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THE EFFECT OF COMMERCIAL SELECTIVE LOGGING ON A RESIDUAL STAND IN TROPICAL RAIN FOREST OF SOUTH-WESTERN ETHIOPIA

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ABEBE, T. & HOLM, S. 2003. The effect of commercial selective logging on a residual stand in tropical rain forest of south-western Ethiopia. A primary natural forest block, that was scheduled for selective logging was mapped and divided into two parts. In one part an assessment of the structure and composition of the forest was carried out. In the other part the effect of selective logging on the residual stand was studied. A one-hectare sample plot was established for the assessment. A total of 154 individuals of 20 species ≥ 20 cm diameter at breast height (dbh) ha^{-1} were recorded in the unlogged primary forest. Out of these the number of commercial species ≥ 20 cm dbh was about 30 trees ha^{-1}. The average harvested stem volume was 46 m^3 ha^{-1}. The estimated proportion of merchantable volume from the total stem volume was 28%. The logging intensity was, on average, two trees ha^{-1}. On average eight trees > 5 cm dbh were damaged for every tree felled. Approximately 10% of the logged-over area was covered by skidding roads, trails, landings and gaps formed by trees felled. The number of trees ≥ 20 cm dbh found in this study was comparable to the pan-tropical average for tropical rain forest. Damage levels were low compared with figures from most tropical regions.

Key words: *Aningeria adolfi-friederici* - commercial logging - regeneration - tropical forest management

ABEBE, T. & HOLM, S. 2003. Kesan tebangan memilih komersial terhadap dirian baki hutan hujan tropika di tenggara Etiopia. Satu kawasan hutan semula jadi primer yang dijadual untuk tebangan memilih dipetakan dan dibahagi dua. Di bahagian pertama, penilaian struktur dan komposisi hutan dijalankan. Di bahagian yang satu lagi, kesan tebangan memilih terhadap dirian baki dikaji. Penilaian dijalankan dengan membina plot sampel seluas satu hektar. Sejumlah 154 individu daripada 20 spesies yang mempunyai diameter aras dada (dbh) ≥ 20 cm direkod di hutan primer yang tidak ditebang. Daripada jumlah ini, bilangan spesies komersial ≥ 20 cm dbh adalah lebih kurang 30 pokok per hektar. Purata isipadu batang yang ditebang adalah 46 m^3 ha^{-1}. Bahagian isipadu boleh niaga adalah 28%. Purata keamatan tebangan ialah dua pokok per hektar. Secara purata setiap batang pokok yang ditebang akan merosakkan lapan pokok > 5 cm dbh. Lebih kurang 10% kawasan sudah kerja dilitupi jalan penarik, rintis, betau dan ruang akibat pokok tumbang. Bilangan pokok ≥ 20 cm dbh dalam kajian ini boleh dibandingkan dengan nilai purata seluruh tropika bagi hutan hujan tropika. Tahap kerosakan dalam kajian ini adalah rendah berbanding kebanyakan kawasan tropika.

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Introduction

Ethiopia, with a land area of 120 million ha, is one of the largest countries in sub-Saharan Africa. The highlands (above 1500 m) constitute around 45% of the total area. They are inhabited by about four-fifths of the human population of the country and two-thirds of its livestock population. In ancient times, the Ethiopian highlands were mostly covered by different types of forests in which the closed high forests accounted for about 87%, but today reduced to only about 5.6% (Anonymous 1994). The current annual loss of the forest area is estimated to be between 150 000 and 200 000 ha (Anonymous 1994). The main causes for this loss are the clearing of forest for conversion into agricultural land and the uncontrolled exploitation of forest for commercial timber production.

Ethiopia's remaining closed high forest includes various types of rain forests concentrated in the relatively less populated southern and western parts of the country. The central and northern parts of the country are mostly deforested. However, the only information available on the condition of these forests is the nationwide reconnaissance inventory reported by Chaffey (1979) that was carried out between 1974 and 1979.

The management of natural forests for timber production is more complicated than that of plantations. Growth rates in the natural forest are often slow, and regeneration efforts do not always lead to the expected results. A review of tropical rain forest management and silvicultural systems can be found in Neil (1981), Jonkers (1987) and Lamprecht (1990).

In spite of encouraging developments, tropical rain forest management is still at its rudimentary stage (cf. Jonkers 1987). Only a very small proportion of the remaining forest in the humid tropics is under scientific management (Lanly 1982, Schmidt 1987). Furthermore, the outdated diameter-limit system of selective felling is still widely applied throughout the tropics.

With regard to Ethiopian closed high forests, management has been limited to trying to protect the forest from encroachment by farmers, exploitation by selective felling, and, particularly in degraded and logged-over sites, clearing of residual forests and replanting with exotic industrial tree species. Among the 300 indigenous tree species only 15 are currently utilised commercially (Anonymous 1994). Except for the two coniferous species, *Juniperus procera* and *Podocarpus falcatus*, all currently utilised commercial broad-leaved species are not readily regenerated or reforested. Since harvesting focuses on relatively few species, the demand for timber is mostly satisfied by logging over large areas. In the beginning, felling concessionaires were obliged to plant trees of similar species to replace the trees they had felled. This approach failed because of lack of knowledge on silvicultural characteristics and requirements of the tree species to be planted. Also, control of operations scattered sparsely over thousands of hectares was impossible.

Many authors have reported on the nature and extent of damage caused by uncontrolled logging operations in the tropical forests, e.g. in Africa (Dawkins 1958, Bullock 1980, Willan 1989, Kasenene & Murphy 1991, White 1994), in Southeast Asia (Nicholson 1958, 1979, Fox 1968, Bertault & Sist 1997) and in

South America (Jonkers 1987, d'Oliveira & Braz 1995, Webb 1997). Selective logging typically results in destruction of about 50% of all trees present before logging (Ewel & Conde 1976, Johns 1988). However, the destruction varies greatly with the stocking density of commercially viable timber species, which is dependent upon the botanical composition of the forest, current economic conditions, and the method of logging (White 1994).

Logging in Ethiopia is carried out by state-owned and private sawmills and plywood factories. All of them organise their operations in crude ways. No plans or maps are prepared. The first phase of the operation includes tree selection, marking, felling and bucking. Climber cutting and directional felling are not practised. The second phase of the operation is the extraction of logs. After felling and bucking, heavy equipment, usually a crawler bulldozer, is used to drag the log to a landing. The machine operator makes his own skidding road and trail through the forest by pushing over trees and other undergrowth in his way. At the felling site, because of poor felling practices, the machine operator often has to reposition the log for extraction. This further damages any remaining vegetation near the stump.

Selective logging is now practised in much of the natural forests in south-western Ethiopia, but no studies have been undertaken to investigate how it affects the residual stand, the regeneration, and general condition of the forest. Hence, this study was initiated to investigate these effects.

Materials and methods

Study area

The study was carried out in a forest block of about 110 ha in Godere State Forest, in south-western Ethiopia, at Bebeka sawmill logging sites, located at latitude 7° 11' N and longitude 35° 15' E (Figure 1). Most of the area is covered by transitional rain forest (Friis 1992), which is located between broad-leaved afromontane rain forest in north-east and lowland dry peripheral semi-deciduous Guineo-Congolian type forest in south-west. The elevation at the study site is about 1000 m with gently- sloping topography. On average the annual temperature ranges between 20 and 25 °C. The mean annual rainfall is close to 2000 mm, with rain all year round, but mostly in September (Friis 1992). The bedrock is largely composed of volcanic rock, mainly with alkali olivine basalt and tuffs. The soils in the study area are red or brown ferrisols derived from volcanic parent material (Mohr 1971).

Before 1991, Godere forest was part of Yeki-Godere State Forest. Yeki-Godere forest was demarcated and designated as a state forest in 1988. Total demarcated area was about 101 000 ha. Timber extraction in the area began in 1985. The area supports the Bebeka sawmill situated in Metti, a town 10 km away from the study site. Bulldozers are used to drag logs out to landings and roads. Logs are then loaded onto lorries and driven to the sawmill. In addition to natural forest, there are shifting cultivation and new settlement enclaves. Also located within the forest is the 3000-ha Tepi State Coffee plantation.

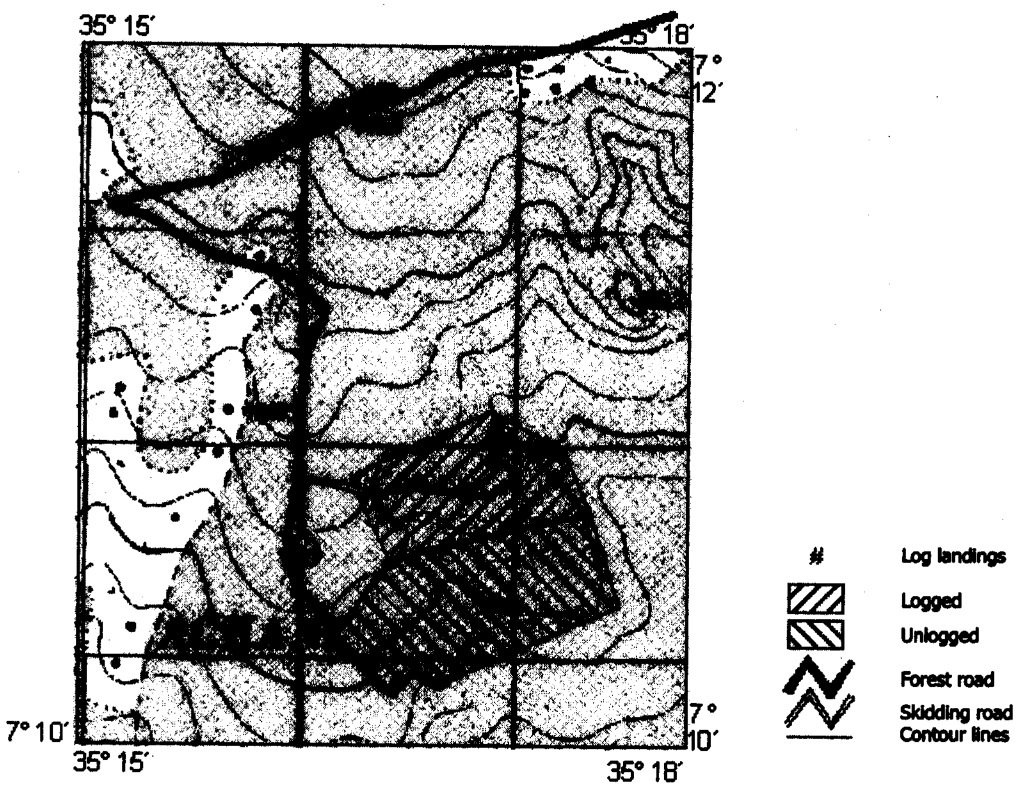

Figure 1 Study area in south-western Ethiopia

Methodology

Mapping of the forest block was conducted with the help of a global positioning system (GPS) using boundaries derived from a topographic map of the area with a scale of 1:50 000. The study block was divided into two parts. Assessment of the growing stock (composition and structure) of the primary forest was carried out in one part of the block (62.8 ha) and commercial selective logging was conducted in the other 47.2 ha.

Primary forest

The assessment of the primary natural forest was carried out by establishing a one-hectare square plot. The plot was then subdivided into 25 quadrats of size 20 × 20 m each (Figure 2). The data collection was conducted on nested subplots following a method described by Alder and Synnott (1992).

The diameter of trees without buttresses was measured at 1.3 m above ground using diameter tape. For buttressed trees, the measurement was taken at 0.3 m above the end of the buttress using a Spiegel Relascope. Each tree was labelled with a numbered tag. Tree identification was made with the help of loggers and a field local guide and was directly cross-checked according to Thirakul (1994).

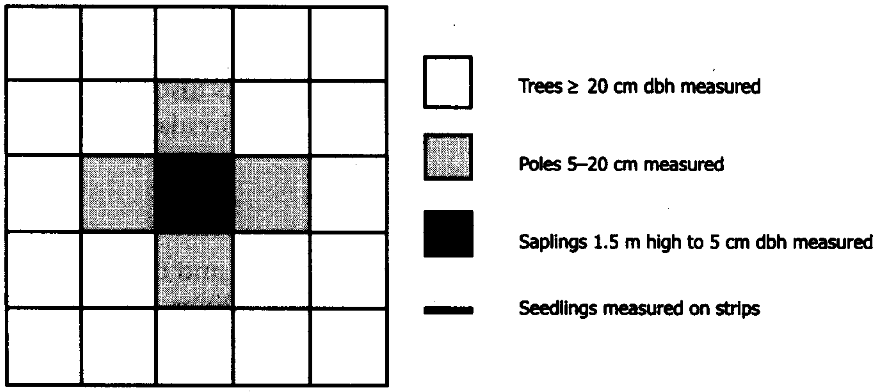

Figure 2 Arrangements of tiered subplots for assessing of the natural primary forest taken from Alder & Synnott (1992)

Selective logging

Foresters from Godere District Agriculture Office selected and marked the trees for felling. Logging was carried out by Bebeka sawmill using conventional methods, namely, axe felling, bucking and extraction using crawler bulldozer. Common bucking length of logs was 4 m. The logging was carried out between May and July 1999. Of a total of 91 trees felled, 23 sample trees were randomly selected from the logged-over area. Each sample tree was identified to species level and measured for stump diameter, stump height, total tree length, merchantable bole length, buttress length, crown point diameter, number of merchantable logs and diameters of the merchantable logs (bottom, upper).

Simultaneously, residual trees were measured for diameter at breast height (dbh) and checked for damage. The damage type was recorded into three damage classes (DC) following the method of Nicholson (1985) after slight modification. The classes include: DC 1 for slight damage, DC 2 for severe damage (defined as any wound affecting the wood surface, or more than 2 m long, or affecting more than 20% of the girth, or crown breakage of more than two-thirds), and DC 3 for trees smashed.

In order to estimate the proportion of the logging area covered by skidding road and skidder trails, the length of skidding roads and trails were measured using electronic distance measuring equipment. The bulldozer blade width was taken as the width of the skidding roads and trails. To estimate the area of landings, the maximum and minimum sides of landings were measured to the nearest metre using a measuring tape.

The gaps formed by felled trees were determined by adding the gaps created along the stem and at the location of the fallen crown. The gap areas created along the stems were determined by assuming a rectangular shape. Using the stump as reference point, the distance to the crown point was measured with a tape and taken as one side of the rectangle. The other side of the rectangle was determined by adding five meters (2.5 m on both sides) to the stump diameter. The gaps at the location of the fallen crown were determined by measuring the length between crown point and the tip of the crown. This distance was taken as diameter of a circle and the gap area was calculated by a circular approximation.

Analysis

The first step in the analysis of primary forest structure and composition was a straightforward estimation of the number of seedlings, saplings, poles and mature trees. The proportion of commercial and non-commercial species in each size class was estimated, and the proportion of commercial and non-commercial species ≥ 20 cm dbh by diameter class was computed.

In the selectively logged area, data from the felled sample trees were analysed by simple descriptive statistics. Total stem volume was determined by summing merchantable bole volume and buttress volume. The merchantable bole volume was estimated from the measurement made between the top of the buttress and the crown point of each log. The buttress volume was estimated from the measurement of butt log made from the base to the buttress convergence point. The merchantable bole volume of felled sample trees was estimated by summing up the volumes of its constituent logs. The volume of the logs was calculated using Smalian's formula (Philip 1994). The proportion of merchantable bole volume from the total stem volume was estimated using a ratio estimator as given by Thompson (1992). The formula utilised was

$$r = \frac{\sum_{i=1}^{n} y_i}{\sum_{i=1}^{n} x_i} = \frac{\bar{y}}{\bar{x}}$$

where

r = sample ratio estimator,
y = merchantable bole volume,
x = total stem volume, and
n = number of sample trees.

The mean square error (MSE) was estimated as:

$$\mathrm{MSE}(r) = \left(\frac{N-n}{N\bar{x}^2}\right)\frac{s_r^2}{n}$$

where

N = number of population units and
s_r^2 = the sample variance of $y_i - rx_i$.

A chi-square test was conducted to determine whether the proportion of smashed trees (DC 3) was dependent on diameter. The test was conducted by first combining the data from the damage classes DC 1 and DC 2. Also all diameters above 60 cm were put together to simplify the interpretation of the analysis.

Finally, the proportion of logging area covered by skidding roads, trails, landings, and gaps formed by felled trees was computed.

Results

Forest structure and composition of primary forest

A total of 154 individuals of 20 species ≥ 20 cm dbh per hectare were recorded in the unlogged primary forest. From these, only five were commercial species with four species, namely, *Aningeria adolfi-friederici, Morus mesozygia, Ekebergia ruppeliana* and *Antiaris toxicaria* being commercially exploited. The fifth *Cordia africana,* is now a protected species.

Summary data on the size class distribution and the number of commercial and non-commercial species in each size class are provided in Table 1. The diameter distribution of commercial and non-commercial species ≥ 20 cm dbh is shown in Figure 3.

Table 1 Sample plot summary of the primary forest showing the number of commercial and non-commercial species for each size class in hectare basis

Species	Size class			
	Mature trees	Poles	Saplings	Seedlings
Aningeria adolfi-friederici	14	30	-	4375
Antiaris toxicaria	6	20	-	1625
Cordia africana	4	-	-	-
Ekebergia ruppeliana	1	-	-	-
Morus mesozygia	3	-	-	-
Non-commercial species	126	170	550	1375
Total	154	220	550	7375

Commercial selective logging

From a total of 91 felled trees (dbh ≥ 60 cm), 85 were *A. adolfi-friederici,* five were *M. mesozygia* and one was *E. ruppeliana.* A summary data of the 23 sampled felled trees is given in Table 2.

The average harvested volume was 46 m^3 ha^{-1}. The estimated total harvested stem volume including buttress volume from the 47.2 ha commercial selective logging area was 2128.7 m^3 with standard error of 167.0 m^3. From the total stem volume the proportion of merchantable bole volume was 28% with root mean square error (RMSE) of 5%.

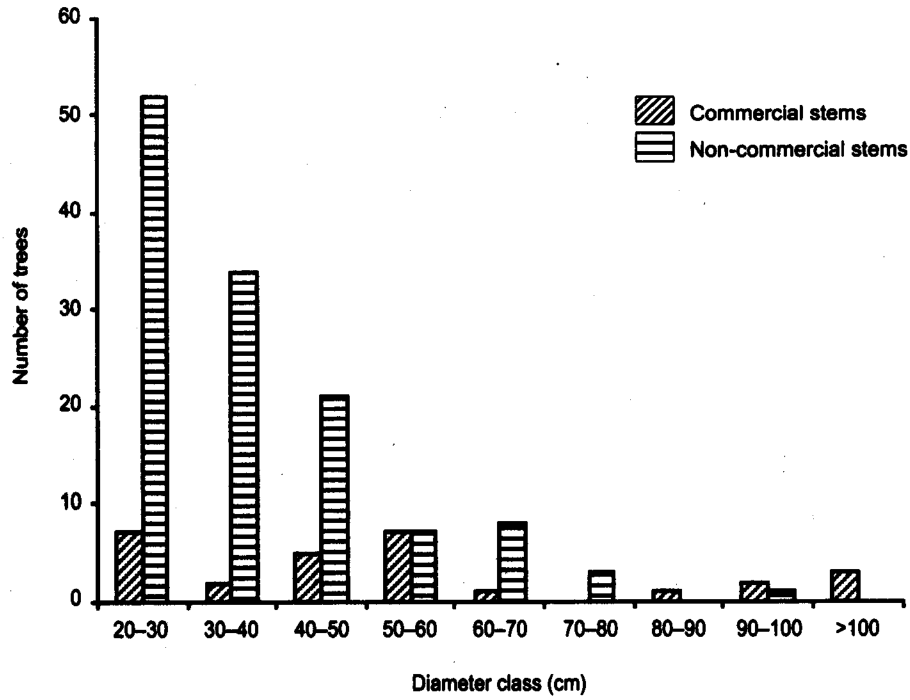

Figure 3 The frequency of commercial and non-commercial species ≥ 20 cm dbh by diameter class

Table 2 Summary data for the 23 sampled felled trees

Measurement	Mean (n = 23)	Standard deviation
Stump diameter (cm)	220.0	50.0
Stump height (m)	0.8	0.1
Total tree length (m)	37.5	2.9
Buttress length (m)	6.8	2.3
Merchantable bole length (m)	12.8	4.0
Crown point diameter (cm)	70.0	20.0
Number of logs with 4 m length	3.1	1.0

The average logging intensity was two trees ha^{-1} or 46 m^3 ha^{-1}. On average, for every tree felled, eight residual trees > 5 cm dbh were damaged during felling. Average total damage was 16 trees ha^{-1}. Selective logging damage according to damage and diameter classes for trees > 5 cm dbh is shown in Figure 4. The χ^2 test showed a significant difference in the proportion of smashed trees between diameter classes (χ^2 = 14.1, df = 5, p = 0.015).

From the total of 47.2 ha, 1.4% of surface area was covered by skidding roads and trails after logging, 1.3% was used for landing (thus a total of 2.7% of the ground was bare, compacted soil), and 7.6% was covered by gaps formed by trees felled. The average gap size per tree felled was 399.4 m^2.

Discussion

The number of trees (≥ 20 cm dbh) in the primary natural forest (150 trees ha^{-1}) is comparable to the pan-tropical average for tropical rain forest (Alder & Synnott 1992). Out of these the number of trees of commercial species was about 30 trees ha^{-1}. This seems adequate as long as the current logging intensity is maintained. Number of trees in tropical rain forest decreases almost geometrically with increasing diameter class (Rollet 1978). This is evident from the results in this study for trees ≥ 20 cm dbh (Figure 3). Patterns in diameter class distribution of the commercial species are most important in planning for selective management. In this study area, the number of commercial stems ≤ 60 cm dbh (diameter limit for selective felling is 60 cm) was adequate to replace the losses in larger-diameter classes due to selective felling. This can be justified only as far as the selective logging damage to the residual stand is kept at minimum and current logging intensity remains unchanged.

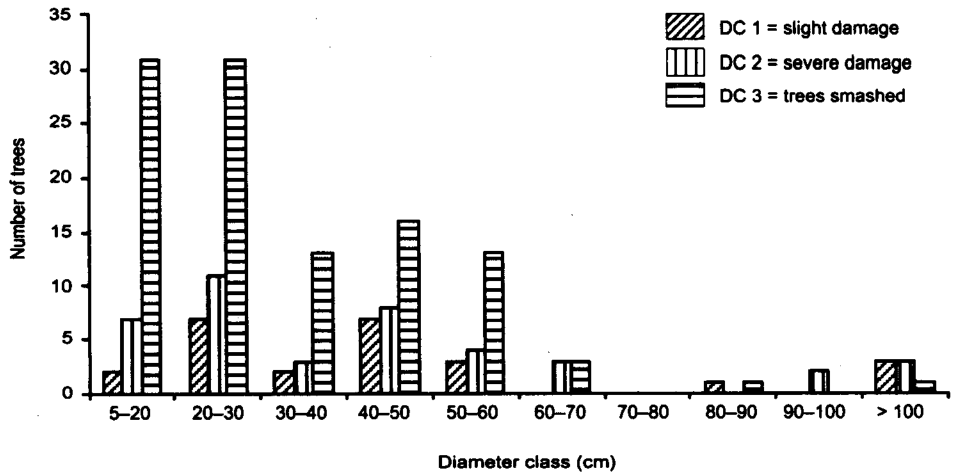

Figure 4 Selective logging damage in each diameter class grouped into three damage classes

The logging intensity in this study was two trees ha^{-1}. One species, *A. adolfi-friederici*, accounted for 93% of trees felled, and together with *M. mesozygia*, accounted for 99%. The remaining part is fulfilled by occasionally cutting the other commercial species, namely *A. toxicaria* and *E. ruppeliana*. *Cordia africana* is currently protected. This is representative of Ethiopian logging preference, which has traditionally concentrated on *A. adolfi-friederici* and has only recently begun to diversify. Logging intensity is also similar to the other parts of Africa, e.g. 1.05 trees ha^{-1} in Cameroon (Bullock 1980), 1 to 2 trees ha^{-1} in Republic of Congo (Fickinger 1992) and 1–2 trees ha^{-1} in Gabon (White 1994). However, in Southeast Asia, the logging intensity is generally high. In Borneo, for example, the logging intensity was found to be more than 10 stems ha^{-1}, i.e. about 100 m^3 ha^{-1} (Nicholson 1958, 1979, Pinard & Putz 1996, Bertault & Sist 1997, Sist *et al.* 1998).

The proportion of merchantable bole volume was 28%, which is relatively low in comparison with the results reported from other tropical countries. In a review of logging waste and residues in tropical countries, Dykstra (1992) estimated felling recovery rates to be 54% in Africa, 46% in Asia/Pacific, 56% in Latin America and the Caribbean, and on average 50% in tropical areas. In this study, the low recovery rate of merchantable bole volume was mainly due to the irregular form and the long buttress of *A. adolfi-friederici* that led to overestimation of buttress log volume. In addition, the technological and know-how limitations have contributed to this low log recovery rate.

In this study, an average of eight trees > 5 cm dbh per tree felled were damaged during felling. Average damage was 16 trees ha^{-1} during felling. From the total of damaged trees 62.2% were smashed. A high proportion (56%) of smashed trees was in the lower dbh classes (5 to 30 cm, Figure 4).

In Southeast Asia, 33% of the total area and 33 to 67% of the residual trees are damaged after logging (Dykstra *et al.* 1996). Ewel and Conde (1976), Whitmore (1984) and Johns (1988) have reviewed studies of logging damage throughout the tropics. Typical figures for incidental loss (percentage of individual killed) outside Africa averaged 50%.

Nevertheless, it is difficult to make comparison between sites since few studies include all measures of logging damage (Johns 1988). Hence, it is recommended that future studies include the assessment of logging damage at different level of logging intensity by measurement of stocking densities before and after logging. Furthermore, it is essential to include measurements of damage level caused by felling and extraction. It would also be appropriate to assess the level of damage with and without climber cutting and directional felling.

In our study, skidding roads, trails, landings and gaps formed by felled trees covered 10.3% out of the total 47.2 ha. From this, 2.7% of the area had soil disturbance, i.e. the soil was found bare and compacted. The density of skidding roads and trails in this study area was found to be low compared with other tropical countries. Skidding trails commonly represent 20 to 40% of the harvesting area (Dykstra & Heinerich 1996).

In the case of Ethiopia, immediate measures should be taken to draft a guideline for selective logging for the state forest management unit that is responsible for the sustainable management of the remaining natural forests. Additionally, further research on the logging damage and on silvicultural treatment of logged-over forest is also recommended.

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