

**POPULATION STATUS OF *ACACIA SENEGAL* (LINNE)
WILLDENOW AND ITS GUM QUALITY IN THE CENTRAL RIFT
VALLEY OF ETHIOPIA**

M. Sc. THESIS

DAGNEW YEBEYEN BURRU

AWASSA UNIVERSITY, AWASSA, ETHIOPIA

APRIL, 2006

POPULATION STATUS OF *ACACIA SENEGAL* (LINNE) WILLDENOW
AND ITS GUM QUALITY IN THE CENTRAL RIFT VALLEY OF
ETHIOPIA

DAGNEW YEBEYEN BURRU

A THESIS SUBMITTED TO THE
DEPARTMENT OF FARM FORESTRY,
WONDO GENET COLLEGE OF FORESTRY, SCHOOL OF GRADUATE
STUDIES AWASSA UNIVERSITY
AWASSA, ETHIOPIA

IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE
DEGREE OF

MASTER OF SCIENCE IN FORESTRY
(SPECIALIZATION: FARM FORESTRY)

APRIL, 2006

DECLARATION

This thesis is the result of my work. It has not been submitted for any degree in any other university and it has never been published nor submitted for any journal by another person.

Submitted by

_____	_____	_____
Name of the student	Signature	Date

Approved by

1. _____	_____	_____
Name of the Advisor	Signature	Date

2. _____	_____	_____
Name of Co–advisor	Signature	Date

3. _____	_____	_____
Name of Chairperson,	Signature	Date

Dept’s Graduate Commission

4. _____	_____	_____
Name of Chairperson,	Signature	Date

Faculty’s Graduate Commission

5. _____	_____	_____
Name of the Dean,	Signature	Date

School of Graduate Studies

ACKNOWLEDGEMENT

I thank God for every thing he does in my life. I am indebted to my families who have been strived a lot to make my life successful. I am grateful to Dr. Mulugeta Lemenih for his valuable help in my thesis work and who is the initiator of the research idea. I thank Dr Sisay Feleke who encouraged and supported me in doing the research work. Many thanks go to Girma Eshete, Saba Ali and Sisay Alemu from Forestry Research Center; Bogale Gelana and Moges G/Amlak from Ethiopian Standards Authority; Fikermariam Haile from Essential Oil Research Center; Rezenom Almaw and Fekadu Hika from Abijata Shalla Lakes National Park; and employees of Abernosa Cattle Ranch who helped me a lot in the field and laboratory works. I thank Professor Jeremy Flower–Ellis from SLU for offering his time to edit the thesis paper. I also thank my colleagues at Forestry Research Center and Wondogenet College of Forestry who share their experiences that helped me in the research work and will undoubtedly help me to my future carrier. I finally thank SIDA and DOIT–AR for financing my research work.

TABLE OF CONTENT

LIST OF TABLES	VI
LIST OF FIGURES	VII
ABSTRACT	IX
1. INTRODUCTION	1
<i>1.1 Background and Justification</i>	<i>1</i>
<i>1.2 Objectives</i>	<i>5</i>
1.2.1. General objective	5
1.2.2. Specific objectives	5
2. LITERATURE REVIEW	6
<i>2.1 Drylands — Challenges and Opportunities</i>	<i>6</i>
<i>2.2 A General Background to Non-Timber Forest Products</i>	<i>11</i>
2.2.1 Non-Timber Forest Products for Conservation of Forest Resources	12
2.2.2 Non-Timber Forest Products for Economy	13
<i>2.3. Acacia senegal and its Socio-economic and Ecological Roles</i>	<i>14</i>
2.3.1 The Genus Acacia	14
2.3.1 Acacia senegal	15
2.3.2 Distribution and Ecology of A. senegal	16
2.3.3 Propagation	17
2.3.4 Use of A. senegal	18
<i>2.4 Gum Arabic</i>	<i>19</i>
2.4.1 Uses of Gum Arabic	20
2.4.2 Harvesting	21
2.4.3 Yields and Economics	22
2.4.4 Quality of Gum Arabic	23

3. MATERIALS AND METHODS.....	26
<i>3.1 Study Site</i>	<i>26</i>
<i>3.2 Data Collection and Measurements.....</i>	<i>29</i>
<i>3.3 Physicochemical Characteristic Analysis of Gum Arabic</i>	<i>30</i>
<i>3.4 Data Analysis.....</i>	<i>33</i>
3.4.1 Vegetation	33
3.4.1.1 Density, Abundance, Frequency, Importance Value Index and Dominance	34
3.4.1.2 Population structure	35
3.4.2 Data on Gum chemistry.....	36
4. RESULTS AND DISCUSSION	37
<i>4.1 Floristic Composition of the Vegetation</i>	<i>37</i>
<i>4.2 Population Structure</i>	<i>41</i>
<i>4.3 Physicochemical Characteristics of the Gum Arabic from Central Rift Valley.....</i>	<i>51</i>
5. CONCLUSION.....	56
6. REFERENCE.....	58

LIST OF TABLES

Table 1. <i>Estimates of land areas affected by desertification in Ethiopia</i>	6
Table 2. <i>Leading world producers of gums and gum resins.</i>	23
Table 3. <i>Physicochemical properties of gum exudates from some Acacia species</i>	24
Table 4. <i>Density, abundance, frequency, dominance and importance value index (IVI) of the tree species in the Central Rift Valley of Ethiopia</i>	39
Table 5. <i>Analytical data for the physicochemical characteristics of the gum arabic samples collected from the Central Rift Valley of Ethiopia</i>	52
Table 6. <i>Evaluation of gum arabic from Central Rift Valley of Ethiopia with other studies and international specifications</i>	54

LIST OF FIGURES

<i>Figure 1. Acacia wood land of the Central Rift Valley of Ethiopia.....</i>	<i>7</i>
<i>Figure 2. Agricultural expansion and over grazing affecting the Acacia Woodland in Central Rift Valley.....</i>	<i>9</i>
<i>Figure 3. A. senegal tree from Central Rift Valley of Ethiopia</i>	<i>18</i>
<i>Figure 4. Study area and distribution of sample plots in the study area.....</i>	<i>28</i>
<i>Figure 5. Distribution of trees in different diameter classes of land cover/land use categories of the Central Rift Valley of Ethiopia</i>	<i>41</i>
<i>Figure 6. Distribution of trees in different Height classes of land cover/land use categories of the Central Rift Valley of Ethiopia</i>	<i>42</i>
<i>Figure 7. Distribution of different tree species in different diameter classes of land cover/land use categories of the Central Rift Valley of Ethiopia</i>	<i>45</i>
<i>Figure 8. Distribution of different tree species in different height classes of land cover/land use categories of the Central Rift Valley of Ethiopia</i>	<i>49</i>

This work is dedicated to my beloved parents

Yebeyen Burru and Wuditu Alemayehu

ABSTRACT

Population Status of *Acacia senegal* (Linne) Willdenow and Its Gum Quality in the Central Rift Valley of Ethiopia

Dagnew Yebeyen Burru

The vegetation of the Central Rift Valley of Ethiopia is under severe threats of degradation. Thus there is a need for urgent measures to abate the situation. Managing the woodlands to offer economic incentive to the local people is probably a viable and lasting strategy to discourage deforestation. One of the possibilities for the dryland vegetation of Rift Valley in this regard is the production of gum arabic from *A. senegal* species, which is one of the conspicuous element in the vegetation of the area. Despite the natural occurrence of *A. senegal* in the woodland, no studies have assessed the population of the species in terms of density, abundance, frequency and dominance on the one hand and its gum quality for commerce. The objectives of this study were, therefore, to (i) investigate the population status of *Acacia senegal* in the area, (ii) characterize the quality of the gum arabic obtained from the species for several quality characteristics, and (iii) compare the obtained quality characteristics of the gum arabic from this area with the qualities of gum arabic reported from known producer and exporter countries as well as against international standards. Population status was studied by comparing the vegetation structure of four different land cover/land use categories common in the region that represented different degree of human interferences. These are intact, relatively intact, open grazing and farmland. Randomized sampling technique was used to locate the sample plots. In each plot, identity of woody species encountered was recorded; diameter at breast height (DBH) and height measurements were done. The status of populations of *A. senegal* and associated species was examined by estimating dominance, density, abundance, frequency, importance value index and population structure. The physicochemical analysis of the gum arabic: moisture, ash, viscosity, pH, specific rotation, N content, tannin and cation metals were determined using standard laboratory procedures. The results show that the density, abundance and importance value index for *A. senegal* is high in all of the land cover/land use categories except in the Abernosa ranch where *A. tortilis* predominate. Frequency of *A. senegal* is the highest on the farmland and in the park and the lowest at Abernosa ranch. In terms of dominance, *A. senegal* is the first in the farmland, the second in the Park and third at Abernosa ranch. The population structure of *A. senegal* shows large population in the lower size classes (good regeneration); however, very few individuals in the higher size classes, possibly as a result of harvesting the mature trees for firewood and charcoal. The physicochemical characteristics of gum arabic collected from *A. senegal* trees in the area yield: moisture content of 15%, ash content of 3.56%, viscosity (centipoises) 10gl^{-1} of 0.9954, pH on 25% solution of 4.04, gel moderate, specific rotation of -32.5 , nitrogen content of 0.35%, Protein content of 2.31%, and no tannin content. Mineral contents of the gum arabic (g/100g) are Ca 0.7, Mg 0.2, Na 0.01, K 0.95, Fe 0.001, P 0.6 and trace for Pb, Co, Cu, Zn, Ni, Cd, Cr, and Mn. The physicochemical characteristics of the gum arabic are similar with qualities reported from major producer and exporter countries such as Sudan and fitted well to international standards in all aspects. Indeed, it is possible to exploit the resource for commercial purpose.

Key words: *A. senegal*, gum arabic, physicochemical characteristics, population structure, density, abundance, frequency, dominance, importance value index.

1. INTRODUCTION

1.1 Background and Justification

The livelihood of vast majority of rural people in Ethiopian drylands depends on the forests and woodlands as sources of agricultural land, firewood and charcoal, as well as non-timber tree products such as food, fiber and medicines. Because the ecological balance in arid and semi-arid environments is delicate, sustainable land use practices are required if people's basic needs for the future are to be fulfilled (Karmann and Lorbach, 1996). The vegetations in the dryland areas of the country are facing serious problems of degradation. The prolonged degradation of dryland areas continues to affect the productivity and genetic diversity of forest, woodland and bushland resources. Superimposed by recurrent drought, the ultimate outcome of deforestation and degradation of these dryland vegetation resources may be desertification (Tefera *et al.*, 2005). These drylands which are currently being threatened by advancing desertification are, however, important as production zones of crops and livestock, and as areas with diverse vegetation cover in Ethiopia. Therefore, unless significant adaptation measures are soon taken to abate the growing desertification, the socio-economic and ecological costs that Ethiopia is about to face will be unbearable (Tamerie, 1997; Mulugeta and Demel, 2004). This calls for the design of economically feasible, socially acceptable and ecologically viable management and conservation strategies for dryland ecosystem (Tefera *et al.*, 2005).

The dryland areas in Ethiopia which fall within the range of UNEP's definition of desertification cover 71.5% of the country's total land area (Tamerie, 1997). Of the total

estimated area of drylands in Ethiopia, 25 million ha is covered with woodland and bushland (Tefera *et al.*, 2005). Accordingly, the woodland and savannah region covers some 20% of the total land area of Ethiopia. From this woodland and savannah, the *Acacia* woodland and savannah occupy various environments and accounts for some 11% of the total land area of Ethiopia. Such woodlands are also known for their plant, animal, and habitat diversity. Nonetheless, they are also very fragile ecosystems that could be drastically affected by over exploitation and mismanagement (Mekuria *et al.*, 1999).

The exploitation and management of “Non–Timber Forest Products” (NTFPs) is increasingly proposed as a potential means of ensuring sustainable management of forests and their biodiversity (e.g. Mulugeta and Demel, 2003 & 2004). NTFPs are frequently touted as important to household consumption, and as a way to maintain or to increase the value of standing forest and thus to discourage deforestation (Wilkie *et al.*, 2001). Thus, management of NTFPs cannot be seen separately from general forest management, which, unlike forest plantation, affects vegetation and biodiversity in general (Kleinn *et al.*, 1996).

In the dryland woodlands of Ethiopia several species in the genus *Acacia*, *Boswellia*, *Commiphora* and *Stericulia*, known to hold commercially important NTFPs such as gum arabic, frankincense and myrrh, are predominating the vegetation composition (Mulugeta *et al.*, 2003). Ethiopia is known as one of the world leading producers and exporters for some of these NTFPs with significant socio–economic contributions at both national and local level (Mulugeta and Demel, 2003 & 2004). Apart from essential oils, which provide an array of flavours and fragrances, gums, resins and latexes are perhaps the most widely used and traded

category of NTFPs other than items consumed directly as foods, fodders and medicines (FAO, 1995b), which indicates the potential for commercial promotion of the products in Ethiopia. Besides their economic significance several species of *Acacia*, *Boswellia* and *Commiphora* could be managed to provide, concurrently, multiple ecological services that will help to fight desertification and soil erosion by water and wind, contribute to the conservation and enhancement of biodiversity, improve soil fertility, and provide an opportunity for C-sequestration (Mulugeta and Demel, 2004).

One of the most recognized NTFPs product of the dryland vegetation of Africa in general and that of Ethiopia in particular is gum arabic. Gum arabic is a dried exudate obtained from the stems and branches of *Acacia senegal* (L.) Willdenow or *Acacia seyal* (FAO, 1999). The major source of presently traded gum arabic (95%) is *Acacia senegal* (L.) Willd., with the remaining 5%, from *Acacia seyal* sold as an entirely separate product (gum talha) (Seif el Din and Zarroug, 1996).

The use of gums has declined today, compared with the early part of the 20th century. The decline is a preference for raw materials of consistent, predictable quality, which are not subject to the vagaries of weather, insect pests, stability in producing countries, and price. Despite the changes the demands for gum will continue and even bound to increase in the future for several reasons such as consumers' preference for natural products (FAO, 1995b). This is good news for people in the producing countries, provided that due attentions are given to such aspects as quality control and sustainable management of the resources.

Gums from different species (*A. senegal* and *A. seyal*) exhibit characteristics that are intrinsically different. Even within the same species, different varieties produce gum with different characteristics. Recognizing these differences in the species and/or varieties is important in producing gum arabic for desired end use (Chikamai, 1997). Because of the stringent regulations imposed on all food additives, gum arabic, like all other food ingredients, is subjected to extensive toxicological control by countries, organizations and users of the product, which aim to protect the consumer of processed foods containing additives, and thus to ensure the freedom of gum arabic from toxicological hazards. To achieve this end and get in to the market, gum arabic for commerce must conform to certain chemical specifications (Seif el Din and Zarroug, 1996).

Chemical analysis and quality assessment have been carried out on gum exudates from a large number of *Acacia* species (as well as gum– arabic– like exudates from other genera), but relatively little detailed information is available on the intra–specific variation of *A. senegal* gum. In–depth physicochemical screening is needed, to learn more about between–site, between–tree and seasonal variations in gum quality (FAO, 1995b). Moreover, compared to other producer countries, very little studies have so far been done on the physicochemical characteristics of gum arabic of Ethiopian origin. Besides, not only the quality of the gum that affects commerce but also the resource base that influences the steady supply of the product once promoted was little studied. This also calls for assessment of the population status of *Acacia senegal* in the area under consideration so as to establish the production potential of gum arabic in the region.

1.2 Objectives

1.2.1. General objective

The main focus of this study was to acquire information on the status of *Acacia senegal* (L.) Willd. species in the Central Rift Valley and to examine the quality of the gum arabic obtained from it.

1.2.2. Specific objectives

The following are the specific objectives for the study:

1. To investigate the population status of *Acacia senegal* in the Central Rift Valley area;
2. To assess the effect of different intensity of human interference on the population of *A. senegal* species;
3. To characterize the quality of gum arabic from the *Acacia senegal* trees in the Central Rift Valley area; and
4. To compare the physicochemical characteristics of the gum arabic of the area with other studies on gum arabic from known exporting countries and against international specifications.

2. LITERATURE REVIEW

2.1 Drylands — Challenges and Opportunities

Drylands are defined as areas where mean annual precipitation is less than half of the potential evapo–transpiration (FAO, 1993b). Thus, drylands embrace arid, semi–arid, dry sub–humid lands as well as more desertic (hyper–arid) areas. These lands are characterized by low and erratic precipitation, which is reflected in relatively low and notably unpredictable levels of crop and livestock production. In some parts, for instance in Ethiopia, Kenya and Uganda, a bimodal regime prevails and although the total annual rainfall may be higher, the distribution of the rainfall and the intensity of the dry season impose a semi–arid regime (FAO, 1995d).

Table 1. *Estimates of land areas affected by desertification in Ethiopia*

Bioclimatic zone	Area (1000 km²)
Hyper–arid	53 – 55
Arid	300 – 310
Semiarid	207 – 250
Dry Sub–humid	300
Total	860 – 915

Source: Mulugeta and Demel (2004)

Approximately, 55 % of the land surface of Africa is arid or semi–arid (FAO, 1995d), in which up to 80% is in the Inter–Governmental Authority on Development (IGAD) countries, in which Ethiopia is a member (Barrow, 1997). In Ethiopia alone the total dryland area,

including the dry sub-humid zone, amounts to 860,000 km² (Tamerie, 1997), which is one of the largest in the region (Table 1).

Over two-thirds of all Africans rely directly or indirectly on forests for their livelihood. In some situations forests provide an income; in others they act as a safety net for the poor. Forests also fulfill many important ecological functions (CIFOR, 2005). Forests/Trees are used for a wide variety of purposes nowhere more so than in the drylands where woody vegetation survives better and produces more in the drier times (Barrow, 1997).



Figure 1. Acacia wood land of the Central Rift Valley of Ethiopia

Despite the significant importance of forests in the livelihoods of dryland communities, there has been a significant increase in forest loss over much of Sub-Saharan Africa during recent

years. East Africa, for example, lost 10 per cent of its forest covers between 1990 and 2000 (CIFOR, 2005). Thus, the enormous dryland vegetation resources of Eastern Africa in general and that of Ethiopia in particular are facing serious problems of degradation. Vegetation resources, particularly the woody plants, in these areas are declining both in quantities, due to deforestation, and in quality as a result of degradation. The main causes of the degradation have been cutting of woody plants for various purposes such as agriculture land expansion, firewood and charcoal and over grazing (Tefera *et al.*, 2005, see also Figure 2). While our knowledge about the woodlands and the valuable species constituting them is scanty, the area of the woodlands and populations of these species are rapidly declining before we have the chance to study and document them (Abeje *et al.*, 2005).

Removal of perennial plant cover in dryland zones causes reduction of soil organic matter, induces soil erosion by water and wind, causes soil crusting by the splashing effects of raindrop, and salinization by evaporation. The ultimate consequences of all these processes are the degradation of the carrying capacity and regeneration capability, loss of biodiversity, depletion of water availability due to destruction of catchments and aquifers and, finally, abandonment of the area as desertified land (Mulugeta and Demel, 2004). These and other signs of desertification, such as accelerated soil erosion by wind and water, increasing salinization of the soils of drylands, reduction in soil moisture retention, increase in surface runoff, variability in stream flows, decline in species diversity and plant biomass, and reduction in the overall productivity in dryland ecosystems (Tewolde Birhan, 1989; EFAP, 1994; Tamire, 1997) are evident across the drylands of Ethiopia. Besides the looming desertification, drylands in Ethiopia are showing clear signs of vulnerability to global climatic

change. In the past few decades, these drylands have been suffering from increasingly erratic and decreasing amounts of annual precipitation. Frequent drought, fodder and crop failure, and famine are becoming common phenomena in the dryland regions of Ethiopia (Mulugeta and Demel, 2004).



Figure 2. Agricultural expansion and over grazing affecting the *Acacia* Woodland in Central Rift Valley

Sustainable conservation and utilization of the remaining dryland vegetation resources and rehabilitation of those that have already been degraded would provide economic, social and ecological benefits. This requires the design of economically feasible, socially acceptable and ecologically viable management and conservation strategies of dryland vegetation (Tefera *et al.*, 2005). For dryland natural resource management to be important and developed, it has to

have value, particularly economic value at a local and national level (Barrow, 1997). The low, erratic and poorly distributed rainfall in the arid and semi-arid regions, especially in areas with less than 400 mm, places greater value on perennial vegetation, especially multipurpose trees such as the *Acacia* than annual crops (FAO, 1995d). To the same end, many of the indigenous trees and shrubs in the vast arid and semi-arid lowlands including the dry sub-humid area, hold known or potential promise for the production of economically valuable products, principally oleo gum resins such as gum *Acacia* (gum arabic and gum talha), frankincense, myrrh, hinna, and gum karaya (FAO, 1995a; Mulugeta and Demel, 2003). These potentials are opportunities to be exploited for the reversal of desertification, conservation of biodiversity and adaptation of dryland ecosystems to potential global climate change (Mulugeta and Demel, 2004).

In terms of commercial importance and livelihood support, gum and resin producing trees and shrubs in the drylands of Ethiopia occupy a central position both at local and national scales. At the local household level, gum and resins are collected and sold to generate income. Both direct collection, in most cases, and hired labor by forest concessionaires play a substantial role as a source of income to households. At the national scale, gum arabic, frankincense and myrrh are the most valued products. They constitute some of the few export articles from which Ethiopia earns its foreign currency (Mulugeta and Demel, 2004). Besides, the same species that provide gums and resins can offer multiple roles that contribute to dryland development. For instance, they provide fodder for animals, protect against desertification, contribute to biodiversity conservation and enable dryland communities to adapt well to possible climate changes. Indeed, the role of the vegetation in the economics of the dryland

communities through the provision of gums and resins also integrated and balanced with other opportunities for dryland management can contribute to the economic well-being and long-term viability of, such otherwise marginal, drylands (Barrow, 1997).

2.2 A General Background to Non-Timber Forest Products

Non-Timber Forest Products generally embraces all materials of a biological origin excepting timber which is being extracted on an industrial scale obtained from forested landscape. The range of NTFPs includes foods, spices, medicines, fodder, essential oils, resins, gums, latexes, tannins, dyes, rattan, bamboo, fibers, a great variety of animal products and ornamental plants (FAO, 1993a). NTFPs have been harvested by human populations for subsistence use and trade for thousands of years (Ticktin, 2004). The trade of NTFPs dated back to old times. For instance, ancient Egyptians imported gum arabic from Sudan for use in paints and in the mummification process. International trade in sandalwood oil also dates back to the twelfth century A.D. In recent years forests have been increasingly recognized as rich reservoirs of many valuable biological resources, not just timber (FAO, 1995c). Over the past two decades, NTFPs obtained from plant resources, including seeds, flowers, fruits, leaves, roots, bark, latex, resins and other non wood plant parts, have gained much attention in conservation circles (Ticktin, 2004).

The increased attention paid to NTFPs in recent times stems from a perception that management for NTFPs is more compatible with sustainable use of tropical forests than management for timber or shifting agriculture and the growth in awareness that the use or sale of NTFPs is important parts of the livelihood systems of very large numbers of people, outside

as well as inside tropical forests. There has also been an increase in commercial demand for many non-timber outputs of tropical forests — rattan, oils, resins, pharmaceutical extracts, *etc.* — and a realization that it is likely that there are other species and products of significant industrial value in such a rich and diverse genetic resource (Arnold and Pérez, 1996). The development and implementation of sustainable production and conservation of NTFPs, with rigid product quality control, efficient marketing and equitable distribution of benefits to all concerned, from the producer to the consumer, is a key component for a successful programme for achieving more sustainable management of the forest resources, including better conservation of their biodiversity (Vantomme, 1997). It has also been argued that this potential could be considerably enhanced by drawing on indigenous knowledge and building on the sustainable systems of use that local people often seemed to have created. In consequence, interest in NTFPs has been linked to the issue of empowering local people, and recognizing and legally securing their rights to manage their forest resources (Arnold and Pérez, 2001).

2.2.1 Non-Timber Forest Products for Conservation of Forest Resources

Interest in NTFPs has grown with the increasing awareness of tropical forest problems and destruction. NTFPs have been heralded by some as a means of slowing forest destruction by increasing the overall worth of the forest and by shifting the emphasis of forest exploitation from trees to products whose harvest is believed to be less ecologically destructive (Falconer, 1996). Since the early 1990s, NTFPs have been assumed to contribute effectively to the preservation of tropical forests and the improvement of forest dwellers' economic situation by raising awareness of the value of natural resources (Schröder, 2001). The maintenance of a

forest-like structure associated with production of NTFPs is generally acknowledged as being positive, contributing to some of the classical forest environmental functions such as carbon storage, nutrient cycling, erosion control, hydrological regulation, and biodiversity conservation, while providing an important source of income (Arnold and Pérez, 2001).

2.2.2 Non-Timber Forest Products for Economy

In recent years, a growing body of scientific research has suggested that, given certain basic conditions, NTFPs can help communities to meet their needs without destroying the forest resource (FAO, 1995c). In fact, NTFPs are well known worldwide for their contributions to national and local economies (Mulugeta *et al.*, 2003). For instance, in India over 50% of forest revenues and 70% of forest export income comes from NTFPs (Shiva, 1993). Some valuation exercises suggested that the potential income from sustainable harvesting of NTFPs could be considerably higher than timber income or income from agricultural or plantation uses of the forest sites. NTFPs are also widely important as a subsistence and economic buffer in hard times (Arnold and Pérez, 2001). NTFPS contribute to household self-sufficiency, food security, income generation, accumulation of savings and risk minimization, and fill seasonal and other food or income gaps (Arnold and Pérez, 1996).

Like wise NTFPs, such as gums and incense, resins and spices, or honey and wax from beekeeping, play an important role in the consumption patterns and income diversification of rural communities of Ethiopia (Vivero Pol, 2002). NTFPs often play critical roles as “safety-nets” by providing food or income in times of shortage, as important dietary supplements, especially for children, and as cultural symbols. Generally speaking, it is important to

recognize these values, even if they are difficult to quantify, and to protect them where possible (Wollenberg and Belcher, 2001).

2.3. *Acacia senegal* and its Socio–economic and Ecological Roles

2.3.1 *The Genus Acacia*

Acacia are trees or shrubs, sometimes climbing; the native species almost always armed with prickles or stipular spines. Leaves bipinnate or, in introduced species, modified to phyllodes; gland usually present on upper side of petiole, glands often also present at insertion of pinnae (Asfaw and Thulin, 1989). *Acacia* flowers are small, regular and are usually bisexual. Each flower contains basically 4 or 5 sepals and petals. The sepals may be free or united into a calyx and the petals free or united into a corolla. The stamens are numerous and arise from under or just above the base of the ovary. A threadlike style protrudes shortly beyond the stamens. The ovary is sessile or shortly stalked and its outer surface may be smooth or covered in minute hairs. Each flower is subtended by a small bracteole whose shape varies according to species (FAO, 1995d).

There are some 1100 species, mostly tropical and subtropical, the majority in Australia, and some 130 in Africa (Asfaw and Thulin, 1989). *Acacia* species are widely distributed through the drier regions of tropical and southern Africa, often the dominant tree and in some areas forming mono–specific communities (FAO, 1995d). *Acacia* woodland is a major vegetation form in the arid and semi–arid parts of Ethiopia (Getachew and Ståhl, 1999). It covers nearly

11% of the total land area in the country (Getachew and Ståhl, 1998). This is an important genus for its many uses to man and his domestic animals. Most species produce abundant nectar and pollen, which are good for honeybees. Both domestic and wild animals browse on the leaves, shoots and pods. Roots and bark are fibrous and can be used as rope substitutes. Many species produce gums and resins that may be used medicinally and are eaten in times of food shortage (Asfaw and Thulin, 1989). *Acacia* species are Nitrogen-fixing; but their potential for use in agroforestry, apart from a few species, has been neglected. Some can be effectively utilized for shade, shelter, live fences, soil stabilization as well as for street trees and ornamentals. Grasses and herbs alone cannot support a livestock industry in the semi-arid regions; browse, especially from *Acacia* species, plays an essential part (FAO, 1995d).

2.3.1 *Acacia senegal*

Acacia senegal is a deciduous shrub or tree up to 15 m high, crown variable, flat to rounded; bark yellowish-brown to purplish black, rough or smooth, scaly; branchlets with prickles just below nodes, either in threes with central one hooked downwards and laterals curved upwards or with laterals absent; leaves pinnate, pinnae (2-)3 – 8(-12) pairs, leaflets 7-25 pairs; inflorescence spicate, 2-12 cm long, pedunculate, flowers white or cream; pods dehiscent, yellowish to brown, flat, papery oblong 2-19 X 1-4 cm; seeds subcircular-lenticular, olive brown, 8-12 mm in diameter (FAO, 1988). Varieties of *A. senegal* present in Ethiopia are (Asfaw and Thulin, 1989):

Var. kerensis

- Shrub, branching from near the base.

Var. senegal

- Bark not papery and peeling; young branchlets sparingly to densely pubescent
inflorescence axis mostly pubescent.

Var. leiorhachis

- Bark yellow, papery and peeling; young branchlets glabrous or almost so;
inflorescence axis glabrous or almost so.

2.3.2 Distribution and Ecology of *A. senegal*

Acacia senegal var. *senegal* is found in Mauritania, Senegal, Gambia, Ghana, Burkina Faso, Cote d'Ivoire, Mali, Niger, Nigeria, Cameroon, Zaire, Central African Republic, Rwanda, Chad, Sudan, Ethiopia, Somalia, Uganda, Kenya, Tanzania, Mozambique, Oman, Pakistan, and India. It has been introduced into Egypt, Australia, Puerto Rico, and the Virgin Islands (Cossalter, 1991). The other varieties of *A. senegal* have a much more restricted distribution than var. *senegal* and provide only very tiny amounts of gum to the market. *A. senegal* var. *kerensis* occurs in parts of Somalia, Uganda, Kenya and Tanzania. *A. senegal* var. *leiorhachis* is also found in parts of East Africa but it occurs also in Central and Southern Africa (Zambia, Zimbabwe, Botswana and South Africa) (FAO, 1995b).

Acacia senegal thrives on dry rocky hills, in low-lying dry savannas. This hardy species survives many adverse conditions, and seems to be favored by low rainfall and absence of frost. It ranges from Warm Temperate Thorn through Tropical Thorn to Tropical Dry Forest

Life Zones (Duke, 1983). It is very drought resistant. It grows on sites with annual rainfall mainly between 300–400 mm, and 5–11 month dry periods. It tolerates high daily temperatures (mean maximum temperatures of up to 45°C or more), dry wind, and sandstorms. *Acacia senegal* prefers coarse-textured soils such as fossil dunes, but it will also grow on slightly loamy sands and skeletal soils such as Lithosols. The best sites have pH of 5 to 8. The tree ranges from 100–1700 m elevation in the Sudan to 1950 m around Nakuru in Kenya (Cossalter, 1991).

2.3.3 Propagation

Acacia senegal propagated well in seeds. Seed should be harvested before pods have dried for easy collection and to avoid insect attack. Freshly extracted seed should immediately be dusted with an insecticide. Seed will remain viable for 3–4 years if kept in opaque, airtight containers (Cossalter, 1991). *A. senegal* seeds abundantly and, although pods and seed may be attacked by insects, germination capacity is generally high. Direct spot-sowing is the normal method of establishment and plantations require intensive weeding over the first 2 yr (FAO, 1983). Fresh seeds with soft seed coats can germinate with out pretreatment, if sown immediately after collection (FAO, 1988). Seed collected in previous seasons, however, requires pretreatment to break seed dormancy. Soaking seed in water for 12–24 hours gives good results and is simple to apply. Seeds can also be nicked (Cossalter, 1991). Another method of propagating *Acacia senegal* is by shoot cuttings and coppicing (Duke, 1983).



Figure 3. *A. senegal* tree from Central Rift Valley of Ethiopia

2.3.4 Use of *A. senegal*

Acacia senegal is an amazing tree. It grows where almost nothing else will survive, enriches the soil with nitrogen, and provides nutritious fodder and gum arabic. Specifically, gum arabic is an extraordinary harvest from *Acacia senegal* which can bring security to the fragile existence of people in the arid lands who depend on livestock or dry-land farming (Holmes,

1997). Wood from *A. senegal* is an excellent slow-burning fuelwood giving intense heat and little smoke, it also used for charcoal making (FAO, 1995d). *Acacia senegal* is important for desertification control through sand dune stabilization and wind breaks. It has role in agricultural systems by restoring soil fertility (Cossalter, 1991). It is an important tree for agroforestry systems in arid and semi-arid areas of Sudan and Western Ethiopia (Asfaw and Thulin, 1989). It is browsed by livestock, especially goats and camels, and is reputed to fatten livestock and enrich milk. It is a good source of bee food. Strips of under bark are used to tan leather, often strengthened with material from *A. etbaica*. Dried, crushed and powdered bark is used to pack infected wounds to disinfect and ward off further infection and gangrene (FAO, 1995d).

2.4 Gum Arabic

The term ‘gums’ is used to describe a group of naturally occurring polysaccharides which find widespread industrial use because of their ability either to form viscous solutions or gels or to stabilize emulsions and dispersions (Casadei, 1997). Gum arabic is a dried exudate obtained from the stems and branches of *Acacia senegal* (L.) Willdenow or *Acacia seyal* (FAO, 1999). *Acacia* gum, also called gum arabic, is a complex arabinogalactan-type polysaccharide exuded by *Acacia* trees (Sanchez *et al.*, 2002). Gum *Acacia* contains neutral sugars (rhamnose, arabinose, and galactose), acids (glucuronic acid and 4-methoxyglucuronic acid), calcium, magnesium, potassium, and sodium (Duke, 1983). The average molecular weight of gum arabic from *Acacia senegal* var. *senegal* is between 4.86 to 6.47 X 10⁵ (Al-Assaf *et al.*, 2005).

2.4.1 Uses of Gum Arabic

The combination of high solubility in water and low viscosity confers on gum arabic its highly valued emulsifying, stabilizing, thickening and suspending properties (FAO, 1995b). Gum arabic is unique and natural product which is used extensively in pharmaceutical preparations, food industries such as in confections and sweetmeats, in the cosmetics industries, and for other industrial products such as ink, paint, paper, matches, ceramic, water-colors, wax polishes, liquid gum, for dressing fabrics, giving luster to silk and crepe, and for thickening colors and mordants in calico-printing (Duke, 1983; FAO, 1988).

Gum arabic is used in the food industry to fix flavors and as an emulsifier, to prevent the crystallization of sugar in confectionery products, as a stabilizer in frozen dairy products; its viscosity and adhesive properties find use in bakery products, and as a foam stabilizer and clouding agent in beer (Cossalter, 1991). Whilst our modern lifestyle has led to an increasing demand for convenience foods our growing awareness of the relationship between food and health has increased the requirement for high-fiber, low-fat food products. These factors have resulted in a considerable interest in the use of hydrocolloids, including various gums, modified starches and gelatin, in foods and this is expected to continue in the years ahead (Casadei, 1997).

In the pharmaceutical industry gum arabic is used as a stabilizer for emulsions, as a binder and coating for tablets, and as an ingredient in cough drops and syrups (FAO, 1995d). In modern pharmacy, it is commonly employed as a demulcent in preparations designed to treat diarrhea, dysentery, coughs, throat irritation, and fevers. It serves as an emulsifying agent and gives

viscosity to powdered drug materials; is used as a binding agent in making pills and tablets and particularly cough drops and lozenges (Duke, 1983).

Gum arabic is used in cosmetics as an adhesive for facial masks and powders, and to give a smooth feel to lotions. Industrially, gum arabic is applied as an adhesive, as a protective colloid and safeguarding agent for inks, sensitizer for lithographic plates, coating for special papers, sizing agent for cloth to give body to certain fabrics, and coating to prevent metal corrosion. Gum arabic is also used in the manufacture of matches and ceramic pottery (Cossalter, 1991). Powdered, reddish–brown gum exudate mixed with fat or grease is used to anoint the body. The fresh gum exudate is being used as a depilatory. A solution of gum, drunk on an empty stomach, is used to relieve chest pains. The eating of gum is reputed to strengthen the stomach muscles; excessive eating of gum can cause flatulence and some discomfort. Gum is highly nutritious, 175 g being sufficient to support an adult for 24 hours (FAO, 1995d).

2.4.2 Harvesting

Gum exudes from cracks in the bark of wild trees. In Africa, it is regularly tapped from trees which are about six years old by making narrow transverse incisions in the bark in February and March. In about a month, tears of gum form on the surface and are gathered. Trees begin to bear between 4–18 years of age and are said to yield only when they are in an unhealthy state owing to poor soil, lack of moisture or damage (Duke, 1983). In Sudan and Nigeria, virtually all gum from *A. senegal* is obtained by tapping the trees; there is very little natural exudation. *A. senegal* does produce gum naturally and all of the gum which is collected comes

from harvesting natural exudates (FAO, 1995b). In Ethiopia gum arabic is collected both from natural stands (Southern part) and by tapping (Northern part).

2.4.3 Yields and Economics

Yields of gum arabic from individual trees are very variable and little reliable data are available on which to base sound estimates of "average" yields. A figure of 250 g of gum per tree per season is often cited as an average yield. Yields of several kg or more have been reported from individual trees. In Sudan, yields from cultivated *A. senegal* are said to increase up to the age of 15 years, when they level out and then begin to decline after 20 years (FAO, 1995b). Virtually all the gum arabic of commerce comes from Africa with Sudan accounting for up to 80% of the world production followed by Chad and Nigeria. About 12 other countries in the Sahel, stretching from Senegal/Mauritania in West Africa to Somalia in the Horn of Africa and southwards to Tanzania are also producers (Mugah *et al.*, 1997). Gum arabic sales peaked at around 1970 at approximately 70,000 t, of which about 70% went into confectionery products. The price for gum arabic is \$US 5000 per tonne (FAO, 1995d). The severe Sahelian drought of 1973/74 resulted in a world shortage of gum arabic and high prices which, in turn, accelerated the replacement of gum arabic by substitutes such as modified starches. Demand for gum arabic has, therefore, been constrained at times by the supply, and under these circumstances end-users who switch to alternatives do not always revert to gum arabic when supply problems are eased (FAO, 1995c). A summary of product types and world major producers and exporters is presented in Table 2.

Table 2. *Leading world producers of gums and gum resins.*

Product type	Producers	World production and export
Gum resins (Frankincense, myrrh and opopanax)	Ethiopia Eritrea Somalia	90%
	Sudan Kenya India	10%
Gum arabic	Sudan Nigeria Chad	90%
	Cameroon Ethiopia Tanzania Eritrea	9.9%
	Others	0.1%
	India	90%
Gum karaya	India	90%
	Others	10%

Source: Mulugeta and Teshale, 2006

2.4.4 Quality of Gum Arabic

Gum arabic from *A. senegal* is a pale to orange–brown coloured solid, which breaks with a glassy fracture. The best grades are in the form of whole, round tears, orange–brown in colour and with a matt surface texture; in the broken, kibbled state the pieces are much paler and have a glassy appearance (FAO, 1995b). The increasing international pressure towards tighter trade specifications and labelling regulations, identity and purity has led to the Revised Specifications (FAO/WHO–JECFA) where gum arabic is defined as originating from *A. senegal* or closely related species, with a specific optical rotation range of -26° to -34° and a Kjeldahl nitrogen content of 0.27–0.39% (FAO, 1995d). Gum arabic has been described in various reports and laboratory analyses as forming an aqueous solution of up to 50%; colourless and free of taste and odour, these solutions do not readily interact with other

chemical compounds. It is readily soluble in water, to give aqueous solutions of low viscosity (Seif el Din and Zarroug, 1996).

Table 3. *Physicochemical properties of gum exudates from some Acacia species*

Parameter	drepa		mala		sese		sele		seya		sefi	
	I ^a	II	I	II	I	II	I ^b	II	I ^a	II	I	II
Moisture % w/w	10.7	14.4	13.2	13.4	15	14.1	13.8	15.3	15	14	14.2	13.4
Ash % w/w	2	1.6	3	2.3	4.5	3.8	4.2	5.2	3	3.5	3.2	2.6
Acid insoluble matter % w/w	0.2	0.35	1.88	0.73	0.88	0.6	0.3	0.21	0.3	0.78	0.65	0.6
CWIG % w/w	0.3	0.43	5.88	3.43	1.57	1.83	8.9	15.67	0.2	0.7	2.7	0.35
HWIG % W/W	0.3	0.4	3.92	2.96	0.96	1.23	2.1	4.03	0.1	1.06	1.7	0.3
Ca (g/100g) ^c	0.66	0.53	0.68	0.59	0.72	0.43	0.75	0.74	1.01	1.06	1.78	0.77
Mg (g/100g) ^c	0.09	0.05	0.08	0.05	0.29	0.02	0.17	0.15	0.15	0.09	0.08	0.08
Na (g/100g) ^c	0.08	0.03	0.13	0.03	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.04
K (g/100g) ^c	0.19	0.1	0.28	0.11	0.98	0.09	1.09	1.35	0.2	0.2	0.18	0.17
Methoxyl % w/w	0.81	1.02	1.12	1.1	0.17	0.26	0.3	0.27	1.22	1.29	1.21	1.43
Nitrogen % w/w	0.3	0.32	1.67	0.84	0.33	0.28	0.44	0.48	0.13	0.07	0.21	0.18
Hence, Protein (N x 6.25)	1.88	1.94	10.44	5.25	2.06	1.75	2.75	3	0.81	0.44	1.31	1.12
[a] _D In H ₂ O, deg	101	104	70	86	-25	-26	-50	-55	54	53	54	56
Viscosity (centipose)												
100 g ⁻¹	4	2.9	4.73	5.33	4.61	2.9	33.69	79.22	8.98	6	7.32	5.7
150 g ⁻¹	9.5	5.8	11.06	11.04	9.44	6.14	64.18	181.8	18.83	13.87	19.25	15.39
Optical density	0.18	0.06	0.14	0.1	0.06	0.06	0.19	0.07	0.09	0.08	0.12	0.27
Tannin %w/w	0.33	0.4	0.42	0.48	0.28	0.52	0.37	0.44	0.31	0.59	0.29	0.51
Acid Equivalent Weight	2263 ^d	2607	1615	1940	1575	1922	1583 ^d	1703	1424 ^d	1423	1284	1812

(Source: *Mhinzi and Mrosso (1997)*)

Drepa = *A. drepanolobium*;

mala = *A. malacocephala*;

sese = *A. senegal* var *senegal*;

sele = *A. senegal* var *leiorhachis*;

seya = *A. seyal* var *seyal*; and

sefi = *A. seyal* var *fistula*

One factor observed to influence the quality of gum arabic is botanical origin. Quality of gum arabic differs between and within species (Chikamai, 1997). The Acid Equivalent Weight (AEW's) and total ash levels of the gums from *A. senegal* var. *leiorhachis* and *A. senegal* var. *senegal* are similar. However, apart from these two parameters, the overall impression is that

these two species produce gums with different properties. The viscosity of *A. senegal* var *leiorhachis* gum is significantly higher than that of *A. senegal* var *senegal* at the same concentration. *A. senegal* var *senegal* has been found to have a more negative optical rotation (Mhinzi and Mrosso, 1997; see Table 3).

It is so fundamentally important that we present gums which are not adulterated with gums of another type or species. Gum arabic is increasingly used as a technical product. It is often blended with other gums or materials to produce precise ingredients for food and pharmaceuticals (Holmes, 1997). The same source also emphasized that, the vast sums of money which go into developing new product lines demand that ingredients must be of a relatively invariable nature. Users also want traceability and guarantees that ensure they receive a product which does not expose them to risk.

In order to promote the commerce of gums and gum resins, knowledge on the chemistry for each gum or resin type is crucial. However, none of such characterisation has been carried out for gums of Ethiopian origin. This could be mentioned as one bottle neck for expanded commercialization of gums of Ethiopia. The goal of this thesis is to contribute to this knowledge gap particularly *A. senegal* gum, gum arabic.

3. MATERIALS AND METHODS

3.1 Study Site

The study was conducted in the Central Rift Valley, near Lake Langano, Abijata and Shalla, South of Addis Ababa (Figure 4). The study area lies 7° 29' 59'' to 7° 50' 4'' Latitude and 38° 35' 32'' to 38° 41' 30'' Longitude; at an altitude ranging from 1597 to 1678. The Ethiopian Rift Valley System is part of the Afro–Arabian Rift System. The main parent materials that give rise to the soils of the region are basalt, ignimbrite, lava, gneiss, volcanic ash and pumice, and riverine and lacustrine alluvium (Makin *et al.* (1975) cited in Getachew, 1999). The soils are developed on lake deposits interspersed with pumice. They are coarse–textured, alkaline (pH=7.6–8.2), silty, clay loam and rather infertile (Mekuria *et al.*, 1999).

The region consists of several leguminous tree species such as *Acacia senegal*, *Acacia seyal*, *Acacia tortilis*, *Dichrostachys cinerea*, *Balanites aegyptiaca* and other important shrub and herbaceous species. The natural vegetation in most areas of the central parts of the Rift Valley is sparse woodland dominated by *Acacia*. Because they are utilized in many different ways, the *Acacias* are important to the rural economy (Getachew and Ståhl, 1999). They are important sources of wood fuel. They also provide the rural community with other forest products and benefits such as fodder, construction materials, farm implements, shade, honey, etc. and income; and thus are important components of livelihood (Getachew and Ståhl, 1998). This zone is the most extensive part of the valley floor where it is currently subject to increasing settlement pressure. Both the human population and the livestock population have increased dramatically (Mekuria *et al.*, 1999). The area is overgrazed and trees are cut

extensively for charcoal and fire wood. Livestock and wood products are the major sources of income for the local people (Mohammed, 1993). Agro-sylvopastoral land use system is dominant in the area. Consequently, crop production is an essential element in the land use systems. Cattle rearing in the area are of two types i.e. the traditional way of cattle rearing by the community and the modern way of cattle production implemented by Oromia Agriculture Bureau (Getachew, 1999).

The region is classified as a semi-arid eco-climatic zone. It is similar to the semi-arid regions of East Africa. The climate of the study area is characterized by distinct wet/dry seasons and has bimodal rainfall (Mekuria *et al.*, 1999). The area experiences a climate characterized by rainy season that extends from July to September. The mean annual rainfall is 600 mm. The mean maximum and minimum temperatures are 26.9 and 11.7°C (Getachew, 1999).

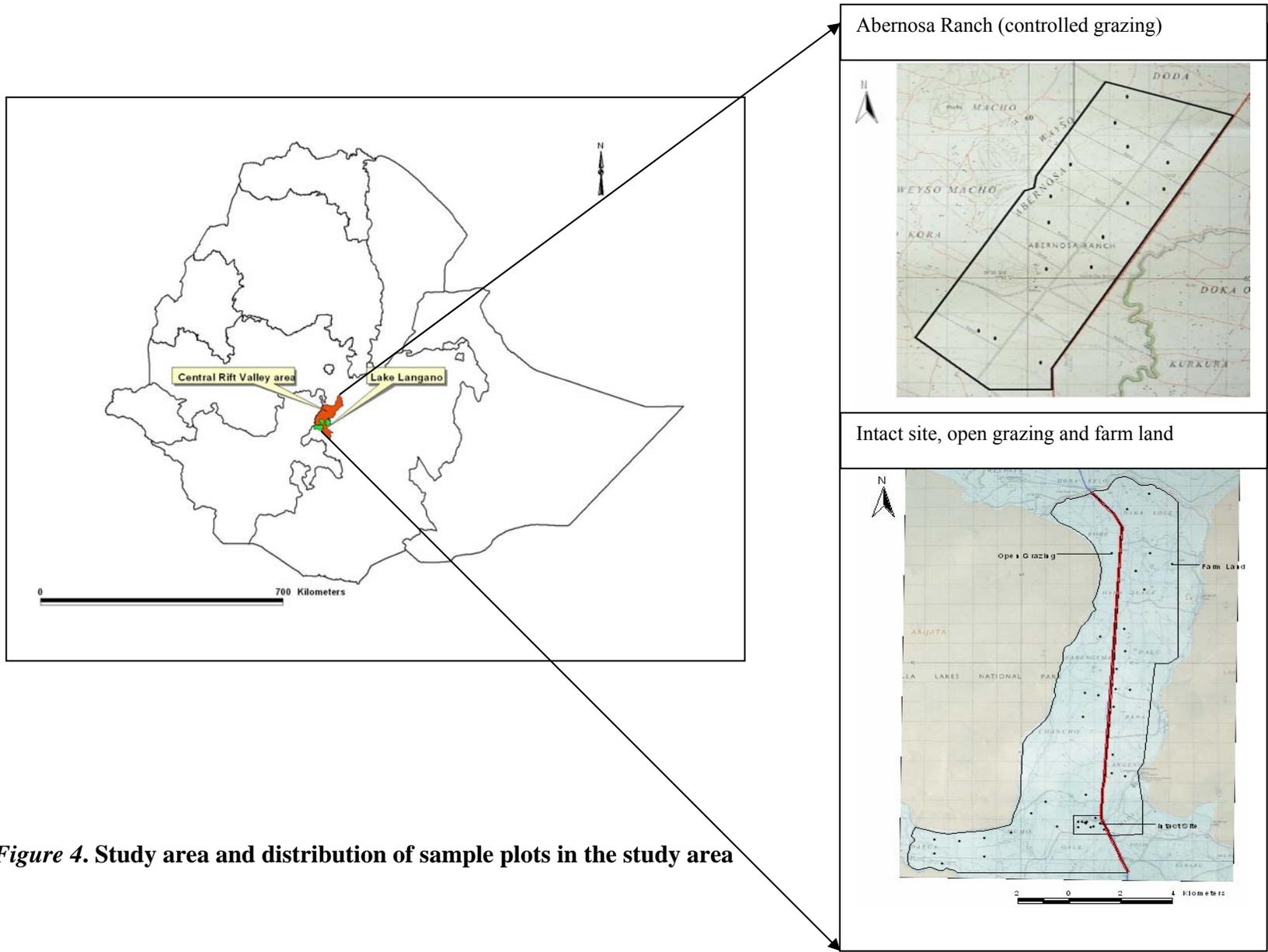


Figure 4. Study area and distribution of sample plots in the study area

3.2 Data Collection and Measurements

A reconnaissance survey was made across the woodland in the central lakes sub–regions part of the Rift Valley, between Arsi Negele and Ziway, in order to obtain an impression of the condition of the vegetation of the site. Four sites, which represented four vegetation conditions namely intact (protected against all intervention), relatively intact (exposed to controlled grazing), open grazing land, and farm fields, were selected. The site considered as intact and relatively intact were the Abijata Shalla National Park (head quarter) and Abernosa Cattle Ranch, respectively (Figure 4). Farmlands of *Hada*, *Langeno*, *Bana*, *Dalu*, *Daka Ilala* and *Daka Lole* areas, and open grazing lands of *Danga*, *Humo*, *Gale*, *Chancho*, and *Harengema* areas were represented the other two sites (Figure 4).

After the sites were selected, sample plots were randomly laid out on the topographic map of the area (scale 1:50,000) by means of square grids (Figure 4). The geographical coordinates of the plot centers were taken from the topomap and fed in to GPS. The sample plots were located on the ground using the GPS navigation system. Sample plots, having 500 m² (12.56 m radius circle), were laid having the coordinates as the center of the circle (De Gier, 1989).

In each plot, the total number of individuals of *A. senegal* and other associated species were counted and recorded. The height and diameter at breast height (DBH) of these individuals, with heights of 1.5 m or more, were measured using hypsometer and diameter tape, respectively. For individuals with a height of less than 1.5 m, their basal diameters and heights were measured using caliper and calibrated sticks (rods), respectively (Abeje *et al.*, 2005).

Gum samples were collected from randomly identified *A. senegal* trees in the area. The collected gum samples were taken to the Forestry Research Center (FRC) and Ethiopian Institute of Agricultural Research, for preparation for chemical analysis.

3.3 Physicochemical Characteristic Analysis of Gum Arabic

Analysis on the physicochemical characteristics of the gum arabic was done in the laboratories of FRC, Ethiopian Quality and Standards Authority and Essential Oils Research Centre. The physico-chemical properties of the gum analyzed included colour, odour, moisture content, ash content, viscosity, pH and gel determination, specific rotation, nitrogen content, tannin content and mineral contents. The procedures used for the analysis of physicochemical properties of the gum arabic samples were presented as follows.

1. Moisture Content

Approximately 2 g of ground gum arabic sample was weighed and oven dried at 105 °C for 5 hour. It was allowed to cool in a desiccator before reweighing. Moisture content was expressed as a percentage of the weight loss from the original weight (FAO, 1999). The experiment was done in three replications and an average was taken.

2. Ash Content

A sample of the gum arabic was first heated on a burner in air to remove its smoke. Then it was burned in a furnace at 550 °C. The Ash content was expressed as a percentage ratio of the weight of the ash to the original weight.

3. pH determination

A 25 % gum solution was prepared and the pH meter was calibrated with a standard solution of known pH. The pH measurements of the gum solution was read from the instrument.

4. Gel determination

The determination of gel was of qualitative. A 25 % gum solution was prepared and its gelling property was determined according to whether there is no gel, light gel, moderate gel and heavy gel.

5. Specific Rotation

Optical rotation was determined for 1.0% w/w solutions (on a dry weight basis) using polarimeter fitted with a sodium lamp. Three readings were made of the rotation of the solution at 25° temperature. The solution was replaced with the reserved portion of the solvent, the same number of readings was made, and the average used as the blank value. The blank value was subtracted from the average observed rotation since the two figures are of the same sign to obtain the corrected angular rotation (FAO, 1991; Idris *et al.*, 1998). The specific rotation for each gum sample was calculated (Al-Assaf *et al.*, 2005):

$$[\alpha]_D^{25} = \frac{100\alpha}{lc}$$

where α is the observed rotation;

l is the path length (dm);

c is the concentration (g/100 ml);

T° is the measuring temperature; and

D is the D–line of Na.

6. Viscosity

A 200 mg gum sample was dissolved in 20 ml 1.0 M NaCl over night (Idris *et al.*, 1998). The solution was then filtered and the measurements were carried out by means of a Townson Mercer Type–Zeitfuchs Cross Arm Viscometer. The viscometer was immersed in a liquid bath at 25 °C temperature. The sample solution was introduced into the viscometer flowing freely, the time required for the solution to pass from the first to the second timing mark was measured, in seconds (Al-Assaf *et al.*, 2005). The viscosity in Centistokes was calculated by multiplying the calibration constant of the viscometer, 0.003512, by the flow time (FAO, 1991). The value of the viscosity was then converted to Centipoises by multiplying the value in Centistokes by density of the solution.

7. Tannin Content

To 10 ml of a 2 % solution of the gum sample was added with about 0.1 ml of ferric chloride. The solution was then centrifuged. A blackish precipitate indicates the presence of tannin (FAO, 1999). Further analysis of the positive test of tannin present was expected to be done by condensation of tannins with formaldehyde. A diluted solution of 100ml in a conical Erlenmeyer flask added with 10ml of 40% formaldehyde and 5ml HCl (1.19gm/cm³). The mixture was refluxed for 30min on a water bath. The observed resin will be weighed and expressed, as % ratio (Obolenskaya *et al.*, 1991).

8. Nitrogen Content

Nitrogen analysis was undertaken by means of a Vapodest Distillation Apparatus. 0.6 gm of the gum sample was used in the analysis. The amount of Nitrogen was calculated by the amount of acid added, that was needed to change, the color of the distilled gum solution. The protein content was calculated using the nitrogen conversion factor (NCF) of 6.6 as proposed by Anderson (1986; cited in Idris *et al.*, 1998).

9. Mineral Content

Ash from sample of gum arabic was prepared and dissolved in concentrated sulfuric acid. The solution was then used for the determination of mineral elements studied, except for Phosphorous, by Atomic Absorption Spectrometer (AAS). The appropriate standard solution was prepared for each metal and used by the AAS to prepare the graph for the determination of the amount of each metal from the gum solution. All measurements were done in triplicates. The detection limit of the AAS was parts-per-million (ppm). The amount of phosphorous in the sample was determined by wet ash method. The amount of Phosphorous was determined by means of a UV-VIS spectrometer at 400 nm wave length.

3.4 Data Analysis

3.4.1 Vegetation

The status of populations of *A. senegal* and associated species was examined by estimating dominance, density, abundance, frequency, importance value index (IVI) and population structure.

3.4.1.1 Density, Abundance, Frequency, Importance Value Index and Dominance

Density was calculated by the number of individuals of a species per unit of area (Abeje *et al.*, 2005). Abundance is defined as the number of stems per plot. Two sets of the abundance values were calculated, i.e., average abundance per plot was calculated by dividing the sum of the number of stems per species from all plots by the total number of plots (maximum frequency). Local abundance was calculated as the ratio of the total number of stems of a species divided by its absolute frequency (Tadesse, 2003). Frequency is defined as the presence or absence of a given species in sample quadrats (Lamprecht, 1989). Absolute frequency of a species was obtained by counting the number of plots in which the species was recorded (Kent and Coker, 1994; Tadesse, 2003). Relative frequency of a species was done by calculating the ratio of the absolute frequency of the species to the total number of study plots (which is equal to maximum frequency) (Getachew, 1999; Tadesse, 2003). Importance Value Index (IVI) allows a comparison of the ecological significance of species in a given forest type and depicts the sociological structure of a population in its totality in the community (Lamprecht, 1989). Therefore, it is a good index for summarizing vegetation characteristics and ranking of species (Kindeya, 2003). The importance value index (IVI) was calculated as the sum of the relative dominance (%), relative abundance (%) and relative frequency (%) of *A. senegal* and associated species (Lamprecht, 1989). The IVI of each species was converted in to a 100 per cent scale (Kindeya, 2003).

The term dominance refers to the degree of coverage of a species as an expression the space it occupies. Dominance is usually expressed by stem basal area. This may be expressed as the absolute dominance (=the sum of the basal areas of the individuals in m² per ha) and relative

dominance (= the percentage of the total basal area of a given species out of the total measured stem basal areas of all species) (Lamprechet, 1989). Basal area is the cross sectional area of a tree trunk measured at diameter breast height (BH, 1.3m). Basal area was calculated for *Acacia senegal* and associated species which had diameter breast height greater than 2.5 cm (Kumelachew and Taye, 2003). The basal area of a tree was calculated as follows:

$$BA = \Pi d^2 / 40000$$

Where BA = Basal area in m²

d = Diameter at breast height in cm.

$$\Pi = 3.14$$

3.4.1.2 Population structure

Population structure is the numerical distribution of individuals of different size or age within a population at a given moment of time (Peters, 1996). To determine the population structure of *A. senegal* and associated species, all individuals of the species encountered in the quadrats were arbitrarily grouped by 4–cm diameter classes (0 – 4 cm, 4 – 8 cm, 8 – 12 cm...52 – 56) and by 2–m height classes (0 – 2 m, 2 – 4 m, 4 – 6 m ...26 – 28). The population structure was depicted using frequency histograms of both diameter and height–class distributions (Abeje *et al.*, 2005). The overall shapes or slopes of these frequency histograms were then compared visually. The histograms were classified into three of the most common size–class distributions exhibited by tropical tree populations (Peters, 1996). These are:

TypeI– displays a greater number of small trees than large trees, and an almost constant reduction in numbers from one size to the next (inverse J shape).

TypeII – shows a characteristic of species that has discontinuous or periodic recruitment.

TypeIII – reflects a species whose regeneration is severely limited for some reason.

3.4.2 Data on Gum chemistry

The physicochemical properties of the gum arabic obtained from the laboratory analysis are compared with results of gum arabic studies done from major producing countries and also with international standards.

4. RESULTS AND DISCUSSION

4.1 Floristic Composition of the Vegetation

The diversity of tree and shrub species in the study area is very low; about eight tree and shrub are recorded from all of the sites in the present study (Table 4). The total number of tree and shrub species registered at the four studied sites is more or less the same. However, the sites with higher disturbance, the open grazing and farmland, are found to own relatively higher number of tree and shrub species (six) than the less disturbed sites (five) (Table 4). Other studies also reported that the natural vegetation in most areas of the Central Rift Valley is low in tree diversity (Mohammed, 1993; Getachew, 1999). The low diversity in tree species composition may be due to ecological limitations, as associated to low and erratic rainfall and soil nutrients deficiency, in the area.

The density, abundance, frequency, dominance and importance value index (IVI) of the tree and shrub species in the different land cover/land use categories studied also reveal a pattern depending on the degree of disturbance (Table 4). Density of tree species is the highest in the open grazing (1584 stems/ha) and lowest in the controlled grazing site (268 stems/ha). In terms of density of each species, *A. senegal* is the species with the highest density in three of the four sites, intact, open grazing and farmland, with the density range from 224 – 632 stems/ha (Table 4).

When compared with earlier studies at Abernosa Cattle Ranch (Mekuria *et al.*, 1999), controlled grazing, the results of the present study for the densities of the species is in agreement for *B. aegyptiaca*, but higher density is recorded for *A. senegal* and lower density for *A. tortilis*, *D. cinerea* and *A. seyal* species. Compared with the study made by Getachew (1999) in Abernosa Cattle Ranch, the results of the present study show a lower density for *A. tortilis*, *A. senegal*, *A. seyal*, and *B. aegyptiaca* but a very high density for *D. cinerea*. In the open system (both at farmland and open grazing), in the present study the densities recorded are generally higher for all species except *D. cinerea*, compared with the study by Mekuria *et al.* (1999). In the Abijata Shalla National Park, the present study shows a higher density for all the tree/shrub species present compared with the study by Mohammed (1993). This may reflect changes in vegetation over time. Despite the low floristic composition, the density of the woody plants in general is quite good for such a dryland environment.

In terms of abundance, *A. senegal* is the most abundant in the intact, open grazing and farmlands, but third in the controlled grazing. In addition, *A. senegal*, a species known to hold multipurpose including high economic significance is observed to dominate the abundance, and own the highest density in most of the land use/land cover existing in the area. This may be associated with the incidence of disturbance in the area. In general, disturbed sites have higher regeneration of woody plants than less disturbed sites if the disturbance is not severe (Rogers *et al.*, 2005). According to the same literature, natural disturbances are essential processes in most ecosystems, and it has been demonstrated that their loss or disruption through anthropogenic intervention may threaten the persistence of certain species. Disturbance may replenish nutrients previously lost to an ecosystem through soil weathering. However, those

Table 4. Density, abundance, frequency, dominance and importance value index (IVI) of the tree species in the Central Rift Valley of Ethiopia

Intact site												
RO	Species	Family	D	RD (%)	N	% N	LN	F	% F	DO	% DO	IVI (%)
1	<i>A. senegal</i>	Fabaceae	224	65.12	11	65.12	14	8	27.59	1.01	28.74	40.48
2	<i>B. aegyptiaca</i>	Balanitaceae	46	13.37	2	13.37	5	5	17.24	0.60	17.03	15.88
3	<i>A. tortilis</i>	Fabaceae	42	12.21	2	12.21	3	8	27.59	1.55	44.06	27.95
4	<i>A. seyal</i>	Fabaceae	28	8.14	1	8.14	2	7	24.14	0.14	3.86	12.05
5	<i>A. etbaica</i>	Fabaceae	4	1.16	0	1.16	2	1	3.45	0.22	6.31	3.64
Open grazing												
RO	Species	Family	D	RD (%)	N	% N	LN	F	% F	DO	% DO	IVI (%)
1	<i>A. senegal</i>	Fabaceae	632	39.90	32	39.90	53	9	25.71	0.59	13.55	26.39
2	<i>A. tortilis</i>	Fabaceae	563	35.52	28	35.52	35	12	34.29	2.99	69.13	46.32
3	<i>A. seyal</i>	Fabaceae	315	19.87	16	19.87	39	6	17.14	0.17	3.92	13.64
4	<i>B. aegyptiaca</i>	Balanitaceae	59	3.70	3	3.70	15	3	8.57	0.05	1.19	4.49
5	<i>M. senegalensis</i>	Celastraceae	8	0.51	0	0.51	3	2	5.71	0.17	3.93	3.38
6	<i>Z. mucronata</i>	Rhamnaceae	8	0.51	0	0.51	2	3	8.57	0.36	8.28	5.79
Controlled grazing												
RO	Species	Family	D	RD (%)	N	% N	LN	F	% F	DO	% DO	IVI (%)
1	<i>A. tortilis</i>	Fabaceae	134	50.25	7	50.25	7	15	38.46	3.19	88.32	59.01
2	<i>D. cinerea</i>	Fabaceae	88	32.84	4	32.84	8	8	20.51	0.04	0.97	18.11
3	<i>A. senegal</i>	Fabaceae	24	8.96	1	8.96	3	6	15.38	0.05	1.34	8.56
4	<i>B. aegyptiaca</i>	Balanitaceae	15	5.47	1	5.47	2	7	17.95	0.32	8.89	10.77
5	<i>A. seyal</i>	Mimosaceae	7	2.49	0	2.49	2	3	7.69	0.02	0.47	3.55
Farmland												
RO	Species	Family	D	RD (%)	N	% N	LN	F	% F	DO	% DO	IVI (%)
1	<i>A. senegal</i>	Fabaceae	407	50.66	20	50.66	22	14	35.9	0.90	63.28	49.95
2	<i>A. tortilis</i>	Fabaceae	365	45.51	18	45.51	20	14	35.9	0.50	35.01	38.81
3	<i>B. aegyptiaca</i>	Balanitaceae	16	1.99	1	1.99	4	3	7.69	0.01	0.82	3.5
4	<i>A. seyal</i>	Fabaceae	9	1.16	0	1.16	1	6	15.38	0.01	0.89	5.81
5	<i>D. cinerea</i>	Balanitaceae	4	0.50	0	0.50	3	1	2.56			1.02
6	<i>M. senegalensis</i>	Celastraceae	1	0.17	0	0.17	1	1	2.56			0.91

RO = Rank order of the average abundance per plot of the species (N) in a descending;

D = Density per ha;

RD = Relative Density;

N = Average abundance per plot;

% N = Relative abundance of the species;

LN = Local abundance;

F = Absolute Frequency;

% F = Relative frequency;

DO = Absolute Dominance ($m^2 ha^{-1}$);

% DO = Relative Dominance; and

IVI = Importance Value Index.

disturbances that alter the structure of populations, communities and ecosystems will have consequences for plants.

Both *A. senegal* and *A. tortilis* are the most frequent species in intact and farmlands, while *A. tortilis* is the most frequent in the rest. *A. senegal* is the second frequent species in open grazing and the third in the controlled grazing. In terms of dominance *A. senegal* rank first in the farmland and second in intact woodland and open grazing, and third in controlled grazing. In most of the sites *A. tortilis* is the dominant. This may be with a reason *A. tortilis* is the most preferred tree species in the area as forage and for charcoal making and fuelwood. So individuals of the species are purposely made to have large size, which make it to be dominant in most of the sites.

A. senegal rank first in IVI in the intact woodland and farmland, second in the open grazing and third in the controlled grazing. *A. tortilis* rank first in the open grazing and controlled grazing sites (Table 4). This shows that *A. senegal* and *A. tortilis* are the two most ecologically important tree species in the study area. In fact, each different tree species has different total IVI in different land cover/land use categories. This indicates that each species has different ecological importance in different ecosystem. Stands that yield more or less the same IVI for the characteristic species indicate the existence of the same or at least similar stand composition, structure, site characteristics and comparable dynamics (Lamprecht, 1989).

4.2 Population Structure

All the land cover/land use categories show Type I distribution both in diameter and height (Figure 5 & 6). This means that the different categories hold vegetation structures that are nearly alike. However, higher regeneration is seen in the open grazing and on farmland. But in these land cover/land use categories smaller number of individuals are present as we move to higher classes.

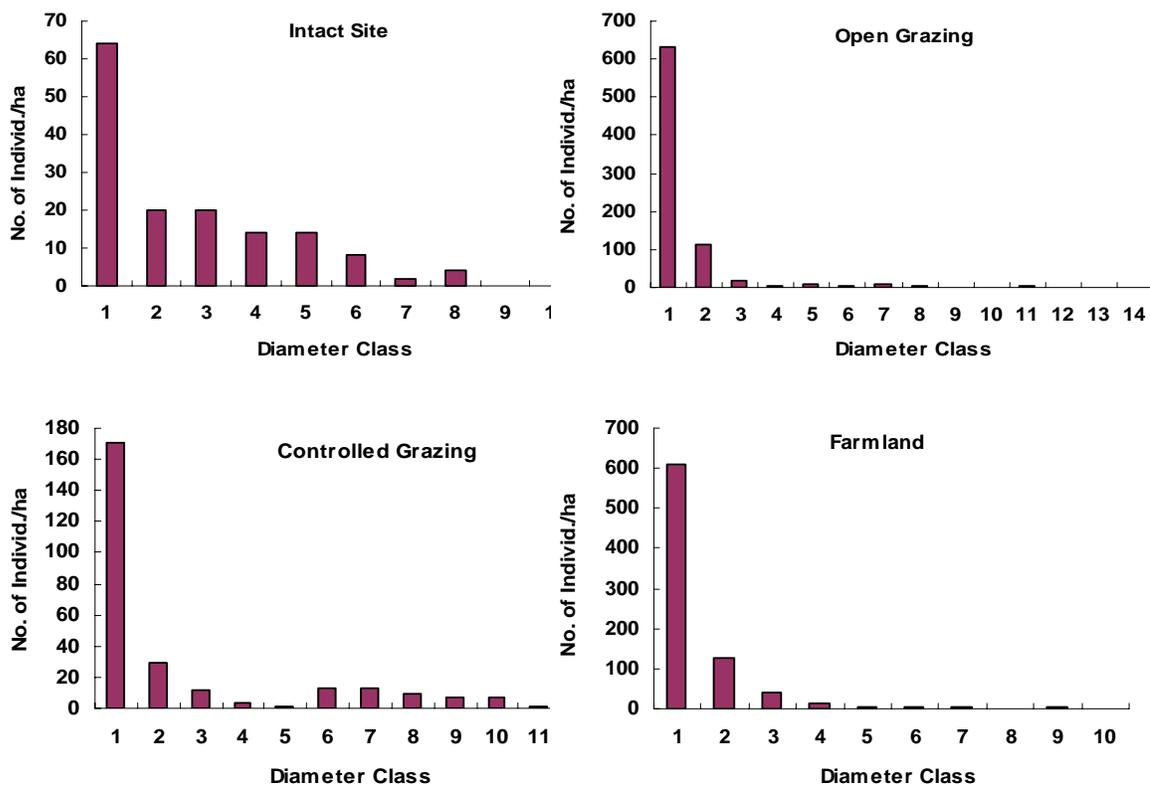


Figure 5. Distribution of trees in different diameter classes of land cover/land use categories of the Central Rift Valley of Ethiopia (Diameter Classes: Class 1 = 0 – 4cm; Class 2 = 4 – 8cm; Class 3 = 8 – 12cm; Class 4 = 12 – 16cm; Class 5 = 16 – 20cm; Class 6 = 20 – 24cm; Class 7 = 24 – 28cm; Class 8 = 28 – 32cm; Class 9 = 32 – 36cm; Class 10 = 36 – 40cm; Class 11 = 40 – 44cm; Class 12 = 44 – 48cm; Class 13 = 48 – 52cm; Class 14 = 52 – 56cm).

Good numbers of individuals are recorded at higher classes for the intact woodland and controlled grazing sites. This shows that there is high extraction for fuelwood and charcoal, which are common in the area, in open grazing and farmland and a relatively better protection in the intact woodland and controlled grazing sites. Not only vegetation population structure varies between sites but also structure of individual species within a site shows variation that worth analysis.

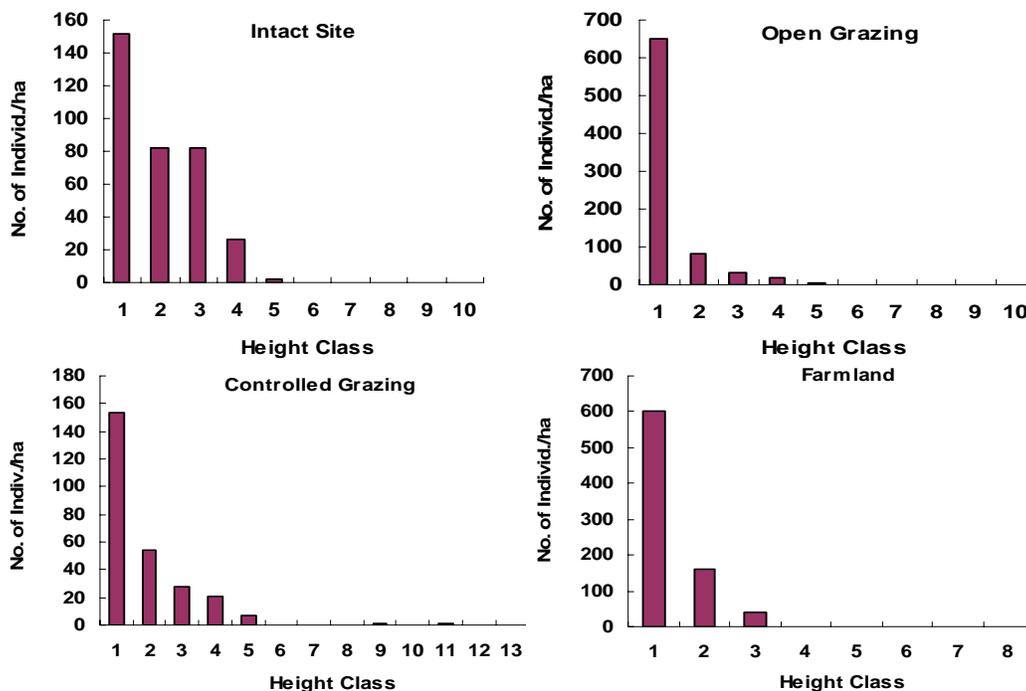
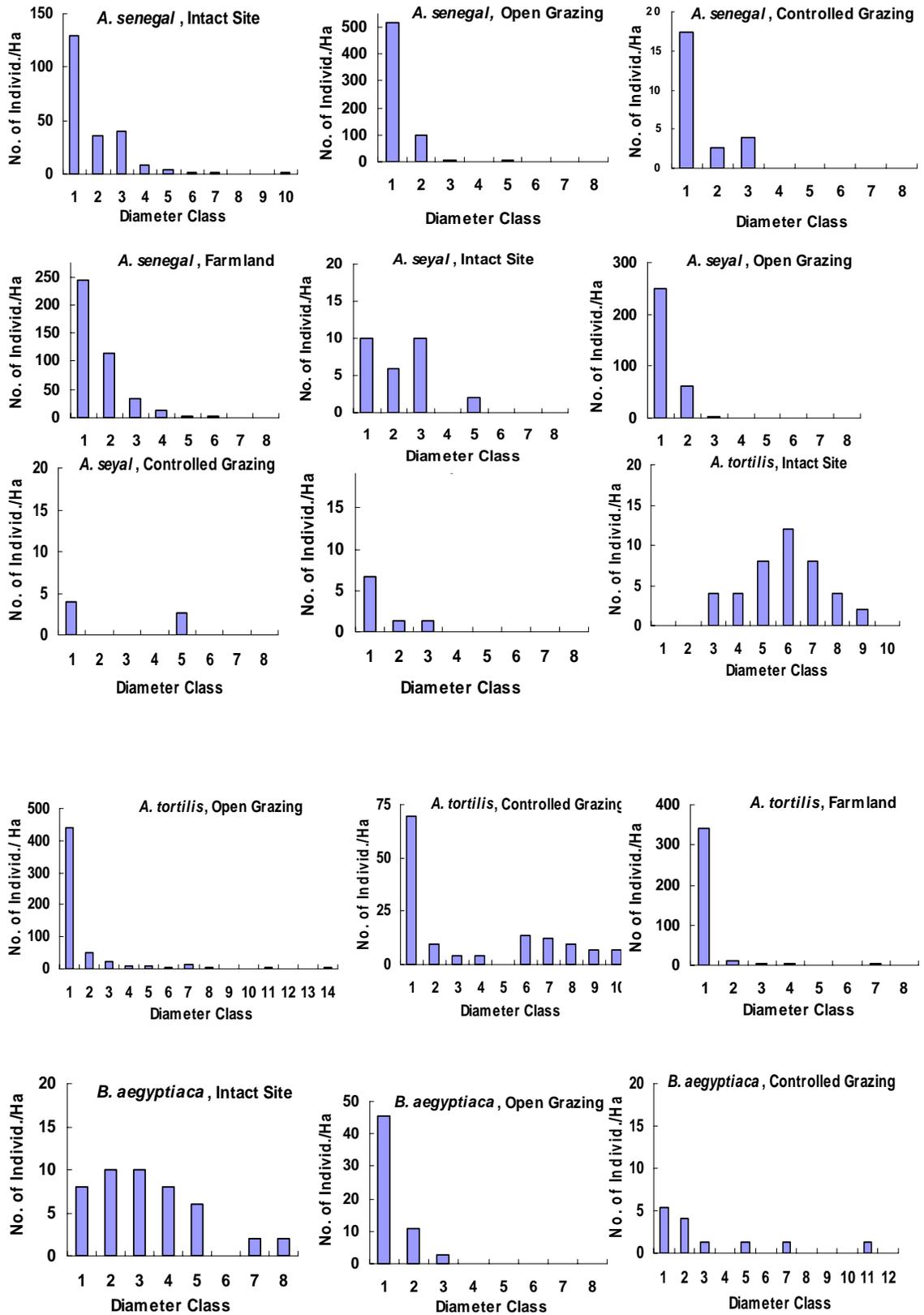


Figure 6. Distribution of trees in different Height classes of land cover/land use categories of the Central Rift Valley of Ethiopia (Height Classes: Class 1 = 0 – 2m; Class 2 = 2 – 4m; Class 3 = 4 – 6m; Class 4 = 6 – 8; Class 5 = 8 – 10; Class 6 = 10 – 12; Class 7 = 12 – 14; Class 8 = 14 – 16; Class 9 = 16 – 18; Class 10 = 18 – 20; Class 11 = 20 – 22; Class 12 = 22 – 24; Class 13 = 24 – 26; Class 14 = 26 – 28).

None of the species is represented by the whole range of diameter and height considered in all of land use categories. *A. senegal* is represented by large proportion of individuals smaller

than 12 cm in diameter and less than 6m in height in all land use categories, except in open grazing, where it is represented by trees less than 8 cm in diameter and 4 m in height (Figure 7 & 8). *A. tortilis* is represented largely by individuals in 8 – 36 cm diameter class and the 2 – 8 m height class in the intact site, and by individuals less than 8 cm in diameter and less than 6 m in height in other land use categories (Figure 7 & 8). *A. seyal* is represented largely by individuals in diameter class less than 8 cm in all land use categories, except in controlled grazing, where it is represented in diameter classes less than 4 cm and between 16–20 cm, and height classes less than 4 m. *B. aegyptiaca* is represented in the area by a large proportion of individuals less than 12 cm in diameter and 4 m in height. *D. cinerea* is represented in the area largely by individuals less than 4 cm in diameter and 4 m height. *M. senegalensis*, *Z. mucronata* and *A. etbaica* are represented by very small numbers of individuals in the area (Figure 7 & 8). *A. senegal*, *A. tortilis*, and *A. seyal* are represented in most plots in the intact site and open grazing; but *Z. mucronata*, *M. senegalensis* and *A. etbaica* are the least represented in the plots. In the farmland, *A. tortilis* and *A. senegal* are represented in almost all the plots but *M. senegalensis* and *D. cinerea* are the least represented. In the controlled grazing, *A. tortilis* is represented in all plots and *D. cinerea* is represented in most of the plots. In addition, in this site *A. senegal* and *B. aegyptiaca* are represented by almost half the number of plots, while *A. seyal* is the least represented.



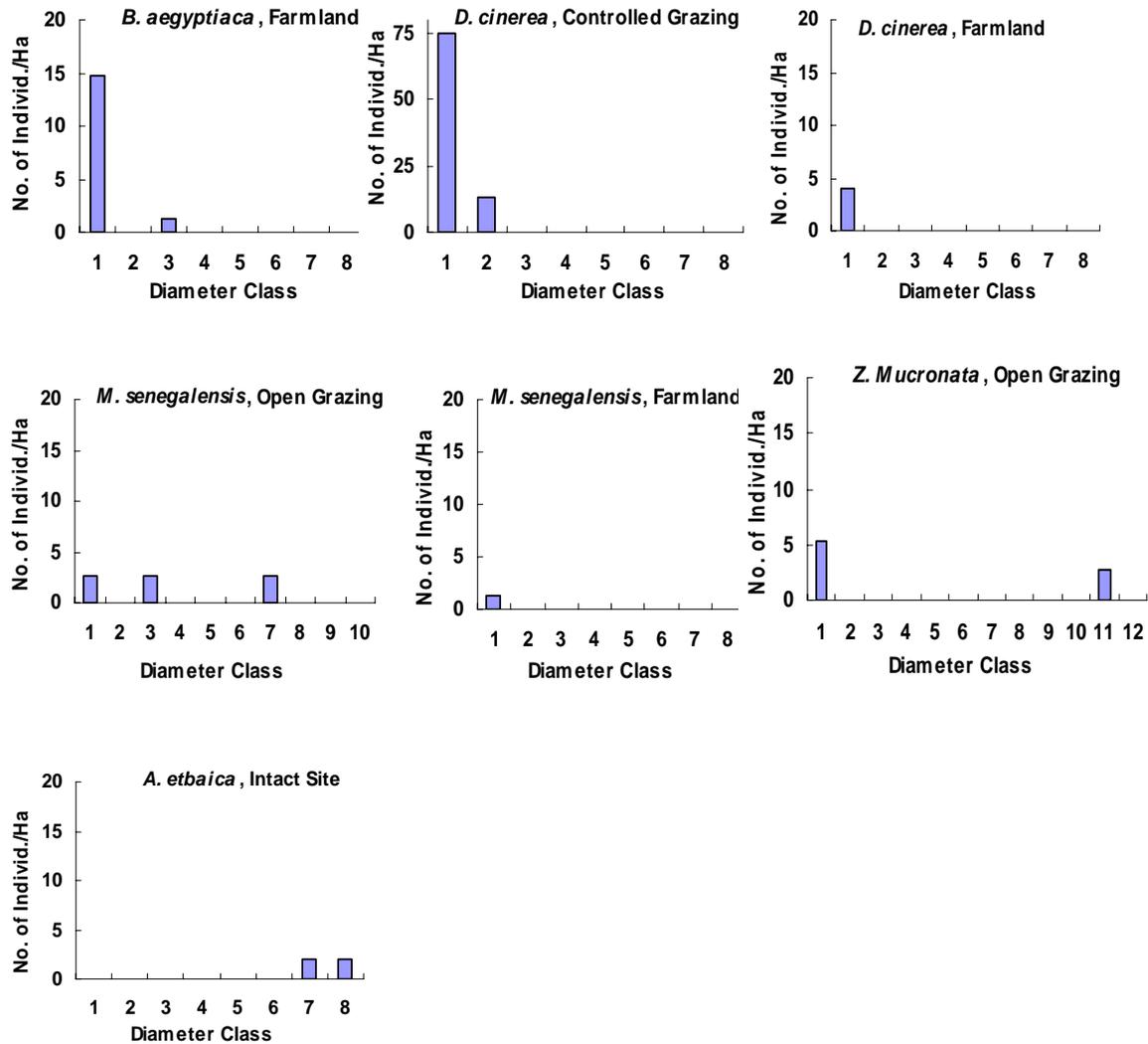


Figure 7. Distribution of different tree species in different diameter classes of land cover/land use categories of the Central Rift Valley of Ethiopia (Diameter Classes: Class 1 = 0 – 4cm; Class 2 = 4 – 8cm; Class 3 = 8 – 12cm; Class 4 = 12 – 16cm; Class 5 = 16 – 20cm; Class 6 = 20 – 24cm; Class 7 = 24 – 28cm; Class 8 = 28 – 32cm; Class 9 = 32 – 36cm; Class 10 = 36 – 40cm; Class 11 = 40 – 44cm; Class 12 = 44 – 48cm; Class 13 = 48 – 52cm; Class 14 = 52 – 56cm).

A. senegal shows an approximately Type I size class–distribution in both diameter and height in all land cover/land use categories of the region. *A. tortilis* and *B. aegyptiaca* show an approximately Type I size class–distribution in both diameter and height in all land use

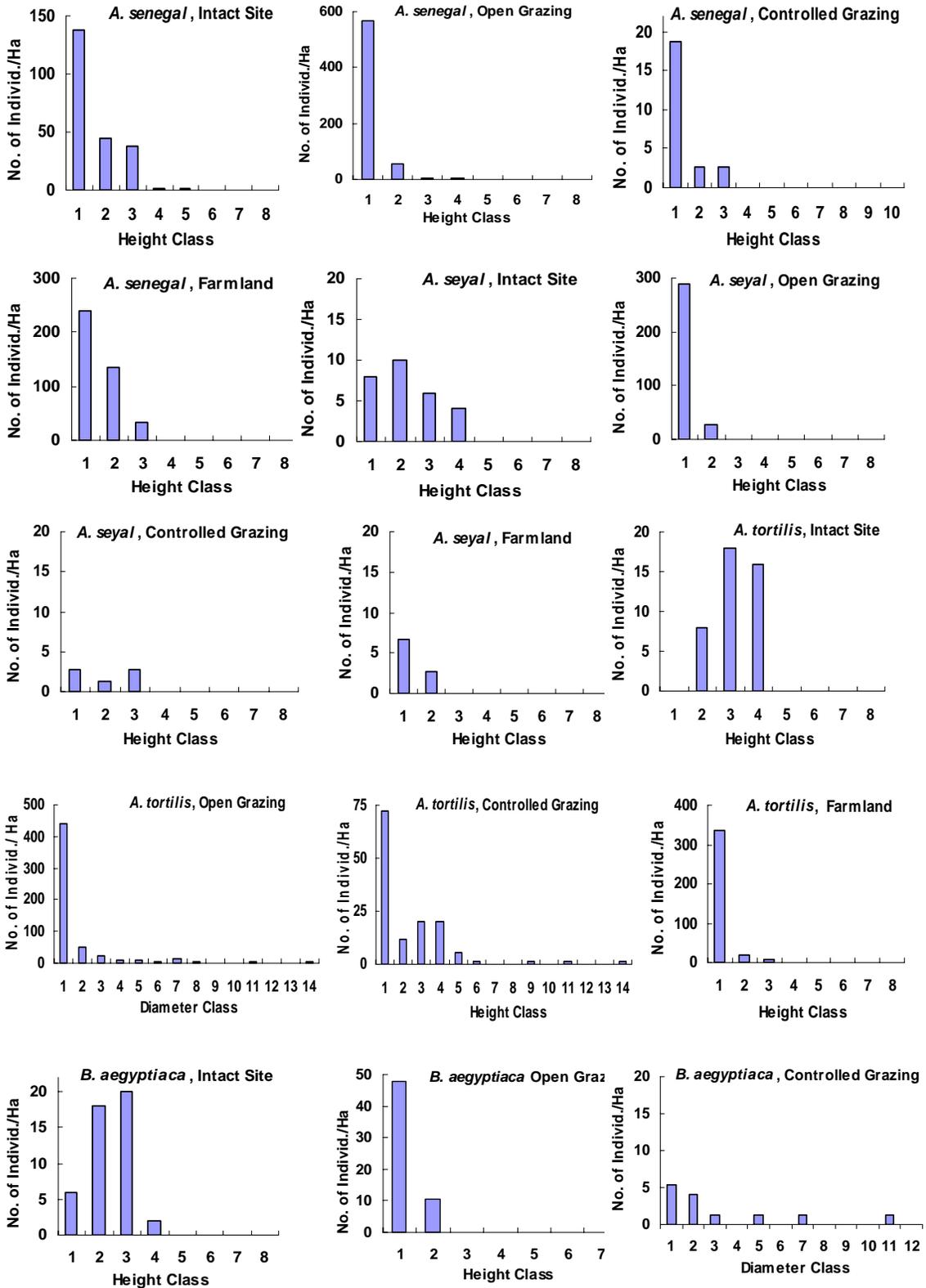
categories except in the intact woodland where it exhibits a TypeII size class–distribution in both diameter and height class–distributions (Figure 7 & 8). *A. seyal* shows an approximately TypeI size class–distribution in both diameter and height in all land use categories of the area, except in controlled grazing, where the numbers of individuals are very few and in patchy to classify in one of the types. *D. cinerea* shows a TypeI size class–distribution in both diameter and height in the controlled grazing and farmland, the only land cover/use categories in which the species present. *M. senegalensis*, *Z. mucronata* and *A. etbaica* are represented by very few individuals in an irregular manner, and do not fall into any of the types of size class–distributions (Figure 7 & 8).

Population structure data have long been used by foresters and ecologists to investigate the regeneration characteristics of tropical trees. Since it is difficult to determine the age of tropical trees, studies on population structure are based on size class–distributions. Most analysis of these types has found that tropical tree populations are characterized by a limited number of different size class–distributions (Peters, 1996). According to the same literature, population structure demonstrate the degree to which a tree species is dependent on canopy gaps for regeneration, as well as it is an extremely useful tool for orienting management activities and, perhaps most importantly, for assessing the impact of resource extraction. The height and diameter class–distribution of the population—population structure—of a species indicates regeneration status as well as past and recent regeneration patterns (Demel, 1996).

A TypeI size class–distribution (as the types are described in the materials and methods section) is characteristic of shade–tolerant canopy trees that maintain a more or less constant

rate of recruitment. There is a large probability that the death of an adult tree will be replaced by the growth of individuals from the smaller size classes and it is considered by many authors the ideal of a stable, self-maintaining plant population (Peters, 1996). But as seen in the histograms of the present study, even though there is a positive regeneration for the species that show TypeI size class-distribution, they have small number of individuals in the higher diameter and height classes due to the reasons discussed at the population structure of the vegetation. Therefore, urgent action is needed to maintain acceptable number of individuals at higher diameter and height classes to use them for the desired end-use like NTFPs and environmental benefits and to have enough mother trees.

A TypeII size class-distribution is a characteristic of species that show discontinuous or periodic recruitment. The actual level of seedling establishment may be sufficient to maintain the population, but its infrequency causes notable discontinuities in the structure of the population as the newly established seedlings and saplings grow into the larger size classes. This type of diameter distribution is quite common among late secondary species that depend on canopy gaps for regeneration (Peters, 1996). But in the case of the species in the study area that show TypeII size class-distribution at the specified land cover/land use category, the result is likely due to external factors than the nature of the species since their population structures in most of the land use categories show TypeI size class-distribution.



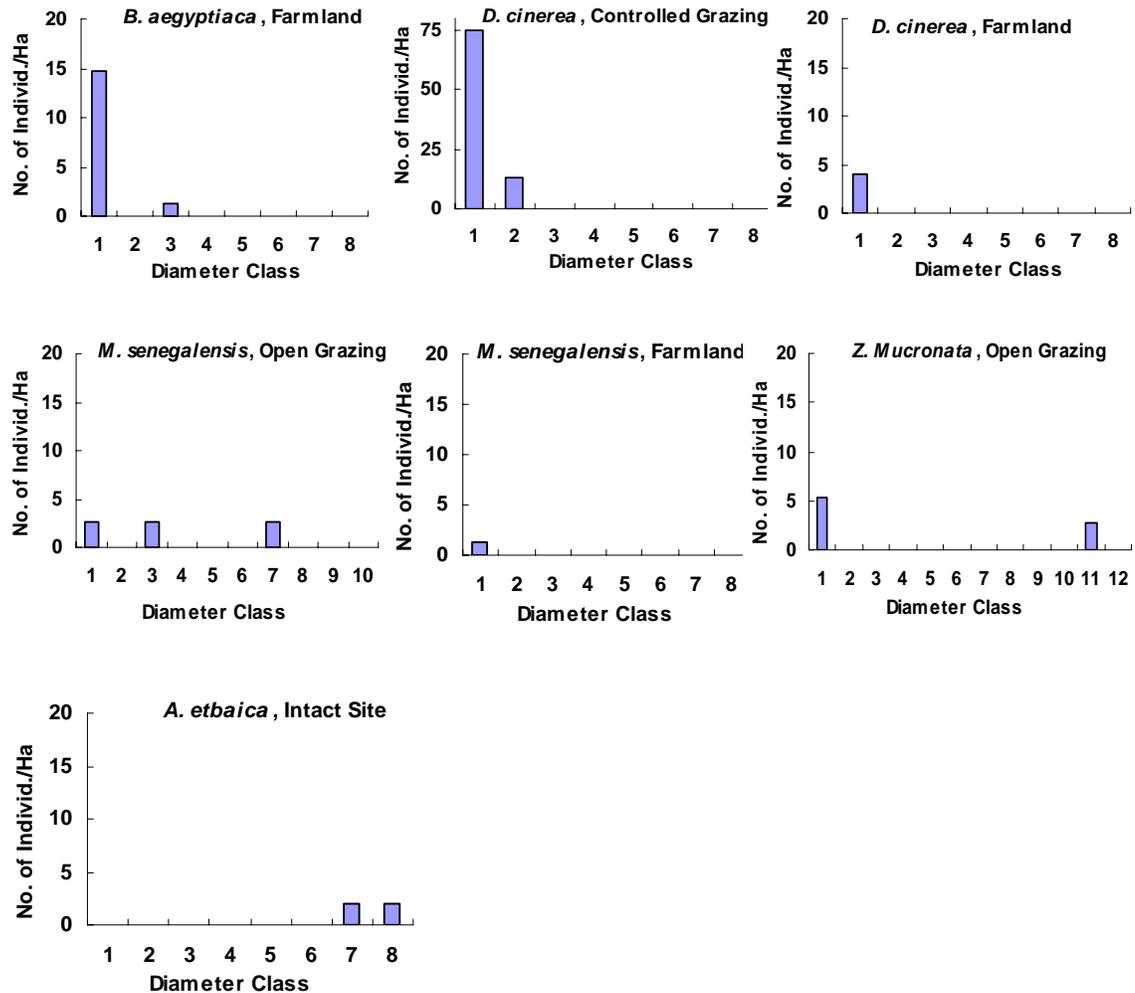


Figure 8. Distribution of different tree species in different height classes of land cover/land use categories of the Central Rift Valley of Ethiopia (Height Classes: Class 1 = 0 – 2m; Class 2 = 2 – 4m; Class 3 = 4 – 6m; Class 4 = 6 – 8; Class 5 = 8 – 10; Class 6 = 10 – 12; Class 7 = 12 – 14; Class 8 = 14 – 16; Class 9 = 16 – 18; Class 10 = 18 – 20; Class 11 = 20 – 22; Class 12 = 22 – 24; Class 13 = 24 – 26; Class 14 = 26 – 28).

M. senegalensis, *Z. mucronata* and *A. etbaica* in all land cover/use categories where they are present and *A. seyal* in controlled grazing don't fall in any types of the size class–distribution. Their densities in the area are also insignificant and are present in irregular manner. Therefore it is difficult to describe and discuss their population structure and the associated implication

attached to it. There is a need for in–depth study on their regeneration mechanisms and environmental factors affecting their population, and to devise appropriate methods and following management actions to facilitate and increase their regeneration.

When compared with earlier studies, the population structure for the controlled grazing concur with results reported by other authors (Mekuria *et al.*, 1999) for the species of *A. tortilis*, *B. aegyptiaca* and *D. cinerea*, but different for *A. senegal* and *A. seyal* in that, in these authors *A. senegal* exhibits TypeIII size class–distribution and *A. seyal* exhibits TypeII size class–distribution. This may be associated to the different factors affecting the populations of the species through time. For the open system including the farmland and open grazing, the population structure concur with the results of the same authors (Mekuria *et al.*, 1999) for the species of *A. senegal*, *A. seyal*, *A. tortilis*, and *D. cinerea* but different for *B. aegyptiaca* where it doesn't depict any type of the three size class–distribution in their study. Periodic monitoring of population structure of a species can therefore be used to assess the ecological health of a tree population and to guarantee the long–term sustainability of NTFPs (Peters, 1996).

A. senegal trees are tapped beginning from smallest size class, less than 5 cm diameter, by making incisions in the stems and branches by stripping away the bark to accelerate exudation of gum arabic (Mohamed, 2005). To determine harvestable number of *A. senegal* trees for gum arabic production in the region, trees having diameter greater than and equal to 3 cm are used. Harvestable number of *A. senegal* trees per hectare in the study area are 106, 116, 12, and 209 for intact site, open grazing, controlled grazing and farmlands respectively. The

estimated amount of yield of gum arabic in the region based on the average number of harvestable number of *A. senegal* trees (111) and estimated average amount of gum arabic per tree per season (250 g; FAO, 1995b) is 27.71kg per hectare per season. The estimated income earned from the gum arabic (calculating from export prices of Ethiopia's gum arabic, 0.68 – 2.50 US\$ per kg; Mulugeta, 2005) will undoubtedly supplement the unpredictable agricultural production in the area. In addition, there is also very high regeneration of *A. senegal* species in the area; so that, if there is good management in the area, there is a possibility to get more harvestable trees in one to two years. There fore, it is encouraging to start the gum arabic business in the region.

4.3 Physicochemical Characteristics of the Gum Arabic from Central Rift Valley

The color of the gum arabic collected from the Central Rift Valley is pale–white to orange–brown. It is solid and breaks with a glassy fracture, just like gum arabic of high quality described in literatures (e.g. FAO, 1999). The gum is tasteless and odorless. It is readily soluble in water and insoluble in Ethanol. Table 5 shows the analytical data for the physicochemical characteristics of the gum arabic samples in the laboratory.

The fact that gum arabic, specially the one from *A. senegal*, is a major component of food additive, made that the specifications set on its quality attributes are very strict. This strict requirement is so because there are several adulterants of *Acacia* gums traded as ‘gum arabic’, which, however, should not be used as food additives. Some of the specifications set on gum arabic by different regulatory bodies (e.g. JECFA, USP, BP, IP) are shown below and against these the quality of the gum arabic of the Rift Valley evaluated (Table 6).

Table 5. Analytical data for the physicochemical characteristics of the gum arabic samples collected from the Central Rift Valley of Ethiopia

No.	Characteristics	Values
1	Moisture content %	15
2	Ash content %	3.56
	Viscosity (Centipoise)	
	10 gl^{-1}	0.9954
3	7.5 gl^{-1}	0.9552
4	pH (25% sol.)	4.04
	Nitrogen content	0.35
5	% w/w	
	Protein %	2.31
6	(N x 6.6) ^a	
7	Specific rotation, degrees ^a	-32.5
	Tannin content	0
8	% w/w	
9	Gel (25% sol.) ^b	Moderate
10	Ca (g/100g)	0.7
11	Mg (g/100g)	0.201
12	K (g/100g)	0.95
13	Na (g/100g)	0.014
14	Fe (g/100g)	0.001
15	P (g/100g)	0.6
16	Pb (g/100g)	ND
17	Mn (g/100g)	ND
18	Co (g/100g)	ND
19	Cu (g/100g)	ND
20	Zn (g/100g)	ND
21	Ni (g/100g)	ND
22	Cd (g/100g)	ND
23	Cr (g/100g)	ND

ND – Not detected;

a = At 25 °C temperature; and

b = Based on the classification category: no gel, light gel, moderate gel and heavy gel.

The average moisture content of the gum arabic samples from *A. senegal* trees of Central Rift Valley is 15 %. This is similar to the studies done by Mhinzi and Mrosso (1997) for Tanzania and Idris *et al.* (1998) and Karamalla *et al.* (1998) for Sudan. The analyzed samples of gum arabic are slightly acidic, on average measured pH value of 4.04 and this is in good agreement with most of the reports (E.g. Mhinzi, 2003 for Tanzania), and in close agreement with the reports of Chikamai (1977) and Karamalla *et al.* (1998), which they put the pH on the range 4.3 – 5.1 and 4.3 – 4.4 respectively. The specific rotation, – 32.5, concurs with the results of

Idris *et al.* (1998), Karamalla *et al.* (1998), and Al-Assaf *et al.* (2005). The determination of gel property of the gum arabic samples was qualitative. The characteristic of the gum arabic from Rift Valley is moderate gel. The nitrogen content of the samples (0.35 %w/w) and hence the protein content, 2.31, are similar to reports of Chikamai (1977), Mhinzi and Mrosso (1997), Idris *et al.* (1998), and Karamalla *et al.* (1998). The absence of tannin content for the *Acacia* gum collected from the Rift Valley are in agreement with some reports (Chikamai, 1977; FAO, 1999); whereas Mhinzi (2003) in his paper indicated that *Acacia senegal* and *Acacia seyal* gums collected from Tanzania show 0.28% – 0.58% and 0.58% – 1.19% tannin content respectively. The viscosity of the gum arabic samples in centipoises (10gl^{-1}) is 0.9954. The viscosity of the gum arabic could not be compared with other studies since the concentration of the gum solution used for the measurement of viscosity in the present study is different from other studies.

The maximum limit of total ash for food and pharmaceutical quality of *Acacia* gum is 4% w/w (Chikamai, 1977; Mhinzi and Mrosso, 1997; Karamalla *et al.*, 1998; and FAO, 1999), and is in good agreement with the result obtained in the present study, 3.5%. Characterization of gum arabic by mineral content is not common in most of the literatures. However, the Ca, Mg, Na and K content of the present gum arabic samples (0.7, 0.2, 0.01 and 0.95% respectively) is similar to the report of Mhinzi & Mrosso (1997). The alkali and alkaline elements in the *Acacia senegal* gum show the trend as follows $\text{K} > \text{Ca} > \text{Mg} > \text{Na}$. The slight increase of Na and probably of K is due to the high concentration of these elements in the soil parent material, volcanic ash, of the Rift Valley. The Lead content of gum arabic samples is

Table 6. Evaluation of gum arabic from Central Rift Valley of Ethiopia with other studies and international specifications

No.	Quality parameter	Values for gum arabic from Rift Valley	JECFA ^b	USP ^b	Bp ^b	Ip ^b	Values for gum arabic from four countries ^{a,b}	FAO (1999)	Mhinzi, and Mrosso (1997)	Karamalla et al. (1998)	Idris et al. (1998)	Al-Assaf et al. (2005)	Evaluation of gum arabic from Rift Valley
1	Moisture content %	15	< 15%	< 15%	< 15%	< 15%	13–15	< 15%	14.1–15	8.1–14.05	12.5–16		Good
2	Ash content (%)	3.56	< 4%	< 4%	< 4%	< 4%	3.0–3.9	< 4%	3.8–4.5	2.75–5.25			Very Good
3	Viscosity (centipoises) 10 gl ⁻¹ 7.5 gl ⁻¹	0.9954 0.9552											–
4	Intrinsic viscosity (ml/g)						15–22			1–73		9.7–26.5	–
5	pH (25% sol.)	4.04					4.3–4.4			4.3–5.1			Fair
6	Nitrogen content (% w/w)	0.35					0.27–0.44		0.28–0.33	0.23–0.43	0.22–0.39		Very Good
7	Protein %	2.31					1.8–3.0		1.75–2.06		1.5–2.6	1.8–2.1	Very Good
8	Specific rotation (degrees)	–32.5	ns	ns	ns	ns	–30––34		–25––26	–23––29	–27––36	–29––33	Very Good
9	Tannin content (% w/w)	0	0	0	0	0	0	0	0.28–0.52				Very Good
10	Gel (25% sol.)	Moderate					Not determined						–
11	Ca (g/100g)	0.7							0.43–0.72				Very Good
12	Mg (g/100g)	0.201							0.02–0.29				Very Good
13	K (g/100g)	0.95							0.09–0.98				Very Good
14	Na (g/100g)	0.014							0.01				Very Good
15	Fe (g/100g)	0.001											–
16	P (g/100g)	0.6											–
17	Pb (g/100g)	ND						<2 mg/kg					Very Good
18	Mn (g/100g)	ND											–
19	Co (g/100g)	ND											–
20	Cu (g/100g)	ND											–
21	Zn (g/100g)	ND											–
22	Ni (g/100g)	ND											–
23	Cd (g/100g)	ND											–
24	Cr (g/100g)	ND											–

ND – Not detected; NS – Not specified; a = Ranges of values for *A. senegal* var. *senegal* from four countries: Sudan, Nigeria, Kenya and Uganda; and b = Source–Chikamai (1997).

negligibly low to be detected at the laboratory investigation on Atomic Absorption Spectrometer. Given that gum arabic is used as food additives the amount of heavy metals like Pb has to be minimal, and this is set as less than 2ppm (FAO, 1999). The gum arabic from *Acacia senegal* of Central Rift Valley, analysis shows a better result which is not detectable at ppm level. The contents of Fe and P in the present gum arabic samples are 0.001 and 0.6% respectively, and Co, Cu, Zn, Ni, Ca, Cr and Mn are also small enough to be detected.

Therefore, the present work has shown that the physicochemical characteristics of *Acacia senegal* gum samples from Central Rift Valley of Ethiopia exhibit similar characteristics and even better result to the international standards set for gum arabic and to the reports from different producer and exporter countries of gum arabic. This together with the dominance of the species in the Rift Valley woodland clearly reflects the potential of the product for commerce and thus contribution to livelihoods and national economy.

5. CONCLUSION

The population status of tree species of the Central Rift Valley of Ethiopia shows generally presence of good regeneration. However at higher size classes the number of individuals dramatically falls probably due to high rate of harvest taking place in the area. Nonetheless, *A. senegal* which is one of economically important tree species is found to have higher density, good regeneration, and high IVI in most of the land uses in the Central Rift Valley of Ethiopia. If appropriate management activities are applied, the nature of the population structure of most of the tree species including *A. senegal* is of stable type. Indeed, there is a possibility to start the gum arabic business in the region with the existing harvestable number of *A. senegal* trees in the area, as this could supplement the income from agricultural production in the area. There is a possibility of recruiting harvestable number of *A. senegal* trees in the near future since there is very high regeneration of *A. senegal* trees in the area.

With regard to the physicochemical characteristic of the gum arabic samples, the characteristics of the samples are in good agreement with the studies at other places for the gum arabic from *A. senegal* variety *senegal* and international standards. Thus the gum arabic from the Central Rift Valley of Ethiopia possess identical quality to gum arabic of commerce from *A. senegal* variety *senegal* for commercialization purpose. The following recommendations are forwarded for effective commercialization of gum arabic in the Central Rift Valley of Ethiopia:

1. Improved management of the woodland is needed.
2. Appropriate tapping technology should be developed or indorsed from experienced countries to the area; and training should be given to the farmers as to the tapping, gum collection/harvesting, processing and storing, *etc.* activities.
3. Yield study should be followed in order to determine the amount of gum arabic produced from the area whether the amount satisfy for commercialization purpose.
4. Tree improvement activities should be done in order to enhance the amount of gum produce per tree.
5. The same kind of study should be done in other parts of the country where there are enough *A. senegal* populations present.
6. Market studies should go hand–in–hand with the development of the countries' *A. senegal* resource base for gum arabic production.
7. Devising mechanism as to promoting the countries' potential for value–addition and industrialization of gum arabic is essential.

6. REFERENCE

- Abeje Eshete, Demel Teketay and Hulten, H., 2005. The Socio–Economic Importance and Status of Populations of *Boswellia papyrifera* (Del.) Hochst in Northern Ethiopia: The Case of North Gondar Zone. *Forests Trees and Livelihoods*, Vol 15; pp 55–74. A B Academic Publishers, Great Britain.
- Al-Assaf, S., Phillips, O. G., and Williams, A. P., 2005. Studies on *Acacia* Exudate Gums. Part I: The Molecular Weight of *Acacia senegal* Gum Exudates. *Food Hydrocolloids*, Vol. 19; pp 647–660.
- Arnold, J. E. M. and Pérez, M. R., 1996. Framing the Issues Relating to Non–Timber Forest Products Research. In: *Current Issues in Non–Timber Forest Products Research* (Eds. Pérez, M. R. and Arnold, J. E. M.). Proceedings of the Workshop “Research on NTFPs”, 28 August – 2 September 1995, Hot Springs, Zimbabwe. Center for International Forestry Research, Jakarta.
- Arnold, J. E. M. and Pérez, M. R., 2001. Can Non–Timber Forest Products Match Tropical Forest Conservation and Development Objectives? *Ecological Economics*, Vol. 39(3); pp 437–447.
- Asfaw Hunde and Thulin, M., 1989. Mimosoideae. In: *Flora of Ethiopia*, Pittosporaceae to Araliaceae (Eds. Hedberg, I. and Edwards, S.). The National Herbarium, Biology Department, Addis Ababa University and The Department of Systematic Botany, Uppsala University, Vol. 3. Addis Ababa. pp 71–96.
- Barrow, E. G.C., 1997. Indigenous Knowledge and its Application in Resolving Conservation and Utilization Problems. In: *Conservation, Management and Utilization of Plant*

- Gums, Resins and Essential Oils* (Eds. Mugah, J. O., Chikamai, B. N., Mbiru, S. S. and Casadei, E.). Proceedings of a Regional Conference for Africa Held in Nairobi, Kenya, 6 – 10 October 1997. Nairobi.
- Casadei, E., 1997. International Regulations for Natural Products Used as Food Additives. In: *Conservation, Management and Utilization of Plant Gums, Resins and Essential Oils* (Eds. Mugah, J. O., Chikamai, B. N., Mbiru, S. S. and Casadei, E.). Proceedings of a Regional Conference for Africa Held in Nairobi, Kenya, 6 – 10 October 1997. Nairobi.
- Chikamai, B., 1997. Production, Markets and Quality Control of Gum Arabic in Africa: Findings and Recommendations from an FAO Project. In: *Conservation, Management and Utilization of Plant Gums, Resins and Essential Oils* (Eds. Mugah, J. O., Chikamai, B. N., Mbiru, S. S. and Casadei, E.). Proceedings of a Regional Conference for Africa Held in Nairobi, Kenya, 6 – 10 October 1997. Nairobi.
- CIFOR, 2005. *Contributing to Africa's Development Through Forests*. Strategy for Engagement in Sub-Saharan Africa. Center for International Forestry Research. Center for International Forestry Research, Jakarta.
- Cossalter, C., 1991. *Acacia senegal*: Gum Tree With Promise for Agroforestry. NFT Highlights, No. 91-02.
- De Gier, A., 1989. Woody Biomass for Fuel, Estimating the Supply in Natural Woodlands and Shrublands. International Institute for Aerospace survey and Earth Science (ITC), Enschede, The Netherlands.
- Demel Teketay, 1996. Seed Ecology And Regeneration in Dry Afromontane Forests of Ethiopia. Ph.D. Thesis, Swedish University of Agricultural Sciences, Umeå. 36 pp.

- Duke, J. A., 1983. Handbook of Energy Crops. Unpublished. http://www.hort.purdue.edu/newcrop/duke_energy/Acacia_senegal.html. Accessed on August 15.
- EFAP, 1994. Ethiopian Forestry Action Program (EFAP), Vol. II–The Challenge for Development. Ministry of Natural Resources Development and Environmental Protection, Addis Ababa, Ethiopia.
- Falconer, J., 1996. Developing Research Frames for Non–Timber Forest Products, Experience from Ghana. In: *Current Issues in Non–Timber Forest Products Research* (Eds. Arnold J. E. M. and Pérez, M. R.). Proceedings of the Workshop “Research on NTFPS”, 28 August – 2 September 1995, Hot Springs Zimbabwe. Center for International Forestry Research, Jakarta.
- FAO, 1983. *Handbook on Seeds of Dry–Zone Acacias*. A Guide for Collecting, Extracting, Cleaning, and Storing the Seed and for Treatment to Promote Germination of Dry–Zone Acacias, by Doran, J.C., Turnbull, J.W., Boland, D.J., and Gunn, B.V. Food and Agriculture Organization of the United Nations, Rome.
- FAO, 1988. *Non–Timber Uses of Selected Arid Zone Trees and Shurbs in Africa*, by Booth, F.E.M. and Wickens, G.E. FAO Conservation Guide 19, Food and Agriculture Organization of the United Nations. Rome.
- FAO, 1991. The Guide to Specifications. General Notices General Analytical Techniques Identification Tests, Test Solutions and other Reference Materials. *Food and Nutrition Paper*, No. 5, revision 2. Food and Agriculture Organization of the United Nations. Rome. http://apps3.fao.org/jecfa/additive_specs/docs/t0368e/t0368e00.htm Accessed on November 2, 2006.

- FAO, 1993a. *Conservation of Genetic Resources in Tropical Forest Management*. Principles and Concepts. Food and Agriculture Organization of the United Nations. Rome.
- FAO, 1993b. *Key Aspects of Strategies for the Sustainable Development of Drylands*. Food and Agriculture Organization of the United Nations. Rome.
- FAO, 1995a. *Flavours and Fragrances of Plant Origin*. Non-Wood Forest Products 1. Food and Agricultural Organization. Rome.
- FAO, 1995b. *Gums, Resins and Latexes of Plant Origin*. Non-Wood Forest Products 6. Food and Agriculture Organization of the United Nations. Rome.
- FAO, 1995c. *Non-Wood Forest Products for Rural Income and Sustainable Forestry*. Non-Wood Forest Products 7. Food and Agriculture Organization of the United Nations. Rome.
- FAO, 1995d. 1995. *Role of Acacia Species in the Rural Economy of Dry Africa and the Near East*, by Wickens, G.E. FAO Conservation Guide 27. Food and Agriculture Organization of the United Nations. Rome.
- FAO, 1999. Compendium of Food Additive Specifications Addendum 7. *Food and Nutrition Paper*, No. 52. Add. 7. Joint FAO/WHO Expert Committee on Food Additives 53rd Session Held in Rome, 1-10 June 1999. Food and Agriculture Organization of the United Nations. Rome.
- Getachew Eshete, 1999. The Impact of Different Land use Types on Structure, Regeneration and Soil Properties of *Abernosa Acacia* woodland, Eastern Shoa, Ethiopia. Ethiopian MSc in Forestry Programme Thesis Works, Report No. 1999:41, Skinnskatteberg.

- Getachew Eshete and Ståhl, G., 1998. Functions for Multi-Phase Assessment of Biomass in *Acacia* Woodlands of the Rift Valley of Ethiopia. *Forest Ecology and Management*, Vol. 105; pp 79–90.
- Getachew Eshete and Ståhl, G., 1999. Tree Rings as Indicators of Growth Periodicity of *Acacias* in the Rift Valley of Ethiopia. *Forest Ecology and Management*, Vol. 116; pp 107–117.
- Holmes, I., 1997. Gum Arabic – Life in a Saturated Market. In: *Conservation, Management and Utilization of Plant Gums, Resins and Essential Oils* (Eds. Mugah, J. O., Chikamai, B. N., Mbiru, S. S. and Casadei, E.). Proceedings of a Regional Conference for Africa Held in Nairobi, Kenya, 6 – 10 October 1997. Nairobi.
- Idris, O. H. M., Williams, P. A., Phillips, G. O., 1998. Characterization of Gum from *Acacia senegal* Trees of Different Age and Location Using Multidetector Gel Permeation Chromatography. *Food Hydrocolloids*, Vol. 12; pp 379–388.
- Karamalla, K. A., Siddig, N. E. and Osman, M. E., 1998. Analytical Data for *Acacia senegal* var. *senegal* Gum Samples Collected between 1993 and 1995 from Sudan. *Food Hydrocolloids*, Vol. 12; pp 373–378.
- Karmann, M. and Lorbach, I., 1996. Utilization of Non-Timber Tree Products in Dryland Areas: Examples from Southern and Eastern Africa. In: *Domestication and Commercialization of Non-Timber Forest Products in Agroforestry Systems*. Non-Wood Forest Products 9. Food and Agriculture Organization of the United Nations, Rome.
- Kent, M. and Coker, P., 1994. *Vegetation Description and Analysis*. A Practical Approach. John Wiley & Sons Ltd. England. 363 pp.

- Kindeya Gebrehiwot, 2003. Ecology and Management of *Boswellia papyrifera* (Del.) Hochst. Dry Forests in Tigray, Northern Ethiopia. Doctoral Dissertation submitted for the degree of Doctor of Forest Sciences of the Faculty of Forest Sciences and Forest Ecology. Georg–August–University of Göttingen, Göttingen 2003.
- Kleinn, C., Laamanen, R. and Malla, S. B., 1996. Integrating the Assessment of Non–Wood Forest Products into the Forest Inventory of a Large Area: Experiences from Nepal. In: *Domestication and Commercialization of Non–Timber Forest Products in Agroforestry Systems*. Non–Wood Forest Products 9. Food and Agriculture Organization of the United Nations, Rome.
- Kumelachew Yeshitela and Taye Bekele, 2003. The Woody Species Composition and Structure of Masha–Anderacha Forest, South–Western Ethiopia. *Ethiopian Journal of Biological Sciences*, Vol 2(1); pp 31–48. Biological Society of Ethiopia, Addis Ababa.
- Lamprecht, H., 1989. *Silviculture in the Tropics*. Tropical Forest Ecosystems and their Tree species – Possibilities and Methods for their Long–Term Utilization. Institute for Silviculture of the University of Göttingen. Technical Cooperation–Federal Republic of Germany, Berlin. 296 pp.
- Mekuria Argaw, Demel Teketay, and Olsson, M., 1999. Soil Seed Flora, Germination, and Regeneration Pattern of Woody Species in *Acacia* Woodland of the Rift Valley in Ethiopia. *Journal of Arid Environment*, Vol. 43; pp 411–435.
- Mhinzi G. S., 2003. Intera–species Variation of the Properties of Gum Exudates from *Acacia senegal* var. *senegal* and *Acacia seyal* var *fistula* from Tanzania. BCSE, 171; pp 67–74.
- Mhinzi, G. S. and Mrosso, H. D. J., 1997. Chemotaxonomic Aspects of Gum Exudates from Some *Acacia* Species. In: *Conservation, Management and Utilization of Plant Gums*,

- Resins and Essential Oils* (Eds. Mugah, J. O., Chikamai, B. N., Mbiru, S. S. and Casadei, E.). Proceedings of a Regional Conference for Africa Held in Nairobi, Kenya, 6 – 10 October 1997. Nairobi.
- Mohamed, A. G., 2005. Improvement of Traditional *Acacia senegal* Agroforestry: Ecophysiological Characteristics as Indicators for Tree–Crop Interaction on Sandy Soil in Western Sudan. Academic Dissertation. University of Helsinki. Helsinki.
- Mohammed Abdi, 1993. Impact of Human Activity on Abijata Shalla Lakes National Park Ecosystem. Thesis Prepared for Partial Fulfillment of the M.Sc. Degree in Management of National Resources. Agricultural University of Norway. NORAGRIC, AAS.
- Mugah, J. O., Chikamai, B. N., Mbiru, S. S. and Casadei, E., 1997. Conservation, Management and Utilization of Plant Gums, Resins and Essential Oils. Proceedings of a Regional Conference for Africa Held in Nairobi, Kenya, 6 – 10 October 1997. Nairobi.
- Mulugeta Lemenih, Tarekegn Abebe and Olsson, M., 2003. Gum and Resin Resources from some *Acacia*, *Boswellia*, and *Commiphora* species and their Economic Contributions in Liban, South–East Ethiopia. *Journal of Arid Environments*, Vol.55; pp 465–482.
- Mulugeta Lemenih and Demel Teketay, 2003. Frankincense and Myrrh Resources of Ethiopia: I. Distribution, Production, Opportunities for Dryland Development and Research Needs. *SINET: Ethiopian Journal of Science*, Vol. 26(1); pp 63-72, Faculty of Science, Addis Ababa University, Addis Ababa.
- Mulugeta Lemenih and Demel Teketay, 2004. Natural Gum and Resin Resources: Opportunity to Integrate Production with Conservation of Biodiversity, Control of Desertification and Adapt to Climate Change in the Drylands of Ethiopia. Paper Presented to the First

- National Workshop on Conservation of Genetic Resources of Non Timber Forest Products (NTFPs) in Ethiopia, 5–6 April 2004. Addis Ababa.
- Mulugeta Lemenih, 2005. Production and Marketing of Gums and Gum Resins in Ethiopia. In: *Production and Marketing of Gum Resins: Frankincense, Myrrh and Opoponax* (Eds. Chikamai, B. and Casadei, E.). NGARA Publication Series 5. Network for Natural Gums and Resins in Africa, Nairobi. pp 55–70.
- Mulugeta Lemenih and Teshale Wolde Amanuel, 2006. Natural gum and Incense resources of Ethiopia: II. Socio-Economic Significances, Potential for Commercialization and Constraints. Paper Presented to the 1st Public Meeting under the Theme Non–Timber Forest Products; a Win–Win for Poverty Reduction and Environmental Protection, 17 March, 2006. Addis Ababa.
- Obolenskaya, A. B, Elenskaya, Z. P. and Leonovich, A. A., 1991. Laboratory Work on Wood Chemistry and Cellulose. “*Ecology*” Moscow. ISBN 5–7120–0264–7, 320 pp.
- Peters, C. M., 1996. The Ecology and Management of Non–Timber Forest Recourses. *World Bank Technical Paper 322*, Washington.
- Rogers, G., Walker, S. and Lee, B., 2005. The Role of Disturbance in Dryland New Zealand: Past and Present. *Science for Conservation 258*. New Zealand Department of Conservation. Wellington.
- Sanchez, C., Renard, D., Robert, P., and Schmitt, C., 2002. Structure and Rheological Properties of *Acacia* Gum Dispersions. *Food Hydrocolloids*, Vol. 16; pp 257–267.
- Schröder, J. M., 2001. NTFP Use and Sustainability: The Example of *Prunus africana* in Cameroon. In: *ETFRN News*, No 32/01, European Tropical Forest Network, The Netherlands. pp 12–14.

- Seif el Din, A. and Zarroug, M., 1996. Production and Commercialization of Gum Arabic in Sudan. In: *Domestication and Commercialization of Non-Timber Forest Products in Agroforestry Systems*. Non-Wood Forest Products 9. Food and Agriculture Organization of the United Nations, Rome.
- Shiva, M. P., 1993. Solutions to Overcome Impediments in Forest Development Through MFP Based Management. Paper Presented to the International Seminar on Minor Forest Products in Forestry, 17–18 April, Dehra Dun.
- Tadesse Woldemariam Gole, 2003. Vegetation of the Yayu Forest in SW Ethiopia: Impacts of Human Use and Implication for *in situ* Conservation of Wild *Coffea arabica* L. Populations (Ed. Vlek, Paul L.G.). *Ecology and Development Series*, No. 10. Göttingen.
- Tamire Hawando, 1997. Desertification in Ethiopian Highlands. *RALA Report No. 200*. Norwegian Church AID, Addis Ababa, Ethiopia. 162 pp.
- Tefera M., Demel T., Hulten, H. and Yonas Y., 2005. The Role of Enclosures in the Recovery of Woody Vegetation in Degraded Dryland Hillsides of Central and Northern Ethiopia. *Journal of Arid Environments*, Vol. 60; pp 259–281.
- Tewolde Birhan Gebre Egziabhier, 1990. The Importance of Ethiopian Forests in the Conservation of Arabica Coffee Gene pools. In: *Proceedings of the Twelfth Plenary Meeting of AETFAT* (Ed. Ihlenfeldt, H.D.). Mitt. Inst. Allg. Bot. Hamburg 23a. Hamburg. pp 65–72.
- Ticktin, T., 2004. The Ecological Implications of Harvesting Non-Timber Forest Products. *Journal of Applied Ecology*, Vol. 41, Issue 1; pp 11.

- Vantomme, P., 1997. FAO's Global Program on the Development of Non-Wood Forest Products (NWFP'S). In: *Conservation, Management and Utilization of Plant Gums, Resins and Essential Oils* (Eds. Mugah, J. O., Chikamai, B. N., Mbiru, S. S. and Casadei, E.). Proceedings of a Regional Conference for Africa Held in Nairobi, Kenya, 6 – 10 October 1997. Nairobi.
- Vivero Pol, J. L., 2002. Forest Is Not Only Wood: The Importance of Non-Wood Forest Products for the Food Security of Rural Household in Ethiopia. In: *Forests and Environment* (Eds. Demel Teketay and Yonas Yemishaw). Proceedings of the Fourth Annual Conference, Forestry Society of Ethiopia, 14–15 January 2002, Addis Ababa. pp 16–31.
- Wilkie, D. S., Clark, L., and Godoy, R., 2001. NTFPs: Economic and Conservation Potential in Central Africa. In: *ETFRN News*, No 32/01, European Tropical Forest Network, The Netherlands. pp 32–34.
- Wollenberg, E. and Belcher, B., 2001. NTFPs – Income for Rural Populations or Not? In: *ETFRN News*, No 32/01, European Tropical Forest Network, The Netherlands. pp 30–32.