Structure and Regeneration of Mangrove Forests in Ungwana Bay, Kenya

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Egerton University

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DECLARATION AND RECOMMENDATION

I declare that this is my original work and has never been presented for the award of degree in any other university and that all the sources I have used have been acknowledged.

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ABSTRACT

Mangroves are unique tropical and sub-tropical ecosystems of great economic, ecological, and environmental importance. They are usually found along sheltered coastlines. Worldwide, mangrove ecosystems have been over-exploited and areas previously under mangroves converted for other land uses. In the pilot area of Ungwana bay, the major pressures on mangroves include overexploitation, conversion of mangrove forests into salt works and aquaculture. The aim of the present study was to conduct quantitative assessment of mangroves in Ungwana bay. Forest structure was studied using the quadrat method and was stratified based on aerial photographs at a scale of 1:25,000. Belt transects perpendicular to the shoreline were laid in Kipini, Mto Tana and Ngomeni forests covering different vegetation types. A total of 34 quadrats measuring 10x10 m were studied in 5 transects at Kipini, 116 quadrats in 17 transects at Mto Tana and 44 quadrats in 8 transects at Ngomeni. The seven mangrove species encountered in Ungwana bay are: *Avicennia marina, Bruguiera gymnorrhiza, Ceriops tagal, Rhizophora mucronata, Heritiera littoralis, Sonneratia alba* and *Xylocarpus granatum.* Based on importance values, the dominant mangrove species were *A. marina* and *R. mucronata.* The stand densities in Kipini, Mto Tana and Ngomeni forests were 936, 743 and 2074 stems/ ha respectively. Mangroves in Kipini had the highest basal area (47 m^2ha^{-1}) followed by those in Mto Tana (32.68 m^2ha^{-1}) and Ngomeni (25.73 m^2ha^{-1}). Complexity index (CI) showed that mangroves in Kipini were structurally more complex (CI 41.9) than those in Ngomeni (CI 25.3) and Mto Tana (CI 8.6). There were more seedlings (3848, 25217 and 72262 saplings/ha in Mto Tana, Kipini and Ngomeni respectively) than mature trees (743, 936 and 2074 stems/ha in Mto Tana, Kipini and Ngomeni respectively) in all the forests indicating that normal regeneration occurred. Natural regeneration (> 2500 seedlings/ha) in all sites was considered adequate. In conclusion, Ungwana bay forests are productive. It is recommended that future cutting plans for Ungwana bay mangroves should take into consideration the quantitative data obtained from this study.

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ABBREVIATIONS

DBH (D_{130})	Stem diameter at breast height over back, measured at 130 cm above ground.
FAO	Food and Agriculture Organization of the United Nations
IV	Importance value
KFS	Kenya Forestry Service
KMFRI	Kenya Marine and Fisheries Research Institute
KWS	Kenya Wildlife Services
MASMA	Marine Science for Management program of WIOMSA.
RC	Regeneration class
WIOMSA	Western Indian Ocean Marine Science Association

DEFINITION OF TERMS

Forest: An ecosystem characterized by more or less dense and extensive tree cover.

Forest structure: The architecture of a particular forest. The structure of any given forest is determined in terms of species composition, diversity, tree height, stem diameter, basal area, tree density, and the age-class distributions

Form factor: A constant used when calculating wood volume to account for the tapering of the stem. In this study, we have adopted a form factor of 0.7 calculated for *R. mucronata* by Roberts and Ruara (1967) and Ferguson (1993) on all species.

Linear regeneration sampling: A sampling technique based on systematically laid out lines used to assess regeneration status.

Management plan: A concise plan setting out all the requirements, controls and activities to be applied over space and time in a logical sequence to arrive at the desired objectives.

Merchantable wood resources: Parts of a tree which can be utilized for poles, timber and firewood. In Kenya, mangrove poles are categorized and marketed based on their diameter classes: *fito* (*2-4* cm DBH), *Pau (4-5* cm DBH), *mazio(5-9* cm DBH), *boriti (9-13* cm DBH), *Nguzo(13-20* cm DBH), *banaa(>20* cm DBH).

Propagule: a dispersal unit in mangroves sometimes referred to as a seed.

Sapling: A sprouted propagule more than 1meter tall.

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

Viviparity: Denotes a condition whereby the embryo develops while still attached to the parent plant.

CHAPTER ONE

INTRODUCTION

Mangroves are salt-tolerant woody vegetation found along tropical and sub-tropical coastlines, in sheltered bays, lagoons and estuaries (Tomlinson, 1986). They are among the most productive ecosystems in the world and offer essential ecological and environmental services such as shoreline stabilization (Mazda, 1997), carbon sequestration (Ong, 1993), nursery and feeding ground for marine fisheries (Robert and Duke, 1987). Economically, mangroves provide wood and fishery resources to mankind (FAO, 1994; Dahdouh-Guebas *et al.,* 2000).

On a global scale, mangroves are estimated to cover an area of between 180,000 and 200,000 km^2 (Spalding *et al.*, 1997). However, mangrove cover is fast shrinking mainly due to conversion into agricultural fields, fishponds, saltpans and human settlement (FAO, 1994, Farnsworth and Ellison, 1997). The global loss of mangrove forests has been estimated at 50 % of the original area (FAO, 2005). As a result, there is increased global awareness on the need to sustainably utilize mangrove resources.

Kenyan mangroves are estimated to cover 540 km^2, most of it in Lamu and Tana River Districts (Doute *et al.,* 1981). It is estimated that 70% of the wood requirements by the people living adjacent to mangrove forests are provided by mangroves (Wass, 1995). However, mangroves are continuously being over-exploited and converted for other land uses. This means that the current utilization practices are unsustainable and if left unchecked will result to economic losses to the coastal communities.

There is need to asses the conditions of the remaining mangrove cover in Kenya as a basis for designing and implementing sustainable use practices. Assessment of the forest conditions will facilitate provision of site-specific up-to-date quantitative data, which will guide silvicultural practices. One way of assessing mangrove ecosystem is through assessment of the forest structure (Dahdouh-Guebas, 2001). Knowledge on vegetation structure and regeneration potential of a specific forest is a prerequisite to designing forestry directives like annual allowable cuts and designating specific cutting areas (Caloz and Collet, 1997). Ultimately, structural assessment will contribute to development of sustainable forest management plans (FAO, 1994; Saenger, 2002) which lacks for Kenyan mangroves. This study was designed to asses the structural conditions of mangrove forests in Ungwana bay and complements published data on other Kenyan mangrove forests (Kairo, 2001; Kairo *et al.*, 2002; Bosire *et al.*, 2003; Said *et al.*, 2008; Bosire *et al.*, 2006).

Pioneer surveys had earlier been carried out on some of the Kenyan mangrove forests (Roberts and Ruara, 1967; FD, 1983). However, changes in the mangrove age and consequently the structural characteristics of these forests necessitate the inventory of the current stand stocks (Bosire *et al.*, 2006). The most recent surveys have been carried out in Kiunga (Kairo and Kivyatu, 2000), Mida Creek (Kairo, *et al.*, 2001) and in Gazi bay (Bosire *et al.*, 2003). No, similar studies have been carried out in Ungwana bay, where the only considerable stand of *Heritiera littoralis* in Kenya is found.

The present study was part of MASMA project on assessing the forest structure, fishery production and socio-economic aspects of Ungwana bay mangroves. Therefore, the results obtained will provide a multi-sectoral approach towards the development of sustainable mangrove management plans.

1.1 Statement of the problem

The benefits derived from mangroves in Kenya have declined as evidenced by limited good quality poles, reduced fishery in mangroves, coastal erosion and deterioration of groundwater quality due to salt water intrusion. Judging from this scenario, Kenyan mangroves can be considered degraded and the present mangrove utilization approaches as unsustainable. The situation calls for implementation of sustainable utilization practices. However, there is insufficient up-to-date quantitative information on the extend of the degradation that could be used to formulate sustainable utilization practices.

1.2 Study objectives

1.2.1 Overall objective

Inventorying mangrove wood resources in Ungwana bay as a contribution to sustained supply of mangrove goods and services.

1.2.2 Specific objectives

1. Documenting the floristic composition and distribution of mangrove species in Ungwana bay.
2. Quantifying the standing stocks of mangrove in Ungwana bay.
3. Assessing composition and patterns of natural regeneration in the mangroves of Ungwana bay.

1.3 Research questions

1. What are the species present and their distribution patterns in Ungwana bay?
2. How much standing stock of mangrove wood is available in Ungwana bay mangrove forests?
3. Which species are naturally regenerating and what are their patterns in Ungwana bay mangrove forests?

1.4 Justification of the study

Some of the mangrove forests adversely affected by anthropogenic pressure in Kenya are in Ungwana bay. Mangroves are clear-felled for saltpans expansion, aquaculture establishment and subsistence use. It is estimated that about 100 ha of mangrove area has been converted for aquaculture in Ngomeni area and about 10,000 ha of tidal swamps converted for saltworks between Ngomeni and Karawa areas of Ungwana bay (Abuodha and Kairo, 2001). Such a vast amount of salt production has a harmfull effect on mangroves (Kigomo, 1991).

However, a comprehensive updated information on available yields, natural regeneration, and forest conditions in the study area is lacking. The above information is a necessary prerequisite to the designing of forest management plans which are now a necessity as outlined in the Forest Act (2005). Thus, the current study is designed to provide updated mangrove stand data information and also asses the natural regeneration patterns of the key mangrove species in Ungwana bay.

The information generated from the current study will contribute to the development of mangrove database which will act as a guide to appropriate silvicultural practices. Information on forest regeneration will provide a basis for deciding restoration programmes.

CHAPTER TWO

LITERATURE REVIEW

2.1. Background information

Kenyan mangroves are found in the tidal estuaries and creeks distributed along the 574 km coastline. Estimate of the total area of mangroves varies from 50,000 to 97,000 ha depending on the survey and the author (Doute *et al.*, 1981; FAO. 1991; Spalding *et al* 1997; UNEP-WCMC, 2003). Lamu and Tana River districts contain more than 70 % of the total area on mangroves while less extensive formations are found in Funzi-Shirazi and Vanga areas (Doute *et al.*, 1981).

2.2. Mangrove ecology

Mangrove trees are evergreen and inhabit sheltered shores, between mid tide and high tide levels of the spring tide. Mangrove forests are characterized by a diverse collection of trees and shrubs that have adapted to salty inundated environments (FAO, 1993). The trees range from low, scrubby plants in marginal environments to tall trees reaching 40 m under favorable environments (Tomlinson, 1986). The variations in canopy heights depend on climate, topography, and extend of human disturbance. In most cases, there is absence of reproducing understorey herbs and shrubs in the mangrove forests (Janzen, 1985). Some of the hypothesis developed to explain the absence of understorey vegetation include: evolutionary, metabolic, environmental, and resource availability (Corlett, 1986; Lugo, 1986; Snedaker and Lahmann, 1988). Forest gaps are common in hypersaline areas of the mangrove forests.

Mangrove community is a discrete community but has close relationship to other communities (Tomlinson, 1986). The plant communities often found in the mangrove zone are referred to as “mangrove associates”. They include communities of trees like *Barringtonia, Hibiscus tiliaceus,* and *Thespesia* which grows landwards to the mangrove zone. The landward areas may be occupied by *Ipomoea, Suriana* and *Tournefortia* beach communities. Disturbed and degraded mangrove areas are often occupied by *Acrostichum aureum,* whereas the elevated open-sandy areas are occupied by *Sesuvium portulacastrum* and *Salicornia* species (Kathiresan and Bingham, 2000). *Casuarina* forests may also grow behind mangroves when the soil is sandy and well aerated.

A wide variety of organisms are associated with the mangrove system (FAO, 1993). These include a number of epiphytes, parasites and climbers among the flora, and large numbers of crustaceans, molluscs, fishes and birds among the fauna (FAO, 1993). The fauna associated with the mangrove community is discussed in detail by Macnae (1968). Mangroves have an important detritus-based food chain which supports variety of fish, crustaceans and shellfish (Little *et al.*, 1988).

The main abiotic factors influencing the structure and function of mangrove ecosystem includes: tidal range, freshwater input, soil characteristics, climate, and geomorphology (Thom, 1982). The tidal range in association with the intertidal slope determines the potential extent and structural characteristics (FAO, 1994). Fresh water runoff influences mangrove forest structure, largely through reduction of salinity (Saenger *et al.,* 1983; Tack and Polk, 1999). Hypersaline or drought stressed areas tend to support sparse assemblages of scrubby trees that are short, brittle, and slow growing relative to trees growing in riverine or basin mangrove forests (Lugo and Snedaker,1974).

Soft and generally fine - grained alluvial sediment enhances proper mangrove structural development (FAO, 1994). A saline environment is required for stable mangrove ecosystems, as many species are less competitive under non-saline conditions (Lugo, 1980). High salinity (above 35 ppt) is however harmful to the growth of most mangrove species.

Climatic factors influencing the mangrove community include temperature and rainfall. Mangroves can grow in areas where the air and soil temperature ranges from about 15 - 30 ^{o} C and 20-35^{o} C respectively (Clough, 1992). Thus, their latitudinal limits are controlled by temperature patterns (Blasco, 1984; Dahdouh-Guebas *et al.,* 2001). As much as mangroves do not rely absolutely on rainfall, rainfall determines the rate of mangrove siltation and reduces incidence of hyper salinity (FAO, 1994). Mangrove distribution also follows the dynamics of coastal geomorphology (Thom, 1967).

2.3. Adaptations

Mangroves have evolved structural and physiological adaptations that help them to survive and reproduce in their habitat. They have developed aerial roots under the form of pencil roots (*Avicennia marina*), peg roots (*Sonneratia alba*), knee roots (*Bruguiera gymnorrhiza*), plank roots (e.g. *Xylocarpus granatum*) and prop roots (*Rhizophora mucronata*) for gaseous exchange (Tomlinson, 1986). They also display adaptations of seeds, some form of viviparity and specialized means of seed dispersal in order to ensure successful regeneration. Mangrove trees cope with the salinity problem by excreting excess salts (e.g. *A. marina*), excluding salt uptake (*R. mucronata, Ceriops tagal* and *S. alba),* accumulating salts (*S. alba, Lumnitzera racemosa* and *X. granatum*), and annual leaf fall (Tomlinson, 1986). Most species have got thick leaves with a thick waxy cuticle on the epidermis and others have hairs on the underside of leaves to reduce evapo-transpiration. The stomata are sunken and mostly on the underside of leaves.

Plate 1. A healthy mangrove stand in Lamu, Kenya. (Source: Niko Koedam)

2.4. Zonation

One of the most noted feature in mangrove forest structure is the conspicuous zonation of tree species into monospecific bands parallel to the shoreline (Watson, 1928; Macnae, 1968; Chapman, 1976; Tomlinson, 1986). Zonation patterns have also been noted along the length of an estuary (Smith *et al.,* 1989) such that some species are common at the mouth of the estuary and absent in the fresher, headwater regions of the estuary (Bunt *et al.*, 1982). Zonation is modified by local topography and may be obscured by broad overlap in species distributions (Lugo and Snedaker, 1974). However, zonation may be absent in some mangals (Tomlinson, 1986). Knowledge of zonation and factors influencing it is essential in guiding mangrove restoration through determining the appropriate habitat for preferred species.

Several hypotheses have been formulated to explain mangrove zonation. Zonation has been attributed to response to geomorphological factors (Thom, 1967; Woodroffe, 1992), physiological adaptation to gradients across the intertidal zone (Watson, 1928; Macnae, 1968), differential dispersal of propagule (Rabinowitz, 1978; Van Speybroeck, 1992) and differential predation of propagules (Smith, 1987; Dahdouh-Guebas *et al.,* 1998). Other hypotheses include: response to salinity (Ball, 2002), interspecific competition (Clarke and Hannon, 1971; Ball, 1980), particle size concentration (Clarke and Hannon, 1971; McKee, 1995) and soil sulphide concentration as well as redox potential (Mattijs *et al.*, 2000). The theory of plant succession due to land building (Davis, 1940), has been criticized (Rabinowitz, 1978).

In Kenya, the typical zonation patterns as evident in Gazi bay (Figure 1) shows that *S. alba* grows closest to the low water line, followed by *R. mucronata, B. gymnorrhiza*, *C. tagal*, *A. marina, L. racemosa* and *X. granatum* respectively (Kairo, 1995).

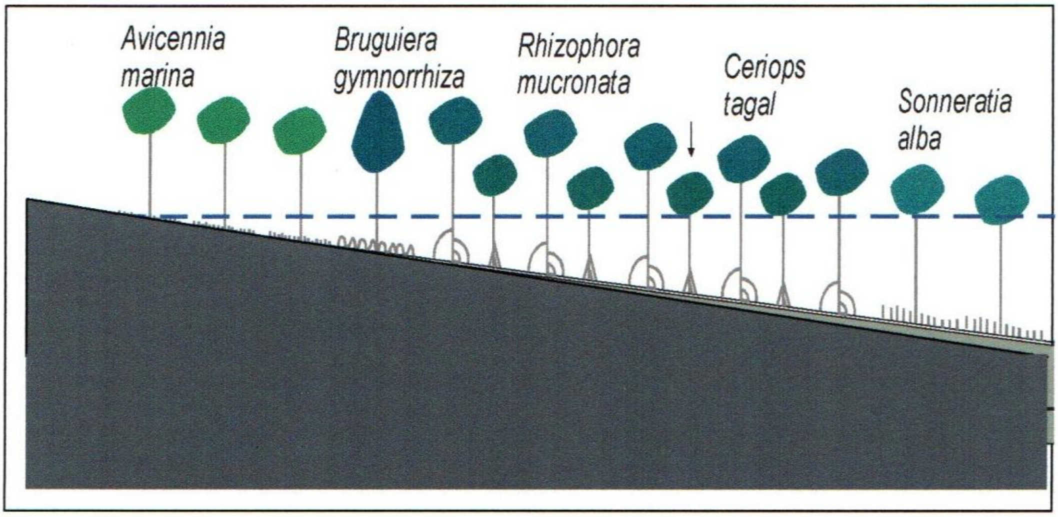

Figure 1. Diagrammatic illustration of mangrove zonation in Kenya. Source: (Mattijis *et al*, 1999)

2.5.Value of mangroves

Mangrove wetlands are multiple use systems that provide protective, productive and economic benefits to human community worldwide. The total economic value of mangroves based on marketable and non-marketable ecosystem components has been approximated to be US$ 181 billion (Contanza *et al.*, 1997; Barbier, 2000). However, mangrove economic values vary according to the location, length of time being considered, beneficiaries of the service, the method used and the assumptions made (UNEP-WCMC 2006).

The economic values of mangrove resources include provision of wood products such as timber, poles, posts and firewood. They are also source of non-wood products such as fodder, medicines, dyes and fishery products (Hamilton and Snedaker, 1984; FAO, 1994). Ecologically, mangroves are spawning grounds for fish and endangered fauna like sea turtles as well as feeding habitats and runways of numerous migratory birds (Saenger, 2002). They also provide habitats for several vertebrates and invertebrates (Kimani *et al.,* 1996). Mangrove forests store high amounts of organic carbon and contribute significantly to the global carbon cycle (Kathiresan and Bingham, 2000). Detritus from mangrove forests to the offshore waters also form an important source of food for microscopic organisms in the food chain (Saenger, 2002).

Environmental values of mangroves include the protection of estuarine shores and lagoons from erosion. Mangroves also control floods and prevent siltation of adjacent sea grass beds and coral reef (Wolanski, 1992). It is now widely accepted that areas without mangrove vegetation along their coastline were the hardest hit by the recent tsunami disaster (Dahdouh-Guebas, 2005; Kathiresan and Rajendran, 2005).

Sustainable management plans should be put in place to sustain the high productivity of mangrove resources. Sustainable use involves either sustainable harvest or sustainable economic returns while at the same time the system can be maintained in as natural or close to its natural status as possible (Saenger *et a*l., 1983). Management policies formulated on the basis of inadequate knowledge of the resource may result in unanticipated and irrevocable loss of valuable mangrove resources (Burbridge, 1984). One of the successfully managed mangrove forests in the word today includes the Sundarbans in India and Bangladesh and the Matang forests in Malasyia.

2.6. Mangrove forest structure

Mangrove forests have been classified according to their structural and functional characteristics (Golley *et al.,* 1962). They have been broadly categorized as; riverine, basin, fringe and dwarf types (Lugo and Snedaker, 1974). A single mangrove area can contain two or more forest types. The structural complexity and productivity of mangrove formations increases as size progresses from the dwarf to the riverine type (Lugo and Snedaker, 1974; Pool *et al.*, 1977; 1982; Twilley, 1995).

Mangrove forest structure is the result of interactions between species responses to abiotic stress factors, disturbance, dispersal and competition (Berger *et al.*, 2006). The magnitude and periodicities of forcing functions such as tides, nutrients, hydro-period and stresses such as cyclones, drought, salt accumulation and frost may largely determine the community structure (Cintron and Schaefer-Novelli, 1984). Seed predation by crabs is also an important determinant of the forest's species composition and structure (Smith, 1987). Similarly, processes of gap-phase dynamics, natural disturbance, and forest mosaics are important in determining mangrove forest structure (Smith, 1987).

Description of a forest structure includes measures of species composition, diversity, stem height, stem diameter, basal area, tree density, and the age-class distributions. Spatial distribution patterns of the component species in the forest may also be included. This may reveal insights about the historical and environmental processes, such as regeneration, climate, mortality and competition, which have shaped current structure (Youngblood *et al.*, 2004). Such knowledge can help facilitate the development of silvicultural systems and management strategies that meet changing objectives and goals for forested lands (Boyden *et al.*, 2005).

One of the simplest forms of forest stand characterization is the measurement of stem diameter at breast height (DBH) which is usually at 1.3 m above ground level (Cintron and Schaeffer-Novelli, 1984). Other characteristics such as height, crown diameter can often be predicted from stem diameter (Cintron and Schaeffer-Novelli, 1984). Maximum DBH of 122 cm has been reported for old growth mangrove forests in U.S.A (Robertson, 1962) and over 60 cm for mangrove forests in Malaysia, Thailand and Micronesia (Putz and Chan, 1986; UNDP/UNESCO 1991; Devoe and Cole, 1998). The American mangroves had a maximum height of 28 m (Robertson, 1962). A maximum DBH of over 80 cm and canopy heights of 35 m has been recorded for mangroves in Kenya (Ferguson, 1993; Kairo, 2001).

2.7. Natural regeneration

An important principle of sustainable forest management is ensuring that an adequate resource of advanced growth natural regeneration survives harvesting operations at the end of rotation. Seed production of mangroves is generally abundant and there are no problems with the natural regeneration of exploited areas provided that sufficient numbers of existing seedlings or new ones survive the consequences of harvesting (Hamilton and Snedaker, 1984).

Linear regeneration sampling (LRS) technique provides an overview of the site regeneration potential in terms of seedling abundance, distribution and sizes (FAO, 1994). Seedlings above 40 cm in height are often referred as "established regeneration", and those below 40 cm height as "potential regeneration" (FAO, 1994). However, this classification should be adapted to local conditions because in species such as *R. mucronata,* propagules may well exceed 40 cm height without being considered as "established regeneration".

Studies in Matang forests in Malaysia suggested that for adequate regeneration, the minimum number of parent trees (standards) should be 12 trees/ha (Tang, 1978). Other studies in the same forest suggested juvenile density of 5,000 to 10,000 as sufficient for regeneration (UNDP/UNESCO, 1991). Chong (1988) suggested that adequate natural regeneration requires a minimum of 2,500 seedlings. Based on above figures, most of the previously studied mangrove forests in Kenya had sufficient natural regeneration capacity (Kairo, 2001; Bosire *et al.,* 2003; Said *et al.*, 2008).

The most important site conditions that influence natural regeneration are the nature of the substrate, age of swamp, inundation class, water salinity, erosion and accretion action of the sea (Hamilton and Snedaker, 1984). Mangrove regeneration is also affected by propagule predation rates (Smith *et al.*, 1989; Dahdouh-Guebas *et al.*, 1998) and removal of over-storey which is detrimental to the light demanding mangrove species. Excessive physical damage during logging as well as excess amount of logging debris also threatens regeneration. Other hazards include absence of standards and weed competition (FAO, 1994). When species with less preferred poles dominate the composition of the regenerated area, or when regeneration is not sufficiently abundant, natural regeneration cannot be relied upon (Hamilton and Snedaker, 1984). One of the silvicultural practices to improve natural regeneration and diameter growth in mangroves is thinning (Devoe and Cole, 1998)b.

2.8. Status of mangroves in Kenya

Nine mangrove species belonging to six families have been recorded in Kenya (Table 1). Two species, *R. mucronata* and *C. tagal* constitute 70 % of the forest formation. The others are *A. marina, B. gymnorrhiza, H. littoralis, L. racemosa, S. alba, X. granatum* and *X. moluccensis* (Kokwaro, 1985).

Mangroves have a wide range of uses in Kenya (Table 1). Historical records indicate that along with the slave and ivory trades, mangrove poles made a major regional trade commodity by the 9^{th} century (Rawlings, 1957). However, overexploitation and degradation of mangrove forests led to a presidential ban on export in 1982. Despite the ban, mangrove deforestation continued in order to satisfy the growing local demand of mangrove wood products (Dahdouh-Guebas *et al.*, 2000; Kairo *et al.*, 2002). This is evidenced by the actual average harvest per year from 1983 to 1993 (average 30 scores/yr), which was similar to that for the period 1941-1956 (average 31.7 scores/yr) (Ferguson, 1993; Figure 2). In 1997, the government banned the exploitation of all natural forests including mangroves but lifted it in 2002 to protect the coastal community's livelihood (Bosire, 2006).

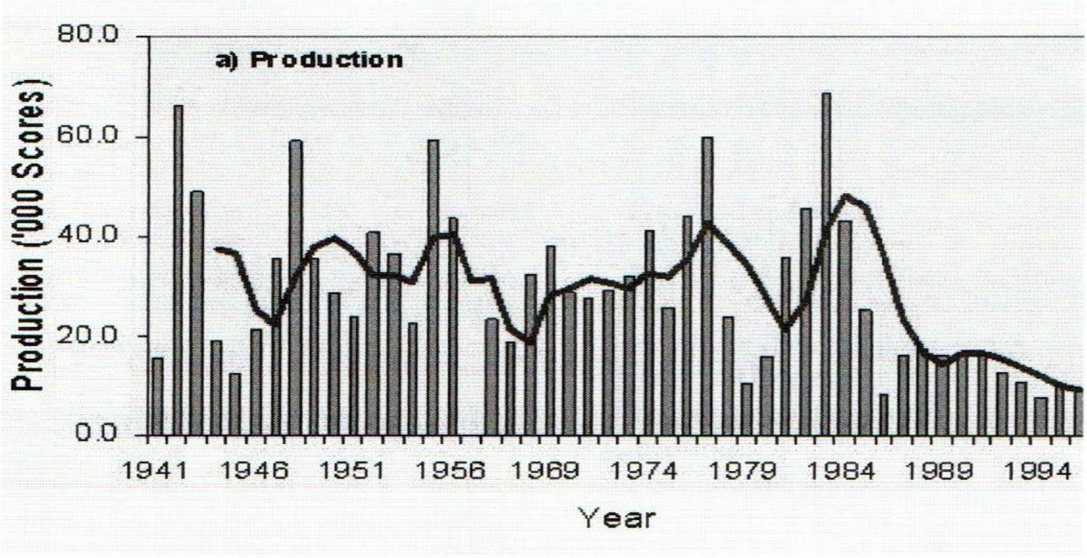

Figure 2. Mangrove trade in Kenya from 1941-1994. Source: Kairo (2001).

The impact of mangrove deforestation in Kenya is reflected in the degradation of forest quality rather than quantity (Kairo, *et al.*, 2002). This translates into a loss in the economic and ecological values of mangrove forests. The pressure to harvest the market-preferred pole sizes (Diameter classes 8-13 cm) has led to structural changes in the mangrove forests whereby the inferior species are replacing the superior ones (Kairo, 2001). Climatic changes, especially the 1997-98 El Nino has also contributed to massive sedimentation in mangrove forests leading to extensive destruction (Bosire, 2006). Such destruction is evident in some areas of Gazi bay.

Some of the underlying factors impeding successful mangrove forest conservation in Kenya include: insufficient quantitative information to guide cutting plans, rising human population along the coast (up to 2.5 million people; GOK, 2008) and lack of adequate trained manpower in the field since most professional foresters focus on terrestrial systems (Waithaka and Mwathe, 2003). Government bureaucracy and meagre budgetary allocation are also to blame (Waithaka and Mwathe, 2003). The enactment of Environmental Management and Co-ordination Act (EMCA) in 1999 and the new Forest Act (2005) which proposes restructuring of the Forest Department is seen as the panacea to the problems dodging forest conservation and management in Kenya. This will promote implementation of sustainable silvicultural practices.

Table 1: Mangrove species found in Kenya and their uses

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

(Source: Dahdouh-Guebas *et al.*, 2000)

Plate 2. A degraded mangrove stand at Ngomeni site in Ungwana bay. Source: Ferguson (1993)

Past studies on mangrove forestry in Kenya have tended to concentrate on distribution (Gang and Agastiva, 1992; Ferguson, 1993), utilization (Kokwaro, 1985; Dahdouh-Guebas, *et al.*, 2000), community composition (FD, 1983; Van speybroeck *et al.*, 1993; Gallin and Beeckman, 1989) and zonation (Graham, 1929; Kokwaro, 1985; Beeckman *et al.*, 1989; Gang and Agastiva, 1992; Ruwa 1993). Regeneration studies include Van Speybroeck (1992). Recent studies have concentrated on specific aspects of the mangrove environment e.g. vegetation dynamics (Dahdouh-Guebas, *et al.*, 2001, Dahdouh-Guebas, *et al.*, 2002, Dahdouh-Guebas, *et al.*, 2004), restoration (Kairo, 1995, Kairo *et al.*,2001, Bosire *et al.*, 2003, 2005, 2006 and 2008), biomass and productivity (Kirui *et al.*, 2006, Tamoo *et al.*, 2008, Kairo *et al.*, 2008), socio economic (Ochiewo, 2005), ecosystem functions (Kirui *et al* ., 2008) and anthropogenic stresses (Abuodha and Kairo, 2001).

Recent quantitative assessment studies have been carried on Kiunga (Kairo and Kivyatu, 2000), Mida creek (Kairo *et al.*, 2002) and Tudor creek (Said *et al.*, 2008). Generally, these structural studies concluded that Kenyan mangroves are composed of nine species, display species zonation in some sites, mostly have sufficient natural regeneration, have site specific structural attributes and are selectively harvested leading to lose of quality. The current study aims at supplementing the quantitative studies so as to obtain a broader picture of Kenyan mangroves.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

Ungwana bay is situated in the northern coast of Kenya, 150 km from Mombasa City. The bay extends from Ras Ngomeni (3° 05′S, 40° 00′ E) in the south to Ras Shaka (4° 01′S, 40° 20′ E) north of Kipini covering a 100-km length along the coast. It lies between and and and Rivers Tana and Sabaki, with annual discharges of $4.7x10^9$ m^3 and $1.3x10^9$ m^3 respectively, discharge into the bay (Angweny,1980). Ungwana bay experiences tropical climate influenced by the monsoon winds in two distinct periods; the northeast monsoon (NEM) from September to February and the southeast monsoon (SEM) from March to August. Annual mean rainfall ranges from 508 mm to 1150 mm with long rains from March to July and short rains from October to December. Annual mean temperatures range from 28 to 32 °C (Maclanahan, 1988). The tidal amplitude ranges from 1.0 to 4.0 m.

Ungwana bay is characterized by the presence of a barrier island with lagoons near the present and former outfalls of the Tana delta (Ferguson, 1993). Mangroves occur along riverbanks, creeks, within sheltered bays and estuaries. A periodic disturbance by river meanders, flooding, and human activity have created a patchy distribution of forest vegetation along Tana River (Medley, 1992). The mangrove forests in the area can be broadly divided into three blocks namely; Kipini, Mto Tana and Ngomeni forests. Mangrove forests in Kipini surround the current mouth of Tana River while those in Mto Tana are near the old mouth. In Ngomeni, fringe mangrove forests occur in several patches separated by creeks and sandbanks. Extensive salt pans and abandoned aquaculture ponds are a common scene in Ngomeni.

3.2 Biodiversity

All the nine species of mangroves in Kenya are found in Ungwana bay (Ferguson, 1993). However, only seven species were encountered during the current study. Mangrove forests in Kipini contain combinations which do not occur elsewhere due to the large and permanent fresh water influx which gradually mix with salt water swamps (Ferguson, 1993). Consequently, the area is dominated by large *A. marina* and combinations of *H. littoralis*, *X. granatum* and *B. gymnorrhiza* species frequently mixed with mangrove associates such as *Barringtonia racemosa* (Ferguson, 1993). *Heritiera littoralis,* which is rare in other Kenyan

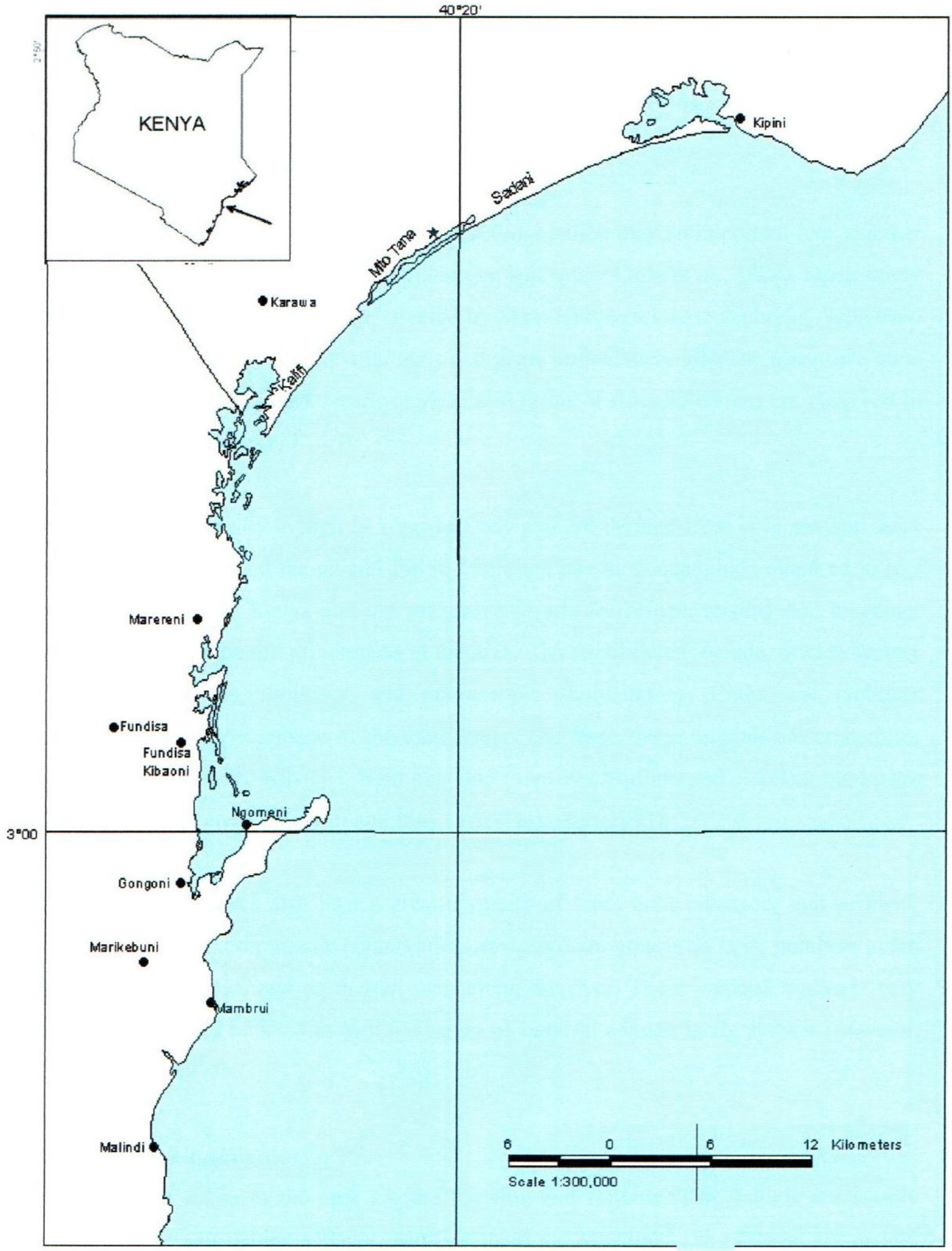

Figure 3. Map of the study area: Ungwana bay. Source: KMFRI (2001).

mangrove forests and grows well under fresh water influence, form mono-stands characterized by tall trees in Kipini. Newly establishing mangroves are found at Mto Tana and are dominated by *A. marina* shrubs with gaps occupied by mangrove-associated species like *Barringtonia racemosa* and *Sueda monoica* (Ferguson, 1993). The dominant mangrove species in Ngomeni is *R. mucronata.*

Other aquatic flora includes sea grass, algae and fungi which play an important role together with bacteria in the rapid breakdown of mangrove leaf litter (Little *et al*., 1988). Open sandy areas that are common in the area are covered by *Sesuvium portulacastrum* herbs, *Salicornia* species, grasses and sedges. Terrestrial trees that grow immediately after the mangrove zone include neem, palms and pines. Nearby agricultural farms of rice and banana are observed in some parts of Ungwana bay.

Mangrove faunal diversity is high in Ungwana bay and are derived from both sea and land. Ferguson (1993) described the animal life in Ungwana bay as outstanding compared to any other mangrove area in Kenya and use mangrove forests for refuge, feeding and breeding. Almost all animal phyla are represented in the area. The small fauna include; a wide variety of crabs, fish, snakes, molluscs, and microscopic zooplanktons. Crabs and molluscs contribute the largest percentage of the total fauna. The major large animals are crocodiles, hippopotamus, buffaloes, baboons, bush pigs and monkeys. Buffalo and elephant marks are frequent in the drier areas in Kipini and Mto Tana (Ferguson, 1993).

Ungwana bay mangroves also host a great diversity of birds both migratory and resident. Piscivorous birds like cormorants (*Phalacrocorax carbo*) are present in large numbers along the sandy shores. Others rest on the tall trees along the river. These wetland birds are very important as they can be used as key indicators of harmful change in the habitat (Martens, 1993).

3.3 Socio-economic activities

The predominant tribes in the area are the Giriama and Bajunis. The Bajunis are mainly fishermen and live in fishing villages. Most of them are Muslims. The Giriama are mainly agro pastoralist but also do some fishing. Salt and mangrove harvesting also form an integral part of their economic activities. The fishing activity here is mainly mangrove and artisanal fishery involving the use of low cost vessels and gears such as outrigger canoes, basic fishing lines and hooks, basket traps, spears, small nets and one or two man boats. The most notable fishing settlements in the Ungwana bay are Kipini and Ngomeni. There is diminishing catches (Ochiewo, 2005) possibly due to increased anthropogenic pressures on the fish habitat. Women are mostly employed as labourers for salt extraction while mangrove harvesting and fishing are male dominated activities (Kairo, 2001). The infrastructure is moderately developed with most of the roads being sandy.

Mangrove cutting for extraction of poles and firewood is widespread in Ungwana bay. Conversion of mangrove forests for aquaculture and salt harvesting is evident in Ngomeni area of Ungwana bay. Salt production has been done in Ungwana bay since 1920 and it is estimated that about 10,000 ha of tidal swamps have been converted for saltworks between Ngomeni and Karawa areas of Ungwana bay (Abuodha and Kairo, 2001). Clear felled areas for expansion of salt pans into the mangrove forests are a common sight in the area. Shrimp farming, which had also been established in Ngomeni, destroyed more than 100 hectares of mangrove area (Abuodha and Kairo, 2001).

3.4 Sampling procedures

3.4.1. Vegetation structure

Ungwana bay mangroves were divided into three subsystems on the basis of their geographical distribution: Kipini, Mto Tana and Ngomeni forests. Vegetation data in each compartment was obtained using stratified sampling technique. This was accomplished with the aid of panchromatic aerial photographs at a scale of 1:25000 and was based on the physiognomy of the vegetation covering as much as possible, most stand conditions. Transects were laid out from the boundaries of the forests and the water edges inwards across the vegetation types already marked on aerial photographs. Vegetation was inventoried using standard 10 x 10 m^2 quadrats for adults and 5 x 5 m^2 for juveniles (randomly placed inside the 10 x 10 quadrats) laid along the transects. The distance between quadrats depended on the variability of the vegetation along the transects. A total of 34 quadrats of 10x10 m were studied in 5 transects at Kipini, 116 quadrats in 17 transects at Mto Tana and 44 quadrats in 8 transects at Ngomeni.

Vegetation parameters measured included tree heights and diameters at over back breast height measured at 1.30 m above ground (DBH). All trees greater than 5 cm DBH in each quadrat were measured identified and position marked. Tree heights were measured using a

Suunto clinometer or a graduated rod for short trees. The stem diameter of *R mucronata* was measured 30 cm above the highest prop roots. Tree basal area (BA) was derived from diameter measurements using the relation:

$$BA = \frac{(\pi \, DBH^2)}{4} \text{ cm}^2 \quad \textit{Where, } \pi = 3.14.$$

The relative density, relative dominance and relative frequency for each species were calculated following the procedures of Cintron and Schaeffer-Novelli (1984) as follows;

Relative density = (No. of individuals of a species/ total no. of individuals) x 100

Relative dominance = (Total basal area of a species/ basal area of all species) x 100

Relative frequency = (Frequency of a species/ sum-frequency of all species) x 100

The Importance value (I.V) for each species was calculated by summing its relative density, relative frequency and relative dominance (Cintron and Schaeffer-Novelli, 1984). Importance values aids in the determination of the relative contribution of each species to the overall stand structure.

The vegetation complexity index (C.I) is used to structurally characterize forest stands to aid in the comparison of different forest types. Complexity index for the study area was obtained by multiplying number of species, basal area (m^2/0.1 ha), maximum tree height (m) and number of stems/0.1 ha x 10^{-3} in a 0.1 ha plot (Holdridge *et al.,* 1971).

Pole quality was assessed based on the form of the lead stem and assigned either Form 1, 2 or 3. Form 1 stems denote those whose lead stem is straight and therefore excellent for construction but Form 2 stems need slight modification to be used for construction. Poles which are unsuitable for construction were assigned Form 3 (Kairo, 2001).

Spatial distribution patterns of trees were analyzed using Morisita's index (I_o) described by Greig-Smith, (1983). Morisita's index is:

$$I_o = q \sum_{i=1}^{q} \frac{Ni\,(n_i-1)}{N\,(N-1)}$$

Where; q is the number of quadrats, n_i is the number of individual species in the i^{th} plot and N is the total number of individuals in all q quadrats. If $I_o>1$, the population is clustered, but when $I_o=1$, the population is randomly dispersed. The population is evenly dispersed when $I_o<1$.

The stand volume of Ungwana bay mangroves was estimated using the following model:

$$V= (\pi d^2/4) \times h \times f$$

Where, V= volume (m^3), π =3.14, d=DBH in cm, h= tree height in m, and f = form factor. The form factor in forestry is determined by the way the stem tapers. In this study, the form factor used was 0.7 calculated for Lamu mangroves (Roberts and Ruara, 1967; Ferguson, 1993).

3.4.2. Linear regeneration sampling

Linear regeneration sampling (LRS) method (Sukardjo, 1987; FAO, 1994; Kairo *et al.*, 2002) was used to assess natural regeneration pattern. The number of juveniles, species and heights were recorded inside 5 x 5 m^2 subplots. Seedlings <40 cm height were classified as regeneration class 1 (RC I) and saplings from 40-150 cm height were classified as RC II. Saplings of >1.5m height but <5cm DBH, were classified as RC III.

3.5 Data analysis and presentation

Data was analyzed using MINITAB 14.0 and Microsoft Excel programmes. General Linear Model (GLM) was used to compare the tree heights along the tidal range, tree density, canopy heights, basal area, density of different pole sizes, density of straight poles and standing volume among the three sites of Ungwana bay. It was also performed to compare the juvenile distributions, density and regeneration classes among Kipini, Mto Tana and Ngomeni. All *Post-hoc* analysis were done using Turkey test.

Stand tables were constructed for Ungwana bay mangroves. These tables are useful in characterizing stand structure in a given area and assessing forest condition. Graphical illustration was employed to present information on species distribution, dispersion and structural characteristics.

Stand density was harmonized using De Liocourt's negative exponential model (Clutter *et al.*, 1983) which states that the ratio between the numbers of trees in successive diameter classes of uneven aged stand is roughly constant. If that ratio is q, then number of trees in successive diameter class is represented by the following sequence:

$aq^{n-1}, aq^{n-1}, aq^{n-2}, \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots aq^{1}, a$

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Results

4.1.1. Species distribution and composition

The distribution of mangrove species is shown in Figures 4 and 5. Mean canopy heights did not follow a consistent pattern with respect to tidal position and across locations. In Mto Tana, trees were tallest (8.5 m mean height) in the low intertidal forest position and tended to decrease with increasing tidal height. Kipini and Ngomeni forests showed tendencies of having the tallest trees (mean heights of 23 and 10 m in Kipini and Ngomeni respectively) occurring in the lower mid-intertidal position, and after which, tree heights decreased on both sides of the forests.

The juvenile's distribution was similar to those of their respective adult species but not in all sites (Figs. 4 and 5). In some cases, juveniles of different species colonized zones occupied by adults of a different species. *Avicennia marina* adults occurred both landwards and seawards while their juveniles were only present landwards in all the three areas. Adults of *C. tagal* occupied the mid zones in all areas and their juvenile distribution was almost similar. *Bruguiera gymnorrhiza's* adult and juvenile distributions resembled that of *C. tagal* except in Mto Tana where juveniles were found in the seaward sites only.

Whenever present, *S. alba* adults and juveniles were often encountered as the first species from the seaward edges followed by *R. mucronata.* Interestingly, *S. alba* juveniles were absent in Kipini despite their adult presence. Adults of *R. mucronata* were found in seaward zones in Mto Tana but were distributed from mid to low tidal points in Kipini and Ngomeni sites. Their juveniles followed a similar pattern except in Kipini where they were restricted to mid zones only. *Xylocarpus granatum's* adult population was mainly concentrated near the water edges, although they were distributed in small clumps throughout the entire transect in Kipini. Their juveniles followed the same pattern in Mto Tana but were found seawards in Kipini and were absent in Ngomeni site. *Heritiera littoralis* were restricted to Kipini where the adults were concentrated landwards but juveniles were found in both seaward and the landward sites.

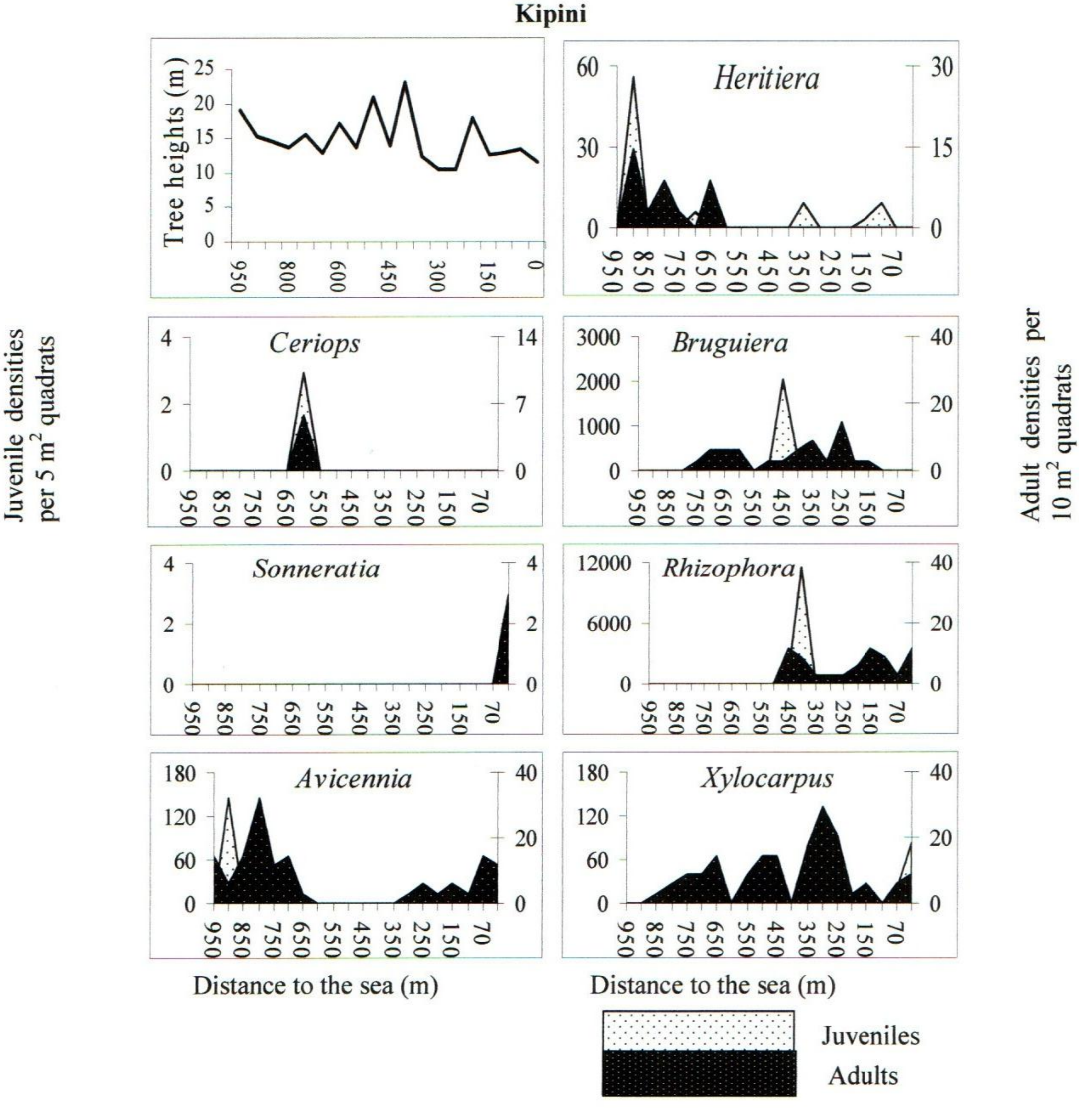

Figure 4: Distribution of mangrove species in Kipini

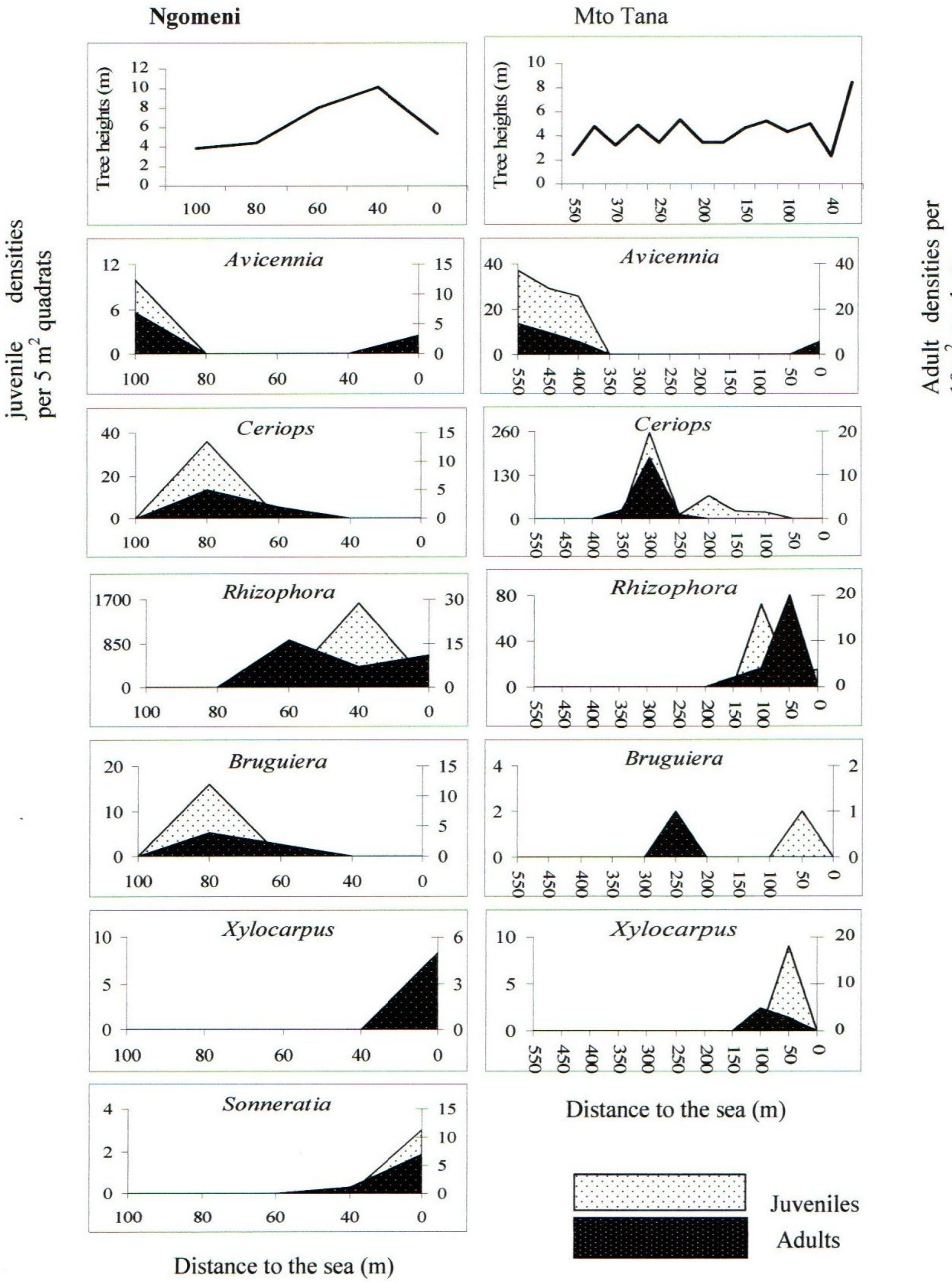

Figure 5: Distribution of mangrove species in Ngomeni and Mto Tana.

The spatial dispersion patterns of adult trees and juveniles for key species obtained using Morisita's index are shown in Figure 6. The species selected were the two dominant each area as specified by the dominance values in Table 2. The dispersion patterns are described along a transect running landwards from the sea edge. *Avicennia marina* and *H. littoralis* adults and juveniles were evenly distributed ($I_o<1$) from the seaward to the most landward edges in Kipini mangroves. The adult *A. marina* and *R. mucronata* populations were evenly distributed ($I_o<1$) in Mto Tana mangroves while their juveniles were clumped ($I_o>1$) at the mid zones but evenly distributed at both the land and water edges. In Ngomeni site, *A. marina* and *R. mucronata* adult and juvenile populations were evenly distributed ($I_o<1$) throughout the transects.

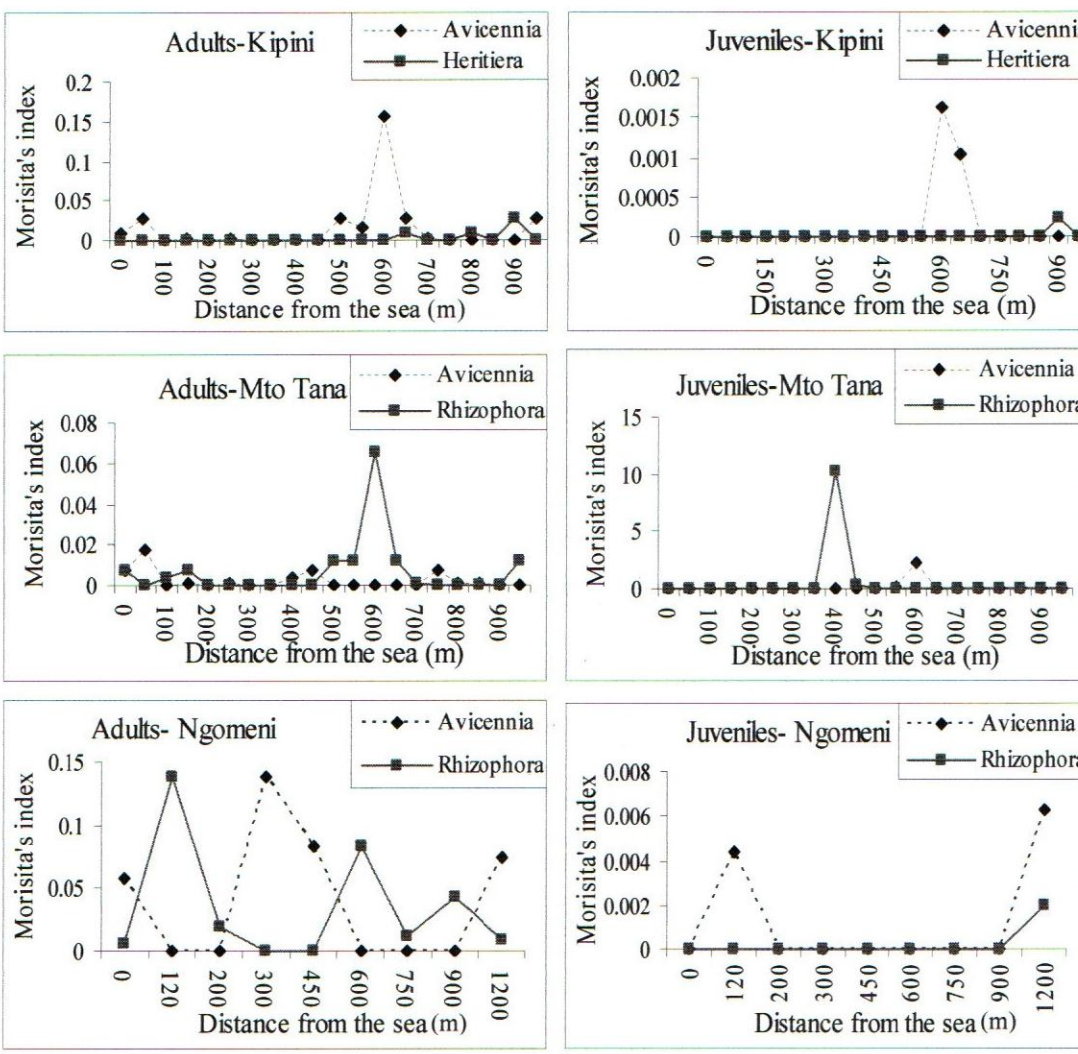

Figure 6: Values of Morita's index along the intertidal zone for the key mangrove species in Ungwana bay

4.1.2. Tree Structural Characteristics within the sites

The structural characteristics of the mangroves are shown in Table 2. The number of species recorded was seven in Kipini, six in Ngomeni and five in Mto Tana. In Kipini, *A. marina* tree density (359 stems/ ha) was significantly greater ($p < 0.05$) compared to that of the other species. The tree densities were not significantly different ($p > 0.05$) among the following groups of species; *X. granatum* (197 stems/ha) and *H. littoralis* (174 stems/ha), R. *mucronata* (106 stems/ha) and *B. gymnorrhiza* (88 stems/ha), *C. tagal* (9 stems/ha) and *S. alba* (3 stems/ha). However, the differences between the groups were significant ($p < 0.05$).

Stand density for *A. marina's* (583 stems/ha) was significantly greater ($p < 0.05$) in Mto Tana compared to that of other species. Tree densities of the other species were similar ($p > 0.05$) and were in the following ascending order; *R. mucronata* (80 stems/ha) > *C. tagal* (44 stems/ha)> *B. gymnorrhiza* (22 stems/ha) >*X. granatum* (14 stems/ha).

In Ngomeni, the density of *R. mucronata* (781 stems/ha) was significantly greater ($p < 0.05$) compared to that of *A. marina* (560 stems/ha) and *C. tagal* (506 stems/ha) whose tree densities were also significantly greater to that of *B. gymnorrhiza* (135 stems/ha) and *S. alba* (84 stems/ha). The density of *X. granatum* was 8 stems/ha' which was significantly lower than the other species in the area.

The mean tree heights ranged from 8.0 ± 1.7 m (*C. tagal*) to 16.3 ± 5.8 m (*R. mucronata*) in Kipini. The mean heights of *R. mucronata, S. alba* (16.0 ± 0 m) and *H. littoralis* (15.7 ± 7.2 m) were not significantly different ($p > 0.05$) from each other but were significantly greater ($p < 0.05$) than those of *A. marina* (13.8 ± 7.5 m), *B. gymnorrhiza* (13.2 ± 6.1 m), *X. granatum* (11.8 ± 5.0 m) and *C. tagal* (8 ± 1.7 m).

In Mto Tana, the average tree heights ranged from 5.5 ± 2.3 m (*X. granatum*) to 9.3 ± 2.9 m (*R. mucronata*). The mean heights of *R. mucronata and B. gymnorrhiza* (8.2 ± 2.5 m) were similar ($p > 0.05$) but were significantly greater ($p < 0.05$) than those of *A. marina* (6.6 ± 3.1 m), *C. tagal* (6.4 ± 2.2 m) *and X. granatum* (5.5 ± 2.3 m).

Table 2: Structural characteristics of mangrove forests in Ungwana bay.

Site	Species	Tree density (stems/ha)	Mean tree height (m) (± s.d)	Basal area (m^2/ha)	Relative values (%) Frequency	Dominance	Density	I.V (%)
Kipini	*A. marina*	359 [a]	13.8±7.5 [a]	19.3 [a]	25.9	40.9	38.4	105.3
	H. littoralis	174 [d]	15.7±7.2 [b]	14.2 [b]	14.9	30.1	18.6	63.5
	X. granatum	197 [d]	11.8±5.0 [a]	5.8 [b]	20.9	12.3	21.1	54.3
	R. mucronata	106 [b]	16.3±5.8 [b]	5.4 [b]	17.3	11.4	11.3	40.0
	B. gymnorrhiza	88 [b]	13.2±6.1 [a]	2.4 [b]	17.3	5.1	9.4	31.7
	S. alba	3 [c]	16±0 [b]	0.1 [b]	1.2	0.1	0.3	1.7
	C. tagal	9 [c]	8±1.7 [a]	0.1 [b]	2.5	0.1	0.9	3.5
Mto Tana	*A. marina*	583 [a]	6.6±3.1 [b]	23.9 [a]	64.1	73.0	78.5	215.6
	R. mucronata	80 [b]	9.3±2.9 [a]	5.5 [b]	9.2	16.9	10.7	36.8
	B. gymnorrhiza	22 [b]	8.2±2.5 [a]	1.3 [c]	7.6	3.9	2.9	14.5
	C. tagal	44 [b]	6.4±2.2 [b]	1.3 [c]	16.0	3.8	5.9	25.8
	X. granatum	14 [b]	5.5±2.3 [b]	0.8 [c]	3.1	2.3	1.9	7.3
Ngomeni	*R. mucronata*	781 [a]	8.0±4.7 [a]	12.7 [a]	33.7	51.2	39.5	124.3
	A. marina	560 [b]	6.5±3.4 [b]	6.9 [b]	24.6	27.7	27.9	80.2
	C. tagal	506 [b]	4.1±1.8 [c]	2.9 [c]	24.1	11.2	23.1	58.4
	B. gymnorrhiza	135 [c]	8.3±4.9 [a]	1.7 [d]	11.9	6.7	6.7	25.6
	S. alba	84 [c]	6.9±2.4 [b]	1.4 [e]	9.5	6.1	4.9	20.6
	X. granatum	8 [d]	5±0 [c]	0.1 [e]	1.8	0.3	0.4	2.5

Means in a column within a site followed by superscripts differ ($p < 0.05$)

I.V= Importance Value

The mean heights of *B. gymnorrhiza* (8.3 $\pm$ 4.9 m) and *R. mucronata* (8.0 $\pm$ 4.7 m) in Ngomeni were significantly greater ($p < 0.05$) than those of *S. alba* (6.9 $\pm$ 2.4 m) and *A. marina* (6.5 $\pm$ 3.4 m). Mean heights of the latter two species were significantly greater ($p < 0.05$) than those of *X. granatum* (5.0 $\pm$ 0 m) and *C. tagal* (4.1 $\pm$ 1.8 m).

The basal area of *A. marina* (19.3 m^2/ha) in Kipini was significantly greater ($p < 0.05$) than those of the other species. There was no significant difference ($p > 0.05$) in the basal areas of *H. littoralis* (14.2 m^2/ha), *X. granatum* (5.8 m^2/ha), *R. mucronata* (5.4 m^2/ha), *B. gymnorrhiza* (2.4 m^2/ha), *S. alba* (0.1 m^2/ha) and *C. tagal* (0.1 m^2/ha).

In Mto Tana, the basal area of *A. marina* (23.9 m^2/ha) was significantly greater ($p < 0.05$) compared to that of *R. mucronata* (5.5 m^2/ha) which was the second most dominant species. *Rhizophora mucronata* basal area was also significantly greater ($p < 0.05$) than those of *B. gymnorrhiza* (1.3 m^2/ha), *C. tagal* (1.3 m^2/ha) and *X. granatum* (0.8 m^2/ha) whose basal area was similar ($p > 0.05$).

The basal area of *R. mucronata* (12.7 m^2/ha) was significantly greater ($p < 0.05$) compared to that of other species in Ngomeni. The basal area for *A. marina* (6.9 m^2/ha) was also significantly greater ($p < 0.05$) than that of *C. tagal* (2.9 m^2/ha) whose area was significantly greater ($p < 0.05$) that that of *B. gymnorrhiza* (1.7 m^2/ha). The basal area for *S. alba* (1.4 m^2/ha) and *X. granatum* (0.8 m^2/ha) were the least and were not significantly different ($p > 0.05$).

Based on species Importance Value (I.V), *A. marina* was found to be the most dominant species in Kipini and Mto tana with I.V values of 105.2 and 215.6 respectively. *Rhizophora mucronata* had the highest I.V value in Ngomeni. The species with the least Important Values were *S. alba* in Kipini (1.6) and *X. granatum* in both Mto Tana (7.3) and Ngomeni (2.5).

4.1.3. Tree Structural characteristics among the sites.

The stand density in Ngomeni (2074 stems/ha) was significantly greater ($p < 0.05$) than that in Kipini (936 stems/ha; Table 3). Mangroves in Kipini had a significantly greater stand density ($p < 0.05$) than those in Mto Tana (743 stems/ha).

Trees in Ngomeni were the shortest. The mean tree heights ranged from 6.5 $\pm$ 3.9 m in Ngomeni to 13.6$\pm$ 6.6 m in Kipini (Table 3). The trees in Kipini were significantly taller ($p < 0.05$) than that in the other two sites. Average tree heights were similar ($p > 0.05$) in Ngomeni and Mto Tana sites.

The basal areas of mangroves were 47.0, 32.68 and 25.73 m^2/ha in Kipini, Mto Tana and Ngomeni sites respectively. Mangroves in Kipini had a significantly greater ($p < 0.05$) basal area than those in the other two sites. Mangrove basal areas in Mto Tana and Ngomeni were similar ($p > 0.05$).

Kipini mangroves were the most developed structurally, with complexity index (CI) of 41.9 followed by those in Ngomeni (C.I value of 25.3) whereas Mto Tana was the least structurally developed mangrove forest (C.I of 8.6).

Table 3: Comparison of the mangrove structural characteristics in Ungwana bay forests.

Site	No. of species	Tree density (stems/ha)	Mean height (m) ($\pm$s.d)	Basal area (m^2/ha)	Complexity Index
Kipini	7	936^a	13.6 ± 6.6^a	47.0^a	41.9
Mto Tana	5	743^b	6.9 ± 3.0^b	32.7^b	8.6
Ngomeni	6	2074^c	6.5 ± 3.9^b	25.7^b	25.3

Means in column followed by different superscripts differ ($P<0.05$)

4.1.4. Stocking rates and volume

The stocking rates of different mangrove species in the study area is shown in Table 4. In Kipini, category 5-9 cm DBH poles (94 stems/ha) for *A. marina* were significantly more ($p <0.05$) than those of *X. granatum's* (59 stems/ha) and *B. gymnorrhiza's* (33 stems/ha). Those of *R. mucronata* (12 stems/ha) *C. tagal* (6 stems/ha) and *H. littoralis* (3 stems/ha) were significantly lower ($p<0.05$). There were no *S. alba* mangroves within this category.

Table 4: Stand table for mangrove forests in Ungwana Bay

Site	Species	Stems per hectare per diameter class. 5.0-9.0 cm DBH	9.1-13.0 cm DBH	13.1-20.0 cm DBH	20.1-35.0 cm DBH	>35.0 cm DBH	Volume (m^3/ha)
Kipini	*A. marina*	94 [a]	24 [a]	55 [a]	156 [a]	29 [a]	253.6 [a]
	H. littoralis	3 [c]	29 [a]	35 [a]	76 [a]	29 [a]	148.5 [a]
	R. mucronata	12 [c]	12 [a]	24 [a]	38 [a]	21 [b]	74.5 [b]
	X. granatum	59 [b]	41 [a]	50 [a]	35 [a]	12 [b]	67.3 [b]
	B. gymnorrhiza	33 [b]	18 [a]	9 [b]	21 [b]	9 [b]	29.3 [c]
	S. alba	*	*	3 [b]	*	*	0.5 [d]
	C. tagal	6 [c]	3 [b]	*	*	*	0.3 [d]
	Total	207	103	200	326	100	573.9
Mto Tana	*A. marina*	345 [a]	125 [a]	86 [a]	23 [a]	4 [a]	35.6 [a]
	R. mucronata	32 [b]	13 [b]	21 [b]	13 [a]	1 [a]	10.7 [b]
	B. gymnorrhiza	6 [c]	7 [b]	6 [c]	3 [b]	*	2.2 [c]
	C. tagal	32 [b]	8 [b]	3 [c]	1 [b]	*	1.7 [c]
	X. granatum	9 [c]	1 [c]	2 [c]	2 [b]	*	1.0 [c]
	Total	425	154	118	43	5	51.2
Ngomeni	*A. marina*	289 [a]	110 [a]	131 [b]	26 [b]	4 [a]	62.4 [b]
	R. mucronata	265 [a]	185 [a]	206 [a]	125 [a]	*	71.9 [a]
	B. gymnorrhiza	67 [b]	22 [c]	31 [c]	15 [b]	*	13.7 [d]
	S. alba	*	31 [c]	53 [c]	*	*	2.7 [d]
	C. tagal	381 [a]	94 [b]	27 [c]	4 [c]	*	24.2 [c]
	X. granatum	3 [b]	*	3 [d]	2 [c]	*	0.1 [e]
	Total	1006	445	453	173	4	174.9

* No mangroves within this category

Values in brackets represent percentages.

Means in a column followed by different letters ([a,b…]) differ ($p<0.05$)

The 9.1-13.0 cm category of poles in Kipini for *X. granatum* (41 stems/ha), *H. littoralis* (29 stems/ha), *A marina* (24 stems/ha), *B. gymnorrhiza* (18 stems/ha) and *R. mucronata* (12 stems/ha) were similar ($p < 0.05$) but significantly fewer ($p < 0.05$) *C. tagal's* (3 stems/ha) poles were recorded. There were no *S. alba* poles in this category.

In Kipini, *A marina* (55 stems/ha), *X. granatum* (50 stems/ha), *H. littoralis* (35 stems/ha) and *R. mucronata* (24 stems/ha) 13.1-20.0 cm DBH poles were significantly more ($p < 0.05$) compared to those of *B. gymnorrhiza* (9 stems/ha) and *S. alba* (3 stems/ha). There were no *C. tagal* poles of this category. In the category 20.1-35.0 cm DBH poles, *A marina* (156 stems/ha) poles were significantly greater ($p < 0.05$) than those of *H. littoralis* (76 stems/ha), *R. mucronata* (38 stems/ha) and *X. granatum* (35 stems/ha). Those of *B. gymnorrhiza* (9 stems/ha) were significantly fewer ($p<0.05$). There were no *C. tagal* and *S. alba* poles in this category. In the > 35 cm DBH category poles, Kipini mangroves had significantly more ($p < 0.05$) *A. marina* (29 stems/ha) and *H. littoralis* (29 stems/ha) poles compared to those of *R. mucronata* (21 stems/ha), *X. granatum* (12 stems/ha) and *B. gymnorrhiza* (9 stems/ha). No stem of this size were recorded for *C. tagal* and *S. alba*.

In Mto Tana, 5.0-9.0 cm DBH poles for *A. marina* (345 stems/ha) were significantly more ($p < 0.05$) than those of other species. Those of *R. mucronata* (32 stems/ha) and *C. tagal* (32 stems/ha) were in turn significantly greater ($p < 0.05$) than those of *X. granatum* (9 stems/ha) and *B. gymnorrhiza* (6 stems/ha). The 9.1-13.0 cm DBH size poles were also significantly more ($p < 0.05$) for *A marina* (125 stems/ha) compared to those of *R. mucronata* (13 stems/ha), *C. tagal* (8 stems/ha) and *B. gymnorrhiza* (7 stems/ha) while *X. granatum* had the lowest ($p < 0.05$) number of poles (1 stem ha^{-1}). The 13.1-20.0 cm DBH size poles were also significantly more ($p < 0.05$) for *A marina* (86 stems/ha). The number of *R. mucronata* (21 stems/ha), were second highest ($p < 0.05$) followed by those of *B. gymnorrhiza* (6 stems/ha), *C. tagal* (3 stems/ha) and *X. granatum* (2 stems/ha) which were materially similar ($p > 0.05$). In the 20.1-35.0 cm DBH pole category, *A marina* (23 stems/ha) and *R. mucronata* (13 stems/ha) poles were significantly greater ($p < 0.05$) than those of *B. gymnorrhiza* (3 stems/ha), *X. granatum* (2 stems/ha) and *C. tagal* (1 stem ha^{-1}). The largest size poles (> 35.0 cm DBH) recorded for *A. marina* (4 stems/ha) and *R. mucronata* (1 stem ha^{-1}) were similar ($p > 0.05$).

In Ngomeni, *C. tagal* (381 stems/ha), *A marina* (289 stems/ha) and *R. mucronata* (265 stems/ha) 5.0-9.0 cm DBH poles were significantly more ($p < 0.05$) than those of *B. gymnorrhiza* (67 stems/ha) and *X. granatum* (3 stems/ha). There were no *S. alba* poles in this category. In the 9.1-13.0 cm DBH size poles category, *R. mucronata* (185 stems/ha) and *A marina* (110 stems/ha) poles were significantly more ($p < 0.05$) than those of the other species present. In 13.1-20.0 cm DBH size poles, there was significantly more ($p < 0.05$) *R. mucronata* poles (206 stems/ha) followed by those of *A marina* (131 stems/ha). Poles of *S. alba* (53 stems/ha), *B. gymnorrhiza* (31 stems/ha) and *C. tagal* (27stems/ha) were similar ($p > 0.05$) while *X. granatum* had significantly the lowest ($P < 0.05$) number of poles (3 stem ha^{-1}). *Rhizophora mucronata* poles (125 stems/ha) were also significantly more ($p < 0.05$) than those of other species in the 20.1-35.0 cm DBH pole size category. This was followed by those of *A. marina* (26 stems/ha) and *B. gymnorrhiza* (15 stems/ha) which were significantly more ($p < 0.05$) than those of *C. tagal* (4 stems/ha) and *X. granatum* (2 stems/ha). There were no *S. alba* poles in that category. The > 35.0 cm DBH pole size were only recorded for *A marina* (4 stems/ha).

The stand volumes of harvestable poles are shown in Table 4. The stand volume in Kipini (574 m^3 ha^{-1}) was significant higher ($p < 0.05$) than in Mto Tana (51.17m^3 ha^{-1}) and Ngomeni (174.9 m^3 ha^{-1}). The yields were not significant ($p > 0.05$) between Mto Tana and Ngomeni mangroves.

In Kipini, the stand volumes of *A. marina* (253.6 m^3 ha^{-1}), *H. littoralis* (148.5 m^3 ha^{-1}), *R. mucronata* (74.5 m^3 ha^{-1}) and *X. granatum* (67.3 m^3 ha^{-1}) were significantly higher ($p < 0.05$) than that of *B. gymnorrhiza* (29.3 m^3 ha^{-1}) which was in turn significantly higher ($p < 0.05$) than those of *S. alba* (0.5 m^3 ha^{-1}) and *C. tagal* (0.3 m^3 ha^{-1}). The stand volume of *A. marina* (35.6 m^3 ha^{-1}) was significantly greater ($p < 0.05$) than that of *R. mucronata* (10.7 m^3 ha^{-1}) in Mto Tana. The volumes of *B. gymnorrhiza* (2.2 m^3 ha^{-1}), *C. tagal* (1.7 m^3 ha^{-1}) and *X. granatum* (1.0 m^3 ha^{-1}) were the lowest ($p < 0.05$). In Ngomeni, the stand volume of *R. mucronata* (71.9 m^3 ha^{-1}) was significantly greater than that of *A. marina* (62.4 m^3 ha^{-1}). This was followed by that of *C. tagal* (24.2 m^3 ha^{-1}), *B. gymnorrhiza* (13.7 m^3 ha^{-1}) and *S. alba* (2.7 m^3 ha^{-1}). *Xylocarpus granatum* yielded the least ($p < 0.05$) stand volume (0.1 m^3 ha^{-1}).

Comparison of the stand pole density and pole volumes of the three mangrove forests in Ungwana Bay is shown in Table 5. Poles of 5.0 -9.0 cm in diameter, which are the second most preferred in the Kenyan market, were more ($p < 0.05$) in Ngomeni and least ($p < 0.05$) in Kipini. The wood volume in the same diameter class was significantly higher ($p < 0.05$) in Ngomeni (12.1 m^3 ha^{-1}) and Mto Tana (5.8m^3 ha^{-1}) and lowest ($p < 0.05$) in Kipini (3.1 m^3 ha^{-1}). Poles of diameter range 9.1-13 cm are the most preferred in the Kenyan market. There were no differences ($p < 0.05$) in their stocking between sites. However, wood volumes were greatest ($p < 0.05$) in Ngomeni and least in Kipini ($p < 0.05$).

Ngomeni mangroves had significantly higher ($p < 0.05$) stems/ha in diameter class 13.1-20.0 cm (451 stems/ha) than in Kipini (200 stems/ha) and Ngomeni (118 stems/ha). The wood volumes in the same diameter class were significantly higher ($p < 0.05$) in Ngomeni (58.4 m^3 ha^{-1}) and Kipini (41.9 m^3 ha^{-1}) and lowest ($p < 0.05$) in Mto Tana (17.1 m^3 ha^{-1}). The stocking rates 20.1–35.0 cm size class were more ($p < 0.05$) in Kipini (326 stems/ha) compared to those in Ngomeni (172 stems/ha) and Mto Tana (42 stems/ha). The wood volumes followed a similar pattern. Stocking density of diameter class > 35.0 cm were significantly greater ($p < 0.05$) in Kipini (100 stems/ha) than in Mto Tana (5 stems/ha) and Ngomeni (4 stems/ha). Similarly, the wood volume was significantly greater ($p < 0.05$) in Kipini (264.6 m^3 ha^{-1}) compared to that in Ngomeni (8.7 m^3 ha^{-1}) and Mto Tana (4.5 m^3 ha^{-1}).

Table 5: Comparison of the stand table attributes between the three mangrove forests in Ungwana Bay.

Site	Utilization classes (DBH)									
	5-9 cm		9.1-13 cm		13.1-20 cm		20.1-35 cm		>35 cm	
	Stems/ha	Volume (m^3/ha)	Stems/ ha	Volume (m^3/ha)	Stems/ha	Volume (m^3/ha)	Stems/ha	Volume (m^3/ha)	Stems/ ha	Volume (m^3/ha)
Kipini	207^{a}	$3.1\ (0.5)^{b}$	103^{a}	$7.7\ (1.3)^{c}$	200^{a}	$41.9\ (7.3)^{a}$	326^{a}	$256.5\ (44.7)^{a}$	100^{a}	$264.6\ (46.1)^{a}$
Mto Tana	424^{b}	$5.8\ (11.3)^{a}$	154^{a}	$12.5\ (24.4)^{b}$	118^{a}	$17.1\ (33.3)^{b}$	42^{b}	$15.5\ (30.3)^{b}$	5^{b}	$4.5\ (8.8)^{b}$
Ngomeni	1005^{c}	$12.1\ (6.9)^{a}$	442^{a}	$17.8\ (10.2)^{a}$	451^{b}	$58.4\ (33.4)^{a}$	172^{b}	$78.4\ (44.8)^{b}$	4^{b}	$8.7\ (4.9)^{b}$

Means in a column followed by different letters in superscript differ ($p < 0.05$).

Values in brackets represent percentages.

Figure 7 is a scatter plot display of mangrove tree heights versus diameters in Ungwana bay.

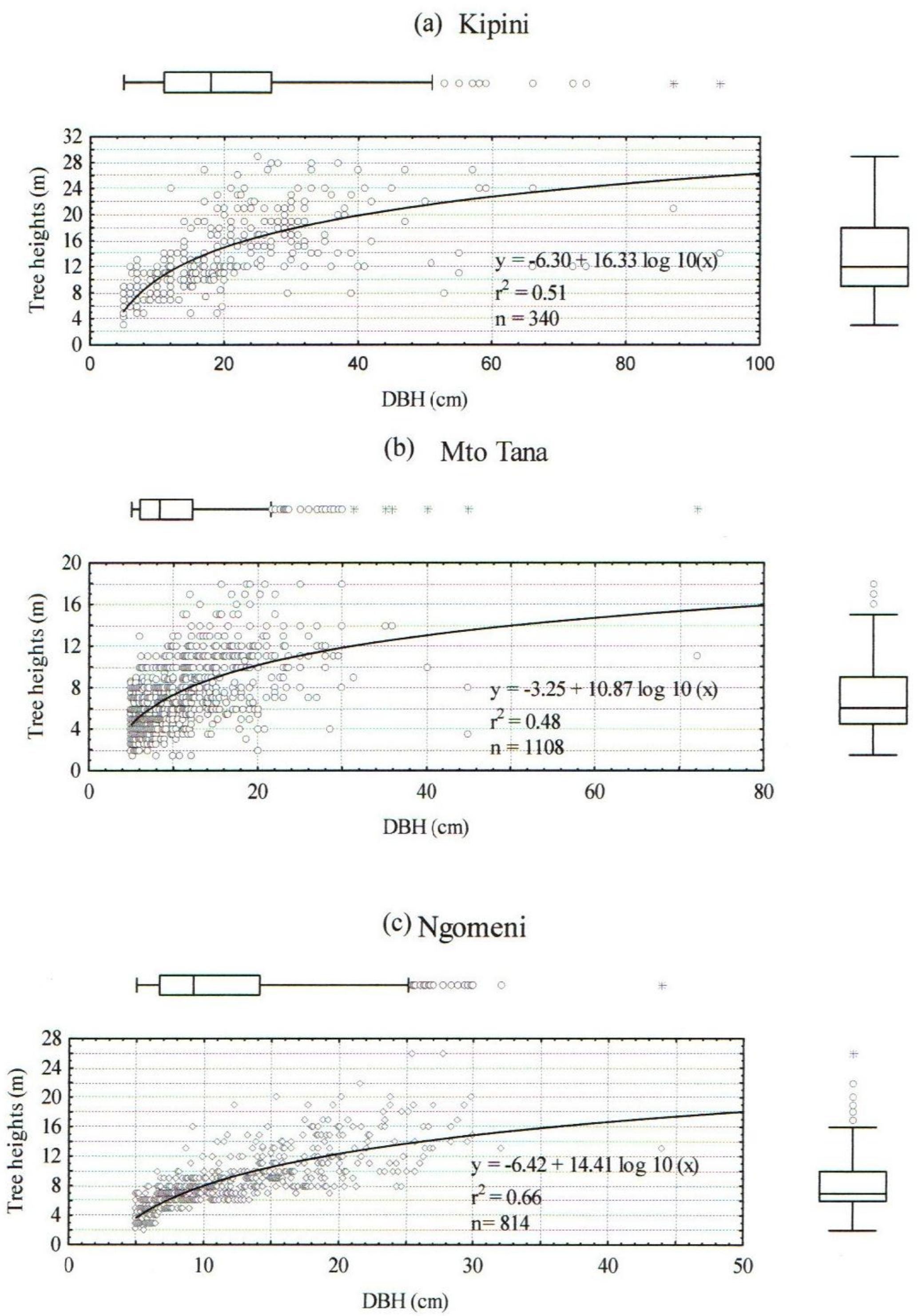

Figure 7: Height and diameter distribution of mangrove forests in Ungwana bay. The box-plots display percentile distribution in each case with the extremities corresponding to the minimum and maximum observed values in the data sheet.

The tree heights and diameters differed significantly ($p < 0.05$) among the three sites. Fifty percent of the trees in Kipini had stem diameters between 11- 28 cm and heights between 9 - 18 m. In Mto Tana, 50% of the trees had a DBH of 6-12 cm and height of 5-9 m. Fifty percent of the trees in Ngomeni had stem diameters in the range of 6.5-14 cm and heights of 6- 10 m.

4.1.5. Stand quality

The number of poles of quality class 1 poles was significantly greater ($p < 0.05$) in Ngomeni (214 stems/ha) forest than in Kipini (123 stems/ha) and Mto Tana (66 stems/ha) forests (Table 6). However, there was a higher proportion of quality class 1 poles in Kipini (13.1 %) than in Ngomeni (10.4 %) and Mto Tana (8.9 %) forests.

Quality class 2 poles were significantly higher ($p < 0.05$) in Kipini (672 stems/ha) followed by those in Ngomeni (564 stems/ha) and lowest in Mto Tana (342 stems/ha) forests. Similarly, there were a higher proportion of quality class 2 poles in Kipini forest (71.8 %) followed by those in Mto Tana (46.0 %) and Ngomeni (27.2 %) forests.

Ngomeni forest had significantly more abundant ($p < 0.05$) quality class 3 poles (1296 stems/ha) than in Mto Tana forests whose poles (335 stems/ha) were significantly more ($p < 0.05$) than those in Kipini forest (141 stems/ha). There was a higher proportion of quality class 3 poles in Ngomeni (62.5 %) followed by that in Mto Tana (45.1 %) and Kipini forest (15.1 %) respectivelly.

In Kipini forest, *R. mucronata, H. littoralis and A. marina* quality 1 pole densities (41; 35 and 35 stems/ha respectively), were significantly greater ($p < 0.05$) than those of *B. gymnorrhiza* (9 stems/ha) and *X. granatum* (3 stems/ha). The mean tree DBH and heights were significantly greater ($p < 0.05$) for *R. mucronata* (26 cm; 20 m), *H. littoralis* (22.2 cm; 21.7 m), *A. marina* (23.3 cm; 19.3 m), and *B. gymnorrhiza* (16 cm; 13.3 m) than that of *X. granatum* (10 cm; 8 m).

Quality class 2 poles in Kipini forest were significantly more ($p < 0.05$) for *A. marina* (247 stems/ha) followed by those of *X. granatum* (181 stems/ha). There was no significant difference between those of *H. littoralis* (99 stems/ha), *B. gymnorrhiza* (76 stems/ha) and

Table 6: Characteristics of pole quality in Ungwana bay.

Site	Species	Quality 1			Quality 2			Quality 3		
		Stems /ha	Mean DBH (cm)	Mean Tree Height (m)	Stems /ha	Mean DBH (cm)	Mean Tree Height (m)	Stems /ha	Mean DBH (cm)	Mean Tree Height (m)
Kipini	*R. mucronata*	41^{a}	26+19.7^{a}	20+9.8^{a}	57^{c}	23.3±10.7^{a}	16±35.6^{a}	9^{c}	18.5±7.6^{a}	13.3±5.5^{a}
	H. littoralis	35^{a}	22.2+7.8^{a}	21.7+9.3^{a}	99^{c}	26.8+17.6^{a}	14.7±6.2^{b}	38^{b}	32.4±23.2^{a}	12.6±3.6^{a}
	A. marina	35^{a}	23.3±4.7^{a}	19.3±3.1^{a}	247^{a}	25.5±13.2^{a}	16.5±5.8^{a}	76^{a}	23.6±19.9^{a}	9.3±6.1^{b}
	B. gymnorrhiza	9^{b}	16±17.3^{a}	13.3±8.3^{a}	76^{c}	15.7±9.8^{b}	13.4±6.0^{b}	5^{d}	8.0±0.0^{b}	7.0±0.0^{b}
	X. granatum	3^{c}	10±0^{b}	8±0^{b}	181^{b}	16.6±11.0^{b}	12.1±5.1^{b}	13^{c}	10.4±4.3^{b}	9.3±2.5^{b}
	S. alba	*	*	*	3^{d}	14.0± 0.0^{b}	16.0 ± 0.0^{a}	*	*	*
	C. tagal	*	*	*	9^{d}	7.7±2.0^{c}	8.0± 1.73^{c}	*	*	*
	Total	123 (13.1)			672 (71.8)			141 (15.1)		
Mto Tana	*A. marina*	40^{a}	11.8±5.4^{c}	9.6±2.1^{b}	253^{a}	11.2± 6.7^{c}	8.1± 3.1^{b}	290^{a}	8.4± 4.3^{b}	4.9± 1.9^{b}
	R. mucronata	10^{b}	16.4±6.9^{a}	12.3±2.1^{a}	53^{b}	12.9± 7.1^{b}	8.8± 2.9^{a}	17^{b}	11.9± 6.5^{a}	9.1± 2.3^{a}
	C. tagal	10^{b}	9.5±4.8^{d}	7.7±1.9^{c}	21^{c}	8.0±4.1^{d}	6.1± 1.7^{c}	13^{b}	7.8± 2.6^{b}	4.2± 2.2^{c}
	B. gymnorrhiza	6^{c}	14.7±6.0^{b}	10.3±1.8^{b}	11^{c}	12.4± 6.6^{b}	8.1± 2.4^{b}	5^{c}	8.5± 2.6^{b}	6.1± 1.4^{b}
	X. granatum	*	*	*	4^{d}	15.9± 7.3^{a}	6.3± 2.6^{c}	10^{b}	9.6± 6.5^{b}	5.3± 2.2^{b}
	Total	66 (8.9)			342 (46.0)			335 (45.1)		
Ngomeni	*R. mucronata*	118^{a}	15.6+6.9^{a}	9.5±5.4^{a}	200^{a}	12.2± 4.6^{b}	7.0 ± 4.8^{b}	463^{a}	12.0± 5.6^{a}	6.9± 3.8^{b}
	C. tagal	68^{b}	8.7+2.8^{c}	3.9±0^{c}	10^{b}	8.0 ± 3.8^{c}	4.0 ± 3.3^{d}	337^{b}	9.0± 4.8^{c}	4.9 ± 3.3^{c}
	A. marina	14^{c}	11.5+5.9^{b}	7.3±6.0^{a}	203^{a}	12.2± 5.9^{b}	7.8± 5.0^{b}	343^{b}	10.4 ± 7.2^{b}	6.8 ± 4.0^{b}
	B. gymnorrhiza	11^{c}	9.9+5.6^{c}	7.5±5.7^{a}	30^{c}	16.4± 5.7^{a}	8.7± 3.5^{a}	94^{c}	11.2± 5.0^{b}	7.8 ± 4.5^{a}
	S. alba	3^{d}	12.7+7.3^{a}	6.5±2.1^{b}	30^{c}	11.5 ± 6.5^{b}	6.8 ± 4.1^{c}	51^{c}	10.5± 4.5^{b}	7.0± 4.3^{a}
	X. granatum	*	*	*	*	*	*	8^{d}	8.1± 3.2^{c}	5± 2.2^{c}
	Total	214 (10.4)			564 (27.2)			1296 (62.5)		

Values in brackets are percentages.

Means in a column followed by different letters ($^{a,b,..}$) differ ($p<0.05$)

* No mangroves recorded

R. mucronata (57 stems/ha) poles. The number of these poles was however significantly greater (p <0.05) than those of *C. tagal* (9 stems/ha) and *S. alba* (3 stems/ha). The mean pole DBH were significantly greater (p <0.05) for *H. littoralis* (26.8 cm), *A. marina* (25.5 cm) and *R. mucronata* (23.3 cm) compared to those of *B. gymnorrhiza* (15.7cm), *X. granatum* (16.6 cm) and *S. alba* (14 cm). Mean stem DBH of *C. tagal* (7.7 cm) were significantly smaller (p <0.05). The mean heights were significantly greater (p <0.05) for *A. marina* (16.5 m), *R. mucronata* (16 m) and *S. alba* (16 m) than those of *H. littoralis* (14.7 m), *B. gymnorrhiza* (13.4 m) and *X. granatum*(12.1 m) while the shortest (p <0.05) trees were recorded for *C. tagal* (8 m).

The number of quality class 3 poles for *A. marina* (76 stems/ha) in Kipini were greater (p <0.05) than those of *H. littoralis* (38 stems/ha) followed by those of *X. granatum* (13 stems /ha) and *R. mucronata* (9 stems/ha). *Bruguiera gymnorrhiza* had significantly fewer (p <0.05) class 3 poles (5 stems/ha). No size class 3 poles were recorded for *S. alba* and *C. tagal.* The mean tree DBH of *H. littoralis* (32.4 cm), *A. marina* (23.6 cm) and *R. mucronata* (18.5 cm) were significantly greater (p <0.05) than those of *X. granatum* (10.4 cm) and *.B. gymnorrhiza* (8 cm). Similarly, *R. mucronata* (13.3 m) and *H. littoralis* (12.6 m) quality 3 poles were significantly taller than those of *A. marina's* (9.3 m), *X. granatum's* (9.3 m) and *B. gymnorrhiza's* (7 m).

In Mto Tana, quality class 1 poles were more (p <0.05) for of *A. marina* (40 stems/ha) followed by those of *R. mucronata* (10 stems/ha) and *C. tagal* (10 stems/ha) and the lowest were for *B. gymnorrhiza* (6 stems/ha). The stem DBH of poles (9.5-16.4 cm) were significantly different (p <0.05) between all the species. Quality class 1 poles of *R. mucronata's* were significantly taller (p < 0.05; 12.3 m) than those of *B. gymnorrhiza* (10.3 m) and *A. marina* (9.6 m).

Quality class 2 poles in Mto Tana were dominated (p <0.05) by *A. marina* (253 stems/ha) followed by those of *R. mucronata* (53 stems/ha). Poles of *C. tagal* (21 stems/ha) and *B. gymnorrhiza* (11 stems/ha) were second most dominant (p <0.05) while *X. granatum* (4 stems/ha) poles were the least. Mean pole DBH of *Xylocarpus granatum* poles (15.9 cm) was the highest (p <0.05) followed by those of *R. mucronata* (12.9 cm) and *B. gymnorrhiza* (12.4 cm) while that of *C. tagal* (8 cm) was the smallest. *Rhizophora mucronata's* Quality class 2 poles were significantly taller (p < 0.05; 8.8 m) than those of *B. gymnorrhiza* (8.1 m) and *A.*

marina (8.1 m) while those of *X. granatum* (6.3 m) and *C. tagal* (6.1 m) were the shortest ($p < 0.05$).

Quality class 3 poles in Mto Tana were dominated ($p < 0.05$) by those of *A. marina* (290 stems/ha) followed by *R. mucronata* (17 stems/ha), *C. tagal* (13 stems/ha) and *X. granatum* (10 stems/ha). *Bruguiera gymnorrhiza* (5 stems/ha) were the least. The mean pole DBH of quality class 3 trees in Mto Tana was largest ($p < 0.05$) for *R. mucronata* (11.9 cm). The *R. mucronata* poles (9.1 m) were also the tallest ($p < 0.05$) while that of *C. tagal* (4.2 m) were the shortest ($p < 0.05$).

In Ngomeni, quality class 1 poles were dominated ($p < 0.05$) by those of *R. mucronata* (118 stems/ha) followed by those of C. *tagal* (68 stems/ha). The C. *tagal* poles were also significantly more ($p < 0.05$) than those of *A. marina* (14 stems/ha) and *B. gymnorrhiza* (11 stems/ha) while those of *S. alba* (3 stems/ha) were the least ($P < 0.05$). There were no quality class 1 poles of *X. granatum*. The mean pole DBH of *R. mucronata* (15.6 cm) *and S. alba* (12.7 cm) were not significantly different ($P > 0.05$) but were significantly greater ($p < 0.05$) than that of *A. marina* (11.5 cm). The pole diameters of *A. marina* were also greater ($p < 0.05$) than those of *B. gymnorrhiza* (9.9 cm) and *C. tagal* (8.7 cm). The pole heights of quality class 1 poles of *R. mucronata* (9.5 m), *B. gymnorrhiza* (7.5 m) and *A. marina* (7.3 m) were significantly taller ($p < 0.05$) than that of *S. alba* (6.5 m). *Ceriops tagal's* poles were significantly shorter ($p < 0.05$; 3.9 m) than those of all the other species.

The quality class 2 poles in Ngomeni were dominated ($p < 0.05$) by those of *A. marina* (203 stems/ha) and *R. mucronata* (200 stems/ha) followed by *C. tagal* (101 stems/ha). *Ceriops tagal's* poles were also significantly more ($p < 0.05$) than those of *B. gymnorrhiza* (30 stems/ha) and *S. alba* (30 stems/ha). The mean pole diameter of *B. gymnorrhiza* (16.4 cm) was significantly greater ($p < 0.05$) than those of *R. mucronata* (12.2 cm) and *S. alba* (11.5 cm). Mean pole diameter of *Ceriops tagal* was small ($p < 0.05$; 8 cm) than that of all the other species. The mean heights of quality class 2 poles comprised of significantly taller ($p < 0.05$) *B. gymnorrhiza* poles (8.7 m) compared to *A. marina* (7.8 cm) and *B. gymnorrhiza* (7.0 m). *Sonneratia alba* trees (6.8 m) were also significantly taller than *Ceriops tagal's* (4.0 m).

Quality class 3 poles in Ngomeni were significantly dominated ($p < 0.05$) by *R. mucronata* (463 stems/ha) followed by *A. marina* (343 stems/ha) and *C. tagal* (337 stems/ha). *Bruguiera gymnorrhiza* (94 stems/ha) and *S. alba* (51 stems/ha) poles. These poles were significantly more ($p < 0.05$) than those of *X. granatum* (8 stems/ha). The mean tree DBH of *R. mucronata* (12 cm) was significantly greater ($p < 0.05$) than those of *B. gymnorrhiza* (11.2 cm), *S. alba* (10.5 cm) and *A. marina* (10.4 cm), which in turn were significantly greater ($p < 0.05$) than that of *X. granatum* (8.1 cm). *Bruguiera gymnorrhiza* (7.8 m) and *S. alba* (7 m) were significantly taller ($p < 0.05$) than *R. mucronata* (6.9 m) and *A. marina* (6.8 m). The last two species were also significantly taller ($p < 0.05$) than *X. granatum* (5 m) and *C. tagal* (4.9 m).

4.1.6. Forest rejuvenation

Overall, the number of juveniles per hectare was significantly higher ($p < 0.05$) in Ngomeni (72, 262 stems/ha) than in Kipini (25,217 stems/ha) and Mto Tana (3,848 stems/ha; Table 7) forests. The difference was not significant ($p < 0.05$) between Kipini and Mto Tana forests. Kipini forest had the highest juvenile ratio (RCI: RC II: RC III) of 289:7:1 followed by Mto Tana's 3.2:1.6:1 and then Ngomeni's 2.6:1.5:1.

There were significantly more ($p < 0.05$) regeneration class 1 (RC I) juveniles in Ngomeni (36,670 seedlings ha^{-1}) and Kipini (24,529 seedlings/ha) forests compared to those of Mto Tana forest (2,120 seedlings/ha). In regeneration classes 2 and 3, there were more ($p < 0.05$) juveniles in Ngomeni (21,320 and 72,262 saplings/ha respectively) compared to those in the other sites.

Table 7: Variation in juvenile production (saplings/ ha) in Ungwana bay forests

Site	RC I	RC II	RC III	Saplings /ha
Kipini	24,529 (289) ^{a}	603 (7) ^{b}	85 (1) ^{b}	25,217 ^{b}
Mto Tana	2,120 (3.2) ^{b}	1,061(1.6) ^{b}	667 (1) ^{b}	3,848 ^{b}
Ngomeni	36,670 (2.6) ^{a}	21,320 (1.5) ^{a}	14,272 (1) ^{a}	72,262 ^{a}

Values in brackets along each row represent the juvenile ratios

Means in a column followed by different letters differ ($p > 0.05$)

Kipini forests recorded significantly more ($p < 0.05$) RC I juveniles of *R. mucronata* (12,909 seedlings/ha) and *A. marina* (8,335 seedlings/ha) than *B. gymnorrhiza* (2,126 seedlings/ha) and *H. littoralis* (1,012 seedlings/ha) (Table 8). The lowest number of seedlings was recorded for *C. tagal* (18 seedlings/ha). There were no *S. alba* juveniles. RC II juveniles were more (p <0.05) for *B. gymnorrhiza* (341 saplings/ha) followed by those of *H. littoralis* (100 saplings/ha) and *X. granatum* (82 saplings/ha). The lowest (p <0.05) number of saplings were from *R. mucronata* (41 saplings/ha), *C. tagal* (26 saplings/ha) and *A. marina* (12 saplings/ha). The highest (p <0.05) RC III juveniles was recorded for *H. littoralis* (38 saplings/ha) and *B. gymnorrhiza* (18 saplings/ha) followed by those of *R. mucronata* (15 saplings/ha) and *X. granatum* (15 saplings/ha). No saplings were found for *A. marina* and *C. tagal.*

Avicennia marina RC I juveniles (1,631 seedlings/ha) were more (p <0.05) than those of *C. tagal* (315 seedlings/ha) and *R. mucronata* (165 seedlings/ha) in Mto Tana forest. *Bruguiera gymnorrhiza* (6 seedlings/ha) and *X. granatum* (2 seedlings/ha) were the lowest (p >0.05). Regeneration class two was significantly dominated (p <0.05) by *A. marina* juveniles (531 saplings/ha) and those of *C. tagal* (481 saplings/ha). The lowest (p <0.05) were of *R. mucronata* (47 saplings/ha) and *B. gymnorrhiza* (3 saplings/ha). RC III juveniles were dominated (p <0.05) by *A. marina* (338 saplings/ha), *C. tagal* (249 seedlings/ha) and *R. mucronata* (78 saplings/ha) and the least was those of *B. gymnorrhiza* (3 saplings/ha).

Rhizophora mucronata (16,617 seedlings/ha) and *C. tagal* (13,694 seedlings/ha) recorded more (p <0.05) RC I seedlings while those of *S. alba* (63 seedlings/ha) were the lowest (p <0.05) in Ngomeni forest. RC II was significantly dominated (p <0.05) by *R. mucronata* (13,206 saplings/ha) followed by *C. tagal* (6,021 seedlings/ha), *B. gymnorrhiza* (1,138 saplings/ha) and *A. marina* (929 saplings/ha). Those of *S. alba* (26 seedlings/ha) were significantly lower (P >0.05). RC III juveniles followed the same trend as RC II.

Table 8: Juvenile density (saplings/ha) in Ungwana bay.

Site	Species	Regeneration Classes		
		RCI	RCII	RCIII
Kipini	*R. mucronata*	12,909[a]	41[c]	15[b]
	A. marina	8,335[a]	12[c]	-
	B. gymnorrhiza	2,126[b]	341[a]	18[a]
	H. littoralis	1,012[b]	100[b]	38[a]
	X. granatum	129[c]	82[b]	15[b]
	C. tagal	18[d]	26[c]	-
Mto Tana	*A. marina*	1,631[a]	531[a]	338[a]
	C. tagal	315[b]	481[a]	249[a]
	R. mucronata	165[b]	47[b]	78[a]
	B. gymnorrhiza	6[c]	3[b]	3[b]
	X. granatum	2[c]	-	-
Ngomeni	*R. mucronata*	16,617[a]	13,206[a]	8,829[a]
	C. tagal	13,694[a]	6,021[b]	3,565[b]
	A. marina	3,685[b]	929[b]	745[b]
	B. gymnorrhiza	2,611[b]	1,138[b]	1,091[b]
	S. alba	63[c]	26[c]	42[c]

Means in a column within a site followed by different letters differ (p >0.05)

RC I: < 40 cm height, RC II: 40-150 cm height, RC III: >1.5m height but <5cm DBH.

Kipini is thought to favour growth of the species (Ferguson, 1993). The observation that tree densities of most species in Kipini and Ngomeni differed is an indication of wide variety of environmental conditions and the different degrees of human pressure on different species in the area. The non-significant differences in the tree densities of all species except *A. marina* in Mto Tana forest, indicates the unfavourable environmental conditions that limits growth of other species.

The ability of *A. marina* to tolerate a wide range of environmental conditions (Wells, 1982) appears to favour its local distribution, making it the most abundant species in Kipini and Mto Tana. The species is not preferred for poles in the Kenyan market, but is harvested for fuelwood. The high density of *R. mucronata* in Ngomeni forest is encouraging since this species is the most preferred in the Kenyan market for its characteristic straight poles.

Rhizophora mucronata, S. alba and *H. littoralis* were significantly taller than the other species in Kipini since they received high amount of water as the first two species occupied the low tidal areas whereas *H. littoralis* was found in areas with fresh water supply. Similarly, *R. mucronata and B. gymnorrhiza,* which occupied the seaward zones, were the tallest in Mto Tana forest. *Sonneratia alba* were significantly shorter than *gymnorrhiza* and *R. mucronata* in Ngomeni forest since their growth has been hampered by the massive siltation at the low tidal areas as well as high human pressure.

The differences in the basal areas of different species in the different forests in Ungwana bay is attributed to the environmental preferences and the effect of human pressure on each species. Basal area is a good measure of the overall stand development and is low for degraded forests. The basal area of *A. marina* was significantly greater than those of the rest of the species in Kipini and Mto Tana forests due to its ability to tolerate a wide range of environmental conditions. The basal area of *R. mucronata* was significantly greater compared to the rest of the species in Ngomeni forest as the species dominated the area.

Overall, mangroves in Ngomeni forest have a high market value as the most important species in the construction industry was the preferred *R. mucronata. Sonneratia alba* was the least important in Kipini while *X. granatum* was the least important in both Mto Tana and Ngomeni sites because of their low numbers.

4.2.3. Structural characteristics among the three sites in Ungwana bay.

The significant difference in tree density, canopy height and basal areas of mangroves in Kipini compared to those of Mto Tana and Ngomeni forests is a reflection of the difference in their 'energy signatures' (Cintron and Novelli, 1984). The magnitude and periodicities of tides, nutrients, hydro-period, droughts, and salt accumulation are known to largely determine the 'energy signature' of a mangrove stand and hence their community structure (Cintron and Schaeffer-Novelli, 1984). The magnitude of human pressure and age also dictates its structural development. Kipini site mangroves contained some of the largest mangrove trees in Kenya with a basal area of 47 m^2/ha.

The high complexity index recorded in Ungwana bay mangroves is in line with earlier studies by Kairo (2001) in that mangrove forests in the northern parts of Tana River are more structurally developed than those to the south. The high productivity in the areas north of Tana River (e.g. Kipini site) is postulated to be linked to the mix of fluvial, tidal and wave energies (Kairo, 2001). The major forcing functions in the area are the Tana River system input and the upwellings caused by the interaction of the East Africa currents and the Somali currents. This increases nutrient cycling in the northern parts of Tana River delta (Kairo, 2001).

Despite the high complexity index, Ungwana bay mangroves have visibly been subjected to widespread over-exploitation as well as conversion for salt development and shrimp aquaculture. Field observation indicate widespread cutting as evidenced by presence of many tree stumps and clear felled areas (Plate 1). In Kipini forest, most of the cut stumps belonged to *H. littoralis,* confirming the fast rate of harvesting of the species earlier reported by Ferguson (1993). Natural conditions and the young age of the forest are possibly responsible for the shrubby nature of mangroves in Mto Tana forest. The erosion, formation of new creeks and development of new mangrove trees which was earlier reported by Ferguson (1993) in the area was confirmed.

The higher scale of mangrove degradation in Ngomeni forest may be one of the causes of its lower basal area and canopy heights and hence low complexity index compared to those in Kipini forest. The freshly cleared forests for salt farming in Ngomeni forest showed that the activity is slowly encroaching into the mangrove areas. This is an attempt to reduce the increased costs of pumping water into the salt pans. Tree mortality along the outer sites of the salt ponds and the changes in vegetation type could be attributed to the induced flooding regime and hypersalinity induced by the salt ponds. Shrimp aquaculture which was established but failed as a viable enterprise in Ngomeni also caused massive mangrove destruction. Extensive sedimentation which has resulted in the death of mangroves in the low tidal area in Ngomeni forest is presumed to originate from Tana River (Ferguson, 1993) and is accelerated by mangrove degradation.

4.2.4. Stocking rates and volume

Poles of diameter class of 5.0-9.0 cm are the second most important to those of diameter class 9.0-13.0 cm as building poles in the local market. However, in Kipini and Mto Tana forests, this class was dominated by *A. marina* poles which are less preferred for building. *Rhizophora mucronata* and *C. tagal* poles, which are the preferred choices, were among the most abundant in Ngomeni site. The most preffered building poles (diameter class 9.0-13.0 cm) were dominated by the high quality *R. mucronata's* poles in Ngomeni forest and the species was also among the most dominant in Kipini forest. Thus, Kipini and ngomeni forests have higher quality stocks of bulding poles.

Pole of dimeter classes more than 13.0 cm, are of less economic value to the local people and are often left standing in the forests. In exploited forests, most of the species dominating these categories are those that are less preferred. For example, *A. marina* poles generally comprised the bigger size classes in Kipini and Mto Tana forests. However, *R. mucronata* 13-20 cm and 20-35 cm diameter poles were more in Ngomeni forest because of their relatively higher numbers compared to the other species in the area. The largest trees (>35 cm DBH) in Ngomeni forest were dominated by those of *A marina.*

The significant high wood volume per hectare in Kipini compared to Mto Tana and Ngomeni forests depicts Kipini forest's superior growth potential among the three sites. In general, the average standing wood volume in Ungwana bay (266.64 m^3 ha^{-1}) can be considered satisfactory as it was higher than that recorded in Kiunga (145.88 m^3 ha^{-1}; Kairo, 2001), which is thought to be almost pristine since it is within a marine park. However, it is important to realize that due to the specific kind of use of the mangrove resources in Kenya, the standing volume is generally not indicative of the possible harvest of preferred diameter classes of poles. This is because the standing volume can be made up by trees of larger diameter classes resulting in large volumes and yet the area may be devoid of the preferred smaller sized poles (Ferguson, 1993). The form factor used to obtain volume estimates in this study was developed for mangroves in Lamu hence might not give exact values. It is recommended that a further study to construct volume tables for Kenyan mangroves be undertaken. The dominance of *A. marina, H. littoralis, R. mucronata* and *X. granatum* poles in Kipini forest reflects the availability of a wide variety of wood in the area. The high volume of *A. marina* poles in Mto Tana forest degrades the forest's economic value whereas the high volume of *R. mucronata* poles in Ngomeni forest reflects the exact opposite.

The stocking rate of 1,251 stems/ha in Ungwana bay forests is comparable to those of other Kenyan mangrove forests like in Tudor Creek (1,145 stems/ha; Said *et al.*, 2008), Gazi bay (1,747 stems/ha; Bosire *et al.,* 2003), Mida creek (1,391 stems/ha; Kairo *et al*, 2002) and Kiunga (1,736 stems/ha; Kairo, 2001). The high number of stems/ha in Ngomeni forest compared to Kipini and Mto Tana forests may be due to increased regeneration that was enhanced by gap creation during tree harvesting. The lower number of stems/ha in Kipini forest mangroves can be explained by their large sizes thus introducing shading effect and the species are shade intollerant. The shrubby conditions and sporadic forest gaps in Mto Tana forest may be responsible for the low stem density.

The variation in abundance and wood volume for most pole sizes, except those of diameter classes 9-13 cm and > 35cm, among the three sites in Ungwana bay is a reflection of the differences in forest ages and varying degrees of human and environmental stresses. The low stem density of market-preferred pole sizes (9.1 -13 cm DBH) and the abundance of the larger poles (20.1 -35 cm DBH) in Kipini forest indicate selective cutting. In Kenya, the large poles are minimally utilized compared to the small poles. This was supported by presence of many tree stumps of the smaller trees in the forests. Kairo *et al.* (2002) reported the same scenario for mangroves in Mida creek. However, the nature of mangroves in Kipini forest may be a reflection of the periodic environmental disturbances occasioned by the dynamic hydrological cycle of the Tana River. When this fact is put into account, mangroves in Kipini forest cannot be considered old-growth despite the dominance of large and scattered trees.

The tree densities in Ungwana bay mangrove forests were observed to generally decline with increase in diameter classes displaying a reversed 'J' shaped curve (Figure 8). This is expected for all un-even aged forests since natural recruitment is continuous. When fitted into size-frequency diagrams, Ungwana bay mangroves did not show an obvious correlation of

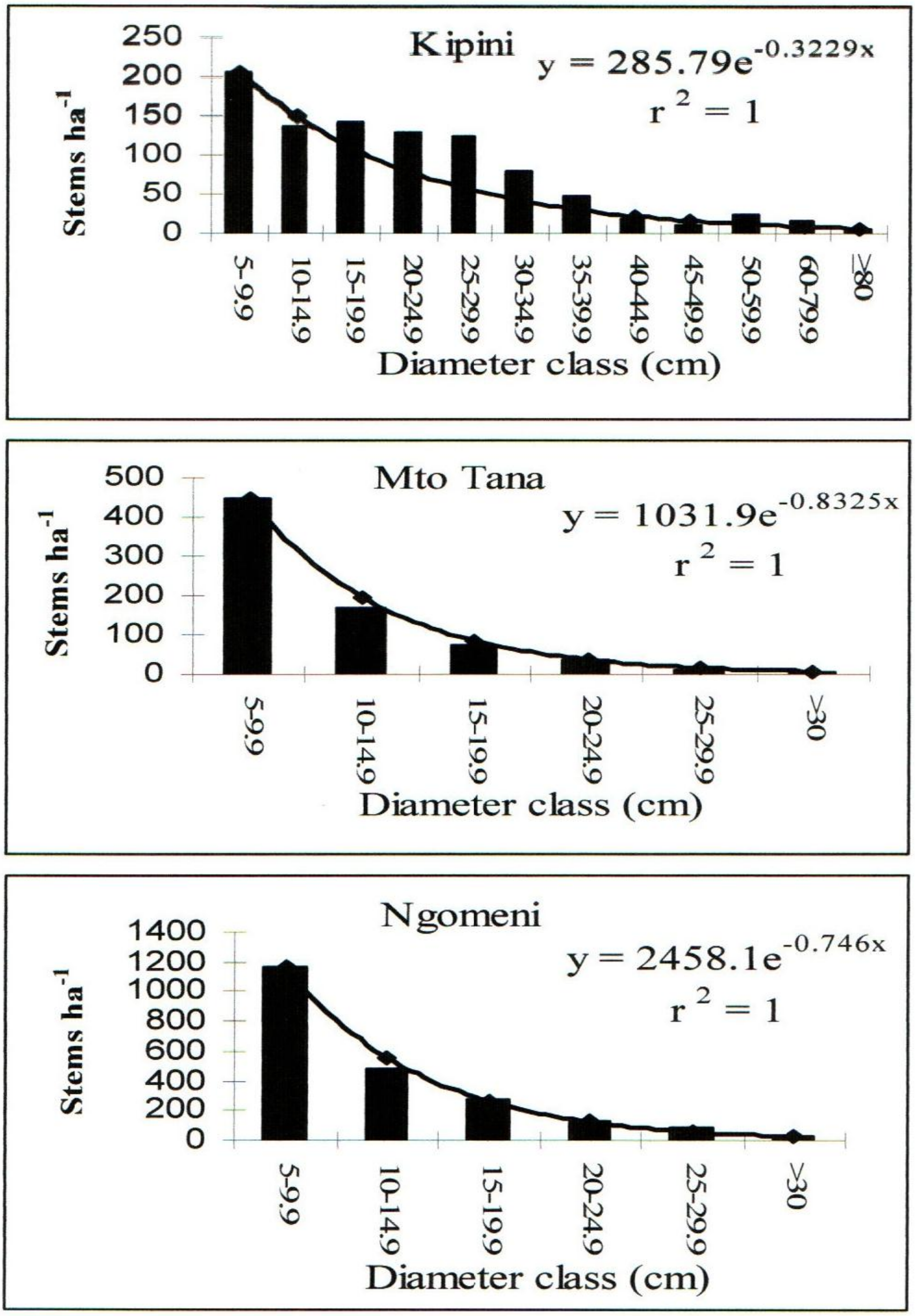

Figure 8: Size class distribution of mangrove forests in Ungwana bay.

the diameter classes and the frequencies hence there were differences between the observed and the adjusted densities (Figure 8 and Table 9). This is possibly due to selective cutting or/and periodic environmental disturbances. In such cases, harvesting of the 'excess' trees is required to effectively manage the forest.

4.2.5. Pole quality characteristics

The differences in quality class 1 poles in the three forests is a result of the differences in species composition, degree of human pressure and environmental conditions. Overexploitation leads to increased removal of higher quality poles leaving behind the crooked poles. Based on this argument, the higher proportion of quality class 1 poles in Kipini forest compared to that in Ngomeni and Mto Tana forests indicates a higher scale of degradation in the latter two sites. Field observation suggested environmental stresses as the main cause of the low quality of trees in Mto Tana forest. However, Ngomeni forest had far more straight poles per hectare than Kipini and Mto Tana forests due to the fact that Ngomeni forest had the highest overall stem density per hectare.

Overall, the mean percentage (10.79%) of quality class I poles in Ungwana bay was low compared to 32.28 % reported in Kiunga (Kairo *et al.,* 2002). The number of quality class I poles were also lower than those of replanted mangrove stands in Gazi bay (Kairo *et al.*, 2008). These statistics show that high quality poles are increasingly getting scarce in the natural mangrove forests in Kenya.

The fact that quality class 2 poles were of a higher proportion in Kipini forest than in Mto Tana and Ngomeni forests also shows that production in Kipini forest is superior. The higher proportion of quality class 3 poles in Ngomeni than in Mto Tana and Kipini forests may be a reflection of adverse human pressure in Ngomeni forest and the favourable effect of hydrological cycles in the other two forests.

Rhizophora mucronata is one of the species that produces most of the straight poles in Kenya (Kairo, 2001). This is evident in Ungwana bay since Ngomeni and Kipini mangroves which were dominated by *R. mucronata* had the highest number of quality 1 poles. Straight *C. tagal* poles with diameters of 2.0 -4.0 cm which were also common are utilized for house construction and fishing stakes (Dahdouh-Guebas *et al.*, 2000).

The domination of quality class 2 by *A. marina* poles in all the three sites was expected as the species growth form is in most cases crooked. This is also reflected in the species dominance of quality class 3. Poles of *R. mucronata* dominated quality class 3 in Ngomeni forest due to their high numbers.

Table 9: Observed and adjusted stand densities for mangrove forests of Ungwana bay.

		Stem Diameter (cm)												
Site	Density	5- 9.9	10-14.9	15-19.9	20-24.9	25-29.9	30-34.9	35-39.9	40-44.9	45-49.9	50-59.9	60-79.9	≥80	Total /ha
Kipini	Observed stems/ha	206	138	141	128	124	79	47	18	10	24	15	6	936
	Adjusted stems/ha	206	149	108	79	57	41	30	22	16	11	8	6	733
Mto Tana	Observed stems/ha	449	166	75	35	11	7	*	*	*	*	*	*	743
	Adjusted stems/ha	449	195	85	37	16	7	*	*	*	*	*	*	798
Ngomeni	Observed stems/ha	1167	484	279	126	88	28	*	*	*	*	*	*	2172
	Adjusted stems/ha	1167	553	262	124	59	28	*	*	*	*	*	*	2194

4.2.6. Forest rejuvenation

The seedling density varied greatly between sites but was on average high, implying adequate recruitment. Based on earlier recommendations of adequate natural regeneration as 5,000 to 10,000 seedlings (UNDP/UNESCO, 1991) and 2,500 seedlings (Chong (1988), natural regeneration can be considered adequate in Ungwana bay mangroves forests. The higher regeneration in Ngomeni site compared to the other sites was probably promoted by a higher scale of canopy exclosure. The domination of *R. mucronata* juveniles in Kipini and Ngomeni forests indicates the potential of retaining a highly valued forest in future. However, there are worries that selective extraction may in the long run lead to colonization of juveniles of less preferred species. The high ratio of RCI ('potential regeneration') to the 'established regeneration' (RCII and III) in Kipini site indicates high seedling mortality probably attributed to shading effect

4.2.7. Comparison of Ungwana bay mangroves with that of other coastal sites

The structural characteristics of previously studied mangrove forests along the Kenyan coast vis-à-vis that of Ungwana bay mangroves is shown in Table 10. Kiunga site is located in Lamu, Kipini in Tana River and Mida site in Malindi. All are in the northern part of the Kenyan coastline. Mangroves in Kiunga had the highest basal area (47.0 m^2/ha), stand density (2142 stems/ha), average canopy heights (26.5 m) and complexity index (62.8). Mangroves in Gazi bay (in the South coast), had the least basal area (3.2 m^2/ha), average canopy heights (8.3 m) and complexity index (0.4). Magroves in Mida had the lowest stand density (119 stems/ha).

Table 10: Structural characteristics of Ungwana bay mangroves compared to those of other Kenyan coastal mangroves.

	Ungwana bay	Kiunga[a]	Mida[b]	Gazi bay[c]
Basal area (m^2/ha)	33.1	47.0	23.6	3.2
Stand density (stems/ha)	1251	2142	119	678
Average canopy ht (m)	9.5	26.5	12.1	8.3
Complexity Index (C.I)	25.2	62.8	7.0	0.4

[a]Kairo, J. G. (2001)

[b]Kairo *et al*. (2002)

[c] Bosire *et al*. (2003)

The comparisons confirms earlier reports that mangrove forests to the north of Kenyan coast are superior in terms of biomass production, heights and basal areas (Kairo, 2001) to those in the southern coast. This has been attributed to a higher scale of past and present anthropogenic pressures in the Kenyan south coast due to ease of accessibility (Kairo, 2001). It is also thought that the northern Kenyan coast has more favourable prevailing edaphic, tidal, and hydrologic conditions (Ferguson, 1993). It is also evident that Ungwana bay mangroves are second best to those in Kiunga. This can be attributed to the pristine nature of Kiunga mangroves as they are located in a National Park which is a protected area. Further studies relating different environmental settings to the mangrove structure and biomass in Kenya need to be undertaken.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The study has developed stand tables for Ungwana bay mangroves. Quantitative data on the amount of wood resources in these forests are shown in terms of stem densities and volume per hectare. This information is useful in the preparation of cutting plans. Knowledge of the stand densities and computation will be vital prior to issuance of harvesting licenses.

Mangrove species composition and distribution in Ungwana bay varied between different sites. This variation is controlled by environmental settings as well as human pressure. Mangroves in Kipini forest, which are riverine and semi-pristine, were the most developed in Ungwana bay. Mangroves in Ngomeni forest were dominated by *R. mucronata* and *C. tagal* which are the highly preferred species in the local market (Kairo, 2001).

Based on the Importance value index, the most dominant species in the pilot area was *A. marina* since it is more resistant species to adverse edaphic conditions. *Heritiera littoralis* require specific environmental conditions (fresh water supply) and was restricted to Kipini forest only.

Ungwana bay mangroves have been subjected to widespread over-exploitation. The degradation was evidenced by the scarcity of high quality poles in the forests. However, the diameter class distribution, stem density and natural regeneration indicated that Ungwana bay mangroves have a great economic potential.

The straight poles (quality class 1) were few in over-exploited forests but greater number of such poles were found in the semi pristine forests. This explains the variation in content of quality class 1 poles between Kipini and Ngomeni mangroves.

Since there was sufficient natural regeneration in Ungwana bay, the forests can sustain themselves without artificial regeneration. Reforestation has been tried in Gazi bay (Kairo, 1995) and proved to be successful. This approach can be applied in the degraded areas at the seaward edges in Ngomeni site to stop further sedimentation inland.

Overall, it can be concluded that Ungwana bay mangrove forests are structurally well developed and have a great utilization potential. Globally, Kipini forests can be compared to well managed forests in other countries like Malaysia, Thailand and Micronesia which have been reported to have trees with over 60 cm DBH (Putz and Chan, 1986; UNDP/UNESCO 1991; Devoe and Cole, 1998). To sustainably utilize Ungwana bay mangrove forests, similar management approaches applied in the above named forests should be instituted.

5.2 Recommendations

- To effectively manage Ungwana bay forests for the future, there is need to first harmonize the irregularities in the size-class distribution (Figure 7). In our case, De Liocourts negative exponential model has been used to produce the exponential curves connecting the smallest and the largest size classes. Harmonization is based on the logic that the structure of a forest is controlled by the smallest and the largest trees. Harvesting of the 'excess' trees should be encouraged in those size-classes where the observed densities are higher than the expected. Assuming that tree sizes is a reflection of their ages, the exponential curves obtained can be used to show the nature of the future managed forest. Removal of the small poles should be minimized while the large-sized poles could be harvested for other uses like charcoal production.

- The study also recommends the designing and implementation of a management plan to sustainably utilize mangroves in Ungwana bay. The management plan should take into consideration the diverse faunal component in the mangrove ecosystem, so as to avoid loss of their habitats. The exceptional stands of *Heritiera littoralis* should be given special protection status, to avoid further degradation.

- Further quantitative data on the forest yields and growth rates should be obtained for other mangrove forests in Kenya. This would provide a general picture on the status of Kenyan mangroves that would guide intervention measures. A data bank exists in KMFRI Headquarters in Mombasa but data is still missing for mangrove forests in sites such as Mtwapa, and Kilifi creeks. The mangrove forests should be mapped to obtain their remaining acreage and the results compared to the existing records. The use of remote sensing and GIS for monitoring degradation should be encouraged as they are more rapid.

- There is need to understand the variability of mangrove forests structure and distribution along the Kenyan coast. Consequently, the structural characteristics of the major mangrove forests along the Kenyan coast should be undertaken in relation to their environmental settings. The forests can then be grouped into compartments with similar structural characteristics and appropriate management procedures applied.

- Integrated mangrove use should also be fronted as a way of diversifying mangrove benefits for the local communities. In this way, mangrove utilization will not only be restricted to wood extraction but will also include other non-destructive uses. Some of the activities which can be integrated with mangrove forestry include: aquaculture, apiculture and ecotourism through construction of mangrove boardwalks.

- Community participation in mangrove forest conservation and management in Kenya should be enhanced. The local communities should be educated on the need to conserve mangroves. Knowledge can be transmitted through organizing public days, short training programmes, chief's *barazas*, posters, videos, among others. The mangrove cutters should be trained on the appropriate forest conservation and management practices. Through this, the cutters will see the need for sustainable harvesting practices. If possible, the government should consider compensating the local community for the ecological services provided by conserved forests (Lamb, 2005).

CHAPTER SIX

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APPENDICES

Appendix 1: Data sheet for forest assessment

Observer……………………

Photo no……………….........   Site………………..   Plot size………….................

Inundation Class (1-5)………   Forest type…………   Total cover………………….....

Species	DBH (cm)	Ht (M)	Form (1-3)	Juvenile Species	Juvenile Density	Regeneration class	Quadrat size

Other observations (e.g. over-cutting, die-bark, influence of fresh water etc.)..........................

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Appendix 2: General Linear Model: Density versus Site (page 27)

Source	DF	SS	MS	F	p
Site	2	815.14	407.57	267.07	0.000
Error	2430	3708.40	1.53		
Total	2432	4523.54			

S = 1.235   R-Sq = 18.02%   R-Sq(adj) = 17.95%

Appendix 3: Summary of a General Linear Model of juvenile species distribution, density and regeneration classes in Kipini, Mto Tana and Ngomeni sites of Ungwana bay. (Page 39)

Variable	Source	df	SS	MS	F	P
Species	Site	2	113.54	56.77	18.31	0.000
Density	Site	2	102.07	51.04	121.54	0.000
Regeneration class	Site	2	7.20	7.20	10.90	0.000

Appendix 4: General Linear Model: Height versus Site (Page 28)

Source	DF	SS	MS	F	p
Site	2	14106.7	7053.3	424.05	0.000
Error	2427	40368.8	16.6		
Total	2429				

Appendix 5: General Linear Model: Basal area versus Site. (Page 28)

Source	DF	SS	MS	F	p
Site	2	0.38669	0.19334	178.80	0.000
Error	2427	2.62443	0.00108		
Total	2429	3.01112			

Appendix 6: General Linear Model of differences in pole quality among Kipini, Mto Tana and Ngomeni sites. (Page 35)

Source	DF	SS	MS	F	p
Site	2	139.83	69.91	15.46	0.000
Error	252	1139.80	4.52		
Total	254	1279.63			