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**Alcoa Foundation's Conservation and
Sustainability Fellowship Program**

INSTITUTE OF
INTERNATIONAL
EDUCATION

Structural Development and Productivity of Replanted Mangrove Plantations in Kenya

A 12-yrs old *Rhizophora* plantation at Gazi bay, Kenya

Final Technical Report -1

Dr. Kairo, J. G.
Alcoa Practitioner Fellow (2006)

Mentor
Dr Lara Hansen
WWF-US

September 2006

Mangrove Rehabilitation Program

KENYA MARINE AND FISHERIES RESEARCH INSTITUTE

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This technical report is the final part of the reports prepared during the course of the project identified on the title page. The conclusions and recommendations given are those considered appropriate at the time of its preparations. They may be modified in the light of further knowledge at subsequent stages of the project.

The opinions expressed in this document are those of the author and do not reflect whatsoever on the part of the Alcoa Foundation and the Institute of International Education.

FOREWORD

Mangrove forests are one of the most important natural resources along the Kenyan coast. They provide goods and services that are of economical, ecological and environmental values to the local and national economy. Consequently, mangrove resources must be managed and utilized in a sustainable way in which ecological and environmental securities of the coastal areas can be achieved at the same time living standard of the local community can be improved.

The management of mangroves in Kenya suffers from an inadequate knowledge; of silvicultural technology, of multiple-use potential of resources, and of techniques and economics of natural regeneration and reforestation. To address part of these problems, Alcoa Foundation's Conservation and Sustainability Fellowship Program funded a project to assess structural development and productivity of mangrove plantations that were established in 1994. The long-term objective of the project is to improve the sustainable management of mangrove forests in Kenya, in order to enhance natural resource productivity, particularly in ways that would sustain continuous flow of desired forest products and services.

One of the most important project output was the preparation of yield tables of the replanted mangrove plantations. The standing biomass of a 12-year old *Rhizophora* plantation was estimated as 106.7 ton/ha, equivalent to 53.3 t C/ha.

The document includes an economic analysis of the replanted mangrove stands. Based on indirect and direct products and services such as; firewood and building poles, coastal protection, research and education, ecotourism, and carbon sequestration the value of a 12 years old *Rhizophora* plantation was estimated at US$ 2,902.87 /ha/yr. It is hoped that governments and other stakeholders in the Western Indian Ocean will find the results useful in promoting mangrove reforestation in the region.

ACKNOWLEDGEMENT

The idea to undertake this project came after the WWF-EAME office circulated an e-mail calling for Alcoa Practitioner Fellowship in October 2005. This document is part of the outputs for the work undertaken between February and August 2006.

I wish to thank all those who contributed to the success of the project. First and foremost, I do thank Hellen Fox (WWF-US) and Lydia Mwakanema (WWF-EAME) for circulating that important e-mail.

I am very grateful to the cruise team, led by Bernard Kivyatu (Forestry Dept.) and Geoffrey Bundotich (Egerton University) for their dedicated efforts in data generation. Others were Joseph Lang'at (MSc Student), Peter Chomba (Jomo Kenya University of Agriculture and Technology), and Fredrick Tamooh (Egerton University).

M/s Caroline Wanjiru handled the section on economic valuation of the replanted forest. Despite many years of working on mangroves, Caroline wouldn't understand why no one has ever ventured to undertake valuation studies on replanted mangroves; particularly the role to fisheries. I am very grateful for Caroline's insight.

Special thanks are due to my Mentor Dr Lara Hansen, WWF-US, for her encouragements throughout the project period. Lastly, I would wish to thank Diana Simon, Peggy Blumenthal and Martin Shaun for arranging the contract for this study.

Mr Bernard Kirui, PhD student in Napier University, kindly formatted this document and prepared it for circulation.

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GLOSSARY

Deforestation: The clearing of forests, conversion of forest land to non-forest uses.

Ecotourism: Nature-friendly tourism, low environmental impact tourism.

Forest degradation: Biotic or abiotic processes that result in the loss of productive potential of natural resources in areas that remain classified as forests. Degraded forest may take a long time to recover thus requiring human intervention.

Multiple uses: More than one use of a resource at one time. It is possible to practice fish culture (silvo-fishery) and bee farming (silvo-apiculture) in mangrove areas without necessarily affecting the functioning of mangrove ecosystem.

Poles: The merchantable part of the mangrove stem. In Kenya mangrove poles are categorized and marketed based on their butt diameter. The most marketable pole sizes are *Boriti* with butt diameter range of 11.5 – 13.5 cm.

Propagule: A dispersal unit in mangroves. In some mangrove literature a propagule is also referred to as a seed.

Reafforestation (US: Reforestation): Replant (an area of land) with forest trees.

Silviculture An area managed for the production of timber and other forest produce or maintained under woody vegetation for such indirect benefits as protection against flood or recreation.

Sustainable forest management: Utilization of forest resources without compromising their use by present and future generations.

Tree biomass: The biomass of vegetation classified as trees including foliage, trunk, roots and branches.

TABLE OF CONVERSION FACTORS

Centimetre (cm) = 0.394 inches
Cubic meters (m^3) = 35.31 cubic feet
Hectare (ha) = 2.471 acre
Kilometre (km) = 0.6214 miles, 1000 m
Tonne, ton (t) = 1,000 kg
Score = 20 poles

LIST OF ABBREVIATIONS

FD	Kenya Forest Department
KWS	Kenya Wildlife Service
KMFRI	Kenya Marine and Fisheries Research Institute
FAO	Food and Agricultural Organization of the United Nations
WWF	Word Wide Fund for Nature
WWF-EAME	WWF – East African Marine Ecoregion
PAR	Photosynthetic Active Radiation

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Plate 1. Degraded mangrove forest at Gazi bay, Kenya

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Plate 2. A 12- year-old *Rhizophora* plantation where the study was conducted, Gazi bay, Kenya.

Plate 3. Pruning session in the 12-years old *Rhizophora* plantation, Gazi bay, Kenya.

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1.0. INTRODUCTION

1.1. Project background

In response to an official release of Alcoa Foundation's Practitioner Fellowship Applications in October 2005, a project entitled '*Structure, regeneration and biomass accumulation in replanted mangrove plantation'* was implemented. The initial pilot area chosen for the project was Gazi bay, in Kenya, where trial mangrove planting has been going on since October 1991. Later, the project was extended to cover the riverine mangrove plantations of Ramisi that were established over the same period.

The project recruited a forest inventory specialist and a natural resource expert to assist in the collection of forestry data from February to March 2006. In addition, four locally recruited village casuals and a MSc. student from a national university were recruited to assist in the project (Appendix 1: List of Personnel Attached to the Project). The project lasted for six months, March – September 2006. Field activities included:

1. Structural assessment of replanted mangrove plantations.
2. Experimental harvesting for the estimation of standing biomass/volume.
3. Assessment of natural regeneration in the reforested mangroves.
4. Soil samplings for the determination of total organic matter.
5. Root sampling for the estimation of below-ground biomass.
6. Silvicultural treatments of the replanted forests, including; thinning, pruning, and enhancement planting.
7. Establishment of Permanent Sample Plots

Around the world, mangroves are estimated to cover an area of between 180,000 and 200,000 km^2 (Spalding *et al*., 1997). In addition to providing a range of products that people need, including building materials, firewood, tannins, fodder and herbal medicines, mangroves are of invaluable local and global ecologic, environmental and social importance. Mangroves serve as *restaurants* and *runways* for many species of fish, molluscs, crustaceans and birds. Being at the edge of the sea, mangroves protect shoreline from coastal erosion. The world mangrove forests have been valued at approximately US$ 181 billions (Constanza *et al.* 1997). Despite their great value, mangroves have one of the highest rates of degradation of any global habitat – exceeding 1 % of mangrove area per year (Spalding *et al*., 1997; FAO 2005). Hence, rehabilitation and sustainable utilization of mangrove resources is an international conservation priority.

Some 540 km^2 of mangroves occurs along the Kenyan coast, much of it in Lamu district. This is only 3 % of the forest area in Kenya, or 1 % of the total area of the country, which makes mangroves a scarce and very valuable resource. It is estimated that along the Kenyan coast, 70 % of wood requirement is met by mangroves (Wass, 1995). Increased demand of mangrove wood products, particularly for firewood and building poles, has led to degradation of the forest in many areas along the coast.

One of Kenya's forest development objectives for the year 2000 and beyond is: 'to increase the forest and tree cover in order to ensure an increasing supply of forest products and services to meet the basic needs of the present and future generations and for enhancing the role of forestry in socio-economic development' (KFMP, 1994). This objective cannot be realized unless concerted efforts to reforest degraded forests are made.

From the viewpoint of rehabilitation of degraded mangrove areas in Kenya, a program of replanting mangroves was initiated at Gazi bay in October 1991. Since the date of planting and managed cutting is known, these plantations offer a rare opportunity to determine how stand structure develops with increasing age of mangrove forests.

For majority of mangrove studies worldwide, biomass and productivity has been estimated in natural stands (e.g. Saintilan, 1997). Only in Matang Mangrove Forest Reserve in Peninsular Malaysia do we find biomass and productivity estimates for managed replanted mangrove stands (Putz and Chan, 1986; Ong *et al*., 1995). To my knowledge and experience this is the first study in Africa to investigate tree growth and productivity in replanted mangrove plantations.

1.2. Outline of official arrangement

Prior to the start of the project, Dr. Lara Hansen, Chief Scientist for WWF's Climate Change Program, was assigned as the fellow's mentor. An induction meeting between the mentor and the fellow (Dr Kairo) was arranged to take place from 8 – 15th Feb 2006 at the WWF Washington DC office. However, the meeting was rescheduled to London in February 2006. A worldwide convening organized by Alcoa Foundation in Brussels, Belgium, from November 29th - 3rd December 2006 allowed Alcoa Fellows to share and present outputs of their projects.

1.3. History of mangrove restoration and management

Scientific management of mangroves has been practiced since the 18th century in Southeast Asia. The longest recorded history of mangrove management for timber is in the Sundarbans. The 6,000 km² of mangrove forests that cover the Sundarbans region of India and Bangladesh, were managed since 1769 and detailed work plans were prepared in the period 1893-1894 (Chowdhury & Chowdhury, 1994). A parallel example is given by the mangroves of Matang (Malaysia) that have been managed since 1902 for the purpose of achieving sustainable timber production (Watson, 1928). Matang mangrove forest reserve is about 41,000 ha and has an average productivity of 34 t/ha/yr on a 30yrs rotation cycle (Ong *et al*., 1995). The Matang forest also provides (1) protection against coastal erosion, (2) breeding grounds for fish, (3) fish stakes, and (4) firewood and building materials.

More recently mangroves have been managed for integrated fish culture (Primavera, 1995) and for eco-tourism (Bacon, 1987). Planting mangroves has also been applied for erosion control in Florida (Teas, 1977), and for experimental mangrove biology in Panama and Kenya (Rabinowitz, 1978; Kairo *et al.,* 2001). Mangroves have also been planted to restore forests killed as a result of oil spills (FAO, 1994).

Sustainable management of mangroves has a big potential to increase the mangrove resource base, provide employment to local population, protect fragile tropical coastlines and enhance biodiversity and fisheries productivity. Mangrove afforestation is already proceeding at a large scale in Bangladesh, India and Vietnam principally to provide protection in typhoon-prone areas (Kathiresan and Rajendran**,** 2005), generate direct economic benefits to the people as well as mitigate areas cleared through shrimp aquaculture (FAO, 1994). Many countries in Africa lack programs to manage mangroves due to limited resources and personnel.

1.4. Conservation status of mangroves in Kenya

Mangrove forests in Kenya have been estimated to cover 54,000 ha. distributed all along the 574 km coastline (Doute *et al*., 1982). There are 9 recorded mangrove species in Kenya (Table 1), the principal species being *Ceriops tagal* (Perr.) C. B. Robinson and *Rhizophora mucronata* Lam., which form more than 70% of the forests (Ferguson, 1993). Recent surveys indicate considerable loss of mangrove resources through over-exploitation of resources (Gang and Agatsiva, 1992; Ferguson 1993; Kairo, 2001; Dahdouh-Guebas, *et al*., 2004), conversion of mangrove area to aquaculture and solar salt works (FAO, 1993), and oil pollution (Abuodha & Kairo, 2001). Degradation of mangroves is directly reflected in the increased coastal erosion (Kairo *et al.,* 2001), shortage of building material and firewood (FAO, 1993), and reduction in fishery (Tiensongrusmee, 1991).

Mangrove management in Kenya suffers from inadequate knowledge; of silvilculture of species, of multiple use potentials of resources, and of techniques and economics of natural regeneration and reforestation. There is no management plan for the mangroves in Kenya.

Table 1. Mangroves of Kenya and their uses

Species name	Local Names (Swahili)	Uses
Avicennia marina (Forsk) Vierh.	mchu	Firewood, and poles
Bruguiera gymnorrhiza (L) Lam.	muia	Firewood, charcoal, fencing posts, poles
Ceriops tagal (Perr) C. B. Robinson	mkandaa	Firewood, charcoal, fencing posts, poles
Lumnitzera racemosa (Willd)	kikandaa	Firewood and poles
Sonneratia alba (Sm)	mlilana	Boat ribs, fishing net floats, firewood,, poles
Rhizophora mucronata (Lam.)	mkoko	Firewood, charcoal, poles, tannin, fence posts, fish traps.
Xylocarpus granatum (Koen)	mkomafi	Timber, poles, firewood, traditional medicine
Xylocarpus mollucensis (Lam.) Roem.	mkomafi dume	Firewood, poles
Heritiera littoralis Dryand in Aint	msikundazi	Charcoal, fire wood, poles, boat mast

(Source: Kairo, 2001)

1.5. Objectives of the study

The overall objective of the study was to improve the sustainable management of mangrove forests in Kenya, in order to enhance natural resource productivity, particularly in ways that would sustain continuous flow of desired forest products and services.

1.5.1 Specific objectives

1. Construction of local stand/volume tables for reforested mangroves.
2. Quantification of standing biomass/volume in order to estimate vegetative carbon of the replanted forests.
3. Analyze composition and patterns of natural regeneration in replanted mangroves.

4. Estimate the stock of sedimentary organic carbon in the replanted mangroves.
5. Investigate the feasibility of investing in mangrove reforestation, based on direct economic products and services*.

Objective 5 was conducted as a separate study and a detailed report submitted separately as well (*see.* Kairo and Caroline, 2006)

2.0. DESCRIPTION OF THE STUDY AREA

Mangrove forests in Kenya are found in tidal estuaries, creeks and protected bays scattered all along the coastline, between latitudes 1° 40’S and 4° 25’S and longitudes 41° 34’E and 39 17’E (Fig. 1). The most extensive mangrove forests occur in Lamu and the Tana river districts. Less extensive mangroves are found in Mida, Kilifi, Mombasa and Gazi-Funzi area, close to the Kenya-Tanzania border. Broadly, mangroves in Kenya may be divided into two blocks; area north and south of Tana River. Mangroves north of Tana river are structurally complex than those in the south largely due to the influence of Tana river as well as the East African Coastal Currents (Kairo, 2001). This study was carried out at Gazi bay and Ramisi, in the south coast of Kenya.

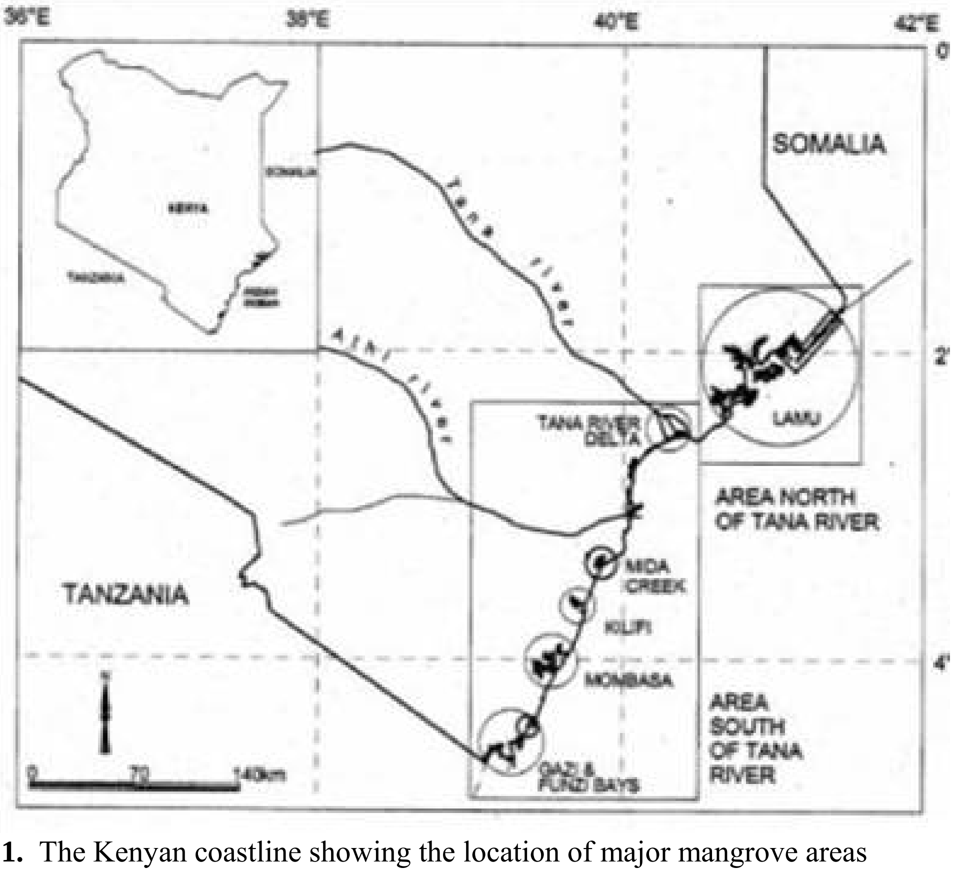


Figure 1. The Kenyan coastline showing the location of major mangrove areas

2.1. Gazi bay

Gazi bay is located at the south coast of Kenya about 50 km from Mombasa in Kwale district (4º 25' S and 39º 30' E). The bay is served by two semi-permanent rivers – River Mkurumudji and Kidogoweni both originating from active agricultural hinterland. Ground water seepage is restricted to a few points in Gazi (Tack and Polk, 1999).

All the 9 species of mangroves described in Kenya are present in Gazi Bay; the dominant species are *Rhizophora mucronata, Ceriops tagal* and *Avicennia marina.* The total area of mangroves in Gazi is approximately 615 ha (Doute *et al*., 1981; Kairo, 2001).

Threats to mangroves of Gazi include over harvesting of mangroves for provision of building poles and firewood. In the period, 1978-1980, some sections of Gazi mangrove forests were clear-cut to provide industrial fuel wood (Abuodha and Kairo, 2001). Recent surveys indicate that 70% of the mangroves of Gazi bay are degraded (Dahdouh-Guebas *et al*., 2004), with some of the affected areas requiring urgent attention.

A pilot reforestation project to rehabilitate degraded mangrove areas, restock denuded mudflats and transform disturbed forests into uniform stands of higher productivity was initiated at Gazi bay in October 1991. Most of the commercially important mangrove species tried, i.e. *Rhizophora mucronata, Avicennia marina*, *Bruguiera gymnorrhiza, Sonneratia alba* and *Ceriops tagal*, proved to be suitable. Initial planting was carried out with a spacing of 1.0 – 1.5 m for propagules and 2.0 m for saplings (Kairo, 1995). By 2004, over 1 million mangrove trees had been planted in degraded mangrove areas of Gazi.

Subsequent development of the reforested areas of Gazi has been studied by examining tree growth and biomass increment (Kairo, 2001; Kairo *et al*., 2001), floral and faunal secondary succession (Bosire *et al.,* 2003; Bosire *et al.,* 2004; Bosire, 2006); and nutrient dynamics (Bosire *et al.,* 2005*)*. The present study investigated structural development and biomass accumulation in approximately 7.0 ha *Rhizophora* plantation established in April 1994.

2.2. Ramisi

Mangrove plantation at Ramisi is situated on the Ramisi river bank, 20 km south of Gazi at Funzi bay (4º 30' S and 4º 39'S). Unlike the fringing mangroves of Gazi, mangroves of Ramisi are riverine, dominated by: *Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal* and *Rhizophora mucronata.* Human induced stresses of the mangroves in Ramisi are similar to those in Gazi. Clear felling operations of the 1970's created huge contiguous blank areas with no natural regeneration to date. Some of the degraded mangrove areas in Ramisi have been recolonized by the giant mangrove fern (*Acrostechum aureum*).

Mangrove planting at Ramisi was carried out in April 1994. At least 13, 000 propagules of *Bruguiera* were planted (Kairo, 1995). Unlike Gazi, no subsequent monitoring has been carried out in the plantations at Ramisi. The present study investigated structural development of this plantation.

3.0. STUDY APPROACH AND METHODOLOGY

3.1. Soil characteristics

Soil samples were randomly collected within 10 x 10 m^2 sub-plots using a 6-cm x 6-cm D-corer. In the laboratory, the samples were weighed and oven-dried for 24 hours at 80^o C after which they were re-weighed to obtain the soil moisture content. About 25 grams of the dry soil sample was subjected to a series of sieves for grain size analysis. Five grams of the remaining sample were oxidized at 455^o C in a furnace for 8 hrs until only inorganic ash was left. What was lost during the oxidation represents the soil organic matter (SOM). Soil organic matter generally contains approximately 56% organic carbon (Brady, 1990). The following equation was used to estimate % soil organic carbon (SOC) from total soil organic matter (Brady, 1990):

$$\% \text{ SOC} = \% \text{ SOM} \times 0.56$$

3.2. Forest structure

Belt transects of 10 m wide were established perpendicular to the waterline. Vegetation was inventoried using standard 10 x 10 m^2 quadrats for adults and 5 x 5 m^2 for juveniles laid along belt transects. A total of 22 quadrats were sampled in Gazi and 10 in Ramisi. All trees with stem diameter greater than 2.5 cm were sampled. Measurements included tree heights (m), stem diameters (cm), measured at 1.30 cm above ground (DBH), and canopy cover (%) (For *Rhizophora* trees stem diameter was taken 30 cm above the highest stilt). From the data, the following parameters were derived; stand density (stems/ha), basal area (m^2/ha), importance value index (IV), and complexity index (C.I), following the procedures explained in Cintron and Schaeffer-Novelli, (1984) and Kairo *et al*., (2002). Stand table data and size class frequency diagrams were prepared for different plantations. Stem quality was assessed based on the form of the lead stem and arbitrarily assigned either form 1, 2 or 3. Form 1 represents most straight poles suitable for building while form 3 represents crooked poles unsuitable for construction (Kairo, 2001)

3.3. Allometric models for determination of plant biomass and volume

3.3.1. *Estimation of plant biomass and vegetative carbon*

In order to be able to estimate total plant biomass and hence vegetative carbon stock in the replanted forests, both above ground biomass (AGB) and below ground biomass (BGB) were estimated. Total plant biomass was obtained by summing AGB and BGB. Vegetative carbon (t C/ha) was calculated from total plant biomass, assuming 50 % of vegetative biomass is carbon (MacDicken, 1997).

3.3.2. *Determination of above-ground biomass (AGB)*

Above ground biomass was estimated using allometric relations between DBH and total plant biomass (Clough and Scott, 1989; Kairo 2001). At least 50 trees of varying diameters were harvested at ground level using handsaws. DBH and heights of all harvested trees were measured.

The aboveground part was separated into stem (trunk), branches, leaves, and in the case of *Rhizophora* prop roots. The total harvested fresh weight of each component was measured in the field, and representative sub-samples were oven-dried to constant weight at 85° C in order to calculate wet-dry weight ratio.

Each sampled individual was then described by its structural parameters and the partitioned (leaves, branches, trunk) and total biomass values. Simple correlations were sought between parameters and the model established for each species applied for all the individuals in the plot. The biomass expansion factor (BEF) was calculated as the ratio of total aboveground biomass to the merchantable volume (Brown, 2002).

3.3.3. *Determination of below-ground biomass (BGB)*

Belowground biomass was estimated using a modified coring method described in Saintilan (1997) whose application is explained by Tamooh (2006). Within 10 x 10 m^2 plots; cores (65 cm length and 15 cm diameter) were made at the parent root base, between and away from the stem as far as the roots from individual stem can possibly extend. A total of 9 cores were made in each stem. Each 10 x 10 m^2 plot had four randomly selected stems making a total of 36 samples per plot. Results obtained were pooled to obtain root biomass per unit ground area.

3.3.4. *Standing volume*

The 50 trees harvested for biomass estimation were also used to develop allometric models for estimating tree volume that was later used to develop volume table. For each of the 50 trees, the butt diameter was obtained at the cutting point. The merchantable stem was divided into 1 m long billets to a top diameter of 2.5 cm; thereafter, the bottom and top diameters of each billet were measured as D_1 and D_2 respectively. The stem volume was estimated using the Smalian formula (FAO, 1994) as:

$$V = (D_1^2 + D_2^2)/2 \times \pi/4 \times L$$

where, V is volume; D_1 and D_2 are bottom and top diameters of the billet respectively;
L is the billet length and $\pi = 3.14$

Specific gravity of different tree components was determined by submerging samples of known mass in water. The volume of water displaced was then divided by mass to obtain specific gravity. To estimate the un-merchantable volume of branches and roots (used locally as firewood), biomass values were multiplied by their specific gravity.

3.4. Composition and pattern of natural regeneration

Linear regeneration sampling (LRS) was used to assess composition and pattern of natural regeneration (Sukardjo, 1987; FAO, 1994; Kairo *et al.*, 2002). Inside 5 x 5 m^2 subplots (within the main 10 x 10 m^2 quadrats), occurrence of juveniles of different species was recorded and grouped according to their height classes and arbitrarily assigned Regeneration Classes (RC) I, II or III. The ratio of RCI: II: III was used to assess the adequacy of natural regeneration (FAO, 1994).

3.5. Primary production

The original idea was to use PAR light attenuation method (Bunt *et al.*, 1979) to estimate canopy productivity. However, lack of a reliable LICOR instrument for PAR measurement as well as the short duration of the project necessitated the use of biomass accumulation rate to estimate stand production.

Leaf area index was determined from 50 leaf samples collected randomly from the forest. Fresh weight of each leaf area was accurately measured and its area was estimated by square grid method. Thereafter, the leaf area-weight relationship was determined and used to compute the leaf area index. Using the leaf area index and the average rate of photosynthesis the net canopy photosynthesis was estimated as:

$$P_N = A \times d \times L$$

where; A is the average rate of photosynthesis (g C m^{-2} leaf area/hr); d is number of hours in a day and L is leaf area index.

The average rate of photosynthesis (A) for *Rhizophora* species has been found to vary between dry (A = 0.216 g C m^2/hour; salinities greater than 35 ppt) and wet seasons (A = 0.648 g C m^2/hour; low salinities) for mangroves in Australia and Southeast Asia (Clough and Sim, 1989). Alongi *et al.* (2004) in Malaysia used *A* values of 0.26, 0.38 and 0.43 g C m^2 leaf area/hour for the 5-, 18-, and 85-year old forests respectively. Therefore, assuming that the average rate of photosynthesis for East African mangroves is similar to that of the mangroves of Southeast Asia and Australia, the empirical value of *A* used for the 12-year old stand at Gazi, was taken to be 0.32 g C m^2/hour.

3.6. Economic analysis

A parallel study on economic analysis of mangrove reforestation was carried out for the replanted *Rhizophora* plantation at Gazi. Economic analysis of mangrove plantation was carried out based on indirect and direct products and services such as; firewood and building poles, coastal protection, ecotourism, research, and education and carbon sequestration.

The expected economic returns of poles and firewood were evaluated using their current market values. The value of mangrove plantations to education and research was calculated using the amount of money allocated to research in the replanted stands at Gazi. Ecotourism benefits were calculated from the net income from a tourist resort operating in Gazi which provided 90 % of the guests who visited the forest in 2005. The value of replanted mangroves to carbon sequestration was calculated using the current carbon offset values in the market, and assuming that 50 % of plant biomass is carbon.

The total benefits and cost of reforestation were subjected to financial analysis. Initial costs (cost for nursery establishment, out-planting and monitoring) and labour cost for other activities such as thinning were considered.

3.7. Data treatment

Data analyses were done using both STATISTICA 7.0 and MINITAB 14.0 software packages. Yield and volume tables were constructed for each of the plantations using EXCEL spreadsheets. Single classification ANOVA was used to compare stocking rates, sedimentary carbon, and natural regeneration in different stands under different silvicultural treatments. Regression models were developed in order to determine the relationship between tree biomass and volume with DBH alone or combined with height.

4.0. RESULTS AND DISCUSSION

4.1. Soil parameters

There was a significant difference ($p<0.05$) in soil moisture, grain sizes and organic matter content amongst soils in the replanted mangroves of Gazi and Ramisi (Table 2). Soil in Ramisi plantations had a higher fraction of silt-clay (76.77 %) than in Gazi (38.24 %). The lowest silt-clay content (15.52 %) was observed in un-reforested plots of Gazi. The percentage of fine sand was higher in the un-forested controls (58.85 %) than in Gazi (41.01 %), and Ramisi (22 %). This was similar to the distribution of coarse sand.

Poor land use practices and deforestation in the hinterlands of Ramisi could be responsible for the high silt content in the plantations. In Gazi plantations, high amounts of silt-clay compared to coarse sand could be as a result of increased sediment accretion function of the replanted *Rhizophora* plantation. The clay contents in Gazi plantations are very much similar to those reported by Bosire *et al.* (2003) in the same area.

High soil organic matter (SOM) in Gazi plantations (31.04 %) could help explain the high moisture content in this plantation (54.50 % of the total weight), as compared to the moisture content in Ramisi (37.79 %) and un-reforested control (8.60 %). SOM values obtained in this study for Gazi plantation are significantly higher than SOM values obtained earlier in the same plantation by Bosire *et al.* (2003). This shows that as mangrove plantation develops it assists in the build up of soil organic matter.

Assuming that soil organic matter contains about 56 % organic carbon (Brady, 1990) we can calculate SOC values of the soils in Gazi and Ramisi using similar assumptions. Soils in the replanted *Rhizophora* plantation in Gazi contained 17.39 % organic carbon compared to Ramisi plantations (4.24 %) and un-forested control at Gazi that had 12.41 %. Although it is easier to deduce why soils in the 12-year old *Rhizophora* plantations had a higher organic matter content, it is difficult to tell why un-forested site in Gazi had higher SOC than Ramisi plantation. The Gazi plantation has built up its soil carbon through accretion process with time. The soils in Ramisi have built up through alluvial deposition and contain significantly higher clay contents than Gazi. Higher clay content could lead to low availability of organic matter, and therefore low organic carbon content.

Table 2. Soil characteristics from Gazi and Ramisi mangrove plantations

Site	Relative grain sizes (%)			Moisture content (%)	%	%
	Silt -clay (<62-µm)	Fine sand (62-500µm)	Coarse sand (500-µm)		Organic matter	Organic carbon
Kinondo	38.24	41.01	20.75	54.55	31.04	17.38
Ramisi	76.77	22.00	1.23	37.8	7.57	4.24
Un-reforested	15.52	58.85	25.63	8.2	22.16	12.41

4.2. Forest structure

4.2.1. Floristic composition and stocking rates

Table 3 provides the structural attributes of the mangroves at Gazi and Ramisi plantations. Based on importance value indices, *R. mucronata* and *B. gymnorrhiza* are the principle species in Gazi and Ramisi respectively. Both species were established as monocultures, however, subsequent developments of the plantations have promoted recolonization of the stands by non-planted species. Colonization of non-planted mangrove species into reforested stands has been confirmed at Gazi plantations by Bosire *et al*., (2003).

Table 3. Structural attributes of a 12-year old mangrove plantations at Gazi and Ramisi

Plantation Area	**Species**	**Relative values (%)**			**I.V**
		Frequency	**Dominance**	**Density**	
Gazi	*B. gymonorhiza*	13.64	0.40	0.97	15.01
	C. tagal	13.64	0.22	2.75	16.61
	R. mucronata	50.00	97.26	94.77	242.03
	S. alba	11.36	0.97	0.71	13.03
	X. granatum	11.36	1.16	0.80	13.31
Ramisi	*B. gymnorhiza*	100	100	100	300

Table 4 provides yield table data for replanted *Rhizophora* and *Bruguiera* in Gazi and Ramisi respectively. The density of *Rhizophora* in Gazi was 4,864 stems/ha, representing more than 94 % of the total stands density. In Ramisi, the standing density for *Bruguiera* plantation was 4,600 stems/ha. Based simply on the stem diameters, one can conclude that 88.5 % of replanted *Rhizophora* in Gazi are of the preferred market sizes. This is much higher than the 22.4 % observed in *Bruguiera* plantations in Ramisi.

Table 4. Yield table data for mangrove plantations at Gazi and Ramisi.

Site	Parameters	Utilization classes (cm)				Total
		Fito < 4.0	*Pau* 4.1-6.0	*Mazio* 6.1-9.0	*Boriti* 9.1-13	
Gazi	Stems/ha	559	1586	2392	327	4864
	*Merchantable volume (m^3 /ha)	1.56	11.63	37.81	9.7	60.71
	Un-merchantable volume (m^3 /ha)					43.09
	Standing biomass (t/ha)	2.35	18.55	66.36	19.39	106.66
	Below ground biomass (t/ha)					24.89
Ramisi	Stem Density/ha	3570	960	70	-	4600
	Volume (m^3/ha)	8.78	5.47	1.12	-	15.37
	Standing biomass (t/ha)	10.23	6.87	1.86	-	18.96

* volume equation used is $y = 0.0000000004x^2+0.00003x+0.00002$, where y = stem volume, and $x = DBH^2H$ (see *also* Table 7)

Compared to the stocking rates of 2,077 stems/ha found in the 'pristine' mangrove stands in Kenya at Kiunga (Kairo *et al*., 2002), the current stocking rates in replanted forests can be said to be excellent. Both Gazi and Ramisi plantations were thinned at 5 and 9 years; and the wood was used for firewood and small sized building poles.

The quality of mangrove poles in the two plantations is much higher than in the adjacent natural stands (Table 5). More than 95 % of the trees in the replanted forests at Gazi and Ramisi are of Quality Class 1 compared to 32.28 % that one would expect in the most 'pristine' mangrove stands such as Kiunga in Lamu (Kairo *et al*., 2002).

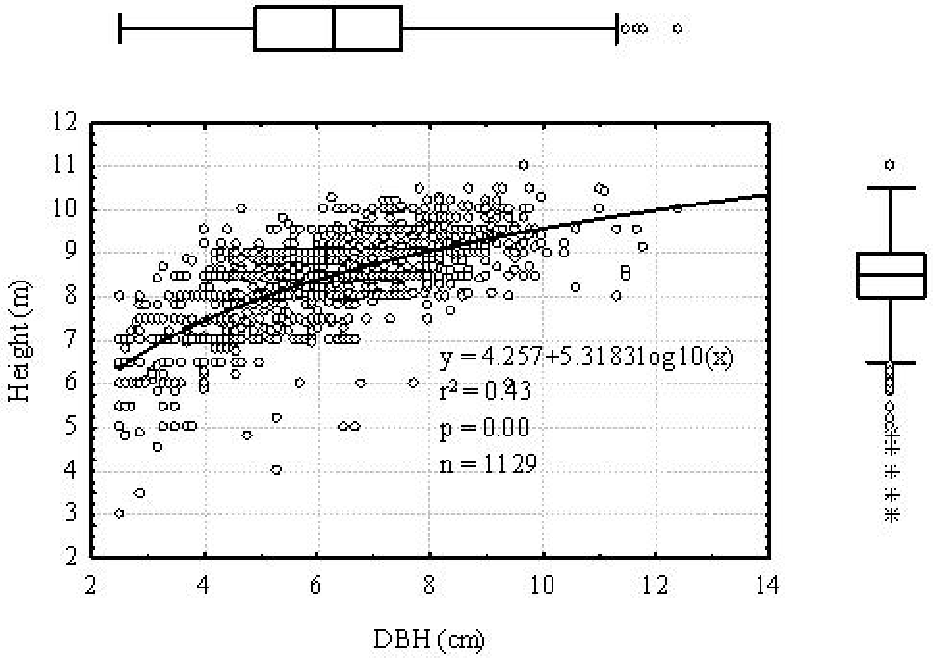
Table 5. Quality of mangrove poles in Gazi and Ramisi plantations.

		Quality Classes			
Site	Species	I	II	III	Total/ha
Gazi	*R. mucronata*	4727	127	9	4864
	%	97.2	2.6	0.2	
Ramisi	*B. gymnorhiza*	4430	90	80	4600
	%	96.3	2.0	1.7	

Figure 2 represents scattergram of height against DBH for Gazi and Ramisi plantations. The mean canopy height of the *Rhizophora* plantation at Gazi was 8.4 ± 1.1 m (range: 3.0 – 11.0 m) with a mean stem diameter of 6.2 ± 1.9 cm (range: 2.5 - 12.4 cm). In Ramisi, canopy height of *Bruguiera* plantation ranged from 2.0 to 6.5 m (mean: 4.7 ± 1.1m) with a mean stem diameter of 3.6 ± 0.8 cm (range: 2.5 - 7.6 cm). There was a significant difference in heights and stem diameters ($p< 0.05$) between the Gazi and Ramisi plantations. The maximum annual height increment (MAI) in *Rhizophora* was 0.92 m/yr compared to 0.54 m/yr in *Bruguiera*. Growth rates for *Rhizophora* compares well with earlier studies by Kairo (2001). Ong *et al*. (1995) reported an average annual height increment of 1.05 m/yr for *Rhizophora apiculata* in Matang forest, Malaysia.

Figure 3 shows histogram displays of diameter class distribution in Gazi and Ramisi plantations. In Gazi, the distribution of replanted *Rhizophora* followed a sigmoid curve (Figure 3 (a)) which is expected for an even-aged forest. Majority of the trees were in the 6.0 to7.0 cm size class. The highest diameter class for *Rhizophora* was 11 – 13 cm. In Ramisi plantation, most of the replanted *Bruguiera* were in the 3.0 – 4.0 size class. The general distribution of the replanted *Bruguiera* show that stems density decreases as diameter increased (Figure 3 (b)). This distribution is a typical reversed ''J'' curves common in natural stands (Kairo *et al*., 2002). The replanted *Bruguiera* could have enhanced natural recruitment of propagules thus a higher density in the lower size class.

(a) Gazi



(b) Ramisi

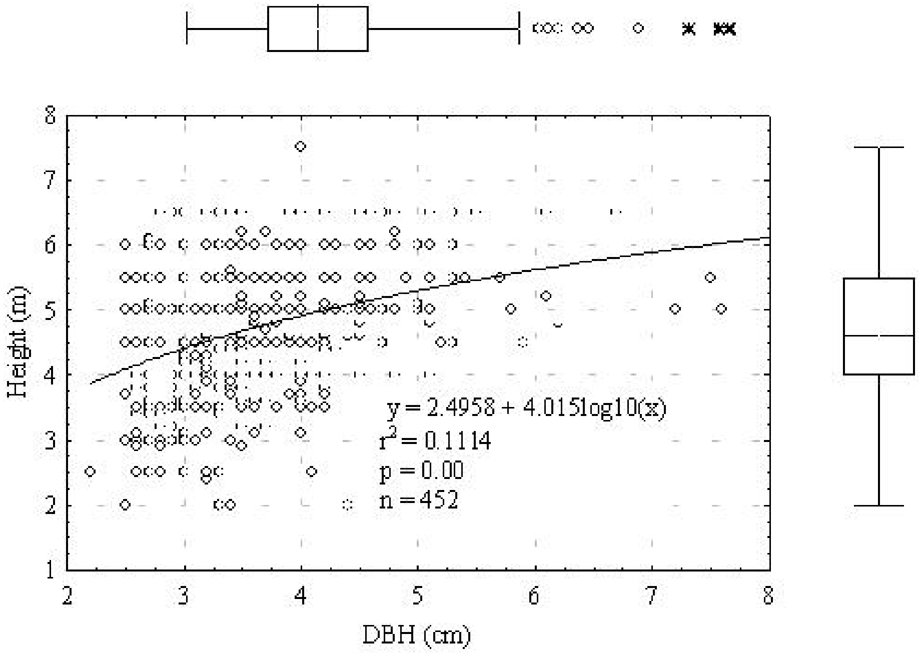
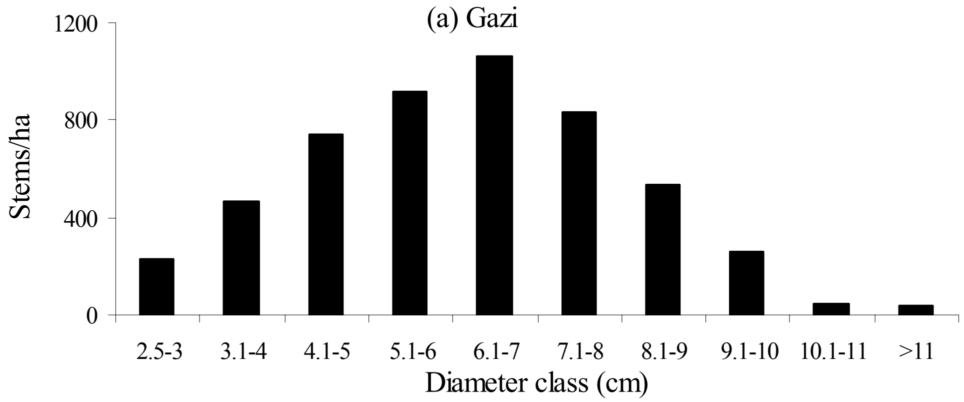


Figure 2. Height-Diameter distribution of 12-year old mangrove plantations (a) Gazi and (b) Ramisi



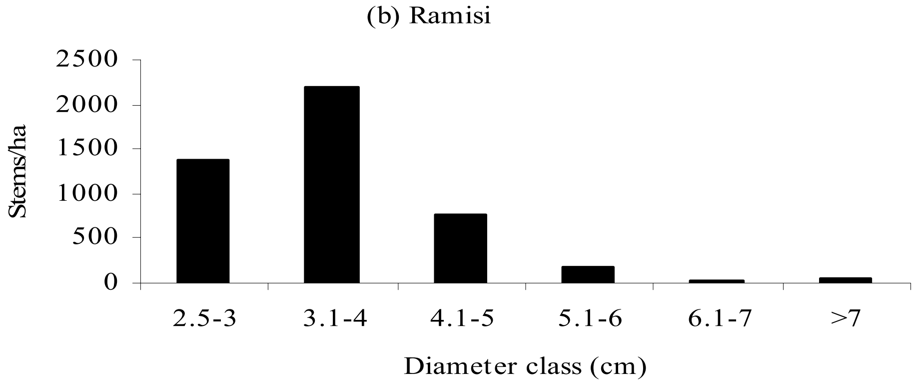


Figure 3. Diameter-class distribution for Gazi and Ramisi plantations.

4.3. Allometric models for determination of plant biomass and volume

4.3.1. Above-ground biomass

The total above-ground biomass in replanted forests was best estimated by 2nd order polynomial equation using Dbh^2H as the independent variable. The biomass equations developed in this study were (*see* also Lang'at, 2006).

R. mucronata

$y_{(AGB)} = 1.6E\text{-}05x^2 + 0.\ 045x + 0.495$

B. gymnorrhiza

$y_{(AGB)} = 1.5E\text{-}04\ x^2 + 0.033x + 0.66$

where; AGB= above ground biomass; $x = DBH^2H$).

Based on these equations the standing biomass of 12-year old *Rhizophora* and *Bruguiera* plantations were 106.66 ton/ha and 18.96 ton/ha respectively (Table **4**). This translates to 53.33 t C/ha and 9.48 t C/ha for the *Rhizophora* and *Bruguiera* stands respectively.

Stem and stilt roots, in *Rhizophora,* accounted for 41.98 % and 30.42 % of the total above ground biomass respectively (Figure 4). The pattern of biomass partitioning in the present study is similar to results obtained when the plantation were 5 years old (Kairo, 2001). A study in a 20-year old *R. apiculata* plantations in Malaysia recorded total biomass (including roots) of 234 t/ha. partitioned as follows; 74 % in stems, 15 % in below-ground roots and stilts and 10.6 % in leaves and branches (Ong, *et al.,* 1995).

Using allometric equations, a biomass table for the 12-yrs old *Rhizophora* plantation was constructed allowing rapid estimation of aboveground tree biomass based on tree height and DBH (Table 6).

Table 6. Biomass table (kg) for replanted *Rhizophora* in Gazi*

DBH (cm)	Height (m)							
	4	5	6	7	8	9	10	11
3	2.72	4.01	5.63	7.60	9.95			
4	3.48	5.24	7.45	10.16	13.43	17.30		
5		6.48	9.32	12.82	17.07	22.16	28.20	
6		7.76	11.23	15.57	20.88	27.28	34.94	
7		9.05	13.21	18.42	24.85	32.67	42.08	53.30
8			15.23	21.37	28.98	38.31	49.62	63.18
9					33.28	44.22	57.56	73.65
10					37.74	50.39	65.90	84.71
11					42.37	56.82	74.64	96.35
12						63.52	83.78	108.58
13							93.32	121.40

*Equation used was: Biomass = 0.00002 $(DBH^2H)^2$ + 0.0454 DBH^2H + 0.495.

The biomass expansion factor (BEF), which is the ratio of total above-ground biomass to merchantable volume was 2.0. The BEF decreased exponentially with increase in stem volume (Figure 5) which is expected for tropical forests (Brown, 2002). The BEF range observed in this study (1.0 to 4.5) is comparable to that reported for tropical hardwoods (Brown, 2002).

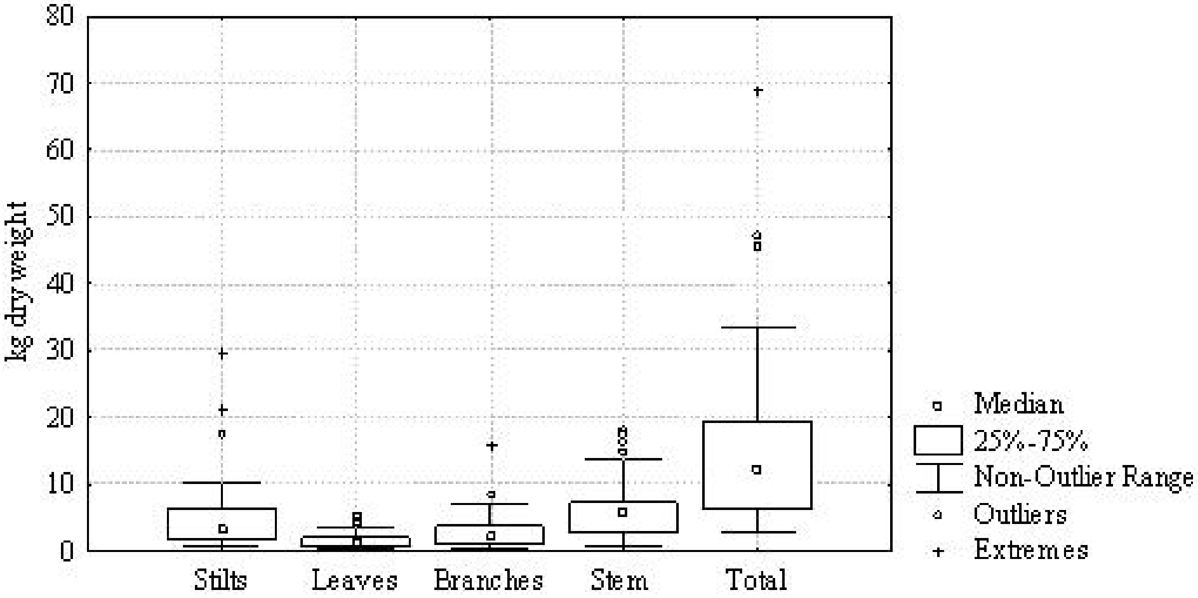


Figure 4. Distribution of above-ground biomass amongst different plant components for *Rhizophora* plantation at Gazi.

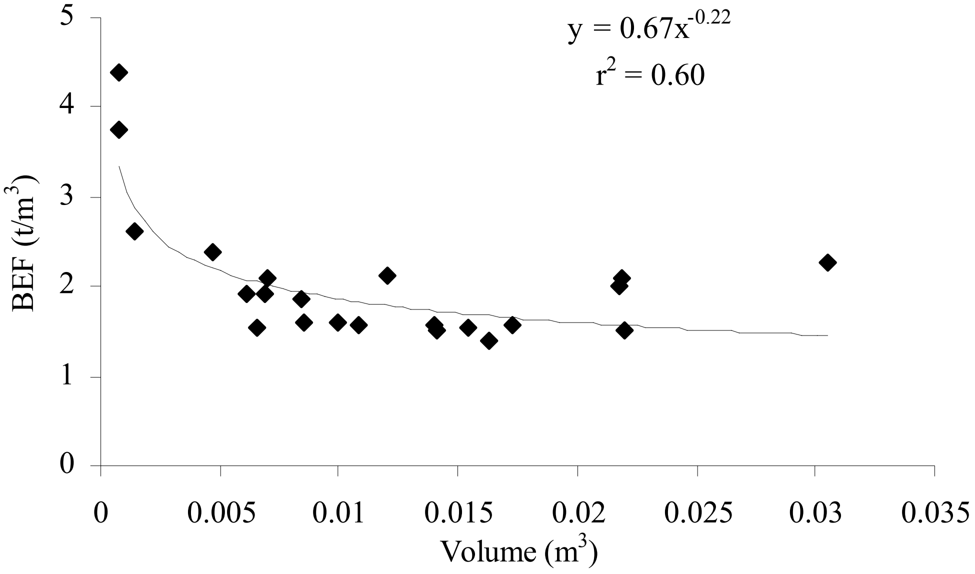


Figure 5. Relationship between BEF and merchantable volume for *Rhizophora* plantation at Gazi

4.3.2. Below-ground biomass

The root biomass value in replanted *R. mucronata* was 24.89 t/ha. Together with the above ground biomass, the total plant biomass of a 12-year *Rhizophora* plantation is 131.56 t/ha, which is equivalent to 65.78 t C/ha. Thus, what is buried below ground of a 12-year *Rhizophora* plantation represents 19 % of the total plant biomass. A review of literature on biomass studies indicates that root biomass values vary from one study to another depending on the method used (e.g. Vogt *et al*., 1998). Our present estimate is in the 9 to 35% range observed for *Rhizophora* studies in Thailand (Alongi and Dixon, 2000).

4.3.3. Standing Volume

Regression models for estimating merchantable and un-merchantable wood volume were developed using DBH^2H as the independent variable (Table 7). The models for Gazi plantation were then used to develop volume tables for replanted *Rhizophora.*

Table 7. Regression models for determination of stem, branch and stilt volume for the *Rhizophora* plantation.

	Equation	r^2
Gazi	$^*y_{(\text{stem vol})} = 4E\text{-}10x^2 + 3E\text{-}05x + 2E\text{-}05$	0.99
	$y_{(\text{branch vol})} = 6E\text{-}09x^2 + 5E\text{-}06x + 9E\text{-}05$	0.99
	$y_{(\text{stilt vol})} = 2E\text{-}08x^2 + 8E\text{-}07x + 6E\text{-}04$	0.99
Ramisi	$y_{(\text{stem vol})} = E\text{-}07x^2 + 3E\text{-}05x + 6E\text{-}04$	0.91

* This equation is equivalent to $y = 0.0000000004x^2+0.00003x+0.00002$; $x = DBH^2H$

Merchantable wood volume for replanted mangrove forests was 60.71 m^3/ha for *Rhizophora* and 15.37 m^3/ha for *Bruguiera* (Table 4). The volume estimated here is less than what one will expect in most natural mangrove stands like Kiunga (465.7 m^3/ha) (Kairo, 2001) and Ngomeni (174.93 m^3/ha) (Bundotich, 2006). However, the volume of *Rhizophora* plantation is significantly higher than the degraded mangroves stands in River Tana (51.17 m^3/ha) (Bundotich, 2006). Considering that the replanted stands have not attained full maturity, there is good opportunity to increase yield of mangrove wood products in Kenya through mangrove reforestation. The un-merchantable volume (branches and stilts) which are utilised by the local communities as firewood had a total volume of 43.09 m^3/ha in Gazi plantations.

To allow quick estimation of wood volume a local volume table was prepared for the replanted *Rhizophora* plantation using 50 trees (Table 8). This table can now be used to estimate tree volume based on DBH and height. The biomass and volume tables are only useful for diameter range in the plantation. However, these tables are expected to be improved as the plantation matures.

Table 8. Volume table (m^3) for replanted *Rhizophora* in Gazi*

		Height (m)							
		4	**5**	**6**	**7**	**8**	**9**	**10**	**11**
DBH (cm)	**3**	0.001	0.002	0.003	0.004	0.006			
	4	0.002	0.003	0.004	0.006	0.008	0.010		
	5		0.004	0.005	0.007	0.010	0.012	0.015	
	6		0.005	0.007	0.009	0.012	0.015	0.018	
	7		0.005	0.008	0.010	0.014	0.017	0.021	0.026
	8			0.009	0.012	0.015	0.020	0.024	0.029
	9					0.017	0.022	0.027	0.033
	10					0.019	0.025	0.030	0.037
	11					0.021	0.027	0.034	0.041
	12						0.030	0.037	0.044
	13							0.040	0.048

*The equation used was $y = 0.0000000004x^2+0.00003x+0.00002$, where y = stem volume, and $x = DBH^2H$

4.4. Composition and pattern of natural regeneration

The density and composition of natural regeneration in Ramisi and Gazi plantations is given in Table 9. The density of juveniles was higher in Ramisi (18,030 saplings/ha) than in Gazi (4,886 saplings/ha). Although majority of the juveniles were of the planted parental canopy, juveniles of non-planted species such as *Bruguiera, Ceriops, Xylocarpus* and *Sonneratia* were also present. Recruitment of non-planted species in monoculture stands of mangroves has been confirmed by Bosire *et al*. (2003). A possible explanation for this could be the creation of microhabitats by growing forests that allow other species to colonize. Whether the recruited species will grow to be mature trees is a subject of another study. The regeneration ratio, RCI: RCII: RC III, obtained in this study (i.e. 5:3:1) is lower than one would expect in a secondary forest undergoing rapid regeneration (*see* e.g. Kairo *et al.,* 2002). Reason for this could be the shading effects created by parental canopy that prevent light from reaching the ground.

Table 9. Juvenile densities in Ramisi and Gazi plantations. Values in parenthesis indicate percentages

		Regeneration classes			
Site	Species	I	II	III	Total/ha
Gazi	*R. mucronata*	2527 (89)	964 (62)	350 (66)	3841
	B. gymnorrhiza	155 (6)	195 (13)	68 (13)	418
	C. tagal	105 (4)	186 (12)	86 (16)	377
	X. granatum	23 (1)	200 (13)	23(4)	245
	S. alba		0	5(1)	5
	Total	2809 (57)	1545 (32)	532 (11)	4886
Ramisi	*B. gymnorrhiza*	3580 (98)	7500 (99)	6740 (99)	17820 (99)
	X. granatum	80 (2)	90 (1)	40 (1)	210 (1)
	Total	3660 (20)	7590 (42)	6780 (38)	18030

4.5. Primary Production

The aboveground biomass increment for the *Rhizophora* plantation was 8.89 t/ha/yr. whereas that of *Bruguiera* plantation was 1.6 t/ha/yr. Together with the belowground biomass, the total biomass accumulation in 12-year old *Rhizophora* plantation was 10.96 t/ha/yr (equivalent to 5.48 t C/ha/yr). Biomass accumulation rates reported here for above ground components are higher than the 5.1 t/ha/yr reported for 80 years old natural plantation of *R. apiculata* in Malaysia (Putz and Chan, 1986). In Matang mangrove forest, Ong *et al*. (1995) reported aboveground biomass increment of 24.48 ton/ha/yr (and 34.0 ton/ha/yr when belowground biomass was included) for 20-year old plantation. It is logical to conclude that biomass accumulation rate is influenced by age, species, management system applied, as well the climate.

Leaf area for *Rhizophora* plantation was linearly correlated to leaf weight using a simple relation of y = 1.7x, (*where;* y = leaf area; x = wet weight (r^2 = 0.91; n = 50). From this relation, the leaf area index (LAI) for the *Rhizophora* plantation was estimated as 3.99. If we assume the average rate of photosynthesis of Gazi mangroves is similar that of mangroves in northern Australia and South East Asia (Clough and Sim, 1989; Alongi *et al*., 2004), we can estimate net canopy photosynthesis of Gazi plantation using LAI as follows:

Let the average rate of photosynthesis per unit leaf area (*A*) be 0.32 g C/m^2/hour

Therefore, net canopy photosynthesis (P_N) = 0.32 g C/m^2/hour x 3.99 x 12 hours
= 15.4 g C/m^2/hour
= 56 t C/ha/yr

Productivity studies in Thailand reported canopy photosynthesis rates for *Rhizophora* ranging from 24.4 t C/ha/yr for 5 yrs old stands to 76 t C/ha/yr for 25 year old stands. Similarly, Alongi *et al.* (2004) reported day time photosynthetic production for 5, 18, and 85 years-old *Rhizophora apiculata* stands as 13, 21 and 35 g C/m^2/day which is equivalent to 47, 76 and 127 t C/ha/yr respectively.

4.6. Economic analysis

Major goods and services from a 12-year old plantation were identified as; firewood and building poles; coastal protection, ecotourism, research and education, carbon sequestration and on-site fishery. The net value of extractable wood products (fuel wood and poles) from the plantation was estimated at US$ 379.17/ha/yr. For non-extractable products, however, the net value ranged from US$ 44.42/ha/yr for carbon sequestration to US$ 770.23 for shoreline protection. The estimated costs of mangrove reforestation and maintenance of the plantation was estimated as US$70.48/ha/yr (Kairo and Caroline, 2006). Therefore, the estimated net benefit of a 12-year old *Rhizophora* plantation is US$ 2902.87/ha/yr (Table 10). For similar parameters analyzed in the present study, Constanza estimated the global value of mangroves as US$3,207 /ha/yr (although shoreline protection and carbon sequestration value were not included) - Table 10. Figures provided in this study can only be viewed as indicative values as detailed Benefit-Cost Analysis requires time and money to achieve. This not withstanding, we can conclude based on the present study that it is economically and socially viable for governments in the region to invest in mangrove reforestation for continued supply of mangrove goods and service. Readers are encouraged to read a separate report by Kairo and Caroline (2006) that details how the entire valuation study was conducted.

Table 10. Summary of the value of mangrove products and services (Value in US$ /ha/yr)

Product & Services	**This study**	Spurgeon (2002)	Meilani (1996)	Sathirathai (1998)	Leong (1999)	Cabrera *et al.* (1998)	Costanza *et al* (1997)
Components Valued	**7**	4	3	4	7	4	5
Area(ha)	**700**	500	481.9	400	379	127000	Global
Site	**Kenya**	Egypt	Indonesia	Thailand	Malaysia	Mexico	
Use Value Fisheries resources	**-**	-	-	83	4991	1578	637
Building poles	**360.67**	-	-			1082	230
Fuel wood	**18.5**	-	-				
Mangrove resources (local direct use)	**-**	-	765	141	102	-	-
Riverine resources	**-**	-	-	-	35	-	-
Aquaculture production	**-**	-	-	-	7,918	-	-
On site fisheries	**113.09**	150					
Education & research	**770.23**	18,000					
Tourism	**9.3**	130,000			915		496
Aquaculture							
Indirect							
Carbon sequestration	**44.42**	-	-	85	-	-	-
Water filtration	**-**	-	-			1193	
Shoreline protection	**1586.66**	1,050	638	3,111	13,842		1701
Nursery habitat	**-**	-	-	-	-	-	143
Preservation value			**1785**	**-**	**33,554**	**1.02**	**-**
Option value			(15)[3]	-	(40,622)	-	-
Existence value			(1,770)		(26,439)	-	-
Bequest value	**-**		-	-	(33,601)	-	-
Total Economic Value	**2902.87**	149,200	3,188	3,420	61,357	2,772	3,207

5.0. CONCLUSION AND WAY FORWARD

Stakeholders interested in mangrove conservation and management will find this document interesting for several reasons:

1. It provides stand table data for the replanted mangroves in Kenya.
2. It provides biomass and volume tables for replanted forest.
3. Based on the stand table data, the rate of biomass accumulation has been estimated for *Rhizophora* and *Bruguiera* plantations.
4. The report provides financial analysis that can guide potential investors interested in mangrove reforestation in their areas.

5. As much as possible the author has tried to compare the results with similar activities elsewhere particularly from South East Asia, Latin America and Australia.

The science of mangrove management is new, not only in Kenya but also in other parts of the world. Recent estimates indicate that about 50 % of the mangroves in Kenya have been lost in the last 50 years (FAO, 2005). Loss of mangroves has affected the local and national economy as indicated by shortage of firewood and building poles, increased coastal erosion and reduction in fishery. Conservation alone is not enough. The degraded mangrove areas must be rehabilitated in order to achieve the objectives of sustainable forest management.

Although this project was for only 6 months; the output achieved will go along way in improving the science of mangrove management in the world in general and Kenya in particular. A list of project output is summarized in Table 11.

Table 11. Magnitude of outputs

Completed Manuscripts

1. Structural development and productivity of reforested mangroves at Gazi bay Kenya – To be submitted to *Forest Ecology and Management.*
2. Allometric Models for estimating Standing Volume and Biomass in a Replanted *Rhizophora* stand in Kenya – To be submitted to *Australian Journal of Marine Sciences*.
3. Economic analysis of replanted mangroves in Kenya – To be submitted to the *Western Indian Ocean Marine Science Association Journal.*

Completed MSc thesis

1. Lang'at J. K. (2006). *Structure, Regeneration and Biomass accumulation of Replanted mangroves at Gazi bay, Kenya*. M.Sc. Thesis. Natural Resources Department, Egerton University, Kenya. Unpublished.

Conference Presentations and Posters

1. Structure, regeneration and biomass accumulation of replanted mangroves at Gazi bay, Kenya. *Poster Presented at the Coastal Ecology Conference IV.* 29 – 31 May 2006. Mombasa, Kenya.
2. Does it pay? Economic analysis of a 12-yr old *Rhizophora* mangrove plantation. *Poster Presented at the Coastal Ecology Conference IV*. 29 – 31 May 2006. Mombasa, Kenya
3. Structural development of a 12-year old *Rhizophora* plantation. Paper accepted for presentation in the 3rd KEFRI Scientific Conference, 6 – 9 November 2006. Nairobi. Kenya.
4. Biomass accumulation in 12 years old *Rhizophora* plantation at Gazi bay Kenya. Paper accepted for presentation in the 7th Congress on Marine Science MarCuba'2006. 4 – 8 December 2006. Havana International Conference Center, Cuba.

Other outputs

1. Training 3 natural resource managers on forest mensuration skills, data analysis and presentation.
2. Establishment of Permanent Sample Plots in the *Rhizophora* and *Bruguiera* mangrove plantations.

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7.0. APPENDICES.

Appendix 1. List of persons working for the project

1. Dr. James G. Kairo – Alcoa Practitioner Fellow
2. Bernard Kivyatu – Forest Inventory Specialist, recruited from the Forest Department
3. Geoffrey Bundotich – Trainee, Natural Resources Manager; Egerton University
4. Caroline Wanjiru – Trainee, Economic valuation
5. Joseph Lang’at – MSc Student; Egerton University, structure and productivity
6. Fredrick Tamooh – MSc Student, Egerton University, root biomass

Appendix 2. Harvest data for *Rhizophora* trees used to derive allometric models

DBH (cm)	**H (m)**	**Above-ground dry biomass (kg)**				**Total**
		Prop root	**Leaves**	**Stem**	**Branch**	
2.9	5.74	0.61	0.65	1.67	0.32	3.24
3.2	4.93	1.01	0.39	0.81	0.49	2.70
3.2	5.53	1.05	0.36	1.48	0.21	3.10
3.7	4.19	0.60	0.50	1.81	0.48	3.38
3.7	5.61	0.63	0.32	1.70	1.05	3.70
3.9	5.05	2.01	0.32	2.23	0.39	4.95
4.0	6.44	1.38	0.71	2.58	0.95	5.62
4.5	6.06	0.95	0.64	2.49	0.93	5.01
4.6	5.82	1.84	0.95	2.16	1.15	6.10
4.6	6.62	2.15	0.73	2.77	1.05	6.70
4.7	7.96	1.52	1.04	6.03	1.23	9.83
4.8	7.77	1.41	1.00	4.24	2.77	9.43
4.8	8.28	2.00	0.67	5.62	1.08	9.38
5.3	8.06	1.89	1.00	5.37	1.83	10.08
5.7	6.99	3.09	2.08	4.83	2.38	12.39
5.7	7.37	4.09	1.76	5.73	3.93	15.52
5.7	7.42	1.79	1.66	5.60	3.14	12.19
5.8	6.32	3.68	0.68	4.06	0.83	9.26
5.8	7.49	6.23	1.59	5.86	2.28	15.96
5.9	6.04	3.51	1.54	4.59	2.03	11.66
6.0	6.94	2.91	1.12	5.80	1.90	11.74
6.4	6.73	2.93	1.89	7.25	5.42	17.48
6.4	7.28	4.51	1.42	5.06	2.37	13.36
6.5	6.27	6.37	1.11	4.90	1.28	13.66
6.5	7.57	4.90	1.81	6.07	3.57	16.35
6.6	7.24	4.50	1.11	6.30	1.67	13.58
6.7	8.01	5.28	1.30	7.28	3.22	17.08
7.3	7.53	10.18	2.88	6.65	3.56	23.26
7.3	8.31	6.87	2.12	9.99	2.38	21.36
7.3	8.35	2.90	2.83	10.68	5.55	21.96
7.7	8.21	6.52	1.86	11.63	3.84	23.85
7.8	8.87	6.78	2.24	13.66	4.40	27.09
8.0	8.89	6.73	3.54	17.99	5.05	33.30
8.7	7.85	21.01	4.09	14.71	7.20	47.02
9.2	8.22	17.30	3.35	16.45	8.67	45.78
9.5	8.60	23.78	6.76	24.16	11.35	66.05
11.5	8.40	29.78	5.47	17.70	15.95	68.90