Ecological aspects and resource management of bamboo forests in Ethiopia

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Abstract

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This thesis describes the extent and condition of the natural bamboo forests of Ethiopia and their actual and potential values for society and environment. It assesses in detail the growth and nutrient dynamics in a selected highland bamboo forest in Southwest Ethiopia (Masha) and suggests solutions for its sustainable management. A specific management aspect is addressed by means of the factors that affect *Oxytenanthera abyssinica* seedling emergence and subsequent growth.

The following were the methodologies employed to obtain the information reported herein. (1) Literature review on the Ethiopian bamboo species in relation to the situation in a global context. (2) A field study on stand characteristics, biomass and nutrient distributions and their temporal variations. (3) A greenhouse experiment on lowland bamboo (*O. abyssinica*) seedling performance under varying seed orientation and sowing depth conditions.

Ethiopia still has large natural bamboo forests in areas that until recently were remote and inaccessible. These resources are now being destroyed under population pressure mainly for agricultural land expansion. The traits of bamboos as the fastest growing multipurpose plants with an excellent capacity to convert solar energy into forest goods and services and, thus, their potential to redress the prevalent deforestation related problems of Ethiopia are highlighted. A workable strategy to harness their potential on sustainable basis is recommended.

Proper management and expansion are considered the principal components of a sound strategy to develop the bamboo resource of Ethiopia. Management approaches are suggested to improve the productivity and product quality of the remnant bamboo forest of Masha, based on diagnostic information on its condition. Expansion of the lowland bamboo forest of Ethiopia is cheaper and more practical using seeds than other propagation materials. Some methods of seed sowing are prescribed to optimise seedling emergence and subsequent growth, as part of a management strategy for lowland bamboo forest recovery and expansion in Ethiopia using seeds.

Keywords: Ethiopia, bamboo forest, radiation, deforestation, biomass and nutrient, plantation, seedling performance

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Contents

Preface

This thesis is a summary of the following four papers, which will be referred to in the text by their Roman numerals.

I. Kassahun Embaye. 2000. The indigenous bamboo forests of Ethiopia: an overview. *Ambio 29*, 518 – 521.
II. Kassahun Embaye. 2001. The potential of bamboo as an interceptor and converter of solar energy into essential goods and services: focus on Ethiopia. Int. *J. Sustain. Dev. World Ecol. 8*, 346 – 355.
III. Kassahun Embaye, Martin Weih, Stig Ledin and Lars Christersson. Ecology of biomass and nutrient distribution in a highland bamboo forest in Southwest Ethiopia: Implications for management (submitted to *Forest Ecology and Management*).
IV. Kassahun Embaye, Lars Christersson, Stig Ledin and Martin Weih. 2003. Bamboo as bioresource in Ethiopia: Management strategy to improve seedling performance (*Oxytenanthera abyssinica*). *Bioresource Technology 88*, 33 – 39.

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Regarding Papers III and IV, I was responsible for planning, data collection, analyses and writing the manuscripts. The other authors discussed and improved the pieces of work all-along the whole processes.

To my parents, brothers and sisters

Introduction

Background

The following premises are the bases of this thesis. Bamboos are multipurpose plants of high economic and environmental value that convert solar radiation into useful goods and services better than most tree species (Paper I). Developing countries like Ethiopia that are aspiring for better welfare and faster rate of development, therefore, need to preserve their remnant bamboo forests and expand their resource base. They must also ensure the steady increase, stability and sustainability of bamboo forest production and utilisation activities (Paper I). This requires careful strategic planning (Paper I, III, IV) based on adequate knowledge on (1) the availability and potential use of the bamboo resources for society and environment, (2) their production technology and growth behaviour. Thus, the focus of this thesis is on the socio-economic and environmental values of the Ethiopian bamboo species and their production ecology.

The fit of the thesis in the overall bamboo development prospect of Ethiopia

Paper I and II report the following three interrelated issues. (1) Bamboo species diversity, distribution, growth potential and use in national and global contexts. (2) Deforestation and its consequences in Ethiopia, (3) the potential of bamboo to redress deforestation related problems. These review articles suggested the urgent need for bamboo development in Ethiopia for socio-economic and environmental benefits. Two complementary strategies could rationally be used to develop bamboo forests in Ethiopia. (1) Management of the remnant bamboo forests for higher production and product quality. Paper III analysed the condition of the Masha natural bamboo forest in SW Ethiopia and suggested management approaches to improve its efficiency. (2) Bamboo forest expansion by planting. Paper IV reported on aspects of lowland bamboo seed germination and seedling growth under varying seed orientation and sowing depth conditions as a strategy for lowland bamboo forest recovery and expansion using seeds. Bamboo forest development and sustainable management in Ethiopia could only be successful if driven by market forces. The necessity for linking bamboo production, processing and marketing systems in a mutually supporting and reinforcing way was strongly recommended in Paper I and III.

Bamboo as a tree plant and a forest resource

Bamboos are tall perennial grasses with tree stature that grow up to about 30 m in height and 35 cm in diameter, for example the giant bamboo *Dendrocalamus giganteus* (Ramanayake and Yakandawala, 1998). The maximum size measured in the indigenous bamboo forests of Ethiopia was 23 m and 20 cm in height and diameter, respectively. They belong to the Poaceae (Gramineae) family and Bambuseae subfamily (Ohrnberger, 1999). The main stem of the aboveground part of the plant is the culm, while the underground part constitutes the rhizome and root system. The rhizome is the structural foundation of the bamboo plant on which its mechanical anchorage, growth, vigour and spacing depends (Liese, 1985; Paper I). New bamboo shoots are produced every rainy season from rhizome buds that attain full height and diameter in about 3 months in a fully developed rhizome-root system, which occurs in 3 to 7 years after seeding or establishment by seed. They are mature, strong and ready for utilisation after 2–3 years. Most bamboo plants flower only once in their lifetime (14 to 50 years in most species) and then die soon after. They emerge again from germinating seeds if the site is not severely disturbed by detrimental factors such as rodents, fire, *etc*. These phenomena were actually observed in the lowland bamboo forest of Pawe, SW Ethiopia. The whole forest flowered and died in 1998. Seedlings emerged in large quantity in the subsequent year.

Bamboo forests are characterised by a complex network of rhizome-root system, which make them excel other forest types in effectively holding soil particles together, thereby preventing soil erosion and promoting water percolation. The aboveground part of a bamboo forest helps reduce erosion by rainfall interception and by sheltering the soil from wind erosion and sun drying. Their high LAI and stand density enable them to perform these functions better than most forest types. Bamboo litterfall improves soil structure and fertility (Fanshawe, 1972; Paper I). Bamboo forest plays a vital role in bio-diversity preservation and has a potential for organic waste purification (Paper I), owing to its fast growth rate and short harvesting cycle. Furthermore, it is a material source for furniture, building, pulp, particleboard, bio-energy, food, forage and medicine (Liese, 1985; Paper I and IV).

The Ethiopian bamboo forests in global context

Bamboo plants grow in the tropical and temperate regions, being preponderant in the former, particularly in Southeast Asia (Banik, 1985). More than 1500 bamboo species are found in the world (Ohrnberger, 1999), covering more than 14 million ha of land. Africa possesses about 40 of these species on over 1.5 million ha (Kigomo, 1988), and two of these species are indigenous to Ethiopia: *Oxytenanthera abyssinica* (A. Richard) Munro (lowland bamboo) and *Yushane alpina* K. Shmann Lin. (highland bamboo). The Ethiopian natural bamboo forest is about 1 million ha, which is about 7% of the world total and 67% of theAfrican bamboo forest area (Paper I).

The lowland bamboo forest of Ethiopia is a clump-forming type with solid culm that constitutes about 85% of the total bamboo forest of the country. The highland bamboo forest is non-clump forming (single-stemmed) species with hollow culm. The former is deciduous while the latter is an evergreen (Paper I and III).

Location and condition of the Ethiopian natural bamboo forests

There are more than 800,000 ha and 100,000 ha of low- and highland natural bamboo forests in Ethiopia. They are found mainly in the south-west, south and central part of the country where annual rainfall is over 600 mm and the rainy season is not less than three months. The eastern part of the country receives too little annual rainfall to support bamboo forest (Paper I). The average stocking of the lowland bamboo forest is 8000 culms ha^{-1} and 6000 culms ha^{-1} in the highland bamboo forest. The average annual increment in terms of culm oven-dry matter is 8.5 to 10 t ha^{-1} (Anonymous, 1997). Mean culm size in the low- and highland bamboo forests is 5 cm and 7 m and 8 cm and 17 m of diameter and height, respectively (Anonymous, 1997). Harvesting by the local people for various uses is very rare with no noticeable impact on the forest stocking or structure. However, increment is counterbalanced by death of trees due to age, disease and insect attack and the forest stocking remains more or less unchanged (Paper I).

These forests had remained out of sight in the remote areas of Ethiopia, preserved by their inaccessible locations. However, they are now accessible as new settlements have been established in the forests and new roads have been built through them to connect the emerging villages. Consequently, they are being cleared at an accelerating rate for agricultural land expansion, burned to promote tender grass growth for grazing and to drive out or kill allegedly harmful insects. Large-scale coffee and tea plantations and urban expansion are also emerging as real and potential threats (Paper I).

The potential of bamboo as converter of radiant energy into goods and services

Plants convert radiant energy into biomass by the process of photosynthesis. The conversion efficiency is linearly correlated with rate of growth and earlier canopy closure. Bamboo forests grow faster than most forests of other species: they reach maximum height and diameter for a site in 3 to 7 years. They have a high leaf area index (LAI; *e.g.*, 10 for Masha bamboo forest, SW Ethiopia) that could absorb 95% of the incident solar radiation (Qiu *et al.*, 1992; Paper II). Moreover, canopy gaps are not critical for new shoot emergence in bamboo forests until maximum stand density is reached for the site. The growth of new shoots depends entirely on photosynthetic products transported from parent trees through the rhizome system (Li *et al.*, 2000; Paper II and III). Thus, bamboos are efficient converters of solar energy into biomass. The living biomass provides vital environmental services by providing shelter for the soil and the organisms harbouring in it against the adverse effects of rain, sun and wind. Harvested biomass is used for production of various essential goods for society.

Objectives

The thesis attempts to explore the condition of the Ethiopian bamboo forests and to suggest management approaches to develop and harness their potential for economical and environmental benefits. The following are the specific objectives of the thesis:

1. To describe bamboo as a tree plant and forest resource in national and global contexts and examine the factors that conditioned the development and use of

bamboo forests in Ethiopia. Further, to suggest measures to realise their economic and environmental potentials (Paper I and II).

2. To bring into attention the indispensable sun as source of ultimate energy for fuelling photosynthesis and the excelling capacity of bamboo species in solar radiation interception, storage and conversion into forest goods and services (Paper II)
3. To assess the condition of a selected bamboo forest through field study and suggest management approaches for its quality and productivity improvements (Paper III).
4. To report some factors that affect bamboo seedling emergence and subsequent growth and their management significance for recovering and expanding lowland bamboo forest in Ethiopia using seeds (Paper IV).

Materials and methods

The thesis is composed of literature review work, a field study and a greenhouse experiment (Table 1). Brief descriptions of the materials and methods used in each study are presented below. The reader is referred to the papers for more details.

Table 1. *Summary of the various studies that constitute the thesis, factors considered and parameters measured.*

Paper	Factors	Parameters	Remark
I and II	Most aspects of bamboo		General information collection through field observation and literature review
III	Biomass, nutrient, stand density, age-structure,	Fresh matter, dry matter, nutrient concentrations, LAI, litter-fall	Field study
IV	Seed orientation, sowing depth	Seedling emergence, survival, height, number of leaves per seedling	Greenhouse study

General information collection and synthesis (Paper I, II)

The bamboo forests in the different parts of Ethiopia were visited, some of them many times during the past five years (1998–2002). Field observations and review of pertinent documents were the methodologies employed to produce Paper I and II, as a background for the field and greenhouse research works.

Field study: the Masha natural bamboo forest (Paper III)

The field study was carried out at Masha natural bamboo forest in Southwest Ethiopia (7º30′ N and 35º30′ E). Five sample plots of 10×10 m size were established at 200 m spacing during the rain season of 1999/2000, in the central portion of the 19000 ha more or less uniform forest. The study was repeated during the dry season of 2000/2001, following the same procedure to examine seasonal changes.

The living bamboo trees within the sample plots were grouped into three age-classes: <1 year, 1–3 years and >3 year. Tree age was identified based on the indicators used by Wimbush (1945) and Banik (1993). Two trees were felled at random from each age-class and sample plot (*i.e.*, 30 trees in total), separated into culm, branch, and leaf components for biomass and nutrient assessments. Rhizome and root parts of felled trees were also sampled for nutrient analyses.

At least two leaves were randomly sampled from the upper and lower half crown of each felled tree (a total of 236 leaves), for leaf area index determination from specific leaf area (SLA) and dry leaf weight (DLW) measurements. Rhizomes and roots were extracted and separated for biomass determination from randomly located 33 soil block samples of 10 cm^3 dimensions. Litterfall samples were collected from randomly located 20 plastic sheets of 50×50 cm size.

Soil samples for nutrient content analyses were collected from three soil profiles of 1.5 m depth spaced at about 1000 m from each other. Sampling within a profile was done at 20 cm interval down to 1 m depth.

Greenhouse study: seed orientation and sowing depth (Paper IV)

Seeds for the set of empirical research on seed orientation and sowing depth were collected from an extensively flowered and heavily seeded lowland bamboo forest in Metekel, Southwest Ethiopia (11º14′ N and 36º16′ E) in January 1999.

Two experiments: seed orientation and sowing depth were conducted using plastic pots of 5 l volume, filled with a mixture of sand and peat (ratio 3 sand: 1 peat). A randomised complete block design was used in both experiments. In the seed orientation experiment, each block consisted of 30 pots. Ten seeds were sown at random and at 2 mm soil depth in embryo-end-up, embryo-end-down and lay-flat orientations and replicated four times, *i.e.*, 10 seeds × 3 treatments (orientations) × 4 blocks (*i.e.*, a total of 120 sample units). In the sowing depth experiment, each block consisted of 20 pots. Five seeds were sown at random and in a lay-flat orientation in each of the various depth categories. The depths were: 0 mm (surface), 2.5 mm, 5 mm and 10 mm and replicated four times, *i.e.*, 5 seeds × 4 treatments × 4 blocks (*i.e.*, a total of 80 sample units). During the experiment, seedling emergence, seedling survival, seedling height and number of leaves per seedling were recorded on a weekly basis.

Summary of results

Urgency for harnessing and expanding the potentials of the Ethiopian bamboo forests

According to the various literatures reviewed and the field observations undertaken, Ethiopia has two indigenous bamboo species and no exotics. About 130 000 ha of Yushane alpine and about 850 000 ha of *Oxytenanthera abyssinica* are found scattered in the south, south-west and central parts of Ethiopia. They are in more or less pure, fully stocked natural forest conditions (Paper I, Table 2). These forests were until recently protected by their remote and inaccessible locations. They are now fast disappearing due to improvements in road networks and establishment of villages within them and their vicinities.

Table 2. *General characteristics of the Ethiopian natural bamboo forests (Anonymous, 1997).*

	Natural bamboo forests	
	Lowland	Highland
Mean altitude	1000-1800 m	2200-3200 m
Mean annual rainfall	1150 mm	1950 mm
Total area	850,000 ha	130,000 ha
Stand density (tree ha^{-1})	8000	6000
Percentage of dead trees	34	27
Aboveground biomass t ha^{-1}	20	51
Culm	Semi-solid to solid	Hollow
Ratio of old to new shoots		5:1
Seeds	Viable	Most empty, not viable

The reviewed documents also provided information on contrasting scenes on the landscape of Ethiopia. There are abundant bamboo resources in some localities, while most parts of Ethiopia are suffering from the adverse consequences of deforestation. The forest decline has resulted in acute shortage of forest products, accelerated soil erosion, adverse climatic changes, drought and decline in agricultural productivity. The Conservation Strategy of Ethiopia (CSE) calls for urgent action with sustained follow up to arrest deforestation, expand the forest resources and promote their rational use (CSE, 1997).

On an annual basis, wood demand is more than thrice sustainable supply from all forests of Ethiopia (Fig. 1). Population growth and improvement in living standard is further widening the gap between projected wood demand and supply. Ethiopia is now a net importer of forest products (Table 3, Paper II). Thus, the documents reviewed and the reality on the ground showed that conservation of the remnant natural forests and re-vegetation of the barren landscape is a matter of utmost importance. Bamboos are reported to possess desirable qualities as a tree plant and forest resource that make them preferable planting materials for various purposes (Paper I and II, see introduction). They are reported to have excellent capacity in intercepting and converting solar energy into goods and services essential for society and environment (Paper II). Thus, the urgency for developing and harnessing the potentials of bamboo forests in Ethiopia was strongly stressed in the reviewed documents.

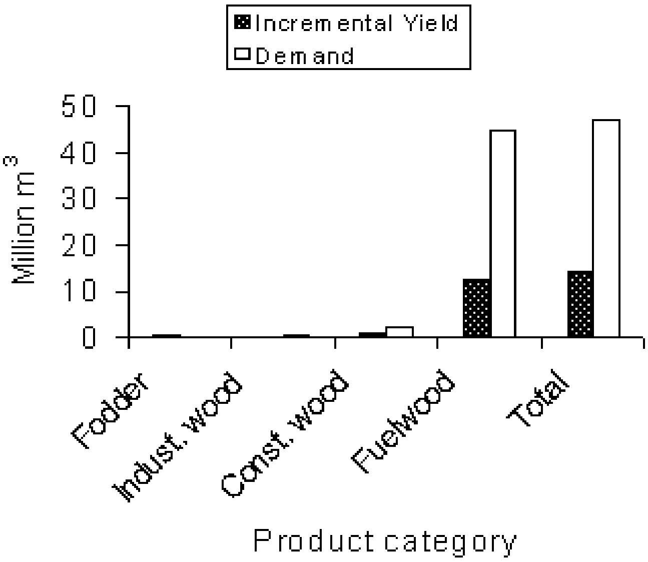

Figure 1: Estimate of wood supply and demand in Ethiopia for 1992 (EFAP, 1994)

Table 3. *Forest products imported into Ethiopia, 1993-1998 (FAO, 2000)*

Item, Quantity (m^3)	Year					
	1993	1994	1995	1996	1997	1998
Sawn-wood	494	360	3185	1300	12000	10000
Veneer sheets	194	104	104	100	2800	2800
Plywood	90	63	2	100	7400	7400
Particle board	22	457	500	500	3600	3600
Pulp (tonnes)	5621	3895	4397	5700	6700	6800

The natural bamboo forests of Ethiopia: condition, biomass and nutrient distributions and their seasonal variations

The reviewed documents indicated that the remnant natural bamboo forests of Ethiopia are in a neglected state through lack of management (Paper I). The condition of the Masha bamboo forest in Southwest Ethiopia was a typical example. This natural forest was characterised by high percentage of mortality (20 %) (Paper III). The living bamboo population was dense (8840 tree ha^{-1}) with high leaf area index (*ca*. 10). The age-structure was heavily skewed towards old trees and the annual litterfall (11 t ha^{-1}) was larger than the current aboveground shoot (<1 year) biomass (8 t ha^{-1}).

About 73% of the 110 t ha^{-1} total aboveground biomass (TAB) were from bamboo trees older than 3 years, which are mature for harvest. On the other hand, the share of new shoots (<1 year) was very small (7% of the TAB). The overwhelming contribution of mature trees (>3 year) was even greater to the leaf and branch sets of biomass, 79% and 77%, respectively. Litterfall was tenfold higher during the rainy than during thedry season.

Variations of nutrient concentration among the various plant parts, between seasons and among age-classes were all highly significant. Nutrient concentration in the plant components generally followed the order foliage > rhizome > root > culm (Paper III). Tree ageing was associated with declining concentration of most nutrients (N, P and K). Plant nutrient concentrations in the various tree components were higher during the dry than during the rainy season.

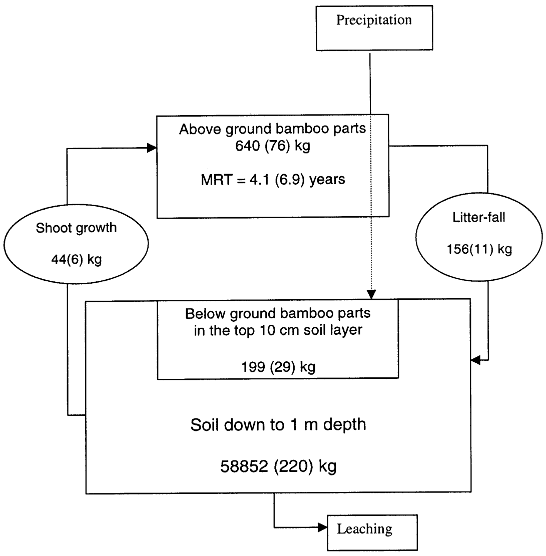

Figure 2: Gross estimation of the nitrogen and phosphorus (in parenthesis) budget of the Masha natural bamboo forest, Southwest Ethiopia, on annual basis. Figures in rectangular boxes indicate (weighted) mean values of the rain and dry season data and arrows indicate nutrient flow. Nutrient addition through precipitation and loss through leaching were not determined.

Three times as much nitrogen removed from the soil for aboveground new shoot growth was returned to the forest floor through annual litterfall. The amount of phosphorus that returned through annual litter-fall was only twice the amount removed for aboveground new shoot growth (Fig. 2).

Seed as a propagation material for lowland bamboo forest expansion: factors that influence *Oxytenanthera abyssinica* seedling performance

Lowland bamboo seeds were found most successful and practical propagation materials (Paper IV). Use of cuttings was not successful while offsets were too cumbersome for large-scale use (see introduction, Paper I and II). The seedling emergence speed of the lowland bamboo seeds was generally fast, less than 14 days, and varied with the type of seed orientation and sowing depth used (Table 4, Fig. 3).

Table 4. *Seedling % of seeds sown, seedling length and number of leaves per seedling of the different seed orientations. Figures in brackets are coefficients of variation.*

	Seed orientation								
	Lay-flat			Embryo-end-up			Embryo-end-down		
Days after sowing	Seedling % of seeds sown	Mean seedling length (cm)	No. leaves /seedling	Seedling % of seeds sown	Mean seedling length	No. leaves / seedling	Seedling % of seeds sown	Mean seedling length	No. leaves / seedling
21	75	3.85 (38%)	1.00 (0%)	45	2.44 (40%)	1.00 (0%)	55	2.90 (29%)	1.00 (0%)
26	75	5.24 (24%)	2.07 (12%)	45	3.90 (37%)	1.56 (34%)	55	4.80 (26%)	2.09 (10%)
32	75	7.89 (27%)	4.27 (14%)	50	6.04 (47%)	3.7 (22%)	45	5.98 (41%)	3.89 (20%)
38	75	9.89 (32%)	5.00 (17%)	55	7.53 (43%)	4.36 (24%)	65	9.05 (35%)	4.62 (14%)
45	80	13.22 (38%)	5.75 (22%)	60	9.16 (47%)	5.33 (26%)	65	11.59 (39%)	5.84 (12%)
52	75	14.54 (44%)	6.07 (16%)	60	10.98 (48%)	5.83 (16%)	60	13.37 (43%)	6.30 (10%)
62	80	20.38 (49%)	6.69 (20%)	60	16.63 (48%)	5.83 (16%)	65	18.65 (48%)	6.31 (16%)

Embryo-end-up and embryo-end-down orientations were the highest and the lowest in cumulative seedling emergence, respectively, in the first two weeks. However, the embryo-end up orientation that had excelled in emergence speed and cumulative emergence percentage in the first two weeks was the least in survival rate after 62 days, lay-flat being the highest (Paper IV). Embryo-end-up orientation also produced significantly lower leaf number per seedling than lay-flat or embryo-end-down (Table. 4). Thus, lay-flat orientation revealed better performance in both, seedling height and number of leaf per seedling traits, than the other orientation types (Paper IV).

Seedling emergence was higher and faster at the surface and 2.5 mm than at 5 and 10 mm depths. Seedling height and number of leaves per seedling increased with sowing depth until an optimum at about 5 mm and decreased thereafter (Fig. 4).

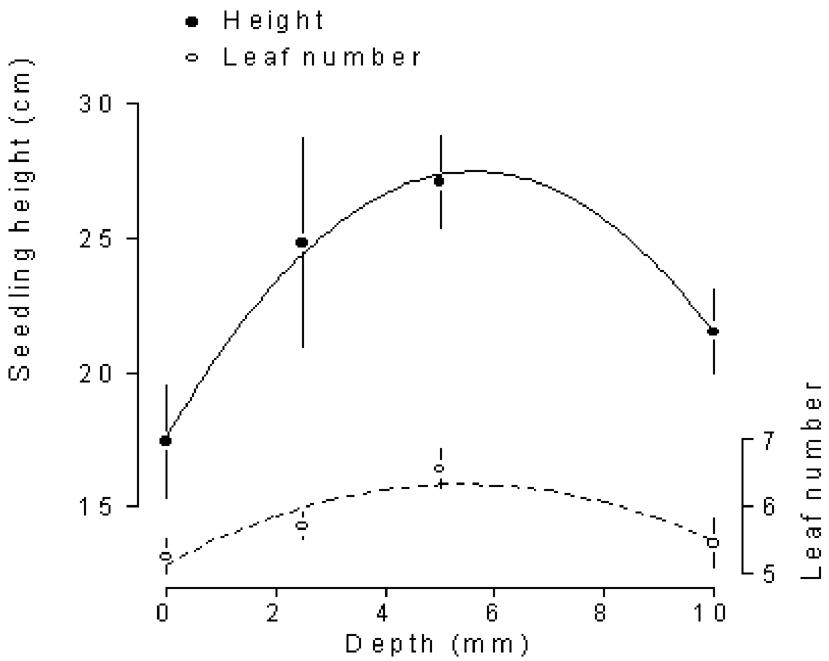

Figure 3: Mean (±SE) height and number of leaves of bamboo seedlings at age 62 days as related to sowing depth of seeds. Quadratic regressions y=0.31x2+3.53x+17.55, r^2=0.41, p=0.034, *n*=16 (seedling height, cm) and y=0.04x2+0.44x+5.14, r^2=0.41, p=0.032, *n*=16 (number of leaves per seedling).

Discussion

There is a paucity of research reports on the indigenous bamboo species of Ethiopia. Thus, some of the discussions on factors that have conditioned the state of the Ethiopian forests are based on speculations when documented empirical evidences are unavailable.

Bamboo growth strategy and its environmental and economic significance

Bamboo species are among the most versatile plants with high economic, environmental and aesthetic values (Liese, 1985). The desirable qualities of bamboo are attributed to its excelling capacity in solar radiation interception and conversion into biomass (Paper II). The whole aerial part of the plant (stem, branches and leaves) is green up to age 2–3 years, maximising the photosynthetic area for high rate of carbohydrate production during the favourable (rain) season. Bamboo plants have evolved a strategy for efficient biomass production even in localities where most of the months are dry and hot. They complete their growth in one flush within the favourable (rain) season (3–4 months) and survive the subsequent unfavourable period (dry season) at reduced respiration rate, mainly for maintenance, or in a more or less dormant condition (Wimbush, 1945). Some of the species like the lowland bamboo of Ethiopia also shed their leaves during the dry season to minimise evapo-transpiration and tissue maintenance costs. Bamboo plants have a strategy for resource sharing to support rather than compete and suppress new shoots, particularly among plants from the same rhizome system (Paper I, II). This enables them to produce more or less similar size culms with rare dominant or suppressed individuals in fully stocked natural bamboo forests (Paper III).

The complex rhizome-root network under the ground surface enables it to out-compete other species and keep its ecological dominance on the site (Tabarelli and Mantovani, 2000). It also helps site productivity by holding soil particles together to prevent soil erosion, providing openings in the soil for water percolation and gas exchange, and creating self-perpetuating environment through nutrient recycling. Bamboo forests usually attain high LAI that could intercept more than 95% of the incident solar radiation (Qui *et al*., 1982, Isagi *et al*., 1993, Paper III). This prevents soil drying and creates a favourable microclimate for beneficial soil organisms that facilitate nutrient cycling by decomposing organic materials. The forest canopy also reduces the erosive energy of rainfall and shelters the soil from wind erosion. All forests possess these qualities, but bamboo forests excel most of them in these desirable characteristics.

Bamboo culm is a preferred material for various applications owing to its straightness, high strength, light weight, easiness of working with it, suitable fibre for pulp production and absence of bark (Suzuki and Jacalne, 1986). Bamboo shoot is of a high nutritional value that can be used as source of food and feed (Ayre-Smith, 1963; Chaozong, 1995). The potential of bamboo as food supplement is of vital importance for Ethiopia, considering the frequent food shortages encountered by the rural people particularly during the rain season when bamboo shoots are actually available in abundance.

Bamboos have also limitations. (1) The gregarious flowering and eventual death of all bamboo trees in a forest is a characteristic that may seriously affect the sustainable supply of raw materials for bamboo-based industries. (2) Bamboo culm in storage and use is more susceptible to termites, insect borers and fungal attack than hard- and softwoods, as it does not contain toxic substances unlike the latter species. (3) Bamboo culm preservation is less effective than most hard- and softwoods because bamboo culm does not possess anatomical pathways (ray tissues), which facilitate radial distribution of preservatives unlike in hard- and softwood stems. Moreover, culm skins (outer and inner) are impervious and, thus, preservative penetration through them is limited. (4) A preservative method that is equally effective, cheap and safe as for hard- and softwoods has yet to be developed (Liese, 1985). (5) The maximum attainable diameter is limited by their primary growth, as they do not increase their diameter through secondary growth (wood cambium) unlike hard- and softwood species.

Factors that have conditioned the bamboo forests of Ethiopia

The principal cause that has led to the neglect, under-utilisation and destruction of the Ethiopian bamboo forests are two: insecurity of land tenure right and lack of economic incentive to value them as useful commodities. All natural forests in Ethiopia belong to the state and the government lacks economic incentive and financial capacity to protect and manage them properly. The limited government attention is focused on natural forests from where timber could be profitably harvested for industrial use. Bamboo forests are not even in the priority list of natural forests selected by the government for management and development (Jarvholm and Tivell, 1987). The lethargy of rural people towards bamboo forest development and management is again related to lack of incentive to obtain financial benefits from their sale. There is no large demand for bamboo culms in rural markets, and transporting them to nearby urban areas is not financially viable. Hundreds of hectares of natural bamboo forests in Metekel, Southwest Ethiopia, were left to decay on the site after flowering in 1997/98 for lack of adequate market for sale even at the cost of harvesting. Moreover, bamboo is considered as a perishable material susceptible to biological and physical deterioration. This perception has led to its neglect by the rural people as a useful renewable resource (Paper I). The various technologies (treatments) available to increase its service life are not practised in the country and are not at all known by the rural communities. Knowledge limitations on its propagation, growth and utilisation have also contributed to the lethargy regarding its cultivation (Paper I).

Official development aid policies also played a part in the neglect of natural bamboo forests in Ethiopia. The focus of the forestry sector has shifted in response to donors polices from traditional forestry, as known in the developed countries, to miscellaneous tree planting activities on non-forest land (Roche, 1997). Agro-forestry, farm forestry, community forestry, *etc*., have taken precedence over natural forests and industrial plantations in eligibility for support by multilateral, bilateral and UN aid organisations and non-governmental organisations (NGOs). Consequently, natural forests have been downgraded in importance and bamboo forests have suffered the most.

Diagnostic information and management approaches to improve the productivity of the natural bamboo forests

The natural bamboo forests of Ethiopia are all in a similarly neglected state in terms of management (Paper I). Therefore, the analyses on the condition of the Masha bamboo forest and the approaches prescribed for its improvement could apply to the other remnant bamboo forests as well, with caution for local variations.

The Masha bamboo forest had a high percentage of dead trees (20%), high stand density (*ca*. 9000 trees ha^{-1}), high LAI (*ca*. 10) and litter-fall mass (11 t $year^{-1}$ ha^{-1}) higher than aboveground shoot production (8 t $year^{-1}$ ha^{-1}). These all are indicators of a forest in the process of degradation for lack of management and timely harvest. The low percentage (13%) of young (<1 year) and prevalence of old (>3 year) bamboo trees (63%) in the forest substantiates the foregoing argument. So are likewise the lower total aboveground biomass of the forest (110 t ha^{-1}) than the mean value (130 t ha^{-1}) reported for 26 bamboo forests in Southeast Asia (Kleinhenz and Midmore, 2001). The lower annual production (8 t ha^{-1}) of the forest than the values reported for bamboo forests in Asia, for example the 30 t ha^{-1} reported by Difan (1985) may also indicate the degradation of the forest. Thus, there is a need to harvest some of the trees to reduce the stand density, improve the age-structure and boost the productivity of the forest.

The higher nutrient concentrations in young plants compared to older ones, in the foliage (leaves and branches) than in the culm and in dry compared to rain season are in agreement with published reports (*e.g*. Youdi *et al*., 1985). These pieces of information should be instructive for harvesting the culm of old trees during the beginning of the dry season and for leaving the foliage in the forest floor to fertilise new shoots through decomposition and mineralisation. The nutrients that would be removed with the old culm harvest could impoverish the site after few cutting cycles and, therefore, fertilisation should be considered to replenish the nutrients in order to ensure high productivity on a sustainable basis.

The forest site has a capacity for a higher rate of biomass production than the present study shows. Rainfall is adequate and well distributed through out the year, the temperature is favourable for plant growth, the drainage is good and the soil is deep, with good structure (Paper III). However, the nutrient status is the principal concern for its sustainable production. The soil is generally poor in P and K. The P content of the soil in particular was far below the 0.07% critical value for nutrient limitation of plant growth in most soils (Barber, 1995). Thus, any intensive management to boost production on this site should consider the application of P and K rich fertilisers at the end of the dry season or early in the rain season.

Most of the nutrients were concentrated within the upper 40 cm of the soil, where almost all the bamboo roots are found. The localised nutrient accumulation in the organic and upper mineral-soil layers over the nutrient-poor substratum indicated the following facts: (1) The forest system is strongly dependent on nutrient cycling through litter and soil organic matter decomposition and mineralisation. (2) The system is inherently of a fragile nature that may quickly lose its productive capacity if the bamboo forest is cleared and the typically high rainfall in the region induced erosion removes the nutrient rich topsoil from the site. The large litter mass returned to the soil surface and the high amount of nutrients contained in it further supports the former (1) argument (Paper III). These points should be instructive not to change the forestland into other land-use system and to prevent organic matter removal from the forest floor by erosion due to excessive harvesting or by fire outbreak.

Strategies for management and expansion of bamboo forests in Ethiopia and approaches for their implementation

A thoroughly thought-out strategy that provide incentives to protect and use the remaining natural bamboo forests on a sustainable basis, and to establish bamboo plantations whereever they could have a protection and production function, is urgently required (Paper I, II). The Ethiopian government needs to establish an effective institution to oversee these developments. It is crucial that the remaining natural bamboo forests have a rightful owner who could properly protect, manage and use them in perpetuity and enhance their value. Part of the remnant bamboo forests should be preserved for future generation without interference. This will enable future studies on the natural course of development in the absence of human-induced disturbances. This could be handled, for example, by the Ethiopian Bio-diversity Research Institute or by the Ethiopian Agricultural Research Organisation. Alternatively, a new autonomous or semiautonomous unit could be established for this purpose, in order to give it more focus and attention. The rest could be distributed to individuals or groups of innovative entrepreneurs who commit themselves to manage and use the natural bamboo forests on a sustainable basis according to an agreed management plan. Systematic and organised harvesting based on a management plan could improve dramatically the growing stock and bolster perpetual yield increment by reducing mortality and creating space for new recruits to emerge and grow (Paper III). Portions of the natural bamboo forests could also be given to the farmers living in and around the forest for communal management and use on the same premises.

People are rational who react in a predictable way to incentives. A properly designed incentive structure that operates through a grant system and market mechanism, as well as technical backup, is required to promote bamboo planting. The grant system has worked well in the developed world to promote specific land uses, *e.g.*, forest establishment, protection and management (Paper II). It could also be adopted by developing countries in its appropriate form, with a built-in mechanism to monitor and evaluate its effectiveness. This is an endeavour where international aid agencies could play a meaningful role with fruitful results. Overhead costs and corruption are likely to be low, since the resources will be given directly to the farmers (landowners) to be used for the intended purpose based on agreed terms and conditions. The momentum gained is also likely to sustain by itself after the support is withdrawn by the aid agencies, as far as there is perceivable demand for the products. Market forces are the ultimate determinant of development. Potential markets should be created for bamboo owners by, *e.g.*, promoting investments in bamboo-based industries such as particleboard, fibreboard, pulp and paper, and cottage industries. In this case, a great deal could be learned from Asian countries experiences (Paper I). Once a potential market is established and a grant system is put in place, protection and expansion of bamboo as useful crop will perpetuate (Fig. 4). Knowledge about propagation, management and utilisation will facilitate the momentum of development (Paper III and IV).

Raising planting materials of the indigenous bamboo species of Ethiopia has been found difficult (Kigomo and Kamiri, 1987; Abels, 1961). However, *Oxytenanthera abyssinica* (lowland bamboo) produces viable seeds through sporadic and gregarious flowering and thus seed procurement of the species is not a problem. Moreover, propagation by seed has the virtue of being easier and cheaper to transport, store and plant than any other propagation material. It has

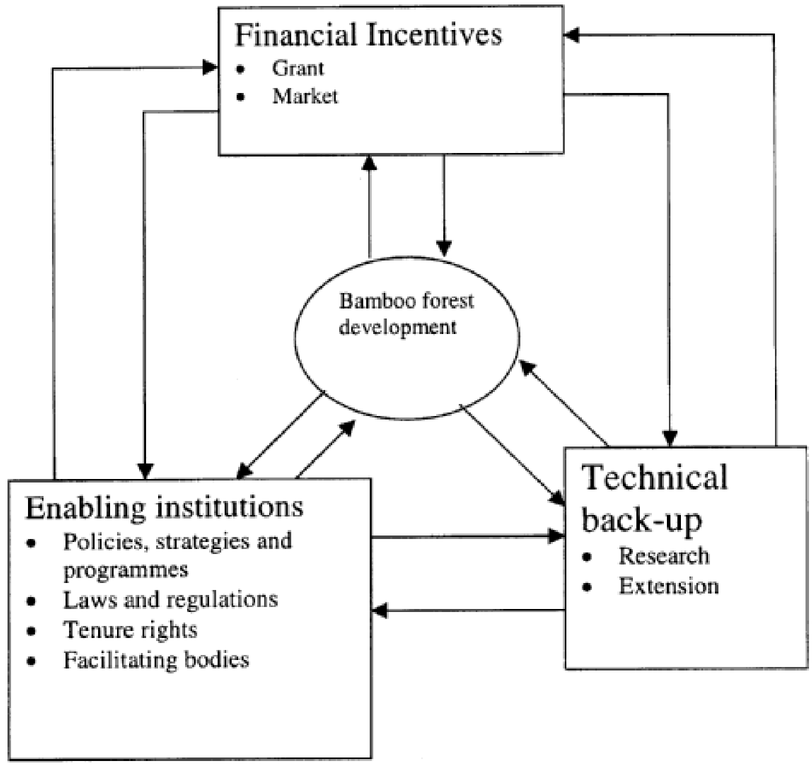

Figure 4: Essential factors to be considered in a balanced and realistic way when designing a workable strategy for bamboo forest conservation, development and utilisation in Ethiopia.

also wider genetic diversity, which is essential to withstand environmental changes and outbreaks of pests and diseases (Liese, 1985; Paper IV). Species require specific growth conditions for maximum growth, which are rarely met in nature but could be optimised particularly in greenhouses and seedling nurseries by changing growth factors to suit their requirements. Sowing depth, seed orientation and soil moisture are found to influence seedling emergence and subsequent growth of the lowland bamboo. Shallow sowing depth (*ca*. 5 mm), lay-flat orientation and a soil always moist but below field capacity are the requirements for optimum performance of the lowland bamboo seedlings (Paper IV). The results are likely to apply also for other bamboo species with similar seed morphology, but it should be kept in mind that some bamboo species, *e.g.*, the Ethiopian highland bamboo, hardly produce any viable seeds. For the Ethiopian lowland bamboo, this set of empirical evidence should be communicated to potential growers through an extension net work. Indigenous tree growth has been constrained by lack of knowledge on their growth and management (Negash, 1996). The farmers and other potential investors are likely to be encouraged by the possibility for successful production of bamboo seedlings of high vigour. Research on vegetative propagation, management, harvesting and utilisation should continue on the two indigenous bamboo species in order to make the necessary technology for enhancing and harnessing their potential value available to would-be investors at affordable cost.

Conclusions

The quality of bamboo as one of the fastest growing perennial grasses with tree stature that intercepts and converts solar energy into economically and environmentally useful biomass, faster than most tree species, should be optimally harnessed. The two bamboo species of Ethiopia should be conserved and developed as resources of national and international interest, as they are indigenous to the country and endemic to Africa. It is likely that bamboo forests of Ethiopia, (67% of African and 7% of the world) could only be conserved and developed if valued as useful crops. Thus, integrated management of their production and utilisation systems is recommended for their sustainable conservation and development, as part of a strategy to remedy the deforestation-related problems of Ethiopia (Paper I, II, III).

Silvicultural treatments and harvesting operations are required to reverse the degradation process of the remnant bamboo forests of Ethiopia (Paper III). Harvesting operations should aim to improve the stand density, age-structure and LAI of the forests while generating adequate revenue out of them. Only the culm of over-mature trees should be harvested, in the off-year cycle for monopodial bamboo species, at the beginning of the dry season when culm nutrient content is relatively lower (Paper III). The foliage of harvested trees and the litter on the forest floor should not be removed from the bamboo forests, as the systems are sustaining mainly on nutrient cycling. Fertilisation, preferably rich in phosphorus and potassium, should be applied early in the rain season to replenish nutrients removed through culm harvest (Paper III). Conversion of bamboo forests into other land-use systems would greatly increase the risk of site productivity loss, because they are sustaining by cycling nutrients, most of which are concentrated in the organic and top soil layers ((Paper III).

Large areas of the denuded landscape of Ethiopia could be planted with bamboo species for quick result wherever site conditions are suitable (Paper I, II). Lowland bamboo forest expansion in Ethiopia could be achieved by means of seeds until other alternatives become practically and economically advantageous (Paper IV). In the case of the lowland bamboo *O. abyssinica*, seeds should be sown in lay-flat orientation, at shallow depth (*ca*. 5 mm) in optimum soil moisture for maximum seedling emergence and growth (Paper IV).

References

Abels, P. 1961. The propagation of bamboos. *Bulletin of the Agriculture of Congo 52(3)*: 591-598.

Abrha, A. 1991. Problems of environment and sustainable development in Africa. In: Suliman, M. (ed.). *Alternative strategies for Africa. Institute for African alternatives*, London. Pp. 13-23.

Anonymous, 1997. *Study on sustainable bamboo management*. Final report. Luso Consult, Hamburg, Germany.

Ayre-Smith, R. A. 1963. The use of bamboo as cattle feed. *East Africa Agriculture and Forestry Journal, 29*: 50-51.

Chaozong, H. 1995. The changes in nutrient composition of bamboo shoots at different ages. In: Rao, A. N., Dhanarajan, G. and Santry, C. B. (eds.). Research on Bamboos, *Proceedings of the International Bamboo Workshop. The Chinese Academy of Forestry, China*.

CSE, 1997. Conservation strategy of Ethiopia. *Environmental Protection Authority, Addis Ababa.*

EFAP, 1994. Ethiopian forestry action programe. *Ministry of Natural Resources Conservation and Development, Addis Ababa*.

Fanshawe, D. B. 1972. Bamboo *Oxytenanthera abyssinica* – its ecology, silviculture and utilisation. *Kirkia 8(2):* 157-166.

FAO. 2000. FAO database for forest products. http://apps.fao.org/cgi-bin/nph-db.pl?subset=forestry

Hardin, G. 1991. The tragedy of the commons. In: Kuenne, R. E. (ed.). Microeconomics: Theoretical and Applied. *Vol. 3. International Library of Critical Writings in Economics, no. 11*, Aldershot, UK.

Hurni, H. 1988. Degradation and conservation of the resources in the Ethiopian highlands. *Mountain Research and Development 8*: 123-130.

Isagi, Y., Kawahara, T. and Kamo, K.1993. Biomass and net production in a bamboo *Phyllostachys pubescens* stand. *Ecological Research 8*: 123-133.

Janzen, D. H. 1976. Why bamboos wait so long to flower*? Annual Review of Ecology and Systematics 7:* 347-391

Jarvholm, A. and Tivell, A. *Industrial forestry development in Ethiopia*. Orgut-Swedforest Consortium, Addis Ababa.

Kigomo, B. N. 1988. Distribution, cultivation and research status of bamboo in Eastern Africa. KEFRI, *Ecology Series Monograph 1*: 1-19.

Kigomo, B. and Kamari, 1987. Studies in propagation and establishment *of Oxytenanthera abyssinica, Bambusa vulgaris* and *Arundinaria alpina* in medium altitude site in Kenya. *Kenya Journal of Sciences (B) 8(1-2)*: 5-13.

Li, R., Werger, M. J. A., de Kroon, H., During, H. J. and Zhong, Z. C. 2000. Interactions between shoot age structure, nutrient availability and physiological integration in the Giant Bamboo *Phyllostachys pubescens*. *Plant biol. 2*: 437-446.

Liese, W. 1985. *Bamboos – Biology, Silvics, Properties and Utilisation*. GTZ, Eschborn, Germany.

MoA. 1982. Forest for community development. *Ministry of Agriculture, Addis Ababa*.

Mohmod, A. L., Abdul, R. O. and Hong, L. T. 1992. The present state and problems of bamboo utilisation for rural development activities in Peninsular Malaysia. *Bamboo Journal. 10:* 10-19.

Ohrnberger, D. 1999. *The bamboos of the world*. Elsevier, Amsterdam.

Poudyal, P. P. 1991. Utilisation of bamboo in the Kathmandu Valley of Nepal. In: Proc. Fourth International Bamboo Workshop on Bamboo in Pacific Asia. *Forestry Research Support Programme for Asia and Pacific (FORSPA) publication 6, technical document GCP/RAS/134/ASB, FORSPA, Chiangmai, Thailand and IDRC, Ottawa, Canada*, pp. 259-262.

Qiu, G. X., Shen, Y. K., Li, D. V., Hudang, Q. M., Yang, D. D. and Goa, A. 1992. Bamboo in sub-tropical eastern China. In: Long, S. P., Jones, M. B. and Roberts, M. J., (eds.).

Primary productivity of grass ecosystems for tropics and sub-tropics. Chapman & Hall, London. Pp. 159-188.

Ramanayake, S.M.S.D. and Yakandawala, K. 1998. Incidence of flowering, death and phenology of development in the giant bamboo (*Dendrocalamus giganteus* Wall. Ex Munro). *Ann. Bot. 82*: 779-785.

Reusing, M. 1998. Monitoring of natural high forests in Ethiopia. German Agency for Technical Co-operation (GTZ): *Advisory Assistance to Forest Administration in Ethiopia, Ministry of Agriculture, Addis Ababa*.

Roche, L. 1997. Official development aid policies and sustainable utilisation of forest resources in developing countries. *Commonwealth Forestry Review 76(2)*: 91-97.

Singh, A. N. and Singh, J. S. 1999. Biomass, net primary production and impact of bamboo plantation on soil redevelopment in a dry tropical region. *Forest Ecology and Management, 119*: 195-207.

Suwannapinut, W. and Thaiutsa, B. 1990. Food composition of some Thai bamboo shoots. *Thai Journal of Forestry, 9*: 67-72.

Suzuki, T. and Jacalne, M. V. 1986. Aboveground biomass and the growth of bamboo stands in the Philippines. *Japan Agricultural Research Quarterly (JARQ) 20(1):* 85-91.

Tabarelli, M. and Mantovani, W. 2000. Gap phase regeneration in tropical montane forest: the effects of gap structure and bamboo species. *Plant Ecology, 148(2):* 149-155.

Teck, C. L., Nasir, N. M. and Kassim, J. 1991. Urea particleboard from Bambusa vulgaris Schrad. In*: Proc. Fourth International Bamboo Workshop on Bamboo Research in Pacific Asia, Chiangmai, Thailand (November 27-30, 1991),* pp. 255-257.

UNDP/World Bank, 1984. Issues and options in the energy sector. *Report No. 4741-ET. Report of the joint UNDP/World Bank energy sector assessment programme*, Washington D. C.

WoldeMariam, M. 1970. *An atlas of Ethiopia*. Poligrafico, Priv. Ltd. Co., Asmara, Ethiopia.

Wimbush, S. H. 1962. The African alpine bamboo. *Emperial Forestry Journal, 24(1)*: 33-39

Zegeye, A. 1994. Environmental degradation, population movement and war. In: Abebe Zegeye and Siegfried, Pausewang (eds.). *Ethiopia in change: peasantry, nationalism and democracy.* British Academic Press, London.

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