Tropical Ecology **48**(1): 37-49, 2007 ISSN 0564-3295

www.tropecol.com

Diversity and status of regeneration of woody plants on the peninsula of Zegie, northwestern Ethiopia

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Abstract: The natural forest of Zegie peninsula on Lake Tana in northwestern Ethiopia was studied to determine the species composition, density, diversity and population structure of woody species and provide information on sustainable management of the woody plants. A total of 113 woody plant species were recorded in an area of 5.28 ha. From all woody plants recorded in the study quadrats (20 x 20 m x 132 quadrats = 5.28 ha), 56% were trees, 33% shrubs and 11% lianas. Density and frequency of the woody species varied considerably among species. The total density of woody plants in Zegie was 3318 ha^{-1}, and ranged between 813 for *Coffea arabica* and 0.2 for *Catha edulis*. Coffee plants were recorded in 115 quadrats (87% of the total) out of the total 132 quadrats studied. In the study, 240 coppiced stumps, 91 dead stumps, nine stems with cut part left and one dead but standing stem were recorded ha^{-1}. The overall Shannon evenness and diversity of woody species in Zegie was 0.84 and 3.72, respectively. The most species-diverse families were Fabaceae/Leguminosae (11 species), Euphorbiaceae (6 species) and Rutaceae and Rubiaceae (5 species each). Nineteen families were represented by only one species. The population structure differed among the woody species. The occurrence of 240 coppicing and 91 dead stumps ha^{-1} clearly demonstrates how the forest is being heavily exploited for wood extraction. The fact that very few mature trees are left in the forest might also suggest reduced seed production that could jeopardize future regeneration of trees and, therefore, the welfare and even existence of the forest as a whole. Our results revealed that the unsustainable exploitation of the forest by the local communities has critically affected species evenness of the woody plants and population structure of the forest as evidenced by the very low density of not only many species but also the forest as a whole. High dependency of the people on wood from the forest for generation of income, high population density and shortage of land coupled with moisture stress are the major problems that could pose serious threat to the forest resources. Therefore, to address these problems and enhance the sustainable utilization of the forest resources, realistic and viable solutions have to be explored and urgently implemented.

Resumen: Se estudió el bosque natural de la península Zegie, lago Tana, noroeste de Etiopía, con el fin de determinar la composición, la densidad y la diversidad, así como la estructura poblacional de las especies leñosas, y proporcionar información sobre su manejo sustentable. Se registraron en total 113 especies de plantas leñosas en un área de 5.28 ha. De todas las plantas leñosas registradas en las parcelas de estudio (20 x 20 m x 132 parcelas = 5.28 ha), 56% fueron árboles, 33% arbustos y 11% lianas. La densidad y la frecuencia de las

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especies leñosas variaron considerablemente entre especies. La densidad total de plantas leñosas en Zegie fue 3318 ha^{-1}, fluctuando entre 813 para *Coffea arabica* y 0.2 para *Catha edulis*. Se registraron cafetos en 115 parcelas (87%) del total de 132 parcelas estudiadas. En el estudio se registraron 240 tocones rebrotados, 91 tocones muertos, nueve tallos que conservaban la parte cortada y un tallo muerto en pie por hectárea. Los valores globales de equitabilidad de Shannon y de diversidad de especies leñosas en Zegie fueron 0.84 y 3.72, respectivamente. Las familias con mayor diversidad de especies fueron Fabaceae/Leguminosae (11 especies), Euphorbiaceae (6 especies), y Rutaceae y Rubiaceae (5 especies cada una). Diez y nueve familias estuvieron representadas por una sola especie. Las estructuras poblacionales difirieron entre las especies. La presencia de 240 tocones rebrotados y 91 muertos ha^{-1} muestra claramente la intensa explotación a la que está sometido el bosque para la extracción de madera. El bajo número de árboles maduros en el bosque también podría sugerir que la producción de semillas es muy reducida, lo que a su vez podría poner en riesgo la regeneración futura de los árboles y, por lo tanto, el bienestar e incluso la existencia misma de todo el bosque. Nuestros resultados revelan que la explotación no sostenible del bosque por las comunidades locales ha afectado críticamente la equitabilidad de especies leñosas y la estructura poblacional del bosque, como lo muestra la densidad muy baja no sólo de muchas especies, sino del bosque en conjunto. La forma tan fuerte en que la gente depende de la madera del bosque para generar ingresos, la alta densidad poblacional y la carencia de tierra, combinados con el estrés hídrico, son los principales problemas que podrían constituir una amenaza seria para los recursos forestales. Para enfrentar estos problemas y fomentar el uso sustentable de los recursos forestales hay que buscar soluciones realistas y viables que puedan ser puestas en práctica urgentemente.

Resumo: A floresta natural da península de Zegie no Lago Tana no noroeste da Etiópia foi estudado para determinar a composição específica, densidade, diversidade e estrutura da população das espécies lenhosas e proporcionar informação sobre a gestão sustentável das plantas lenhosas. Foi registada um total de 113 espécies lenhosas numa área de 5,28 ha. De todas as plantas lenhosas as parcelas de estudo quadradas (20 x 20 m x 132 parcelas = 5,28 ha), 56% eram árvores, 33% arbustos e 11% lianas. A densidade e frequência das espécies lenhosas variaram consideravelmente entre as espécies. A densidade total das plantas lenhosas em Zegie foi de 3318 ha^{-1} oscilaram entre 813 para a *Coffea arabica* e 0,2 para a *Catha edulis*. As plantas de café foram registadas em 115 parcelas (87% do total) em relação a um total de 132 parcelas estudadas. No estudo foram ainda registadas 240 toiças com rebentação, 91 toiças mortas, nove troncos com uma parte cortada deixada e um tronco morto mas permanecendo em pé por ha^{-1}. O índice de igualdade e diversidade de Shannon das espécies lenhosas em Zegie foi de 0,84 e 3,72, respectivamente. As famílias das espécies mais diversas foram as Fabaceae/Leguminosae (11 espécies), Euphorbiaceae (6 espécies) e Rutaceae and Rubiaceae (5 espécies cada). Dezanove famílias estavam representadas por uma única espécie. A estrutura da população deferiu entre as espécies lenhosas. A ocorrência de 240 toiças com rebentos e de 91 toiças mortas por ha demonstra como a floresta vem sendo claramente explorada para a extracção de madeira. O facto de que muito poucas árvores adultas são deixadas na floresta pode também sugerir uma reduzida produção de semente que pode pôr em causa a regeneração futura das árvores e, consequentemente, a sobrevivência e mesmo a existência da floresta no seu conjunto. Os nossos resultados revelaram que a gestão insustentável da floresta pelas populações locais afectou criticamente a densidade das plantas lenhosas e a estrutura da população da floresta com se evidencia pela muito pequena densidade não só de muitas espécies mas também da floresta como um todo. A elevada dependência da população pela lenha para a geração de rendimento, elevada densidade populacional e falta de terra em paralelo com o stress hídrico são os maiores problemas que podem colocar ameaças sérias aos recursos florestais. Por isso, para enfrentar estes problemas e aumentar a utilização sustentável dos recursos florestais, é necessário explorar soluções realísticas e viáveis e implementá-las com urgência.

Key words: Coffee, evenness, frequency, population structure, regeneration, species composition.

Introduction

Ethiopia, with its wide range of ecological conditions ranging from the arid lowlands in the east to rainforests in the west and high altitude Afroalpine vegetation in the central highlands, is rich in its biodiversity (EPA 1997). Although there is controversy over the precise figures of the former forest cover in Ethiopia, historical sources indicate that some 35-40% of the land area might have been once covered with forests (EFAP 1994). With the inclusion of savannah woodlands the estimate rises to some 66% of the country. As a result of continuous deforestation, most of the forests have disappeared, and deforestation continues unabated at a very alarming rate. Today, only few forest patches exist, most of which are in various seral stages. In most of the northern parts of the country, remnant forests can only be seen around churches where, by tradition, trees are not cut by people (Alemayehu Wassie *et al.* 2005). At the current rate of deforestation, i.e. 150,000-200,000 ha yr^{-1} (EFAP 1994), the natural high forests will be gone in a few decades time. The forests are disappearing even before we have a chance to study and document them properly.

One of the areas containing a remnant dry Afromontane forest is the Zegie Peninsula at Lake Tana, the largest lake in the country located in the northwestern part of Ethiopia. Of the total area of the peninsula, about 90% was previously classified as dense forest (Getachew Deriba 1993). Under the shade of the forest trees, *Coffea arabica* L. (hereafter referred to as coffee) has been planted by the local communities. Coffee has been, by far, the main pillar of the economy of the inhabitants at Zegie, and the relationship between the people and the natural environment used to be, more or less, harmonious. However, the current situation indicates a significant change in the previous harmony. Due to the growing population and growing demand on the available resources, the traditional economic pattern can no longer support the population from the sale of coffee alone, the average yield of which has been steadily decreasing (CARE-Ethiopia 1999; Getachew Deriba 1993). The main reasons contributing to this decline are the decrease in rainfall, poor management practices and market failures. The decline of income from coffee production has led to unsustainable exploitation of the forest resources. Particularly, trees are being cut in large numbers for fuelwood that is sold in the nearby town of Bahar Dar. Currently, the peninsula supplies an estimated 90% or more of the fuelwood-based energy to Bahar Dar (Getachew Deriba 1993).

At the present time, fuel wood selling has become almost the only option for earning an income for the entire population on the peninsula, and it is common to hear and see logging activities in all parts of the peninsula. Not only is such activity unsustainable, but also through the loss of shade trees (a requirement for coffee plants), it further contributes to decreased coffee production. With the advent of tree cutting and the associated loss of forest resources that serve as shade and a means of soil and water conservation, the environment in the peninsula has been disturbed. It can be predicted that until realistic and acceptable alternatives can be found, deforestation will undoubtedly continue, and the forest resources will be exhausted in the very near future. This, in turn, may lead to land degradation in the form of soil erosion and loss of soil fertility, drying up of streams on the peninsula, decline and even loss of biological resources as well as degradation of Lake Tana. Ultimately, this may affect the welfare of plants, animals, micro-organisms and the community living in the peninsula as well as the town of Bahar Dar and the country at large.

This being the scenario, very little is known about the Zegie Peninsula in general and its biological resources in particular. Except for a few general botanical studies associated with Lake Tana (Friis 1986, 1992; Pichi-Sermolli 1957; Sebald 1968), no studies have been made on the diversity of woody plants in Zegie Peninsula. Such knowledge/information is critically important to document the relative importance of the biological resources of the area. Therefore, the present study

was initiated to investigate and document the diversity of woody species so as to provide information and recommendations for the management, sustainable utilization and conservation of the forest resources in the peninsula. The specific objectives of the study were to describe the species composition (richness), density (evenness), diversity and population structure of woody species that can form the basis for the sustainable management of woody plants in particular and the forest resources in general.

Material and methods

Study site

The study was conducted at Zegie Peninsula (hereafter referred to as Zegie), north-western Ethiopia (11º 40' to 11º 43' N and 37º 19' to 37º 21' E) (Fig. 1). The peninsula has elevations that range from 1770 m along the banks of the Lake to 1975 m at its summit known by the name Ararat. Its human population is estimated at about 8363 (CARE-Ethiopia 1999). The area is densely populated, 643 persons km^{-2}, as compared to the national average, 34 persons km^{-2} (Anonymous 1988). It has mean annual minimum and maximum temperatures of 10.3 ºC and 27.7 ºC, respectively, while the average annual rainfall is about 1415 mm. The soils of Zegie are predominantly Nitosols followed by Luvisols and Vertisols having pH values of 5.05-6.07 (Getachew Deriba 1993).

Although there has been no direct study of the vegetation of Zegie specifically, it has been studied as part of the vegetation at Lake Tana (Friis 1986, 1992; Pichi-Sermolli 1957; Sebald 1968). The vegetation at Lake Tana has been considered as a transition type to humid evergreen forests of southwestern Ethiopia (Sebald 1968) and also classified as upland dry evergreen forest (Friis 1986) and a special subtype of undifferentiated Afromontane forest (Friis 1992). Of the total area of Zegie, 1219 ha is believed to have been covered once by densely growing forest trees and shrubs (Getachew Deriba 1993). Currently, the community is cultivating about 1132 ha of coffee under the shade of the forest trees. The whole forest area is divided among members of the communities.

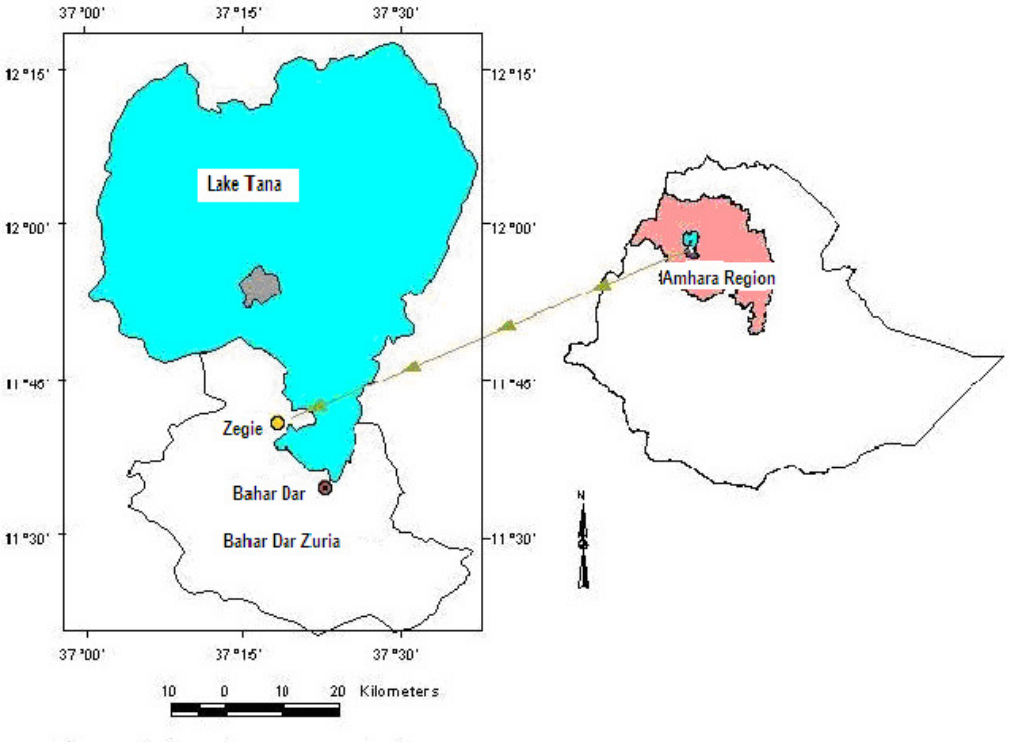

Fig. 1. Location of the study area.

Methods

To investigate the species composition and density of woody plants, line transects, which were laid down following the eight aspects of the site (north, south, east, west, northeast, northwest, southeast and southwest) starting from the summit of Ararat, were used. Sample quadrats measuring 20 x 20 m were laid down along the transects at a distance of 100 m from each other using measuring tape and a Silva compass. A total of 132 quadrats (5.28 ha) were used for the census of woody plants in the site. The total area sampled was 4% of the total forested land. The quadrats were delineated using polyethylene strings tied around four wooden pegs inserted into the soil at the four corners of the quadrats.

In each quadrat, identity, number, height and diameter (DBH) of individuals (with ≥ 2.5 cm) of all woody plants were recorded. Height was measured by hypsometer (type 65, Swedish made), while diameter of small and big trees was measured by using a caliper and diameter tape, respectively. The aspect, altitude and slope of each quadrat were measured using a Silva compass (type 15T), altimeter and clinometer, respectively.

For the purpose of analysing population structure of the woody species, individuals of the same species were categorised into ten diameter and 5 height classes. Seedlings and saplings of woody species that regenerated both from seeds and coppices were recorded. To evaluate the level of disturbance in the forest, all types of disturbances were also recorded. In particular, dead stumps of woody plants were identified by involving knowledgeable persons from the local communities.

Canopy and ground cover in each quadrat were evaluated subjectively and grouped into 3 classes: 1 = ≤ 33% cover (open canopy), 2 = 33% to 66% canopy cover (medium shade) and 3 => 66% canopy cover (high shade canopy). Similarly, the ground cover was classified into 3 classes: 1 = good cover with deep organic layer, 2 = intermediate cover with average organic layer and 3 = thin cover or exposed soil.

Woody plant species outside the study quadrats were also recorded to prepare a complete checklist of plants in the area. The identity of species that were readily identifiable was recorded in the field. For species that were difficult to identify in the field, their local names were recorded, herbarium specimens were collected, pressed and dried properly using plant presses and transported to the National Herbarium at the Department of Biology in the Addis Ababa University for identification.

Data analyses

The number of species at the study site was determined by summing up the number of species identified directly in the field and the National Herbarium. The number of individuals of each woody species per hectare was calculated from the total number of individuals of the species recorded in the 132 quadrats measuring a total area of 5.28 ha. The evenness and diversity of woody plants was analysed using the Shannon Evenness Index (E) and Shannon-Wiener Diversity Index (H) (Jayarman 2000). To analyse the population structure of woody species, all individuals of each species encountered in the quadrats were grouped into arbitrary diameter classes and histograms were developed using the diameter classes versus the number of individuals categorized in each of the classes using Microsoft Excel Computer Software.

Plant nomenclature

In this paper, nomenclature of plants follows Cufodontis (1953-1972), Edwards *et al.* (1995), Edwards *et al.* (1997), Edwards *et al.* (2000), Friis (1992), Hedberg & Edwards (1989) and Hedberg *et al.* (2003).

Results

Species composition

A total of 113 woody plant species, representing 52 families were recorded in the study area both inside and outside the study quadrats (Appendix 1). Among these, 87 woody species (in 38 families) were recorded in all of the 132 quadrats. Of the total recorded woody species in the study quadrats, nine species (in six plant families) were planted. These were *Coffea arabica*, *Citrus aurantifolia*, *Citrus medica*, *Citrus aurantium*, *Rhamnus prinoides*, *Psidium guajava, Mangifera indica, Eucalyptus camaldulensis* and *Catha edulis.* Of these, *Coffea arabica* and *Rhamnus prinoides* are indigenous while the others are introduced. From all woody plants

recorded in the study quadrants, 56% were trees, 33% shrubs and 11% woody climbers (lianas).

Density

The density (number of individuals per ha) and frequency (the percentage of the quadrants in which a species was found) of the woody species recorded in the study quadrats varied considerably among species. The total density of woody plants in Zegie was 3318, and ranged between 813 for *Coffea arabica* and 0.2 for *Catha edulis*. The five species with the highest densities were, in descending order of density, *Coffea arabica, Justicia schimperiana, Rothmannia urcelliformis, Millettia ferruginea* and *Ehretia cymosa* (Appendix 1). These species constituted more than 52% of all stems in the quadrats. The upper forest stratum, reaching a height of above 20 m, was composed of *Millettia ferruginea, Albizia schimperiana, Croton macrostachyus, Celtis africana* and *Prunus africana*. The frequency of occurrence of woody species did parallel with the density, and the five species with the highest frequency were, in descending order of frequency, *Coffea arabica, Millettia ferruginea, Ehretia cymosa, Ritchiea albersii* and *Celtis africana*. During the study, 240 coppiced stumps, 91 dead stumps, nine stems with cut part left and one dead but standing stem (Table 1) were recorded.

Table 1. The density (number of dead and coppiced stumps ha^{-1}) of woody species recorded in the Peninsula of Zegie.

Species	Density		Total
	Dead stumps	Coppiced stumps	
Millettia ferruginea	15	39	54
Diospyros abyssinica	6	37	43
Ehretia cymosa	6	36	42
Rothmannia urcelliformis	12	18	30
Ritchiea albersii	2	25	27
Vanguria volkensii	8	17	25
Vernonia myriantha	3	14	17
Celtis africana	10	5	15
Albizia schimperiana	8	3	11
Croton macrostachyus	5	4	9
Cordia africana	7	1	8
Albizia grandibracteata	2	3	5
Others (19 species)	7	38	45
Total	91	240	331

Diversity

The overall evenness and diversity of woody species in Zegie was 0.84 and 3.72, respectively. The 87 species recorded in the quadrats represented 72 genera and 38 families. The most species diverse families were Fabaceae/ Leguminosae (11 species), Euphorbiaceae (6 species), Rutaceae and Rubiaceae (5 species each). Nineteen families were represented by only one species.

Population structure

The population structure differed among the woody species recorded in the quadrats. Based on similarities of their population structure, the 10 indigenous tree species with the highest density were categorized into two groups. The first group exhibited typical inverted J-shaped curves, i.e. species having many individuals at the lower diameter classes and decreasing number of individuals at successively higher diameter classes (Fig. 2). *Ehretia cymosa*, *Millettia ferruginea, Croton macrostachyus, Cordia africana, Albizia schimperiana* and *Rothmannia urcelliformis* belong to this group. The second group showed missing individuals at some diameter classes (Fig. 3). To this group belong *Celtis africana, Albizia grandibracteata*, *Diospyros abyssinica* and *Ritchiea albersii*. The overall diameter class distribution of all tree species recorded in all the quadrats exhibited a more or less inverted J curve (Fig. 4).

Out of the 78 species for which dbh was measured, 45 were trees, 28 shrubs and 5 woody climbers. The majority of the stems (74%) had a dbh value of less than 2.5 cm, 15% between 2.5-7.5 cm, 8% between 7.5-42.5 cm. Only 3% of the stems had dbh values greater than 42.5 cm. *Ficus vasta* had the largest dbh, 198 cm. A total of 3474 seedlings (height < 0.75 m) and 2200 saplings (height = 0.75-2 m) that originated from seeds were recorded, with a density of 1075 individuals ha^{-1}. Furthermore, 3140 individuals (height < 0.75 m) and 1681 individuals (height = 0.75-2 m) that had coppiced from stumps were recorded, with a density of 913 individual ha^{-1}. *Rothmannia urcelliformis*, *Ritchiea albersii, Millettia ferruginea*, *Diospyros abyssinica* and *Ehretia cymosa* exhibited better regeneration among all tree species recorded in the study quadrats. These

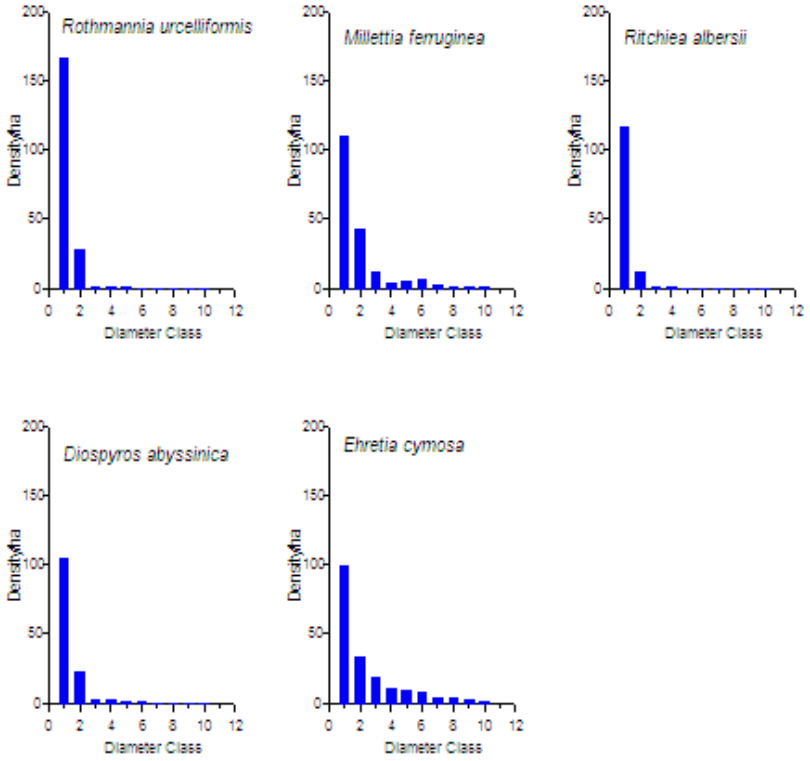

Fig. 2. Diameter class distribution of individuals of *Rothmannia urcelliformis*, *Millettia ferruginea*, *Ritchiea albersii*, *Diospyros abyssinica* and *Ehretia cymosa* recorded at Zegie Peninsula; diameter classes: 1 = < 2.5 cm, 2 = 2.5 - 7.4 cm, 3 = 7.5 - 12.4 cm, 4 = 12.5 - 17.4 cm, 5 = 17.5 - 22.4 cm, 6 = 22.5 - 27.4 cm, 7 = 27.5 - 32.4 cm, 8 = 32.5 - 37.4 cm, 9 = 37.5 - 42.4 cm, and 10 = > 42.5 cm.

species accounted for 30% of the total regenerated individuals/ha both from seeds and coppices.

Canopy cover, ground cover and slope

Estimates of the canopy and ground cover showed that out of the 132 quadrats, 8% were under high shade, 55% under medium shade while the rest (37%) were in open areas. Coffee plants were recorded in 115 quadrats (87% of the total). Eleven quadrats (8%) were laid out at the Ararat summit where no coffee is grown (due to steep slope and rock outcrops). Fourteen of the quadrats landed in the villages. Thirty-nine percent of the quadrats were under good ground cover and deep organic layer, 38% in intermediate and 23% in thin ground cover or on exposed mineral soil areas.

Of the total sample quadrats, 69% were on slopes of less than 10%, 17% on slopes of 10-20% and the rest (14%) on slopes above 20%. Thirteen percent of the quadrats were located at the northern aspect, 11% at the southern, 16 % at the eastern, 15% at the western, 11% at the northeastern, 12% at the southwestern, 12% at the northwestern and 10% at the southeastern aspects.

Discussion

In terms of species richness, Zegie has a higher number of woody species compared with similar dry Afromontane forests in Ethiopia, namely Munessa (Lundgren & Lundgren 1969), Menagesha (Sebsebe Demissew 1988), Gara Ades (Uhlig & Uhlig 1990), Wof-Washa (Demel Teketay & Tamrat Bekele 1995), Chilimo (Tadesse Woldemariam *et al.* 2000) natural forests. This is also evident from the relatively high value of the

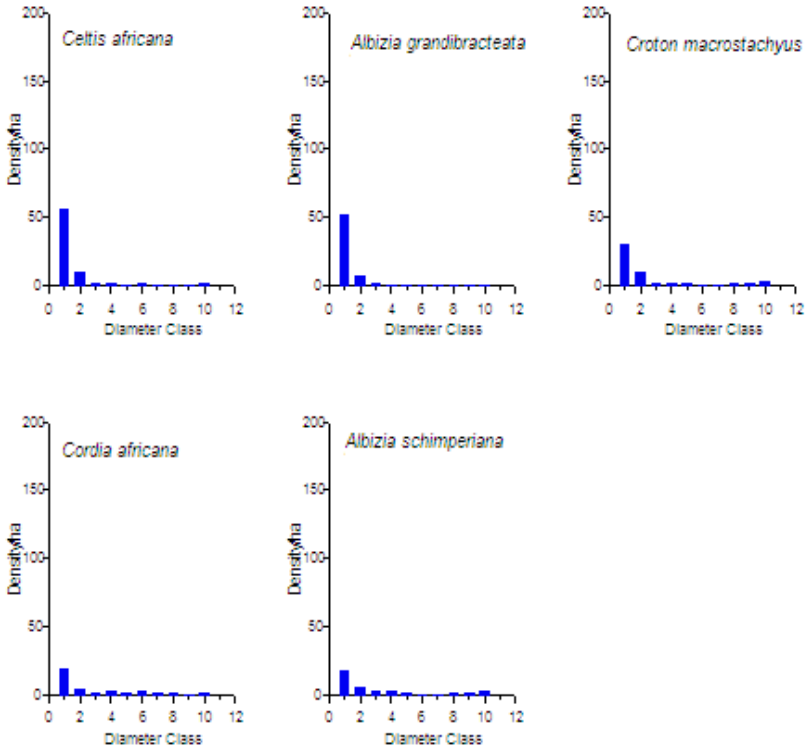

Fig. 3. Diameter class distribution of individuals of *Celtis africana*, *Albizia grandibracteata*, *Croton macrostachyus*, *Cordia africana* and *Albizia schimperiana* recorded at Zegie Peninsula (diameter classes as in Fig. 2).

Shannon-Wiener Diversity Index (H = 3.72) compared with that of Chilimo dry Afromontane forest (H = 2.72) (Tadesse Woldemariam *et al.* 2000).

Of the total woody species recorded in the 132 quadrats, trees constituted the highest number of species, more than 56%, relative to other growth forms. However, more than half of all individuals encountered consisted of only five species. For instance, among the most abundant five species, the first two shrub species, *Coffea arabica* (planted) and *Justicia schimperiana*, contributed 35% of the total density. *Coffea arabica* alone comprised 25% of the total density. This is also reflected by the low value of the Shannon Evenness Index (E = 0.84), which indicates that there is dominance by a few species. Still, the species evenness at Zegie is higher when compared with that of Chilimo forest (E = 0.68) (Tadesse Woldemariam *et al.* 2000). The high abundance of *C. arabica* is attributed to increased planting every year since it forms the main source of the peninsula's economy. *J. schimperiana* has very high regeneration capacity both from seeds and coppices. It is interesting to note that 44 of the species recorded, i.e. 50% of all species, collectively made up only 2.3 % of all individuals. In addition, 19 plant families were represented by only one species. In general, despite the relatively high level of disturbance in the forest of Zegie, the species richness of woody plants was relatively high.

The most abundant and frequent tree species were *Rothmannia urcelliformis, Millettia ferruginea, Ehretia cymosa, Diospyros abyssinica* and *Ritchiea albersii*. However, 72 % of their total individuals and 32% of all individuals recorded in all study quadrats were represented by young plants having stems less than 2.5 cm dbh. Moreover, seedlings less than one meter high represented 42% of all individuals of the five

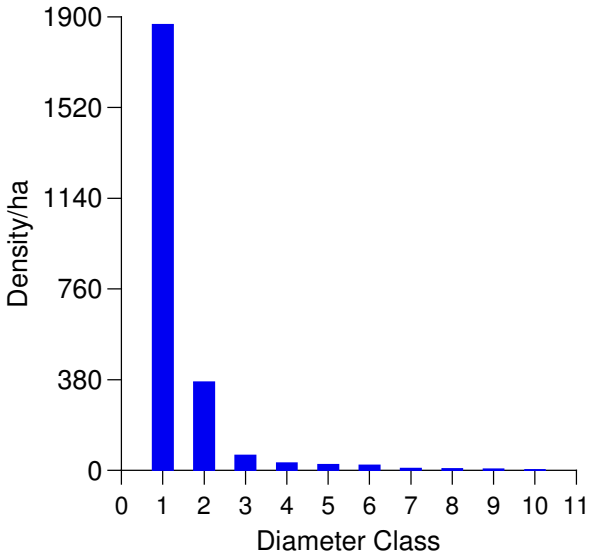

Fig. 4. Diameter class distribution of all trees recorded at Zegie Peninsula (diameter classes as in Fig. 2).

species and 32% of the individuals of all species encountered in the study quadrats.

Population structure of the 10 tree species examined exhibited two patterns. The first pattern (Fig. 2), reflected by *E. cymosa*, *M. ferruginea, C. macrostachyus, Cordia africana, A. schimperiana* and *R. urcelliformis,* represented a more or less inverted J curve, indicating that this group of species has good or healthy regeneration. However, *C. africana, A. schimperiana* and *C. macrostachyus* had few individuals at some of the upper diameter classes, indicating the selective removal of saplings/trees being exercised by the local people for fuelwood and timber. Of the above species, *E. cymosa* and *M. ferruginea* showed a typical inverted J curve, which indicates better regeneration and recruitment conditions than for the others. These species are managed well by the community, since they are the preferred species for coffee shade.

The second pattern (Fig. 3), represented by *Celtis africana, A. grandibracteata*, *D. abyssinica* and *R. albersii,* also showed a more or less inverted J curved population structure but with missing individuals at some of the upper diameter classes, suggesting hampered regeneration due to selective and complete removal of individuals, which could have served as mother trees for future regeneration. The main driving force for the selective destruction of these species is the desire to generate income from the sale of fuelwood by the local people. However, the local people claim that the species, especially the first three, are not compatible with coffee plantations. They pointed out that the litter falling from these trees does not decompose easily, the soil underneath the trees is compacted and trees shed their leaves during the dry season when they are supposed to protect the coffee from strong radiation. The claim by the local people requires validation by additional investigations.

The overall distribution of diameter classes of individuals of all the species encountered in the quadrats (Fig. 4) indicates a relatively high proportion of individuals in the lowest diameter class (seedlings), which form the potential source of recruitment to successively increasing diameter classes that ensures sustained future regeneration of the forest if properly managed. However, the number of individuals in the next higher diameter classes declined considerably suggesting that there is interference that can be attributed to the unplanned and unsustainable exploitation of woody species in the forest by the local people not only for domestic consumption but also for generating income. The occurrence of 240 coppicing and 91 dead stumps ha^{-1} (Table 1) clearly demonstrates how the forest is being heavily exploited for wood extraction. The fact that very few mature trees are left in the forest might also suggest reduced seed production that could jeopardize future regeneration of trees and, therefore, the welfare and even existence of the forest as a whole.

Our results revealed that the unsustainable exploitation of the forest by the local communities has critically affected species evenness of the woody plants and population structure of the forest. This is evidenced by the very low density of not only many species but also the forest as a whole as well as the dominance of individuals at lower diameter and height classes. Despite the escalating exploitation of the forest, diversity of woody plants in Zegie is still relatively high compared with other similar forests. In addition, the presence of a large number of seedlings of woody species in the forest indicates the great potential source for sustainable future recruitment/regeneration of the forest, provided that appropriate management regimes can be

employed. This could help Zegie Peninsula to remain a unique area in the region with its beautiful environment and cultural heritage.

Our findings also indicated that the production of coffee, fruits and *Rhamnus prinoides*, absence or insignificance of crop cultivation and prohibition of animal husbandry are factors that have contributed to a relatively low level of deforestation or clearing of the forest resources in Zegie. The huge untapped potential of fish resources and bee forage plants, the relatively high literacy level, awareness of the majority of the people about family planning and the need to conserve the forest are promising factors for the future sustainability of the forest in Zegie. On the contrary, high dependency of the people on wood from the forest for generation of income, high population density and shortage of land coupled with moisture stress are the major problems that could pose serious threat to the forest resources.

Therefore, in order to mitigate the existing crises and promote the sustainable management of the forest resources, the following recommendations are forwarded:

- Since other interventions may only be realised after some years, depending on their nature, the first short-term and most important option to save the remaining forest urgently is to solve the key problem of the area, i.e. to fill the food deficit. This option also needs to be linked with strong extension services to build awareness of the community about sustainable conservation and utilisation of woody species.
- The government and its institutions should play their respective roles and responsibilities. For instance, development agents should be deployed in the area and perform activities in the fields of forestry, apiculture, fisheries, production of coffee, *Rhamnus* and fruits as well as other relevant activities which could help for sustainability of the forest.
- Intensive family planning services should be provided to control population growth in Zegie, which is one of the driving forces in environmental degradation.
- Regular discussion forums should be arranged for stakeholders so that they can learn from the past weak relationships and work toward a better way of co-operation and co-ordination.
- Creation of job opportunities and providing training opportunities for the younger generation.
- Encouraging the local community, including those in Bahar Dar Town, to use efficient stoves to reduce heavy dependency on the remaining forest.
- Carry out further studies on the patterns of ecosystem functioning, biology and ecology of the major tree species to restore the composition and structure of the forest through enrichment plantations.

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Appendix 1. List of woody species recorded in the 132 (20 x 20 m) study quadrats (total area = 5.28 ha) arranged in descending rank of abundance with their corresponding growth forms, abundance, density and frequency. Species encountered outside the study quadrats are listed in Section B.

Species	Life form	Abundance*	Density**	Frequency***
A. Species recorded in the study quadrats				
Coffea arabica L.[a]	Shrub	4293	813	86
Justicia schimperiana (Hochst. ex Nees)	Shrub	1858	352	64
Rothmannia urcelliformis (Hiern) Robyns	Tree	1072	203	64
Millettia ferruginea (Hochst. Back.)	Tree	977	185	83
Ehretia cymosa Thonn.	Tree	977	185	80
Diospyros abyssinica (Hiern) F.White	Tree	692	131	60
Ritchiea albersii Gilg.	Tree	692	131	73
Maytenus gracilipes subsp. *arguta* (Lees.) Sebsebe	Shrub	686	130	35
Vernonia myriantha Hook.f.	Shrub	634	120	52
Clausena anisata (Willd.) Benth.	Shrub	565	107	42
Vangueria volkensii K. Schum.	Tree	533	101	62
Vernonia amygdalina Del.	Shrub	502	95	46
Celtis africana Burm. f.	Tree	364	69	72
Albizia grandibracteata Taub.	Tree	327	62	27
Croton macrostachyus Del.	Tree	253	48	60
Eucalyptus camaldulensis Dehnh.[b]	Tree	248	47	7
Unidentified sp. (vernacular name = Tir hareg)	Climber	201	38	17
Cordia africana Lam.	Tree	164	31	37
Albizia schimperiana Oliv.	Tree	164	31	53
Stereospermum kunthianum Cham.	Tree	158	30	11
Grewia ferruginea Hochst. ex A. Rich	Shrub	148	28	19

Continued

Appendix 1. Continued.

Species	Life form	Abundance*	Density**	Frequency***
Rhamnus prinoides L'Herit. [a]	Shrub	148	28	20
Acanthus sennii Chiov.	Shrub	127	24	6
Tephrosia elata Deflers	Shrub	121	23	7
Unidentified sp. (vernacular name = Wolete gomen)	Shrub	116	22	28
Senna septentrionalis (Viv.) Irwin & Barneby [c]	Shrub	106	20	19
Euclea racemosa subsp. *schimperi* (A.DC.) F. White	Shrub	95	18	14
Pavetta oliveriana Heirn.	Shrub	95	18	27
Bersama abyssinica Fresen. Subsp. *abyssinica*	Tree	90	17	19
Vepris dainelli (Pichi-Sermolli) Kokwaro	Tree	84	16	17
Buddleja polystachya Fresen.	Tree	74	14	8
Phytolacca dodecandra L' Her.	Climber	74	14	20
Rhus vulgaris Meikle	Shrub	63	12	8
Calpurnia aurea (Ait.) Benth.	Shrub	53	10	19
Solanum gigantum Jacq.	Woody herb	53	10	16
Mimusops kummel A. DC.	Tree	48	9	22
Helinus mystacinus (Ait.) E. Mey. ex Steud.	Climber	48	9	5
Brucea antidysenterica J.F.Miller	Shrub	48	9	19
Prunus africana (Hook.f.) Kalkm.	Tree	37	7	7
Citrus aurantifolia (Christm.) Swingle[b]	Shrub	37	7	10
Cassia petersiana Bolle	Shrub	32	6	11
Dracaena steudneri Engl.	Tree	32	6	11
Podocarpus falcatus (Thunb.) Mirb.	Tree	32	6	5
Allophylus abyssinicus (Hochst.) Radlk.	Tree	32	6	11
Echinops giganteus A. Rich.	Woody herb	32	6	3
Terminalia brownii Fresen.	Tree	26	5	4
Vernonia hochstetteri Sch. Bip. Ex Walp.	Shrub	26	5	0.7
Pterolobium stellatum (Forssk.) Brenan.	Climber	21	4	1.5
Pittosporium viridiflorum Sims	Tree	21	4	9
Premna schimperi Engler.	Shrub	21	4	5
Rhus glutinosa A. Rich.	Tree	21	4	7
Apodytus dimidiata E. Mey. ex Arn. var. a*cutifolia* (Hochst. ex A. Rich.) Boutique	Tree	16	3	6
Steganotaenia araliacea Hochst.	Tree	16	3	4
Albizia malacophylla (A. Rich.) Walp.	Tree	16	3	6
Clematis simensis Fresen.	Climber	16	3	6
Ficus thonningii Blume.	Tree	11	2	6
Dombeya quinqueseta (Del.) Exell.	Tree	11	2	4
Syzygium guineense (Wild.) DC.subsp. *guineense*.	Tree	11	2	4
Flacourtia indica (Burm.f.) Merr.	Tree	11	2	0.7
Chionanthus mildbraedii (Gilg. & Schellenb.) Stearn.	Tree	11	2	3
Olea capensis subsp.*welwitschii* (Knobl.) Friis & Green	Tree	11	2	4
Bridelia micrantha (Hochst.) Baill.	Shrub	11	2	1.5
Entada abyssinica Steud. ex A. Rich.	Tree	5	1	3
Carissa edulis (Forssk.) Vahl	Shrub	5	1	2
Dalbergia lactea Vatke.	Shrub	5	1	2
Mangifera indica L.[b]	Tree	5	1	3
Citrus aurantium L.[b]	Tree	5	1	2

Continued

Appendix 1. Continued.

Species	Life form	Abundance*	Density**	Frequency***
Juniperus procera Endl.	Tree	4	0.8	1.5
Olinia rochetiana A. Juss.	Tree	4	0.8	1.5
Gardenia ternifolia Schumach. & Thon	Tree	3	0.6	1.5
Psidium guajava L.[b]	Shrub	3	0.6	1.5
Euphorbia tirucalli L.	Tree	3	0.6	0.7
Combretum molle R. Br. ex G.Don.	Tree	2	0.4	2
Citrus medica L.	Shrub	2	0.4	1.5
Sapium ellipticum (Hochst. ex Krauss) Pax	Tree	2	0.4	1.5
Euphorbia candelabrum Kotschy.	Tree	2	0.4	0.7
Nuxia congesta Fresen.	Shrub	2	0.4	0.7
Ruttya speciosa Engler.	Climber	2	0.4	0.7
Clematis longicauda Steud. ex A. Rich	Climber	1	0.2	1.5
Ficus vasta Forssk.	Tree	1	0.2	0.7
Ficus sur Forssk.	Tree	1	0.2	0.7
Grewia bicolor Juss.	Shrub	1	0.2	0.7
Olea europaea subsp. *cuspidata* (Wall. ex DC.) Cifferri	Tree	1	0.2	0.7
Ficus ovata Vahl	Tree	1	0.2	0.7
Unidentified sp. (vernacular name = Lenkuki)	Climber	1	0.2	0.7
Phyllanthus ovaliformis Forssk.	shrub	1	0.2	0.7
Catha edulis (Vahl) Forssk. ex Endl.	Shrub	1	0.2	0.7
Total		17519	3318	
B. Species encountered outside study quadrats				
Acokanthera schimperi (A. DC.) Schweinf.	Tree			
Albizia lophantha (Willd.) Benth.	Tree			
Capparis tomentosa Lam.	Shrub			
Carica papaya L.[b]	Tree			
Cassipourea malosana (Bak.) Alston	Shrub			
Cupressus lusitanica Miller [b]	Tree			
Cussonia ostinii Chiov.	Tree			
Ekebergia capensis Sparrm.	Tree			
Erianthemum dregei (Eckl. & Zeyh.) V. Tiegh.	Parasitic shrub			
Ficus sycomorus L.	Tree			
Hypericum quartinianum A. Rich.	Shrub			
Jacaranda mimosifolia D. Don.[b]	Tree			
Jasminum abyssinicm Hochst. ex DC.	Woody climber			
Kanahia laniflora (Forssk.) R. Br.	Shrub			
Myrtus communis Juss.	Shrub			
Unidentified sp. (vernacular name = Quanja)	Woody climber			
Otostegia integrifolia Benth.	Shrub			
Otostegia tomentosa subsp. *ambigiens* (Chiov.) Sebald	Shrub			
Pergularia daemia (Forssk.) Chiov.	Shrub			
Persea americana Mill. [b]	Tree			
Phragmanthera regularis (Sprague) M. Gilbert	Parasitic shrub			
Piliostigma thonningii (Schumach.) Milne-Redh.	Tree			
Rumex nervosus Vahl	Shrub			
Tapinanthus globiferus (A. Rich.) Tiegh.	Parasitic shrub			
Trema orientalis (L.) Bl.	Tree			
Ximenia americana L.	Shrub			

*Individuals in the 5.28 ha; **Number of individuals/ha; ***Percentage of quadrats in which the species was recorded; [a] Planted indigenous species; [b] Planted exotic species; [c] Introduced species but widely naturalized.