes in sites I and II, as evidenced from the size of their felling gaps and intensity of logging. This implies there is a change in forest composition from *Podocarpus* forest to *Croton* forest.

Structural analysis for site II and III revealed that regenerated trees (*Croton macrostachyus*) attained 19 and 25 meters in height after 8 and 14 years, respectively.

Based on the analysis of the structure of the regenerated forest in sites I and II, *Croton macrostachyus* was found to be the early successional tree species that colonized logged fields at Harenna forest, whereas, other species were recognized as late successional ones. These included *Podocarpus falcatus, Celtis africana, Ocotea kenyensis, Filicium decipiens, Strychnos mitis* and *Warburgia ugandensis*. The recolonization of disturbed forest habitats initially by early successional and later by late successional species has also been reported from other tropical forests (Whitmore, 1978, 1993; Swaine and Hall, 1983). The regeneration of *Croton macrostachyus* on logged sites would originate either from the soil seed bank or seed dispersed from the surrounding forest (Getachew Tesfaye *et al.*, 2004).

Logging at Harenna forest produced a patchwork of several logged fields and fragmented the intact natural forest. Selective logging in this forest involved the removal of best individuals without regard for future regeneration of the logged fields in general, and the exploited species in particular. Once the largest and best performing individuals were removed, loggers left the exploited stand behind and moved to unexploited new areas.

Generally, one third of the total woody species (about twenty species) at Harenna forest were exploited for commercial timber. Tarekegn Abebe (2003) reported that only small proportion of woody plant species (such as, *Pouteria adolfi-friederici, Cordia africana, Trilepisium madagascariense, Milicia excelsa, Croton macrostachyus, Ekebergia capensis, Morus mesozygia* and *Polyscias fulva*) were exploited for timber from the Southwest forests of Ethiopia. Thus, the range of tree species used for timber from Harenna forest was relatively higher (wider species utilization) than the Southwest forests. But, species of known high commercial value (such as *Pouteria adolfi-friederici, Prunus africana, Olea capensis* and *Ficus vasta*) were relatively less exploited from the Harenna forest than otherwise. The logging operation in Harenna rather relied on single tree species of *Podocarpus falcatus* (80% of the total harvest). Such intensive exploitation of single species would deplete or substantially reduce the over all population of the harvested species as well as seed sources, thereby reducing its genetic potential. When the most dominant trees in the canopy (like *Podocarpus* in the Harenna forest) are harvested selectively, the other remaining species will be stressed by the dramatic change in understorey light, temperature and moisture (Saueli and Lamp, 1991). Thus, the remaining species are likely to be less fit to the changing environment and the future of sustained timber yield and natural regeneration may be diminished. This was revealed by the composition of the regenerated forest on logged fields. Tropical Timber Organization (ITTO) (1997) stressed the economic advantage of utilization of broader range of species from tropical forests. In countries like Ethiopia, where there is an increasingly high demand for timber, the underutilized species would serve as a good source of additional log volume.

The intensity of log harvest for timber at Harenna forest ranged between 18–48 trees per hectare. A study from the dry Afromontane forests of Ethiopia such as Menagesha and Wof-Washa reported that the log harvest was 50 and 47 trees per hectare, respectively (Tamrat Bekele, 1993). Thus, both Harenna and the dry Afromontane forests had shown more or less comparable log harvest per unit area.

Overall, the potential regeneration of tree species on logged sites varied depending on the logging intensity and extent of canopy disturbance. The change in forest composition from *Podocarpus* forest (primary forest) to *Croton* forest (secondary forest) as a result of selective logging at Harenna may become a problem in the future for the sustained timber production. Exploitation of broader range of species giving priority to those species of higher commercial value, for example, *Pouteria adolfi-friederici, Olea capense* and *Prunus africana* on sustained proportion would improve the situation. In conclusion, the logged fields at Harenna forest were found recovering in composition and structure but with secondary forests dominated by single species. The application of silvicultural management that could foster the regeneration of desirable tree species at logged fields is recommended to overcome the situation.

ACKNOWLEDGEMENTS

The financial support for the study was partly obtained from the Institute of Biodiversity Conservation. Special thank is to the staff of Bale Zone Agriculture Development Department (BZADD) and the Menna District Agriculture Office. Ato Shiferaw Bekele (forest technician) deserves sincere thanks for his assistance in the field and provision of valuable information. We thank the three anonymous reviewers for their valuable comments on the earlier version of the manuscript.

REFERENCES

Ashton, M.S., Gunatilleke, C.V., Singhakumara, B.M.P. and Guntilleke, I.A.U.N. (2001). Restoration pathways for rainforest in southwest Srilanka: A review of concept and models. *For. Ecol. and Manag.* **154**: 409- 430.

Bazzaz, F. (1991). Regeneration of tropical forests: Phylogenetic responses of pioneer and secondary species. In: **Rainforest Regeneration and Management,** pp. 91-115 (Gomez-Pompa, A., Whitmore, T. and Hadley, M., eds.). Parthenon Publishing, UNESCO, Paris.

BZADD (2001). Impact of Encroachment on Biodiversity of Harenna Forest with Particular Reference to Sawmill Logging. Bale Zone Agricultural Development Department (BZADD), Goba- Bale (Mimeographed Report).

Chaffey, D.R. (1979). Southwest Ethiopia Forest Inventory Project. A Reconnaissance Inventory of Forest in Southwest Ethiopia. Land Resources Development Centre, England. Project report.

Demel Teketay (1997). Seedling population and regeneration of woody species in dry Afromontane forests of Ethiopia. *For. Ecol. and Manag.* **98**: 149-165.

Edwards, S., Mesfin Tadesse and Hedberg, I. (1995): **Flora of Ethiopia and Eritrea, Vol. 2(2).** The National Herbarium, Addis Abeba University, Addis Abeba and Uppsala University, Uppsala.

EFAP (1994). Ethiopia Forestry Action Programme, Volume III. The Challenge for Development. Ministry of Natural Resources, Addis Ababa.

Friis, I. (1986). Zonation of forest vegetation on the south slope of Bale Mountains, South Ethiopia. *SINET: Ethiop. J.Sci.* **9**: 29-44.

Friis, I. (1992): **Forests and Forest Trees of Northeast Tropical Africa**. Kew Bulletin Add. Ser. XV: 1-396.

Getachew Tesfaye, Demel Teketay and Masresha Fetene (2002). Regeneration of fourteen tree species in Harenna forest, southeastern Ethiopia. *Flora* **197**: 174-181.

Getachew Tesfaye, Demel Teketay, Yoseph Assefa and Masresha Fetene (2004). The influence of fire on soil seed bank composition and density and regeneration in a humid tropical forest, southeast Ethiopia. *Mount. Res. Dev.* **24**: 354-361.

Gomez-Pompa, A., Whitmore, T. and Hadley, M. (1991). **Rainforest Regeneration and Management**. Parthenon Publishing, UNESCO, Paris.

Hedberg, I. and Edwards, S. (1989). **Flora of Ethiopia, Vol. 3.** The National Herbarium, Addis Abeba University, Addis Abeba and Uppsala University, Uppsala.

Hillman, J. (1988). The Bale Mountains National Park Area, southeast of Ethiopia and its management. *Mount. Res. Dev.* **8**: 253-288.

ITTO (1997). **Rehabilitation of Logged over Forests in Asia Pacific Region.** International Tropical Timber Organization (ITTO), Yokohama.

Lisanework Nigatu and Mesfin Tadesse (1989). An ecological study of the vegetation of the Harenna forest, Bale, Ethiopia. *SINET: Ethiop. J. Sci.* **12**: 63-93.

Magurran, A.E. (1988). **Ecological Diversity and its Measurement**. Princeton University Press, New Jersey.

Miehe, G. and Miehe, S. (1994). **Ericaceous Forests and Heath Lands in the Bale Mountains of South Ethiopia: Ecology and Man's Impact.** Stiftung, Walderhaltung in Africa, Hamburg.

Mooney, H. (1963). An account of two journeys to the Araenna Mountains in Bale Province (southeast of Ethiopia), 1958 and 1959-60. *Proc. Linn. Soci.* **172**: 127-

147.

Muller-Dombois, D. and Ellenberg, H. (1974). **Aims and Methods of Vegetation Ecology**. Wiley, New York.

Runkle, J.R. (1981). Gap-regeneration in some old-growth forests of the eastern United States. *Ecology* **62**: 1041- 1051.

Saulei, S. and Lamp, D. (1991). Regeneration following pulpwood logging in lowland rainforest in Papua New Guina. In: **Rainforest Regeneration and Management,** pp. 313-322 (Gomez-Pompa, A., Whitmore, T.C. and Hadley, M., eds.). Parthenon Publishing, UNESCO, Paris.

Swaine, M. and Hall, J. (1983). Early succession on cleared forestland in Ghana. *J. Ecol.* **71**: 602-27.

Tamrat Bekele (1993). Vegetation ecology of remnant Afromontane forests on the central plateau of Shewa, Ethiopia. *Acta Phytogeogr. Suec.* **79**: 1-59.

Tarekegn Abebe (2003). The influence of selective logging on residual stand and regeneration in a rainforest in southwestern Ethiopia. Ph.D. thesis, Swedish University of Agricultural Sciences (SLU), Umeä, Sweden.

Tesfaye Awas, Minassie Gashaw, Getachew Tesfye and Asfaw Tihune (2003). Ecosystems of Ethiopia: National Biodiversity Strategic Action Plan - Inventory Report. Institute of Biodiversity Conservation and Research, Addis Ababa, Ethiopia.

Uhilg, K. (1988). Mountain forests and the upper tree limit on the southeastern plateau of Ethiopia. *Mount. Res. Dev.* **8**: 227-234.

Vazquez-Yanes, C. and Orozco-Segovia, A. (1990). Seed dormancy in tropical rainforest. In: **Reproductive Ecology of Tropical Forest Plants,** pp. 247-259 (Bawa, K.S. and Hadely, M., eds.). Parthenon Publishing, UNESCO, Paris.

Weinert, E. and Mazurek, A. (1984). Notes on the vegetation and soil in Bale Province of Ethiopia. *Feddes Repertorium* **95**: 373-380.

Whitmore, T.C. (1978). Gaps in the forest canopy. In: **Tropical Trees as Living Systems,** pp. 639-655 (Tomlinson, P.B. and Zimmerman, M.H., eds.). Cambridge University Press, UK.

Whitmore, T.C. (1991). Tropical rain forest dynamics and its implications for management. In: **Rainforest Regeneration and Management**, pp. 67-89 (Gomez-Pompa, A., Whitmore, T. C. and Hadley, M., eds.). Parthenon Publishing, UNESCO, Paris.

Whitmore, T.C. (1993). **An Introduction to Tropical Rainforest**. Oxford University, UK

Whitmore, T.C. (1996). A review of some aspects of tropical rainforest seedling ecology with suggestion for further enquiry. In: **The Ecology of Tropical Forest Tree Seedlings,** pp. 3-39 (Swaine, M., ed.). Parthenon Publishing, UNESCO, Paris.