Journal of Tropical Forest Science 12(4):747–760 (2000)

POPULATION STRUCTURE AND REGENERATION OF THE MAIN TREE SPECIES IN THE ACACIA WOODLANDS OF THE RIFT VALLEY OF ETHIOPIA

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Received February 1999

GETACHEW ESHETE. 2000. Population structure and regeneration of the main tree species in the acacia woodlands of the Rift Valley of Ethiopia. The goal of this study was to characterise the tree population structure under different land use practices in the acacia woodlands of the Rift Valley of Ethiopia. Topics addressed are the species composition, the height and diameter distributions, the number of trees and the regeneration of major tree species. The relationship between the occurrence of regeneration and population characteristics such as number of trees, basal area and crown closure was studied. Results indicate that within the study area the numbers of seedlings (height ≤150 cm), saplings (> 150 cm height and diameter < 50 mm) and mature trees (> 150 cm height and diameter ≥ 50 mm) are 98, 278 and 63 ha^{-1} respectively. *Acacia tortilis* was found to have the highest number of seedlings (65 ha^{-1}) and mature trees (33 ha^{-1}). The highest number of saplings was from *A. senegal* with 139 individuals per hectare. The diameter distribution was J-shaped with most of the trees less than 30 cm in diameter. The arithmetic average height of trees (≥ 50 mm in diameter) was found to be around 6 m. With reference to regeneration, most of the seedlings/saplings were found to be concentrated in a few parts in grazing lands with relatively well stocked sites. A positive partial relationship ($p = 0.07$) between number of mature trees and occurrence of regeneration was found. Given a certain number of trees, crown closure was found to have a negative partial relationship ($p = 0.06$). With regard to land use, the categories "open grazing" and "cultivated land" were found to have a significantly lower number of seedlings. The relatively low frequency of mature trees, with very few trees remaining in the upper diameter classes, the concentration of seedlings to limited parts of the study area, and the low species diversity are some of the indicators of the degradation that has occurred over the past decades. Evidence implicates uncontrolled grazing, browsing, and tree felling for commercial fuelwood and charcoal as the major causes of the degradation.

Keywords: *Acacia tortilis - A. senegal - A. seyal - A. etbaica - Balanites aegyptiaca* - woodland dynamics - sustainable management

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GETACHEW ESHETE. 2000. Struktur populasi dan pemulihan spesies pokok utama di hutan jarang acacia di Lembah Rift, Ethiopia. Tujuan kajian ini adalah untuk mencirikan struktur populasi pokok di bawah amalan penggunaan tanah yang berbeza di hutan jarang acacia di Lembah Rift, Ethiopia. Tajuk yang dipilih ialah kandungan spesies, taburan ketinggian dan garis pusat, bilangan pokok, dan pemulihan spesies pokok utama. Kaitan antara kewujudan ciri-ciri pemulihan dan populasi seperti bilangan pokok, luas pangkal, dan penutupan silara dikaji. Keputusan menunjukkan bahawa dalam kawasan yang dikaji, bilangan anak benih (ketinggian ≤ 150 cm), anak pokok (ketinggian > 150 cm dan garis pusat < 50 mm) dan pokok matang (ketinggian > 150 cm dan garis pusat ≥ 50 mm) masing-masing ialah 98, 278, dan 63 ha^{-1}. *Acacia tortilis* didapati mempunyai bilangan anak benih yang tertinggi (65 ha^{-1}) dan pokok matang (33 ha^{-1}). Bilangan anak pokok yang tertinggi adalah daripada *A. senegal* dengan 139 pokok sehektar. Taburan garis pusat berbentuk J dengan kebanyakan pokok adalah kurang daripada 30 cm. Ketinggian purata aritmetik pokok (garis pusat ≥ 50 mm) didapati kira-kira 6 m. Dengan merujuk kepada pemulihan, kebanyakan anak benih/anak pokok didapati tertumpu kepada beberapa bahagian di kawasan ragut dengan tapak stok yang baik. Kaitan separa yang positif ($p = 0.07$) antara bilangan pokok matang dan kewujudan pemulihan telah didapati. Dengan beberapa batang pokok yang diberikan, penutupan silara didapati mempunyai kaitan separa yang negatif ($p=0.06$). Mengenai penggunaan tanah, kategori "tanah ragutan terbuka" dan "tanah yang ditanam" didapati mempunyai bilangan anak benih yang kurang dengan bererti. Kekerapan yang rendah secara relatif bagi pokok matang, dengan sangat sedikit pokok yang masih ada di dalam kelas garis pusat atas, penumpuan anak benih kepada bahagian-bahagian tertentu di dalam kawasan yang dikaji, dan kepelbagaian spesies yang rendah merupakan tanda-tanda berlakunya pendegradan sejak berabad-abad yang lalu. Bukti-bukti menunjukkan ragutan yang tidak dikawal, dan penebangan pokok untuk mendapatkan kayu api dan arang untuk tujuan komersial merupakan penyebab utama pendegradan.

Introduction

Dry woodlands of Africa, south of the Sahara (Figure 1), occupy an area of over 13 million square kilometers (Griffiths 1961). The definition and characteristics of woodlands are described in Menaut *et al.* (1995), following the so-called Yangambi classification. In Ethiopia, woodlands occupy approximately 20 percent of the total area (Anonymous 1988). Of the total woodland area, approximately 55 percent are acacia woodlands mainly located in the lowlands of the Rift Valley. According to White (1983) and Wormald (1984), these woodlands belong to the Somali-Masai formation.

The acacia woodlands in the Rift Valley of Ethiopia have considerable ecological and management significance in terms of safeguarding the fragile ecosystem and contributing to the national economy. They are important for modifying the harsh environment making it more favorable for other flora and the fauna, providing nesting places and shelter for many resident and migratory birds and some wild mammals (Bolton 1970, Syversten 1995, Tedla 1995). They also protect the soil from erosion and help maintain its fertility (e.g. Belsky *et al.* 1989). Being vital sources of fuelwood, construction material, fodder, honey flora, and so on, the woodlands are also the mainstay of the local population.

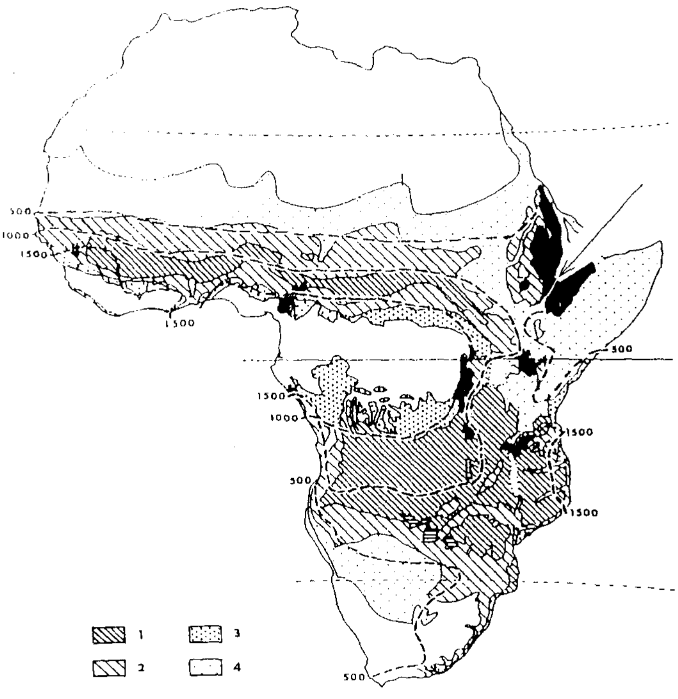

Figure 1. Dry woodlands and forests of Africa (taken from Menaut *et al.* 1995). (1) densely wooded savannas, woodlands, and dry forests; (2) tree/shrub savannas; (3) humid savannas; (4) arid savannas. Broken lines indicate mean annual isohytes. The arrow indicates the location of the study area in the Ethiopian Rift Valley.

Fire and elephant damage, which plays an important role in the dynamics of many similar East African woodlands (e.g. Mwalyosi 1990), is uncommon or absent in the area. Furthermore, termite activity, which is a feature of many woodlands and dry forests (Menaut *et al.* 1995) affecting the soil characteristics (e.g. structure, texture, moisture status, organic matter, etc.) and hence vegetation productivity, structure, and dynamics, is not significant although quite frequent in areas close to the study site. Instead, felling and uprooting of trees for fuelwood and other purposes, cattle browsing, and trampling play a significant role in the early growth and subsequent development of the tree population in this area. In general, animals are important for seed dispersal and for shaping the woody vegetation through browsing. However, wind-dispersal of seeds is also important for some tree species. A comprehensive description of the woodland dynamics which includes the role of fire, regeneration capacity, and the role of termites is given in Menaut *et al.* (1995).

In recent years, negative implications of the environmental degradation in the woodlands of the Rift Valley of Ethiopia have been observed (c.f. Anonymous 1994). Heavy browsing and grazing by goats and cattle, and the loss of the woody plant cover due to uncontrolled felling are the main factors which have contributed to the negative trend (Sandahl & Ohlsson 1978, Fries & Heermans 1992, Anonymous 1994, Tedla 1995). Although Sandahl and Ohlsson (1978) did not indicate how they calculated, they estimated the rate of decline during the late 70s at 60 000 hectares annually in the acacia woodlands of the Rift Valley of Ethiopia. According to Bolton (1970) and Makin *et al.* (1975), the cattle stocking density in these woodlands had, in the 1960s, already exceeded by more than five times the density recommended by range managers. In this connection, there are many visible symptoms of adverse effects on the livelihood of the local population today. Scarcity of fuelwood, fodder, and construction materials, and crop yield decline due to loss of fertile topsoil are among the common problems encountered by the current generation.

Lack of knowledge of the state and dynamics of the woodlands has been one of the problems that has prevented land managers from designing methods to achieve a sustainable use of the resources. In this regard, tree size structure, species composition, and regeneration patterns are some of the elements to be addressed. Knowledge of this kind can be used, for example, in determining appropriate management practices such as identifying priority sites for regeneration, creating exclusion areas to avoid seedling damage by grazing animals, and manipulation of site characteristics to enhance growth conditions. Furthermore, it can also be used to recommend strategies from a multiple-use perspective that can promote the maintenance of biodiversity and ecosystem rehabilitation, while the local population, in the meantime, uses the woodland resources.

This study was part of a larger project designed to outline methods for determining the state in which the acacia woodlands of the Rift Valley of Ethiopia are found. The goal of the study was to characterise the woodlands in the study area in terms of tree population structure under different land use practices, as one step towards understanding the dynamics and future potential of the woodland resources. The species composition, the height and diameter distributions, the number of trees, and the natural regeneration of the major tree species were the topics addressed. The relationship between occurrence of natural regeneration and population characteristics such as number of trees, basal area, and crown closure was also studied.

Materials and methods

Description of the study area

The study area is located in the Rift Valley of Ethiopia, approximately 190 km south of Addis Ababa at 7° 30'–7° 40' N and 38° 35'–38° 45' E (Figure 1). The topography is generally flat to gently sloping with elevation ranging from *c.* 1570 to 1780 m above mean sea-level.

The climatic make-up of Ethiopia and the climate specific to the study area are given by Griffiths (1961), Makin *et al.* (1975), Russell-Smith (1984), and Getachew

& Ståhl (1999). During November to February, when northeasterly winds persist, long periods of dry weather are experienced, with little or no cloud and low relative humidity. Between March and June the weather becomes more unsettled and the rains at this season are light and unreliable. The main rains occur between July and October, when moist winds from the Atlantic and Indian oceans converge over the highlands of the country. The annual rainfall in this area varies between 450 and 700 mm and the mean annual temperature is about 20 °C with the highest temperature occurring in March and the lowest in December.

The soils originate from recent volcanic deposits and lake sediments that are formed largely from ash and pumice. They tend to increase in clay content with distance from the lakes. Textures vary from loamy sand to fine sandy loam or silty loam on the lower terraces, to sandy loam and clay loam on higher terraces. Most of the soils in the study area have a weak top soil structure, and this together with fine sandy structure renders them vulnerable to wind erosion or to surface capping once the protective cover of acacia woodland has been removed. The soils are generally low in organic matter content and have only a moderate capacity for retaining water and nutrients. More details of the soils in the area are given in Makin *et al.* (1975).

The vegetation form is open acacia woodland with *Acacia tortilis, Acacia senegal* and *Acacia seyal*, locally mixed with *Balanites aegyptiaca, Acacia etbaica* and *Euphorbia candelabrum.*

On rocky slopes, towards the southwestern part, tree species like *Maytenus senegalensis, Zizyphus* spp. and *Ficus* spp. are also common. In addition, shrubs such as *Croton dichogamus, Carissa edulis,* etc., occur especially on rocky and degraded sites scattered over the study area. In most parts, the woodland has been heavily disturbed due to human interference and as a result the stocking appears to be severely affected. Details of the past vegetation of the area can be found in Beals (1970), Makin *et al.* (1975) and Russell-Smith (1984).

Land use integrates crop cultivation and extensive cattle grazing as the main forms of rural occupation. There are also a number of lakes (Abiyata, Langano, and Shala) in the area, which are well known as a habitat for many resident and migratory birds. Part of the area is set aside for the Abiyata-Shala Lakes National Park which is a sanctuary for migratory and resident birds and some larger mammals (c.f. Tedla 1995).

Data collection

The data used in this study were collected on two different occasions, the first in 1995 between January and March, and the second in 1997 between April and June. Data from 1995 were collected primarily for another purpose, whereas the present study was one of the focuses for the data acquired in 1997.

Data from 1995 were used only for deriving the height structure of the woodlands. The design was a stratified PPS (probability proportional to size, in this case to area) sampling of compartments with relascope sub-sampling of trees for height measurement (Getachew & Ståhl 1998). The data from 1997 were collected using a systematic plot sampling design. A total of 134 plots were allocated at intervals of 280 m along seven line-transects laid out systematically at a spacing of 3 km across the study area. Each plot was divided into two concentric circular plots with radii of 6 and 12 m for gathering the relevant data. In the small plots, all regeneration of the major acacia tree species (i.e. regeneration from seeds, coppices, and suckers) was tallied and classified by species and height. Based on their diameter and height, the trees were classified into seedlings (height (150 cm), saplings (> 150 cm height and diameter < 50 mm) and mature trees (> 150 cm height and diameter ≥ 50 mm). In plots with 12 m radius the diameter at 0.8 m (D_{08}) (c.f. Getachew & Ståhl 1998) of mature trees was measured and the species recorded. Furthermore, the land use (agriculture, grazing, settlement, and others), general landform (crest, middle or bottom slope), estimates of the slope percentage class, and the soil physical characteristics (texture, depth, stoniness, etc.) were recorded.

Analysis

Straightforward simple random sampling estimates (c.f. Thompson 1992) of the number of seedlings, saplings, and mature trees were made. The biomass, crown closure, and basal area of the mature trees were also estimated. Functions developed by Getachew and Ståhl (1998) were utilised to calculate the biomass and the crown closure.

In order to describe the population structure in terms of height and diameter distributions, the relative frequencies of mature trees at different height (2 m) and diameter (4 cm) classes were calculated. The height structure was derived by estimating the total number of trees within each class considering the relascope sub-sampling of the stratified PPS (to area) design applied during the data collection in 1995. Thus, to infer the number of trees in each class from the sample trees, observations were weighted by the inverse of their inclusion probabilities (c.f. Thompson 1992).

To provide a more detailed description of the regeneration patterns, a logistic regression function was developed. The logistic model was selected due to its usefulness in handling data sets with a binary response. For example, the model was recommended by Hamilton (1974) to estimate event probabilities and was used by Ferguson *et al.* (1986) to predict regeneration probability. Plotwise values of basal area, number of trees, and crown closure were utilised as predictor variables. In order to investigate the influence of land use variation, the prevailing land uses were introduced as indicator variables in the function. Four fertility classes derived by grouping the estimates of landform, slope percentage class and soil physical characteristics were also tested as indicator variables in developing the model. A threshold number of 4 seedlings/saplings was used for categorising a plot into the class "regenerated".

The basal area (G_{08}) was computed from the D_{08} measurements made on all trees within a plot. The crown closure for each plot was computed by dividing the aggregated crown area with the corresponding plot area, assuming non-overlapping canopies. The crown area for each tree was predicted from D_{08} values using a regression function developed in a previous study (Getachew *et al.* 1999). Here, it is worth noting that both basal areas and crown areas were derived from the same D_{08} measurements. The same effect could have been obtained from one single transformation of the D_{08} values. The present approach was chosen to facilitate a simpler interpretation of the results.

Prevailing land uses were grouped into the following three categories:

1. Grazing land with trees (more than one tree per plot in areas outside settlement and rock outcrops)
2. Open grazing (only grass with scattered bushes), settlement with some remnant trees around homesteads, and areas with rock outcrops
3. Cultivated land with scattered trees

The land use categories were created in order to simplify the analysis, although it should be noted that grazing influences the entire area.

The basic form of the logistic regression was utilised, as given by Hosmer and Lemeshow (1989):

$$\pi(x) = \frac{e^{\beta_0 + \Sigma\beta_i x_i}}{1 + e^{\beta_0 + \Sigma\beta_i x_i}}$$

in which $\pi(x)$ is the probability of natural regeneration above the threshold (at least 4 seedlings/saplings), and the βs are parameters, and the xs the predictor variables.

The final model was developed after the significance of the variables and the assumptions of linearity in the logit had been tested according to procedures described in Hosmer and Lemeshow (1989).

As a measure of aggregation of the spatial distribution of seedlings and saplings, the relative frequency of plots in a certain regeneration class was computed after grouping the number of seedlings/saplings into classes.

Results and discussion

Population structure

The frequency distributions of diameter and height are given in Figures 2 and 3. The diameter distribution of trees has often been used to represent the population structure of forests (e.g. Khan *et al.* 1987). The distribution indicates a reversed J-shape distribution with most of the trees being less than 30 cm in diameter. The large proportion of small trees is an indication of woodlands comprising mainly young trees. The absence of large trees can be ascribed to the local people's preference for those trees in commercial fuelwood and charcoal making.

From the height distribution of trees (≥ 50 mm in diameter), the arithmetic mean height was found to be around 6 m. This is within the height range (5–12 m) given in FAO/UNEP (1981) for similar types of woodlands. In reports by Hofstad (1990) and Menaut *et al.* (1995) the height given according to the so-called Yangambi classification for woodlands is between 8 and 20 m. The lower height found in the study area was probably due to the large number of young trees and the relatively poor soil and moisture conditions prevalent in the area. However, comparisons are difficult due to the absence of a height definition in the two mentioned reports.

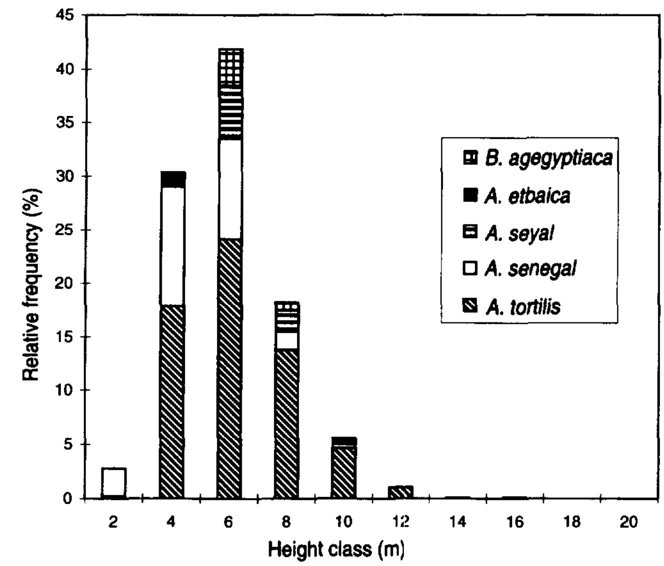

Figure 2. The height distribution (D_{08} ≥ 50 mm) of the major tree species

A summary of specieswise estimates of the number of seedlings, saplings and mature trees (ha^{-1}) is given in Table 1. Seedlings and saplings were mainly from the most frequent species of mature trees. *Acacia tortilis*, with 65 individuals ha^{-1}, had the highest seedling density. The highest number of saplings was from *A. senegal* with 139 individuals ha^{-1}. The presence of a large number of saplings of *A. senegal* is probably due to the feeding preference of the animals for other acacia species. For example, Kiyiapi (1994) reported that *A. tortilis* is preferred by goats for being highly palatable than other acacia species and hence heavily browsed in the Baringo area in Kenya.

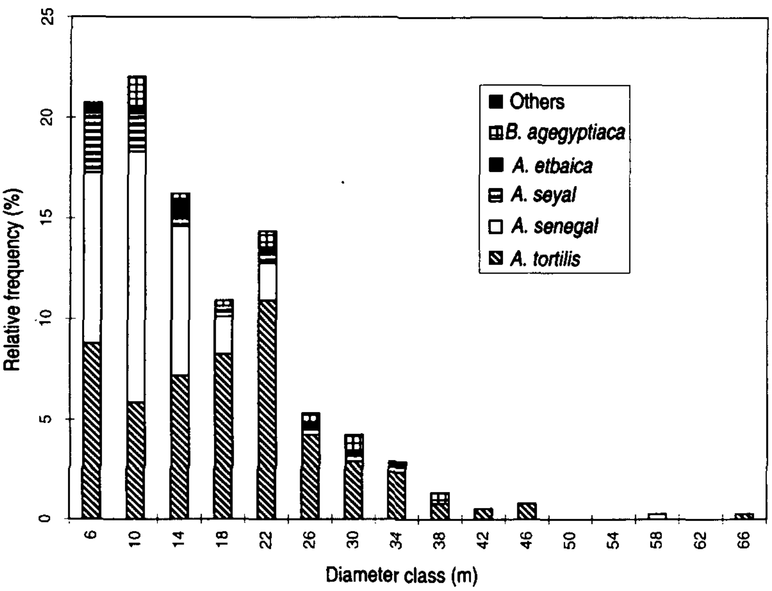

Figure 3. Diameter distribution ($D_{08} \geq 50$ mm) of the major tree species. Note that the lowest class consists of trees between 5 and 6 cm only.

Table 1. Summary results of the specieswise estimates of average number of seedlings, saplings and mature trees of the major tree species. The "se" in the table indicates the standard error of the estimates.

Species	Seedlings (ha^{-1})			Seedlings (ha^{-1})			Mature trees (ha^{-1})		
	Mean	%	se	Mean	%	se	Mean	%	se
A. tortilis	64.7	66	49.87	124.1	45	21.69	32.9	52	4.02
A. senegal	22.4	23	23.30	139.3	50	27.06	20.7	33	4.83
A. seyal	3.3	3	6.92	5.9	2	2.51	4.0	6	1.34
A. etbaica	3.3	3	6.92	5.9	2	3.13	1.3	2	0.56
A. aegyptiaca	4.6	5	13.11	2.6	1	2.08	3.0	5	0.80
Others	-	-	-	-	-	-	0.3	2	0.33

The average number of seedlings (330 ha^{-1}) reported by Abdi (1993) from inside the boundary of the Abiyata-Shala National Park is higher than the number of seedlings (98 ha^{-1}) found in this study (Table 1). This could be expected due to the relatively favorable moisture conditions for germination and initial growth of seedlings close to the lake. However, the number of saplings was approximately the same (278 ha^{-1}) as was found in this study. The number of mature trees (35 ha^{-1}) was lower in comparison to the 63 ha^{-1} found in this study. This too could be expected since the inventory of Abdi (1993) was limited to relatively open areas close to Lake Abiyata.

Table 2. Specieswise and total number of seedlings, saplings and mature trees in different land use categories with their estimated areas. Detailed descriptions on the land use categories are given in the text.

Land use category	Estimated area (ha)	Maturity class	Number of trees per hectare by species						Total
			A. tortilis	*A. senegal*	*A. seyal*	*A. etbaica*	*B. aegyptiaca*	Others	
Grazing under trees	8640	Seedlings	51.5	19.1	2.0	2.0	2.6	-	77.2
		Saplings	110.2	137.9	5.9	5.9	0.7	-	260.6
		Mature trees	27.1	19.5	3.5	1.0	1.8	0.3	53.2
Open grazing, settlement and rock outcrops	926	Seedlings	0.7	0.0	1.3	0.0	0.0	-	2.0
		Saplings	0.7	0.7	0.0	0.0	0.0	-	1.4
		Mature trees	0.7	0.0	0.3	0.0	0.0	-	1.0
Cultivated land	4217	Seedlings	12.5	3.3	0.0	1.3	2.0	-	19.1
		Saplings	13.2	0.7	0.0	0.0	2.0	-	15.9
		Mature trees	5.1	1.2	0.2	0.3	1.2	0.0	8.0

The distribution of seedlings, saplings, and mature trees in the different land use categories is given in Table 2. As expected, most of the three indicated phases were found on grazing lands that still had some remaining trees.

Summary data on the main characteristics of the acacia woodlands in the study area are given in Table 3. The result on crown closure (13%) was found to be substantially lower than the 70–90% given for woodlands in Menaut *et al.* (1995). It is also much lower than the 40% noted by Hofstad (1990). This confirms many of the reports (e.g. Sandahl & Ohlsson 1978, Anonymous 1994, Tedla 1995) indicating that the woodland in the study area is highly degraded. However, there are no available baseline data to support this statement objectively, although the previous state and the development of the acacia woodlands in the Rift Valley of Ethiopia can be traced from reports by Beals (1970), Makin *et al.* (1975), Woldu and Tadesse (1990), and Abdi (1993).

Table 3. Summary data on the different population characteristics of the woodland in the study area. Symbols follow the descriptions in the text.

Variable	Estimate
Mean height (m)	6.1
Mean diameter (D_{08}, cm)	15.9
Average number of seedlings & saplings (ha^{-1})	376
Average number of mature trees (ha^{-1})	63
Average crown closure (%)	13.1
Mean basal area (G_{08}, m^2 ha^{-1})	1.6
Biomass of mature trees (t ha^{-1})	9.7

Occurrence of regeneration

The results of fitting a logistic regression model to predict the occurrence of regeneration are given in Table 4. There appears to be a more or less significant ($p = 0.07$) positive partial relationship between the occurrence of regeneration and the abundance of mature trees. Also, crown closure was found to have a negative partial relationship ($p = 0.06$). This relationship probably indicates that acacias are indeed shade intolerant species. The scarcity of seedlings on cultivated land was expected since seedlings are considered as weeds by the farmers. Also, a low number of seedlings on the "open grazing lands" category is quite natural since the conditions prevailing in these areas do not favour the development of seedlings. Poor site conditions and the absence of mature trees as a source of seed for regeneration are probably some of the factors worth mentioning. The variable "fertility class" was found to have very little effect on the function and was therefore not included in the function. According to the classification results of the logistic regression, the overall proportion of correctly predicted observations is 66%, which is not very high.

Table 4. Estimated coefficients and their p-values for a logistic regression of the occurrence of regeneration

Predictor variable	Estimated coefficient	p-value
Number of trees[1]	0.19	0.07
Crown closure[1]	-4.58	0.06
Open grazing, settlement and rock outcrops[2]	1.31	0.04
Cultivated land[2]	-1.13	0.0007
Grazing land with trees[2,3]	0.18	0.54

[1] - continuous variable
[2] - indicator variable
[3] - reference level

With regard to the spatial distribution of the regeneration, the result in Figure 4 indicates that the proportion of plots with either very few or without any seedlings/saplings (<4 in this case) was quite high (~63 %), and regeneration was concentrated in very few parts (plots) of the study area. This pattern of distribution can also confirm the reports on the state of degradation mentioned earlier in which the woodlands are currently found.

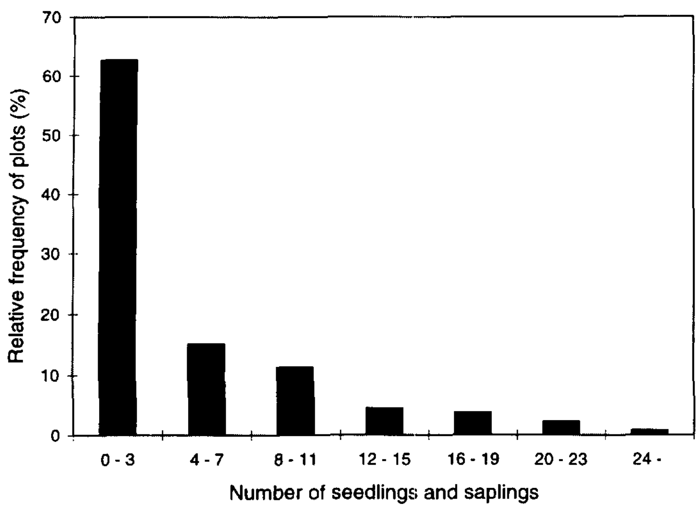

Figure 4. The relative frequency of plots versus regeneration class grouped according to the number of seedlings and saplings observed on the plots

Conclusion

The results from this study show a general picture of the woodlands in the area. The uncontrolled felling and grazing that have been going on in recent years have damaged the vegetation structure in the landscape. The relatively low frequency of mature trees with very few trees remaining in the upper diameter classes, the concentration of seedlings in limited parts of the study area, and the low species diversity are some of the indicators of the degradation that has occurred over the past decades. In general, the regeneration distribution over the area shows poor conditions for the future generation of the woodland ecosystem.

However, conditions also imply a possibility for woodland managers to secure sustainable management of the resources, provided current practices are modified. Protection of regenerated areas from cattle grazing and browsing, control of the illegal tree felling for commercial purposes, demarcation and rehabilitation of severely degraded sites that are already abandoned by the local population are some of the immediate steps that could be implemented.

As the study was based on a regeneration survey from only one time point, it was not possible to address too many issues of woodland dynamics and management at this stage. Hence, it is recommended that future research amongst other things establish what would constitute an adequate number of seedlings, saplings and small trees. This would be important with regard to the knowledge of regeneration dynamics and a key factor in guiding the sustainable use of the resources.

Acknowledgements

I thank Göran Ståhl for critically reading the manuscript and the anonymous reviewers for valuable comments. The finance to accomplish this study was obtained from the Alemaya University of Agriculture and the Swedish International Development Agency (SIDA).

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