ARTIFICIAL REGENERATION AND SUSTAINABLE YIELD MANAGEMENT OF MANGROVE FORESTS AT GAZI BAY, KENYA

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DEDICATION

................*to friends of mangroves*

A mangrove swamp in Kenya, at low tide, under traditional exploitation (Photo: Ferguson; Kiunga, 1992)

DECLARATION

This thesis is my original work and has not been submitted for award of a degree in any other University

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centimetre (cm)	=	0.394 inches, 0.01 metre.
1 Score	=	20 poles
hectares (ha)	=	2.471 acre
kilometre (km)	=	0.6214 mile

LIST OF ABBREVIATIONS

ABBREVIATIONS

av, aver.	=	average
c., circ.	=	about, approximately
^{o}C	=	degrees Celcius
CEC	=	cation-exchange capacity
cm	=	centimetre
cm^2	=	square centimetre
cf.	=	compare
dbh	=	diameter at breast height (1.3 m) or 30 cm above prop root
Ec	=	electrical conductivity
e.g.	=	for example
g	=	gram
ha	=	hectare
i.e.	=	that is
kg	=	kilogram
meq	=	milliequivalent
mm	=	millimetre
mM	=	milli Moles
mmhos	=	millimhos (now milli Siemen
std., s.d.	=	standard deviation
std. err. (s.e)	=	standard error.
n	=	sample size
yr.	=	year
vs	=	against

SYMBOLS

<	=	less than
>	=	greater than
<=	=	equal or less than
=>	=	equal or greater than
/	=	divide
X, *	=	multiply
^{o}	=	degree
'	=	minutes
S	=	summation
%	=	percentage
$\bar{x}$	=	mean
‰, ppt	=	parts per thousand

INSTITUTIONAL ABBREVIATIONS

AAS	African Academy of Sciences
DRSRS	Department of Resource Surveys and Remote Sensing, Ministry of Planning and National Development
FAO	Food and Agriculture Organization of the United Nations
FD	Forest Department, Ministry of Environment and Natural Resource
KIFCON	Kenya Indigenous Forests Conservation Program, Forest Department
KWS	Kenya Wildlife Services
KMFRI	Kenya Marine and Fisheries Research Institute
KBP	Kenya Belgium Project in Marine Sciences-KMFRI
UoN	University of Nairobi
USAID	United States Agency for International Development

GLOSSARY

Broadcast: Sow (propagules) by scattering, (sections 3.3.2 (b), 4.3.2)

Capped / not capped: A condition indicating propagule maturity. A capped propagule is one with the fruit still attached, immature, (section 3.1.3)

Denuded mud-flat: Mangrove areas that are completely altered and are either idly eroding or converted to other land uses: Canopy, 0% (sections 1.5.2, 1.5.3, Appedix 1 (marked Pi, Ht), plate 1 and 2).

Disturbed mangrove forest: Young secondary mangrove stand that is vigorously growing, but subjected to periodic harvest: canopy cover ± 50% (section 1.5.2, Appendix 1 (marked Br and Li)

ELWS: Extreme low water at spring tide (section 2.3)

Germination: A 'loosely' used term implying the phenomena that may be referred to as 'sprouting' of the propagules i.e. the appearance of the plumular (in *Rhizophoracea*) or the cotyledonous leaves (in *Avicennia*) (section 4.2.1).

Nurseried saplings: Saplings originating from the nurseries (section 3.3.2d).

Over-exploited forest: heavily logged forest: Canopy cover, ± 10% (section 1.5.2, appendix 1 (marked Ht), plate 1).

Propagule: A dispersal unit in mangroves. At times being referred to as seed (section 1.6.2, 3.2.1)

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

Sapling: A germinated propagule also being referred to as seedling or wilding (section 1.6.2, 3.2.2)

Score: An extraction unit of mangrove poles, a score is equivalent to 20 poles. The poles are classified into different utilization classes as 'fito', 'pau', 'mazio', 'boriti', 'nguzo' and 'banaa' (see Ferguson, 1993).

Transplanting/ Outplanting: removing sapling with there roots balls and planting them somewhere else. In the text two modes of transplanting are mentioned (section 3.3.2)

a) Zonational transplanting: transplanting in species specific zones.

b) Reciprocal transplanting: transplanting in interchanged species zones.

Undisturbed forest: Natural stand of primary forest; Canopy > 80% (see page i)

Wildings saplings: Saplings originating from the natural environment (section 3.3.2d).

Artificial Regeneration and Sustainable Yield Management of mangrove forests at Gazi bay (Kenya)

ABSTRACT

Mangrove forests in Kenya are estimated to cover about 50,000 - 60,000 ha. However non-sustainable utilization, over-exploitation of resources and conversion to other land uses principally for fish pond, salt pans, infrustructure development are drastically removing this resource base at a highly alarming rate. Loss of mangrove forests in turn is affecting the local economy as indicated by shortage of firewood, building poles, decreasing fishery resources, destruction of corals and exposure of human settlements to tidal waves. Conservation alone is not enough. The damage can be overcome by rehabilitation and reafforestation of mangrove areas.

A mangrove reafforestation project to rehabilitate degraded areas, restock denuded mudflats and transform disturbed forests into uniform stands of higher productivity was launched in October 1991 at Gazi bay. Basically three artificial regeneration techniques were employed: (a) use of propagules (seeds), (b) use of saplings (less than 1.0 m height) and (c) use of 'small trees' up-to 2.0m height.

More than 7,000 propagules, saplings and 'small trees' of *Rhizophora mucronata*, *Ceriops tagal*, *Bruguiera gymnorrhiza*, *Avicennia marina*, *Sonneratia alba*, *Xylocarpus granatum* and *Heritiera littoralis* were planted/transplanted at different heights along the intertidal complex, and monitored for their growth at 14 days, 1, 2, 3 or 4 months interval, for more than a year, depending on the experiment.

Although there was no single technique that could be judged as best for all species and that no common habitat site was suitable for all species, successful reafforestation proved to be largely modified by: (a) a planting site with little or no wave action against the shore to dislodge plantings and (b) proper elevation within the intertidal zone.

Survival rate of the planted propagules and saplings after 12 months varied between 10% in areas heavily exposed to wave action and more than 85% in well protected areas. *S. alba* growing at the most seaward plots, showed the highest growth rate among all the transplanted saplings, with a maximum annual diameter increment of 1.9 cm and height increment of 1.18 m. In almost all the observed parameters *C. tagal* showed the lowest growth rate. Some extensive, fast growing mangrove species e.g. *S. alba, A. marina, X. granatum* and *R. mucronata* (investments returning high rates of 'interests') can sustainably be planted for fuelwood or timber as well as supplying fish and wildlife to nearby human population. For slower growing species e.g. *C. tagal* and *H. littoralis* exploitation must be slower.

Beside field and nursery experiments, air-layering of *L. racemosa, S. alba* and *X. granatum* is also mentioned as a promising technique of providing stock plants for transplanting without removing mangroves from source area. Rooting success was highest in *S. alba* followed by *L. racemosa* and *X. granatum.*

There is a strong argument that increasingly we should recognize the changing demands of the society and our long term dependence on practices that ensure minimum modification of the environment with maximum returns on a sustainable basis.

CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

1.1 General introduction

The studies on mangrove forestry in Kenya have over the years tended to concentrate on distribution, utilization, community composition and zonation of the species (Graham, 1929; Isaac, W and Isaac, F, 1968; Kokwaro, 1986), with little effort being devoted to their silviculture, multiple use potential of the resources and to the economies of natural and artificial regeneration (Van Speybroeck, 1992a). The ecological values of these ecosystems revolve about their naturally high energy production capacity (Christensen, 1983), their contributions to estuarine and marine fertility (Odum and Heald, 1972) and their various ecosystem functions particularly as nursery habitat to numerous fish and shellfish (de la Cruz, 1979). Economically the mangrove ecosystem serves as a source of important products to coastal populations in the form of timber, firewood, charcoal and food (Hamilton and Snedaker,1984). It is only through the acceptance and implementation of proper, non exploitative silvicultural practices that mangrove resources, goods and services can be perpetuated for the overall benefits of the society.

In Kenya the scattered patches of mangrove forests cover about 54,000 ha of the total coastal area. However non-sustainable utilization, over-exploitation of resources and conversion to other land and water uses, primarily fish ponds, infrastructure development and salt pans are drastically reducing the mangrove areas at a highly alarming rate. For example in the North coast of Kenya, during the period between 1921-1976, some 9,922 ha of tidal swamps between Ngomeni and Karawa were converted for salt works (Yap and Landoy. 1986), while in the South coast some huge contiguous blank mangrove areas appear due to over-exploitation of poles and fuelwood. These destructions need not be qualified or quantified. It may be enough to say that. it is one of the highest forms of national tragedy. Indeed it is a tragedy of the commons repeated from one region to another in the absence of proper planning and management. Thus there is certainly a great need (a) to utilize the mangrove resources on a sustainable basis, (b) to reduce the levels of conversion to other land and water uses, and (3) to declare certain mangrove areas especially those in a pristine state as conservation and preservation zones.

An earlier assumption that mangrove forests maintain their own dynamic equilibrium may not hold to date. This is in view of the fact that man's activities in the coastal areas and the pollution effect are increasing. Like the other products of the sea in which the mangrove stands, coastal people regard mangrove as a resource free for taking by anyone with the need or ambition to do so. The economics of the ownerless mangrove forests have had a built in tendency to overcut for either export or local use. In Lamu for example the average export for 5 years after 1904-1905 was 24,650 scores (1 score = 20 poles), rising to an average of 30,009 scores between 1941-1956 (Rawlins, 1957). Even with the ban on export of mangrove poles as from 1982, the actual average harvest per year for the period of 1941-1956 (i.e. 30,009 scores) remained more or less equal to the 31,734 scores of mangrove poles extracted since 1983 upto now (Forest Dept., 1992). In 1992 the recommended extractable mangrove poles from Lamu alone was 72,100 scores. These figures are obviously bound to exceed the natural resiliency capacity (Holling, 1973) of mangrove forests along the Kenyan coast. Thus a comprehensive management strategy (combining both artificial and natural methods) should be implemented for the protection of mangrove swamps and the sustainance of their productivity. Proper and rational management would ensure that ecological costs arising from improper use of land and resources will be minimized if not totally controlled. These costs are basically long term, difficult to valuate but more often exceed the actual cost of developing the mangrove areas. We associate these costs with such impacts as the decline in biodiversity, food chain effects, alteration of energy/material flows and exposure of human settlements to tidal waves.

Can mangrove seedlings (saplings and propagules) grow and survive in habitat where they are not found as either adults or seedlings?, Do seedlings show superior growth in the sites where the adults occur?, Is there a single habitat where all genera of species show superior growth?. These questions if seriously considered might contribute to a sustained yield management approach of mangrove forests along the Kenyan coast. The concept of 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 original status as possible.

Given the heavy pressure on all forms of mangrove wood products particularly for fuelwood and building, the high population growth rate in the coastal area, it is clear that unless the fuelwood and poles are increased very rapidly, there will be more prospective deficit situations and acute shortages in the coming years, leading to increasing hardships to urban and rural poor. The demand for fuelwood and poles in this region may be met through concentrated mangrove reafforestation and intensified management. Reafforestation will not only contribute towards increased wood supplies but also fulfil the development goal for an improved environment, which forms the basis of sustainable utilization and improved standards of living for the people.

A considerable body of knowledge now exists on many different aspects of mangroves reafforestation in various parts of the world e.g. Malaysia, Indonesia, Fiji and Australia (FAO, 1982; 1984; 1985; 1988). This information though of intrinsic value is difficult to synthesize and interpret because of the varying conditions under which the data have been collected. The 'acknowledged' heterogeneity of mangrove ecosystem is due to great variation in environmental condition. This precludes constructing a single model of the dynamics of mangrove systems which can be applied world-wide. Therefore regional regeneration studies of anyone national mangrove resources should be conducted, attuned to the local condition, to safeguard against the indiscriminate utility of the resource. In Malaysia and Indonesia for instance mangrove growing has shown promise in solving the problem of limited supply of mangrove products as well as maintaining the overall ecological balance of the coastal ecosystem.

1.2 Adaptations to the marine environment

Mangrove swamps are found in tropical areas of the world that are protected from wave action and usually have high sedimentation. The mangrove forest is a fringing community of shallow sandy or muddy areas, ranging from highest-tide mark to the intertidal fringe and subtidal regions. Several authors (e.g. Davis, 1940), have noted that the most vigorous growth of mangroves is found in estuaries where there is distinct fresh water inputs rather than in more saline bays or along ocean coasts.

To survive and reproduce in their habitat, mangroves have evolved several structural and physiological adaptations as follows:

a) structural and physiological adaptations of seeds, evolution of viviparity and use of specialized means of dispersal,

b) production in the family *Rhizophoraceae* of specialized secondarily produced branching aerial roots (prop roots) which contain numerous aerenchyma that facilitate aeration of underground roots (Scholander, et al., 1955).

c) production of pencil-like pneumatophores or breathing roots in the family *Avicenniaceae* (*Verbenaceae*), extending vertically above the substrate along the cable roots (Scholander, et al., 1955).

A common feature of mangrove is the development of viviparity, meaning the embryo initiates germination from the seed while still attached to the parent tree. The embryo does not undergo any period of rest. The hypocotyl continues to elongate downward in its suspended position. Shortly before the seedling is shed an abscission layer is formed at the junction between the cotyledons and the hypocotyl. As the hypocotyl increases in weight, the seedling finally breaks loose and falls like a dart into the mud with its conical point (La Rue and Muzik, 1954). The phenomenon of viviparity is most pronounced in the family *Rhizophoraceae* (Tomlinson, 1986).

1.3 Zonation in Mangroves

The arrangement of mangrove species in distinct monospecific zones is one of the most discussed issues of mangrove ecology (Watson, 1928; Macnae, 1968; Chapman, 1976; Tomlinson, 1986). Mangrove zonation is a regular series of vegetational bands parallel to the coastline often being modified by local topography (Lugo and Snedaker, 1974). Zonation patterns are related to freshwater influences and to the frequency and duration of tidal inundation. The position of an individual species in the zonal sequence is presumably an expression of its physiological amplitude for the particular edaphic conditions which exist there and to competitive interactions between species.

Understanding of the zonation pattern and the factors influencing it can often provide a useful ecological and silvicultural guide in the management of mangrove stands, particularly for determining the appropriate habitat for preferred species. There has been much debate in literature (e.g. Lugo. 1980) concerning the relationship between zonation and succession. The idea that zonation recapitulates succession (Davis, 1940) has received criticism (e.g. Rabinowitz, 1978a) as it does not apply in many forests (Lugo and Snedaker, 1974).

Walter and Steiner (1936) while studying the East African mangroves considered the degree of flooding, soil nature and salinity as factors controlling zonation patterns. They recognized zones of *Rhizophora*, *Avicennia* and *Sonneratia*, and stated that, "*Avicennia* bore great fluctuation in soil salinity, whereas *Sonneratia* required a constant chloride content". According to Thom (1967), salinity is simply an eliminator of competition and not the determining factor in zonation. He believes that substratum and water effects (submersion, wave energy) are the important factors controlling zonation and that each species has a given set of tolerance. Johnstone and Flodin (1982) have therefore proposed six types of likely factors influencing the zonation pattern a) inundation and depth of water. b) wave action, c) drainage, d) salinity and freshwater regime, e) substrate, f) abiota and biotic interactions.

Tidal sorting of propagules seems to be a quite finely tuned adaptation. It confines propagules based on their weight, to zones where they have the highest likelihood of contributing to another generation. Species normally found at the higher elevation on the landward edge of the intertidal zone (e.g. *Avicennia*) produce small propagules while those found on the sea ward edge of the swamp have large and heavy propagules e.g. *Rhizophora*. (Rabinowitz, 1978a). Nairobi University students (Botany Department) demonstrated that seedling establishment in Kenyan mangroves only occurs in the species specific zones of the parent tree (Van Speybroeck, 1990). They found evidence to support both the self-planting (Egler, 1948) and the stranding (Lawrence, 1949) hypothesis in mangrove establishment. The former primarily related to natural and non-exploited forests, while the latter being more predominant in over-exploited, disturbed and clearfelled mangrove areas (Van Speybroeck, 1992a).

1.4 Importance of mangroves

Mangroves support genetically diverse communities of terrestrial and aquatic fauna and flora that are of direct and indirect environmental, economic and social values to human societies throughout the world.

1.4.1 Ecological importance

Four major ecological functions of mangrove ecosystem, are identified as follows:

a) Shoreline stabilization and protection:

   The network of prop roots and pneumatophores trap and accumulate sediments and form mangrove peats (Davis, 1940)

b) Water quality control:

   A mangrove system provides a sink trap for pollutants and thereby minimises sea water and prevents siltation of coral reefs. The system filters land run-off as well as removing terrestrial organic matter (Tomlinson, 1986; Semesi and

Howell, 1992)

c) Aquatic nurseries and wildlife habitat:

Mangroves ecosystems are a breeding and feeding ground of many kind of marine and terrestrial animals. Heald (1971) and Odum (1971) have demonstrated the existence of food webs that are dependent on the organic production of mangrove swamps.

d) Mangroves are major producers of detritus that will contribute to off - shore productivity (Heald, 1971, Van Speybroeck. 1992b)

1.4.2 Economic importance.

Hamilton and Snedaker (1984) have explained that mangrove ecosystems have enormous sociological and long-term economic benefits, which can be achieved by providing a policy of maximum retention and conservation of the resource. The conservation of resources can be profitable through sound **land-use management** based on the principles of **sustained yield.** Mangrove forest provide fuel-wood, charcoal, timber and wood for boat building, poles for fish traps, fishing floats, tannin for fish nets and leather industries (Hirsch and Mauser. 1992). Mangrove plants also provide raw materials for paper pulp, sugar, alcohol, honey, cooking oil, vinegar, tea-substitute, fermented drink, vegetable propagules, medicines and also act as fodder and green manure (Walsh, 1974). The high productivity of mangrove waters, estuaries and tropical lagoons, especially those bordered by mangroves has caused them to be the stage of seasonal migration of fishermen.

In Kenya mangrove poles and charcoal have been exported to Iran and Middle East, particularly Saudi Arabia (Rawlins, 1957). Overexploitation greatly depleted the availability of mangrove poles leading to a ban on their export by the government in 1982. This was followed later by a ban on charcoal export.

The mangrove space has also proven variable for other uses. Agriculture, aquaculture, housing and transportation have all encroached on mangrove systems.

Agricultural use of mangal is directed mostly to its conversion and salt resistant rice varieties have successfully been cultivated for example in Sierra Leone (Walsh, 1977). However such an agricultural conversion become short term because the previously anaerobic soils, when oxygenated become highly acidic (Hamilton and Snedaker, 1984). More successful conversion for mariculture and aquaculture has been achieved in the Philippines and Indonesia, yielding fish. shrimp and shell fish (Tomlinson, 1986). At the Kenyan coast, mangrove conversion for pond culture is localized in Ngomeni. Elsewhere, experimental cultivation of oysters, using artificial support is in an advanced stage at Gazi bay. If completed, the project, will demonstrate a viable multiple use potential of the mangrove system.

1.5 Current Status, Utilization and Management of mangrove forests in Kenya

The Kenya coastline extends from 1° 40' S to 4° 41' S approximately 574 km long from Kiunga in the north to Vanga in the South. Along this coastline mangroves are a common feature in deltas, creeks, protected bays. Islands and river estuaries (Fig. 1).

Estimate by the Forest Department (1983), indicate that there are about 64,990 ha of mangroves along the Kenya coast, representing about 0.1% of the total area of the state or approximately 3.8% of the total forest cover in Kenya. Of these about 46,184 ha (71%) occur in Lamu and the surrounding Islands. while 12,642 ha (19%) occur in Kwale district and 6,164 ha (9.5%) occur in Mombasa. Kilifi and Tana river districts. Estimates of total cover of mangrove forests from other sources differ from the above e.g. Doute et al., (1981), give the area as 54,400 ha. while Yap and Landoy (1986) gives 50,000 ha and the World bank (1990): 61,395 ha. This suggests the need for a detailed survey.

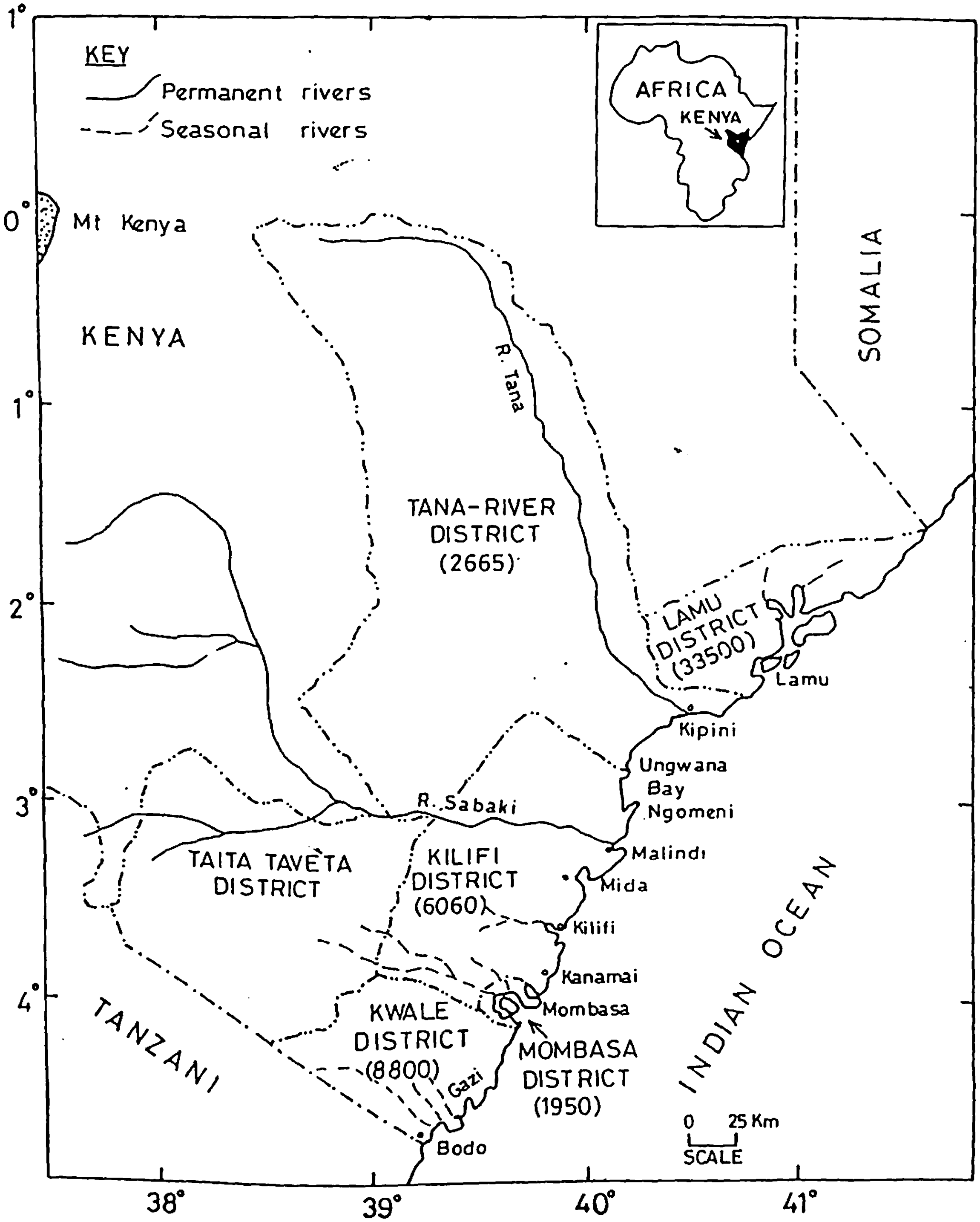


Fig. 1 Kenya coastline. The number in parenthesis indicate the area of mangrove cover in hectares in each district, (Adapted from Ruwa, 1993)

1.5.1 Floristic composition

The Kenya mangroves entails 8 species belonging to six families as shown in table 1. The common species are *Rhizophora, Ceriops, Avicennia* and *Bruguiera*.. *Lumnitzera racemosa* generally forms a shrub.

Family	Botanical name	Local name (Swahili)
Rhizophoraceae	- *Rhizophora mucronata* Lam.	MKOKO
	- *Bruguiera gymnorrhiza* (L) Lam.	MUIA
	- *Ceriops tagal* (Perr) C.B. Robinson	MKANDAA
Sonneratiaceae	*Sonneratia alba* Sm.	MLILANA
Avicenniaceae (Verbenaceae)	*Avicennia marina* (Forsks) Vierh.	MCHU
Combretaceae	*Lumnitzera racemosa* (Willd)	KIKANDAA
Meliaceae	*Xylocarpus granatum* (Koen)	MKOMAFI
Sterculiaceae	*Heritiera littoralis* Dryand in Aint.	MSIKUNDAZI

Table 1: Mangrove species in Kenya.

Other plants found growing near the mangroves habitat are: rounded shrubs of *Sueda monoica*, a succulent herb forming mat of *Arthrocnemum indicum, Sesuvium portulacastrum*,. *Sporobolus virginicus* (a grass) *Sporobolus specutus* (a grass), *Acrostichum aureum* (fern), *Loranthus* sp. a parasite on mangroves and different types of lichens such as *Roceila montagnai*. Walter and Steiner (1936) refers to these species as mangrove associates.

While the detailed botanical descriptions of the species have been covered by Graham (1929) and Kokwaro (1986), a brief description of the mangrove species commonly found indigenous to Kenya is also hereby given:

a) *Rhizophora mucronata* (MKOKO)

It is the most prominent species in many mangrove swamps in Kenya. It can be recognized by its stilt roots which are sent down both from the main stem and from the branches. The leaves are broadly elliptical and strongly mucronate. The propagules which grow and develop hanging from the tree are from 30-60 cm in length. When they fall into the water they float vertically until they settle on a suitable substratum and begin to grow (Egler, 1948). The most favourable habitat for *Rhizophora* is the intertidal mud flats and estuaries where salinity is lower than that of the normal sea-water. Under these conditions *R. mucronota* normally has a straight stem, with fine textured hardwood, and can reach a height of 28 m with a diameter of 46 cm at its climax (Pers.. observation at Kiunga). *Rhizophora* can also be found growing in the most unlikely localities, on coral outcrops. Under this condition the trees are stunted and deformed.

Very large old trees do not seem to set many seeds or the seeds may not be fertile, so that good stands of big trees have practically no undergrowth. *Rhizophora* disperse primarily between March and June (Pers. observation). The species is cut for: firewood, charcoal, scaffolding, poles (building) and tannin for leather. The tree does not coppice when it is felled.

b) *Bruguiera gymnorrhiza* (MUIA)

This is the largest of the Kenyan mangroves growing to a height of 38 m (in Chale Island). *Bruguiera* does not form a distinct zone but occurs scattered within *Avicennia*, *Rhizophora* and *Ceriops* stands. The leaves of *Bruguiera* are very much like those of *Rhizophora* but lack mucronate. The species has no stilt roots but the tree is buttressed at the base and also throws up knee roots. Exposed knee-roots may give leafy shoots but whether these shoots ever develop into large trees or not I do not know nor have I seen this appearance in any work on mangroves. *Bruguiera* has a low coppicing ability, and can thrive in more drier regions than *Rhizophora* (pers. observation). The species is cut for firewood, timber, scaffolds, poles, wood for smoking fish, furniture and tool huddles.

c) *Ceriops tagal* (MKANDAA)

In sandy soil, *Ceriops* occur as a scrub but in optimum condition grow into fair sized trees. Has knee like pneumatophores, a buttressed base and small, yellowish obvate leaves. The propagules are narrow, long and sharply pointed with ridges. The tree is cut for firewood, charcoal, scaffolding, poles (building) and tannin for leather. The species does not coppice when felled.

d) *Avicennia marina* (MCHU)

This species is common in mangrove formations, mostly on the landward side on sandy flats where it becomes the most dominant species. In Gazi *Avicennia* forms a monospecific woodland in the most landward mangrove zone, where tidal inundation is infrequent and soil salinities high. On the seaward side *Avicennia* is found in a mixed pioneer association with *Sonneratia, Rhizophora* or with *Bruguiera,* as seen along the Mkurumuji and Kidogoweni river estuaries. In the landward side the tree occurs as a scrub, while in the seaward side it is a fine well shaped tree normally tall (10-15 m) and very branched.

The pneumatophores of *Avicennia* are erect and resemble stout blunt pencils. The seeds which germinate on the mother are of quite a different character from those of the above species. The green cotyledons folded round each other are in the shape of a compressed sphere.

The species has poor quality wood, and is cut for: firewood, poles (building), charcoal and wood for smoking fish. The tree will often coppice when felled.

e) *Sonneratia alba* (MLILANA)

Sonneratia is common in the sea ward side and can withstand more submergence than any other mangrove species. The species occurs in monospecific stands or in mixed association with *Rhizophora* or *Avicennia.* It appears that *Sonneratia* requires a sandy-silt soil; with a constant salt concentration.

The tree has white flowers with many stamens. The fruit resembles a spinning tops and has many small seeds. The pneumatophores are long and conical. The tree is cut for firewood, boat-building, poles (building/fish traps); and fish floats. The tree coppices readily when felled.

f) *Xylocarpus granatum* (MKOMAFI)

The plant does well in deep clay soil. It is dominant along freshwater stream banks and scattered among *Bruguiera*.. It can easily be recognized by its compound leaves and its large hard football-like, reddish-brown fruits often 12 - 20 cm in diameter. It is a much branched evergreen tree upto 20 m height (in Ngomeni), with ribbon root protruding from the mud for aeration purpose. The tree is cut for: firewood, timber, scaffolds, boat building, poles (building), furniture, tool-handles, carving and wooden ware. The tree has a low coppicing ability.

g) *Lumnitzera racemosa* (KIKANDAA)

It is commonly found as a shrub upto 4.5 m high on the landward side, within reach of the highest tides. Pneumatophores commonly develop as looped above-ground laterals from the main horizontal roots. Leaves somewhat fleshy and spirally arranged, small white flowers which grow in a spike and have prominent green calyces. The species is harvested for firewood and fencing. The shrub has a low coppicing ability.

h) *Heritiera littoralis* (MSIKUNDAZI)

The species favour brackish water medium with more fresh water elements in it (Pers. observ). It does not grow in admixed sea water or more saline sea water. The trees grow upto 28 m high (diameter 60 cm) in River Tana delta. *Heritiera* has leaves that are green above but dorsally entirely covered with silvery scales. The base of the stem is buttressed, with ribbon roots. The tree has small flowers which bear indehiscent woody fruits. *Heritiera* yield high quality wood; the tree is cut for firewood, timber, scaffolding, dhow mast, furniture and carving. Like *Bruguiera*, and *Xylocarpus*, *Heritiera* has a low coppicing ability.

1.5.2 Current status

At present there is no upto date data available to give accurate pictures of the current condition of mangrove forest reserves in Kenya. However various reports (e.g. Yap and Landoy, 1986; Kigomo, 1991; Kairo, 1992, Hirsch and Mauser, 1992) have indicated that extensive bare lands resulting from indiscriminate cutting of the trees occur all along the coastline. The recently concluded mangrove survey consultancy (Ferguson, 1993) is intended to provide a basis for sustainable mangrove planning and will be a vital input towards the establishment of the actual area of the resource base.

Currently the main exploitation of the mangrove forests is the harvest of poles for building and fuelwood (Kairo, 1992, Hirsch and Mauser, 1992). Everywhere along the coast people build houses with a frame of poles, mostly made of mangroves. It is not foreseen that the dependency on this resource will stop. It will therefore be important to assess the number of poles used in a house and to project the number of houses to be build along the coast in the future.

Travelling all along the mangrove forests of Kenya one sees many examples of exploitation that have ended in disasters. Clearfelled forests that will never naturally recover (e.g. Gazi bay (see plate 1), fish ponds and solar salt works ventures that have created wastelands (e.g. Ngomeni (see plate 2), dredged areas that support no life (e.g. Lamu), unchecked sewage disposal and oil pollution (e.g. Mombasa). In addition urban and hotel development have removed large areas of mangrove forests, often devastating far more land than was required and affecting the lives of subsistence coastal dwellers quite unnecessarily (Kairo, 1992). Furthermore, it is still probable that mangrove areas will be developed carelessly because of the low value assigned to the wetlands and to the ever increasingly human population along the coastline.

Plate 1: A clearfelled mangrove forest at Gazi bay (Kinondo), with very little natural regeneration (Photo Kairo, 1992).

Plate 2: Reclamation of mangrove forests at Ngomeni for solar salt pans. (Photo Ferguson, 1992)

1.5.3 Management

The original gazettement of the Kenyan mangrove swamps was by Proclamation No. 44 of 30th April 1932, this gazettement did not however quote the land area. On 20th May 1964, mangroves were declared central forests by legal notice No. 174 and defined as "those pieces of land of approximately 111,366 acres situated between low and high water mark on the coast of Kenya, which were declared to be forest areas by Proclamation No. 44 of 1932". Authority for exploitation and conversion of mangroves for any purpose (e.g. for salt works and fish ponds) is obtained from the Government's Ministry of Natural resources through the Forest Department.

To regulate over-exploitation of the wood products, the Forest Department issues licenses to cut specified products within specified areas (i.e. selective logging). The sizes and quantity of poles or the quantities of fuelwood are specified in the General Forest Licence (GFL) which is for a period of one year. All vehicles transporting mangrove poles are required to have a permit and timber statement. All the extracted poles must bear a forester's hammer mark before being transported. A belt of mangroves along the waterways and shorelines must be kept intact. These regulations although well spelled are never supervised in the field. Neither are there any prescriptions for regulation of the extraction of various mangrove products especially poles and fuelwood. Careful supervision of the harvesting operation to ensure that seed trees are left in adequate numbers appear to be the only possible economic solution. Questions must also be asked about exposure of the mangrove forests to sun, wind and storms. Anyone who has observed normal tidal flow in an intact mangrove stand is aware of the gentle movement of the water. Only floating material moves, there is no wash of the soil surface and in general there is less mixing of the water.

The major problems in mangrove management in Kenya include among others: lack of management plans, the inadequacy in management resources and insufficient skills compatible with the nature and complexity of mangrove ecosystem. Preliminary observations along the the mangrove areas of Kenya. showed that:

1) In many areas facing the sea (e.g. Gazi bay) the fringing mangroves had completely been eliminated by constant cutting, causing severe erosion of the shoreline (see plate 3)
2) In some localities e.g. Shimoni the amount of stumps and stilt roots left on the ground were such that it was impossible to walk through (see plate 4). This barrier has prevented seeds from being dispersed by the tides. At the same time a general absence of parent trees ensured that there would be no natural regeneration for a number of years.
3) the great mass of debris resulting from logging operation (e.g. in Gazi) constantly moved about and flattened many newly established plants.

From the above observations it is obvious that a stricter enforcement of existing rules and regulations should be taken by the Forest Department to ensure that the licensees strictly observe the operation rules. A thorough survey of the logged areas need to be conducted to see how well they are regenerating. One of the major objective of this study was to assess seedling establishment under different logging conditions.

Plate 3: Idly eroding shoreline at Gazi bay after the sea fringing *S. alba* stand was clearfelled for industrial fuelwood. Replanting of *S. alba* in this area is a possible solution that can prevent sea water from reaching the coconut plantation (Photo Kairo)

Plate 4: A completely disturbed mangrove forest at Shimoni (South coast), the great amount of debris and insufficient number of parent trees has prevented free dispersal of propagules by tides. (Photo Kairo)

1.6 Regeneration of Mangroves.

Reproductive ability in mangroves is prolific in almost all situations where seed trees are found (Semesi and Howell, 1992). In the family *Rhizophoraceae* the propagule furnished with a pointed hypocotyl to penetrate the mud. falls freely from the parent. Root development appears to occur rapidly, thereby anchoring the seedling to the substrate. La Rue and Muzik (1954) stated that 50% of the seedlings that fell from the parent tree planted themselves vertically to an average depth of 4 cm so that little washing away occurred. The few which did not penetrate the ground developed roots at the tips and curved upwards so that the stem tips were vertical. Further observation indicated that the figure given by La Rue and Muzik is exceptionally high. Seedlings which do not penetrate the mud but are carried by water can survive when deposited on suitable substrate. While positive evidence has been seen of seedlings so established great distances from the parental tree, Rabinowitz (1978b) and Van Speybroeck (1992a), do believe that successional regeneration is generally achieved from the seedlings which fall into the mud, and are 'fixed' by the parents.

Natural regeneration of mangroves depends on the stability of the soils. Taking too much trees away through cutting diminishes stability of the soil, which causes the propagules and saplings to be washed away with the tides and makes natural regeneration impossible. In Malaysia (a country with the longest history of mangrove management) it has been suggested that to encourage natural regeneration some parental mangrove trees (standards) should be retained during harvesting operation to act as seed bearers for the next generation. The minimum number of standards is 12 trees/ha (Tang, 1978) and these should be strategically retained in those areas that are poor in regeneration. In Thailand the leaving of standards has been replaced by a strip clearfelling system which has been found to allow adequate regeneration.

1.6.1 Artificial regeneration

There are several short comings that are associated with natural regeneration: a) the replacement may not be of the same species removed or even it may be of a none mangrove species e.g. the giant mangrove fern *Acrostichum aureum*, b) absence of mother trees may result to low propagules supply or non at all, c) occupation of seedling sites by excessive logging debris prevent seedling dispersal by water, d) excessive tidal wash which may cause poor establishment, e) predation of propagules by crabs.

Artificial regeneration involves hand planting of mangrove propagules and saplings at a selected intertidal area, with optimism that a high survival is obtained. Planting of mangroves has successfully been done in Malaysia, India, Thailand and Puerto Rico (FAO, 1982; 1985 and 1988).

Prior to 1970 most of mangrove rehabilitation were for silviculture and date back to the 19th Century in the Philippines (Macnae, 1968). This involved large scale plantation establishment upto 15,000 ha. Planting has also been done for: erosion control (Macnae, 1968); coastline restoration (Teas, 1977; Hoffman and Rodgers, 1981) and for experimental analysis of mangrove biology (Davis, 1940; Rabinowitz; 1975).

1.6.2 Techniques used in artificial regeneration

Most planting work has been done using the families *Rhizophoraceae*, *Avicenniaceae* and *Combretaceae* (Rabinowitz, 1975; Teas, 1977) and has involved three major techniques as follows:

1) use of propagules (or seeds)
2) use of saplings (less than 1.2 m high)
3) use of large trees (up to 6 m high).

Attempt to restore the denuded mangrove shoreline in Florida indicated that the survival of the transplanted saplings or propagules was better (85-95% of 60,000 after

4 years) than for transplanted large trees (0% after 6 months). Planting of saplings (0.5-1 m high), from nursery stock or naturally collected. gave the highest survival rate (90-100% after 13 months) compared to planting of propagules and large trees (Teas, 1977).

Several authors (e.g. Pulver, 1976) have noted that two of the most critical factors in successful projects are: 1) a planting site with little or no wave action against the shore, to dislodge plantings, 2) proper elevation within the intertidal zone (Hannan, 1976; Van Speybroeck, 1992a).

In planting areas with high tidal and wave action (Teas. 1977), even with some sort of wave barriers (Webb and Dodd, 1978) or erosion protection such as tires (Teas, 1981), the plantings were nearly 100% unsuccessful. In some of the experiments, simultaneous planting were made in low wave energy sites (Hannan, 1976) and much greater success (65-90%) occurred.

Concerning proper elevation of plantings it is important to first determine the general intertidal zone elevations which will depend upon the tidal range (Lewis, 1982). Once this general zone is delineated the best zone for each species is then determined. The easiest way to establish the zonation is to survey the elevation of existing mangroves at the closest location to the proposed planting site. Rabinowitz (1975) in reciprocal transplanting experiments tested the survival of four species at different elevation from where they are normally found. *Rhizophora* appeared to do well in areas with greater inundation (lower intertidal) while *Avicennia* appeared to do well in all zones.

Other techniques have involved aerial planting with *Rhizophora* propagules (Teas, et. al., 1976) and air layering of *Rhizophora mangle*, *Avicennia germinans* and *Laguncularia racemosa* (Calton & Moffler, 1978).

1.7 OBJECTIVES OF THE STUDY

The main purpose of the study is:

a) To contribute to the understanding of environmental factors affecting mangrove zonation and seedling establishment.

b) Undertake nursery and plantation establishment experiments of mangroves in the deforested areas of Gazi bay

c) To carry out air-layering trials on *Sonneratia.*, *Lumnitzera* and *Xylocarpus* as an alternative of low propagule/sapling supply.

CHAPTER 2

STUDY SITE DESCRIPTION

2.1 Introduction

Gazi (Maftaha) bay where the present study is carried out is located approximately 50 km south of Mombasa in Kwale district (4^{o} 25' S and 39^{o} 50' E). The approximate area of mangrove forest in Gazi bay is 477.5 ha. The significant features of the bay are the many interconnecting waterways one being River Mkurumuji, two large shallow tidal creeks draining mangrove wetlands and an additional hilly terrain. During low tide several sand banks are exposed but the bay remains navigable for fishing and transporting the cut mangrove poles.

Both the small rivers (Kidogoweni in the north and Mkurumuji in the south) are seasonal and temporal depending on the rainfall more inland. River Mkurumiji is the bigger of the two with a catchment of 175 km^2 inland and a minimum and maximum flow of 0.02 m^3/s and 5.90 m^3/s respectively (Mailu and Muturi, 1988). Fresh water seepage is restricted to a few points (Ruwa and Polk, 1986). Gazi was chosen as a study area for the following reasons:

a) The forest structure and composition in Gazi bay appear to be typical of other mangrove sites in Kenya.

b) The water ways and the connecting canals are reasonably navigable even during low tides to allow for access and transportation of equipment and materials.

c) Several coastal villages are nearby so that labour was potentially available.

d) Air photo coverage at scale of 1:25 000 was available.

e) Several inundation classes are represented.

f) Eight (8) of the nine (9) mangrove species listed for Kenya are present at Gazi bay (*X. muluccensis* is not present)

A map showing the broad distribution and vegetational types in the mangrove area of Gazi bay was prepared based on 1:25,000 air photos taken in Feb. 1991. Three study blocks were established stretching from the seaward to the landward side. The location of the blocks are shown in the map (appendix 1) and they are:

(i) Gazi (G-i)

In a successional mangrove forest at the denuded mudflat, in the low lying side of the bay.

(ii) Kinondo (K-i)

In a completely logged area within the landward side of the bay.

iii) Mkurumuji (M-i)

In a secondary mangrove forest along the Mkurumiji river valley.

2.2 Climate

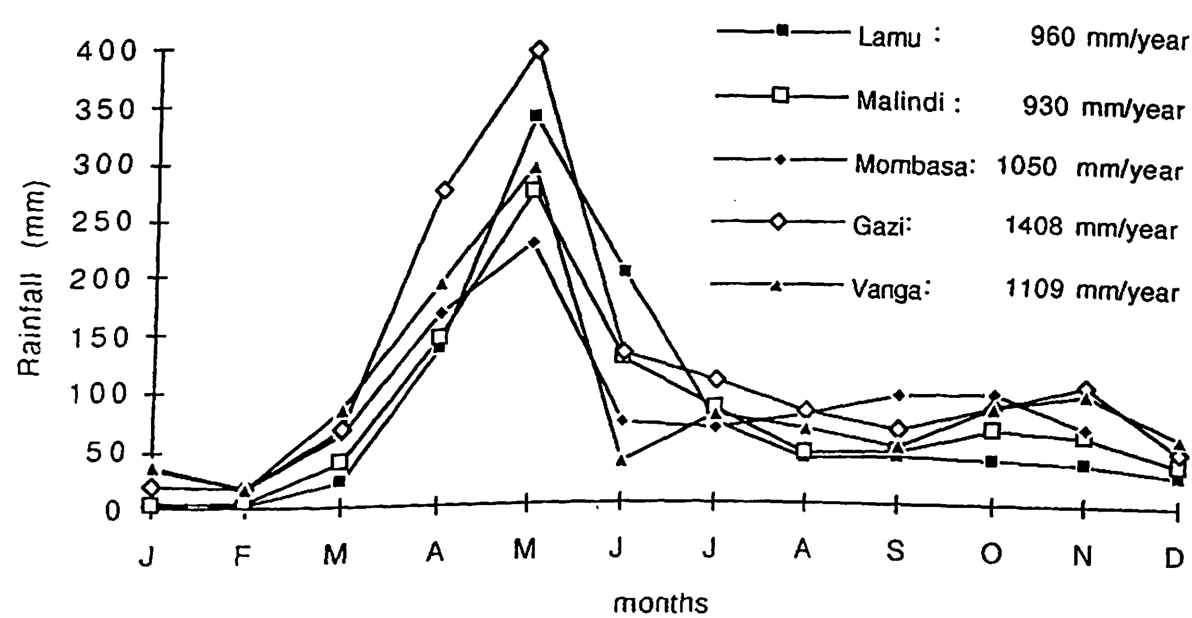
The coastal climate of Kenya is of the savanna type with two dry seasons. The seasonal pattern is dominated by three airstreams (Oosterom, 1988):

- The Arabian north eastern trade winds, forming the northeast monsoon. They prevail during the period of November to March and give rise to a short wet season, which is followed by a relative long dry season.
- The southeast tradewinds, forming the south eastern monsoon. They start to influence the weather by about the month of April and give rise to the main wet season.
- The Congo airstream, connected with the prevailing tradewinds at the African coast. The associated high winds penetrate through Equitorial Africa and cause the change of weather condition in July. In Eastern Africa its influence is felt by a decrease of the southeast trade winds.

The average annual precipitation varies from about 500-900 mm (for northern Kenya) to 1000-6000 mm (southern Kenya at Gazi). The short period between the two Monsoons (March - April and October - November) when the winds may be blowing from either direction is known as the intermonsoons. The intermonsoons periods are characterised by short rains in November and long rains in April. The average annual evapotranspiration varies respectively from 1650 - 2300 mm in the north to 1300 - 2200 mm in the south.

The maximal relative humidity along the coastal region ranges from 65-80% in most of the year with a mean diurnal range of 26-31%. The humidity is normally higher in the morning than in the afternoons. May, June and July are very humid months whereas January, February and March are less humid.

The coastal region is normally hot and humid with little variation in temperature. In Mombasa the mean monthly temperature ranges from 24 ^{o}C during the coldest month of July and August to 29 ^{o}C in the warmest months of February and March. During warm seasons the monsoon winds blowing from the sea keep the air temperature below 36 - 38^{o}C (Norconsult, 1977; McClanahar, 1988). Rainfall and temperature data are presented (for several coastal towns) in fig. 2. Note that on average the south coast towns e.g. Gazi and Vanga receive more rainfall than the north coast towns e.g. Lamu and Malindi.



The mean temperature in Mombasa varies from 24-28.4 ^{o}C over the year
The mean temperature in Lamu varies from 25.1-28.8 ^{o}C over the year

Fig. 2. Rainfall regime of five coastal towns (Adapted from Jeatzhold et.al., 1976)

2.3 Salinity and Tidal cycles

The minimum and maximum surface water salinity along the Kenya coast vary little and ranges from 35 to 36‰ (about 500 mM) (Tiensongrusmee, 1991); while the average varies from 34.8‰ in May (end of dry season) to 35.4‰ in December (end of wet season). The northeast monsoon winds bring sea water with a lower salinity from the Malayan archipelago (along the South Equitorial current) (Moorjani, 1977; Onyango, 1989). This variation is insignificant as far as the plants of the intertidal and shallow waters are concerned. At Gazi a salinity level of 35‰ at incoming tide and 32‰ at the out going tide has been measured (Gallin et al., 1989). At seepage points of Gazi, Ruwa and Polk (1986) were able to record salinity values as low as 16 - 20‰ According to Gallin et al., (1989), these seepage points are restricted to only a few points thus their influence to the mangrove vegetation is of insignificance.

The Kenya coastline experiences mixed semidiurnal tides. The levels reached by each tide differ appreciably from the corresponding tide before and after the tide following. The maximum tidal range does not usually exceed 3.8 m but may sometimes be over 4 m. The tidal regime during the period October 1991 to December 1992 is presented in fig. 3. All the planting experiments were carried out during low tides.

The tides and the winds bring about locally generated waves which are variable in strength depending on the position, whether in protected areas or in bays or exposed sites. Coastal erosion is prominent in exposed sites. In the open ocean, little tidal effect is felt. The Islands have a maximum diurnal spring tide of 1.5 m in amplitude (Brakel, 1982).

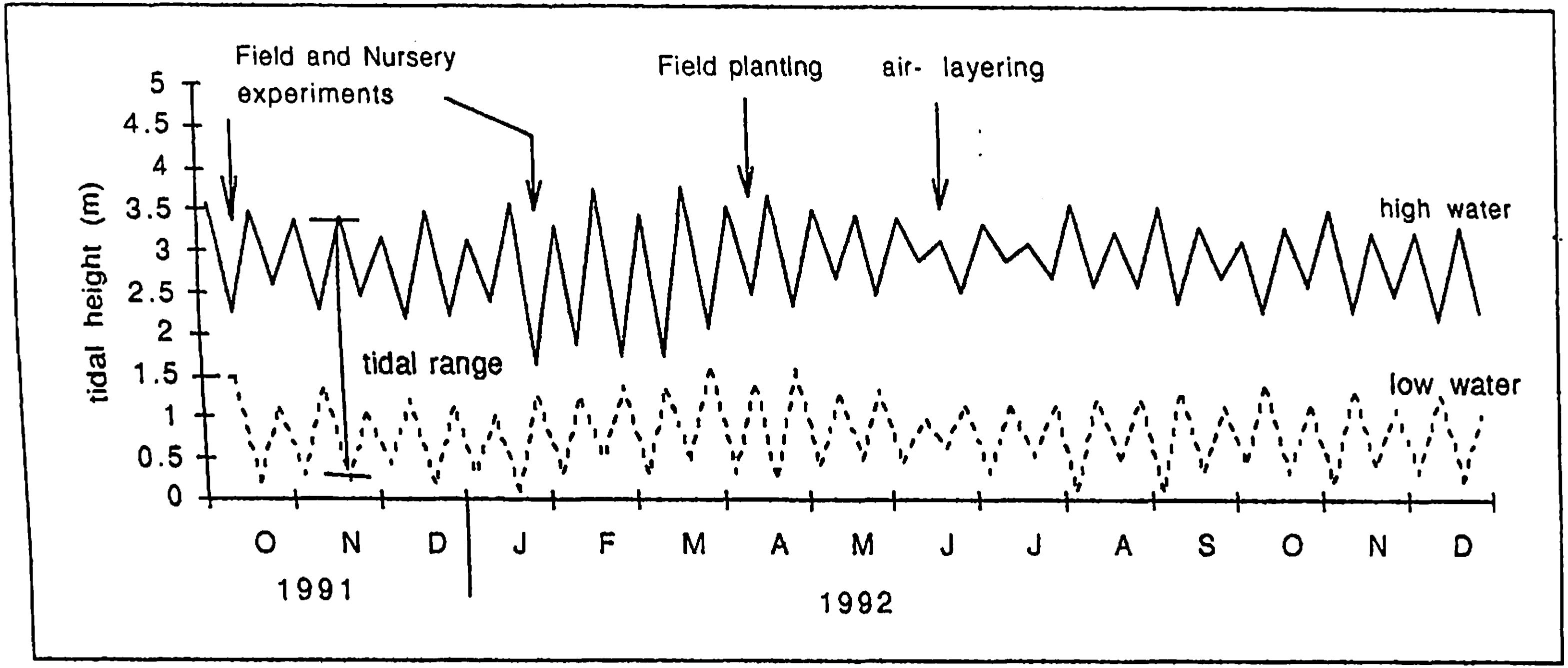


Fig. 3. Monthly variation in tidal cycle for Kilindini harbour. Maximum diurnal range at spring tide is normally below 3.8 m. The corresponding time of mangrove planting experiments at Gazi bay is indicated in the graph. (*Adapted from KPA tide tables: 1991 - 92*).

2.4 Geology

The rock types show a geological succession from the sea ward to the west ranging from the Quarternary rocks (lagoon sand and coral reef), tertiary rocks (e.g. Magarini sands), The Jurassic shales and Triassic sandy stones (for example Maji ya Chumvi Beds, Mazeras Sand stones, Mariakani sandstones) (Michieka, et al. 1978). Where the mangrove forests occur the deposits have been described as recent marine deposits. These marine sediments are predominantly unripened (soft). According to Boxem et al. (1987), the recent alluvial and unconsolidated deposits comprise: (a) stratified sands and silts (flood plains) and (b) compact clays (bottom lands). The deposits are essentially composed of quartz and undifferentiated clay minerals.

Frequently present under the mangrove forest is the coral reef. This fossil reef is found in a 4 - 8 km wide zone along the coast. It consists of coral limestone with sand admixtures. Soils developed on this reef vary from very deep and non rocky to very shallow and extremely rocky directly along the coast. In places with a considerable admixture of quartz rich beach sand were formed (Michieka et al. 1978).

In the most landward side of the mangrove regions are the Kilindini sands. This formation consists of unconsolidated erosion products of Magarini sands, Shimba grid and Mazeras sandstone. The Kilindini sands are described as Pleostocene sands, thought to have been deposited during the pleiotocene in a shallow marine environment, mainly made up of medium and coarse grained sands (Boxem, et aL. 1987).

2.5 Soils

Geologically the coastal area is diverse with tremendous variation in soil types and fertility. Most soils are derived from sand deposits, limestone or shales. The resultant soils are therefore light and well drained. Nearer the coast the soils are sandy and further inland they are a mixture of sands, clay and loam distributed sporadically (Michieka, et al. 1978)

Mangrove soils may appear to have a great potential for agricultural use.

Factors such as flat topography, the potential use of tidal forces for drainage and irrigation, moderate to high nutrient levels, organic materials, or accessibility make them attractive. Closer examination, however shows that mangrove soils can be difficult to manage due to problems of flooding, salinity and the formation of acid sulphate soils. Good agricultural lands reclaimed from mangrove areas are rare. Inspite of spectacular and numerous failures, major reclamation schemes are being conducted in African and Asian mangrove areas leading to major environmental transformations that may have significant negative influences on coastal fisheries (Hamilton and Snedaker, 1984).

2.6 Floristic composition and Zonation

Eight (8) mangrove plant species belonging to 6 families have been described in Gazi bay (Gallin et al., 1989) together with their zonal distribution pattern (Van Speybroeck, 1992a) (table 1). According to Kokwaro (1986) and Gallin et al. (1989), in Gazi there are only 7 species of mangroves. Actually they did not account for the rare *Heritiera* species, which was characterised during our preliminary study.

Generally the lowermost zone closest to the sea is formed by *S. alba* which is probably the most important pioneer species along the open coasts. Behind the *Sonneratia* zone is an area characterized by a mixed vegetation: *Rhizophora* - *Avicennia* -*Bruguiera* community. This is followed by *Ceriops* -*Avicennia* community and *Lumnitzera, Xylocarpus* and *Heritiera* to the land ward side

2.7 Human Activities

There has been extensive exploitation of Gazi mangroves for various purposes over many years. The mangrove forest has been affected most noticeably by wood extraction for industrial fuel and building poles. Wood extraction for fuel has declined following the depletion of the big mangrove trees and nearly inaccessibility of the resource in the remaining parts. Forest areas are however still allocated to

Concessionaires, for building poles and there is also widespread small scale wood cutting to meet the needs of the local people.

Gazi (Maftaha) bay mangrove system is an important area for fishing activities, both commercial and subsistence. The fishermen from the three nearby villages; Gazi, Kinondo and Msambweni find fishing grounds sheltered from the ocean, and a safe landing site on a small beach near Gazi village. The main fisheries are edible crabs and small pelagic fish. Recently small scale, aquaculture ventures have involved artificial raising of oyster ranks by the Kenya Marine Fisheries Research Institute (KMFRI).

The present way of exploitation of the Gazi mangroves must be considered unsustainable. These conclusion is based on the following observations:

a) Severe erosion of the shoreline is taking place due to complete elimination by constant cutting of the fringing mangroves (plate 3).

b) It is becoming hard to find a straight stemmed tree which can be used for building.

c) Clear felled areas with little or no regeneration are occuring all over the area (plate 1).

The study area map (appendix 1) indicates some completely logged areas at Gazi, Kinondo, and Mkurumuji river bank. The Gazi and Mkurumuji plots had previously been logged but are now occupied by secondary regrowth. The most logged area is Kinondo, which is now being recolonized by herbacious halophytes such as *Sueda monoica* and grasses such as *Sporobolus spicatus*.. On personal enquiries, most of the cutting in Kinondo were done more than 18 years ago, and the products sold to a soap factory (in Mombasa), a bakery (in Gazi and Mombasa) and a Calcium product factory -KCP (at Tiwi). Presently the bakery at Gazi and KCP at Tiwi (Kwale district) continue to use the mangrove fuelwood despite shortages. With a decrease in mangrove wood supply these industries are likely to switch to other energy sources. Such an energy switch would lead to loss of particular benefits for example, (a) loss of employment to the people involved in the production and distribution of fuel wood, and (b) loss of revenue to the Central Government. Therefore creation of man made plantations of mangroves is an alternative which can very rapidly enhance the productivity of the mangrove forests, at the same time improve the standard of living for the people.

CHAPTER 3

MATERIALS AND METHODS

3.1 Mangrove environment

3.1.1 Zonation

Given the broad perspectives of afforestation studies, it was realized that there was a need to correlate the edapho-physiographic characteristics (such as soil salinity, soil texture, elevation level and the distance from the sea) with mangrove composition and hence distribution (zonation) in Gazi bay. A line transect, perpendicular to the coastline was used to sample mangrove vegetation. The length of the transect was about 350 m and covered the width of mangrove forests at various sites. At least fifty 5 x 5 m quadrants were marked along the transect. Each quadrant was subjected to ground survey as the first procedure in defining species present, general community characteristics and the nature of plant habitat. Tides and wave processes of the quadrant were examined, involving at times the monitoring of the nature of propagule establishements, either 'fixed' or 'not fixed' (see Van Speybroeck. 1992a). Floristic sketch mapping was undertaken in conjunction with the levelling. The following plant characteristics were noted: species tree size, relative abundance, degree of ground cover, regeneration pattern and incidence of recent damage.

In each quadrant the mangrove vegetation was described according to the principles of the floristic-sociological approach (Westhoff and Van der Maarel, 1979). Species cover and abundance were estimated by using ordinal scale from 1-9 of Van der Maarel (1979), and the actual number of propagules and saplings present in a 5 x 5 m quadrant. The elevation in m above mean water level at spring tide (MLWS) was measured for each quadrant according to the line level method (Dawes, 1980). Heights above MLWS were computed using the tide table (August, 1992) for Kilindini harbour (Mombasa). The elevation level was represented following the inundation classes (1 - 8) modified after Watson (1928). Quadrants inundated daily by all the tides were assigned inundation class 1, while the quadrants that were inundated by exceptional or equinoctial tides were grouped under inundation class 8. Fig 6 gives the definition of the used inundation classes.

3.1.2 Soil analysis

For studies of soil properties, soil samples were collected in different vegetation types, at various distance from the sea to the landward side. Soil samples were taken at 20 cm horizons for laboratory analysis. The soils were air dried before grinding, after which they were passed through graded sieves of mesh diameter range from 2.0 mm to 40 μm for textural analysis.

Detailed analysis of soil samples was performed at the Division of Soil Chemistry, Department of Soil Science - National Agricultural Laboratories (NAL), KARI. Soil pH was measured by a pH-redox meter. The determination of organic matter was carried using the rapid titration method of Walkley and Black. Nitrogen content was carried out using the Kjeldahl digestation method. Cation exchange capacity was obtained using modified sodium saturation method. Sodium content was determined using a flame photometer after extraction in a 1N ammonium acetate at pH 7 with a ratio of 1:5. Calcium and Magnesium were measured with an atomic absorption spectrometer after extraction in a 1 N ammonium acetate at pH 7 with the ratio of 1:10. Salinity was measured by the conductivity meter (mmho/cm). Methods used in the determination of Ca, Na, Mg and K were those described in ASA(1986).

3.1.3 Phenology

Periodicity of the mangrove propagule availability, in relation to season was investigated during the study. Propagule availability was estimated using an ordinal scale reflecting density classification; very abundant, abundant, frequent, rare and very rare (Krebs, 1985). Propagules availability of a given species were referred as being 'very abundant' when several viable propagules were found either in the forest floor or being drifted by tides or still attached to the parent. When a parent holding such mature propagules is slightly shaken the propagules readly fall.

Rare propagule availability is here used to refer to the condition in which we had to search for the propagules. Most propagules are in their early to mid developmental stages, with their 'fruit' (cap) still attached and very few if any are to be found on the forest floor or being drifted.

3.2 Planting of mangroves

The experimental cultivation of mangroves was set along the coastline of Gazi bay in October 1991, with the primary objective of rehabilitating and restoring the denuded mud flats and clearfelled areas of the bay. Species and sample size were not uniform because of the unavailability of the propagules at the time of planting. Much information was obtained from this experiments, however some parts of the experiments should be confirmed by making new experimental cultivations.

Emphasis was placed on investigating the effects of some general ecological factors, such as soil and water salinity, tides, ground level, soil types, size of the propagules, age of saplings and the method of transplanting, on the subsequent performance of the selected mangroves of Kenya. Growth parameters that were compared are illustrated in fig. 4 and include:

a) mortality / survival, germination percentage (for the whole sample);

b) average height increment (in cm), number of internodes, number of leaves, number of lateral branches (for n = 20-30);

c) diameter of the stem (in cm) at first internode (for n = 20-30);

d) specific leave area (in cm^2) per plant (for n = 20 - 30)

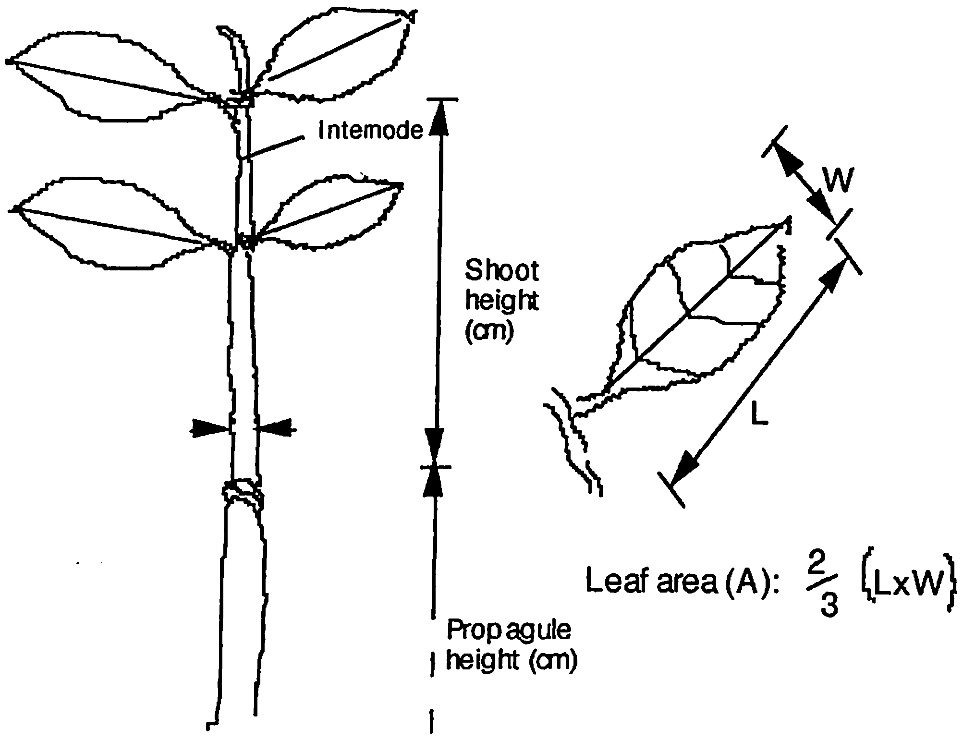


Fig. 4. Biometry of a mangrove sapling.

3.2.1 Collection of propagules

Mature mangrove propagules were harvested from mother trees or litter under trees or from ranks on beaches. Propagules were collected from numerous individuals either by shaking fruiting branches and picking the falls, or by collecting recently fallen propagules from the ground litter over a wide area. Collection techniques for different species were as follows:

a) *Ceriops*, *Bruguiera* and *Rhizophora*

The propagules were collected from water or forest floor or by shaking the parental trees or by climbing the trees. A distinct ring like mark (cotyledonary collar) in the hypocotyl, of *Rhizophora* and *Ceriops*, proximate to the plumate differentiated the young propagules from mature propagules. A mature propagule of *Rhizophora* or

Ceriops has a distinctly longer cotyledonary collor that is yellow in colour. The lengths of the propagules varied from 30.3 - 54.5 cm in *Rhizophora*, 20.9 - 47.1 cm in *Ceriops* and 16.6 - 20.8 cm in *Bruguiera*.. One kilogram of freshly collected *Rhizophora* propagules contained 12 - 15 propagules as compared to 91 - 115 propagules/kg of *Ceriops* and 43 - 46 propagules/kg of *Bruguiera*.. Field collections were made from Kinondo, Gazi and Chale Island.

b) *Avicennia marina*

Mature propagules were collected from water or forest floor or by picking from parental trees. The propagule was given a very slight twist and if it came away without the calyx it was considered ready to fall. On average one kilogramme contained 205 propagules. Field collections were made along the intertidal area of Gazi village.

c) *Xylocarpus granatum* and *Heritiera littoralis*

Mature *Xylocarpus* and *Heritiera* fruits were collected from the ground along River Mkurumuji. *X. granatum* fruits are large in size and weigh 3 - 4 kg. Usually a *Xylocarpus* fruit contained 5 - 13 seeds while a kilogramme of *Heritiera* contained about 50 - 75 fruits.

d) *Sonneratia alba*

Planting did not coincide with the fruiting season of the species, as such no propagules were used in the experiments.

3.2.2 Collection of saplings.

Transplanting saplings were collected from the nurseries or were scooped from the natural forests, by use of spades or transplanting augers. The wildings were removed with root-ball diameter about half the original height of the sapling and transferred to the afforestation area where the second hole was dug to receive the sapling.

3.2.3 Storage of propagules

After collection the propagules were kept in transparent moist plastic bags and stored for not more than three days. In most cases they were planted in the day of collection.

3.3 Experimental design

Planting of mangroves was done at three sites, G-i, K-i and M-i, representing Gazi, Kinondo and Mkurumuji river bank respectively. These sites were selected on the basis of tidal conditions and that they were the best representative of the study area as far as feasible. Gazi plots comprised the low-lying muddy swampy area: soils were coral sand in the region colonized by *S. alba*, and compact sandy-loam to rapidly drying gravelly, in the open areas that were more exposed to winds. Barnacle infestation was a common feature in the low lying plot G-1.

The Kinondo plots were located on a barren, highly sandy area towards the land-ward side. The loose sandy soil extended upto 30 cm in depth, followed by a profile of sticky clay of more than 50 cm in thickness in some places.

The propagation methods used *in this study are classifiable into three categories:*

1) Nursery experiments
2) Plantation establishment on over-exploited areas
3) Air layering

3.3.1 Nursery experiments

Nursery experiments were carried out primarily to study the germination / sprouting and the subsequent performance of mangrove species. Three mangrove nursery sites were selected in areas inundated by spring tides all around the year. One nursery was established at Gazi village near the fishermen landing bay, plot G-3. Two other nurseries were located at the Mkurumuji river banks: M-1 and M-2 (see appendix

1). The Gazi nurseries were prepared under the tree of *Avicennia* shade ranging from 5 - 10 m height. The ground level was such that the beds were inundated with sea water when a tide of 2.7 m height approached the shoreline. The nursery site was first ploughed, all debris and other vegetation being removed. Plastic pots (27 cm height x 12 cm diameter) were filled with either of the two types of soils (a) normal mangrove soil, and (b) the 'peaty portion' of the mangrove soil (the 'peaty' constituted a high percentage of sea grass litter).

The filled polybags were placed side by side in a nursery bed dug to the level of the paper pots. Side drain with greater depth and width were made around the nursery sites to control the inflow of tidal water (fig. 5)

950 propagules of four species: *R. mucronata* (240), *C. tagal* (280), *B. gymnorrhiza* (180), and *A. marina* (250) were sown in the pots at the rate of one propagule per pot. The sowing was done during low tide of October 1991 (for *Rhizophora, Ceriops* and *Bruguiera*) and in April 1992 for *Avicennia* (see fig. 3). Sample size was however not uniform due to the unavailability of propagules during sowing period. 250 *Heritiera* and 300 *Xylocarpus* propagules were sown directly into the tidal mud of Mkurumuji nurseries (see fig. 5)

Data on germination percentage and propagule mortality was collected 3 and 6 months after sowing respectively. The area of the leave was established by measuring length and breadth of all the leaves of a plant:

$$A_i = L_i \times B_i \times \frac{2}{3}$$ (Cain and Castro, 1959).

Total leave area of a plant:

$$A = \sum_{i=1}^{n}(Ai)$$

3.3.2 Planting of mangroves in the field

Planting of mangroves was done during low tide. Three (3) plots in Gazi (G-i) and 4 in Kinondo (K - i) were marked. The microecology exhibited in each of the plots

G-1 to G-3 and K-1 to K-4 is presented in fig. 6. On cumulative basis Gazi and Kinondo blocks presented a belt transect running from the barren highly sandy area (of Kinondo) to low lying muddy area (of Gazi) colonized by *S. alba* (see fig. 7). The plots G-1 to G-3 and K-1 to K-4 laid randomly at different elevation within the belt transect.

The transect represented a number of edapho-physiographic characteristics like ground level, soil salinity and water level. The low lying plot G - 1 (inundation class 1) is inundated daily. The level of subsoil water deepend from 10 cm in the low-lying muddy area around *Sonneratia* zone to more than 150 cm in the highly compact and sandy areas of Kinondo (pers. observ.). The detailed characteristics of the soils in the transect are summarized in table (2).

Two modes of planting / transplanting were used:

a) zonational planting/transplanting

b) reciprocal planting/transplanting

a) An experiment for *R. mucronata, C.tagal* and *B.gymnorrhiza* on suitable level to plant

To ascertain the range of suitable ground level for *R. mucronata C. tagal* and *B. gymnorrhiza* observations were made on the saplings and propagules planted at different inundation/elevation level along the transect, in plots: G-1, G-3, K-1, K-2, K-3 and K-4. Plot G-1 is the low-lying plot bondering the sea. The plot remains submerged for relatively long hours per day. Plot K-4 is the most landward plot, normally inundated once per month. The particular field techniques for different species are given below.

i) *R. mucronata*

1087 propagules and saplings of *Rhizophora* collected from pure *Rhizophora* stands were transplanted. 15 cm of the propagules was embedded in the soil by making a bore with the help of a wooden rod.

Saplings were tranplanted to the reforestation area where the second hole was dug to receive it. During the planting the rootballs were watered and stamped down while replacing soil to/and sealing between the root ball and the side of the hole.

In most cases the interspace was kept at 0.5 - 1.0 x 0.5 - 1.0 m for propagules and 1.5 x 1.5 m for saplings. The plantation was studied monthly (for 12 months) to investigate the pattern of their growth with respect to general physiographic characteristics like ground level, soil salinity, soil texture and shade.

(ii) *C. tagal*

There was no problem in obtaining *Ceriops* propagules and saplings. A total of 1838 propagules and saplings were planted. Nearly 5 cm of the propagule was embedded in the soil. The interspacing and data collection was retained as above.

iii) *B. gymnorrhiza*

The propagules and saplings of *Bruguiera* due to their unavailability could only be planted in few plots. 360 propagules and 460 saplings collected from Chale Island and Kinondo were planted. Data collection and interspacing was retained as before.

b) To establish an efficient method of sowing propagules of *A. marina* in the field

Some experimental plantation of *A. marina* were carried out in plot G-3, by broadcast and direct hand sowing methods. 200 propagules were used in each of the methods.

c) Effects of propagule length on seedling performance

In order to study the relationship between the length of the propagules and its subsequent growth performance, a seperate experiment was conducted under field condition in plot K-1 of Kinondo. 75 propagules of *R. mucronata* collected from a pure *Rhizophora* stand were divided into three classes:

< 370 mm
> 370 and < 450 mm
> 450 mm

Data on growth performance was collected monthly for 12 months.

d) Effects of transplanting method on saplings performance

The effect of transplanting method on sapling performance was only investigated in *Rhizophora*. Natural (wildings) and nurseried saplings of *Rhizophora* were transplanted in plot G-3, in a 2 x 2 m spacing. Data on subsequent growth performance was collected monthly for 12 months.

e) To compare the performance of *S. alba* under different transplanting age

The study was conducted in a denuded mud flat (of plot G-1), near the oysters farm. The site was plain with a gentle slope towards the Gazi creek. For greater part of the time it remained under water when the experiment was initiated. Impact of tides and wave action was profound. Soils were coral sand with a high organic matter content. *In-situ* soil salinity as measured, using a hand held refractometer was 37‰.

530 saplings were transplanted on a 1.0 x 1.0 m spacing. The saplings were divided into three classes: small (7.8 cm), medium (33.1 cm) and large (63.3 cm). The small saplings at the time of transplanting had 2 - 8 leaves ($X = 5.62 \pm 1.30$). While large saplings had more lateral branches than the medium sized saplings. The proportions of the saplings at the time of transplanting were: small (n= 230), medium (n= 100) and large (n= 100). Mortality and growth performance was studied monthly for 12 months.

f) Restoration by use of 'small trees'

In plots G-2 and G-3 an experiment was carried out using 'small trees' with a view of developing a potential method of obtaining more rapid growth and substrate stabillization than could be expected from the planting of either propagules or saplings.

22 *R. mucronata* small trees, with a height range of 1.0 - 1.8 m and 91 *Avicennia*, (height: 0.64 - 1.25 m) were transplanted in a 2 x 2 m grid. The diameter of the stem at the time of transplanting ranged from 2 - 9 mm for *R. mucronata* and 3 - 5

mm for *A. marina.* The trees were scooped from the soil with a root ball diameter a half the original height, and moved at least 20 m using a team of 3 men, before being placed in hand prepared sites. The plots were checked bimonthly to assess mortality and growth performance.

3.4 Air layering

During the wet season of June 1992, 25 trees each of the species: *Sonneratia alba, Lumnitzera racemosa* and *Xylocarpus granatum* , of different heights were randomly selected in the intertidal area of Gazi bay. 5cm wide girdles were made in branches that were less than 2.5 cm in diameter, using a girdling knife. On the ease of bark removal, *Sonneratia alba* was the easiest for girdling, followed by *Xylocarpus granatum* and *Lumnitzera racemosa* .

Layers were placed between the internodes if possible, however some included the adjacent nodes if internode length was less than 5cm. The exposed area was wrapped with either moss; vermiculite powder with a rooting hormone (Soradix 3 for hard stem) or mangrove forest litter, soaked in distilled water. A plastic was then laid above the rooting medium and tied at the ends with plastic stretch tapes. No tree was treated with more than three layers. After 5 months layers were checked for signs of root development and respective growth.

3.5 Statistical analysis

It was opted to make use as much as possible of a graphical representation of the results. Comparison of species performance at their respective elevation above datum level were performed using simple classification ANOVA at either 95% or 99% significant level (Zar, 1984). Linear correlation and regression analysis are used to visualize the relationship between propagule size and the subsequent sapling performance (table 4).

Graphical representation of data distribution in fig. 17 and fig. 18 follows the box plot display (Chambers et al., 1983). A box plot summarises the distribution of a parameter by means of 5 specific values from the data set: the median (= the 50 percentile), the upper and lower quantile (the 75 and 25 percentiles) and the upper and lower extremes (the 90 and 10 percentiles). Outlier values in the box plot fall above and below the upper and lower extremes and are represented by extreme points.

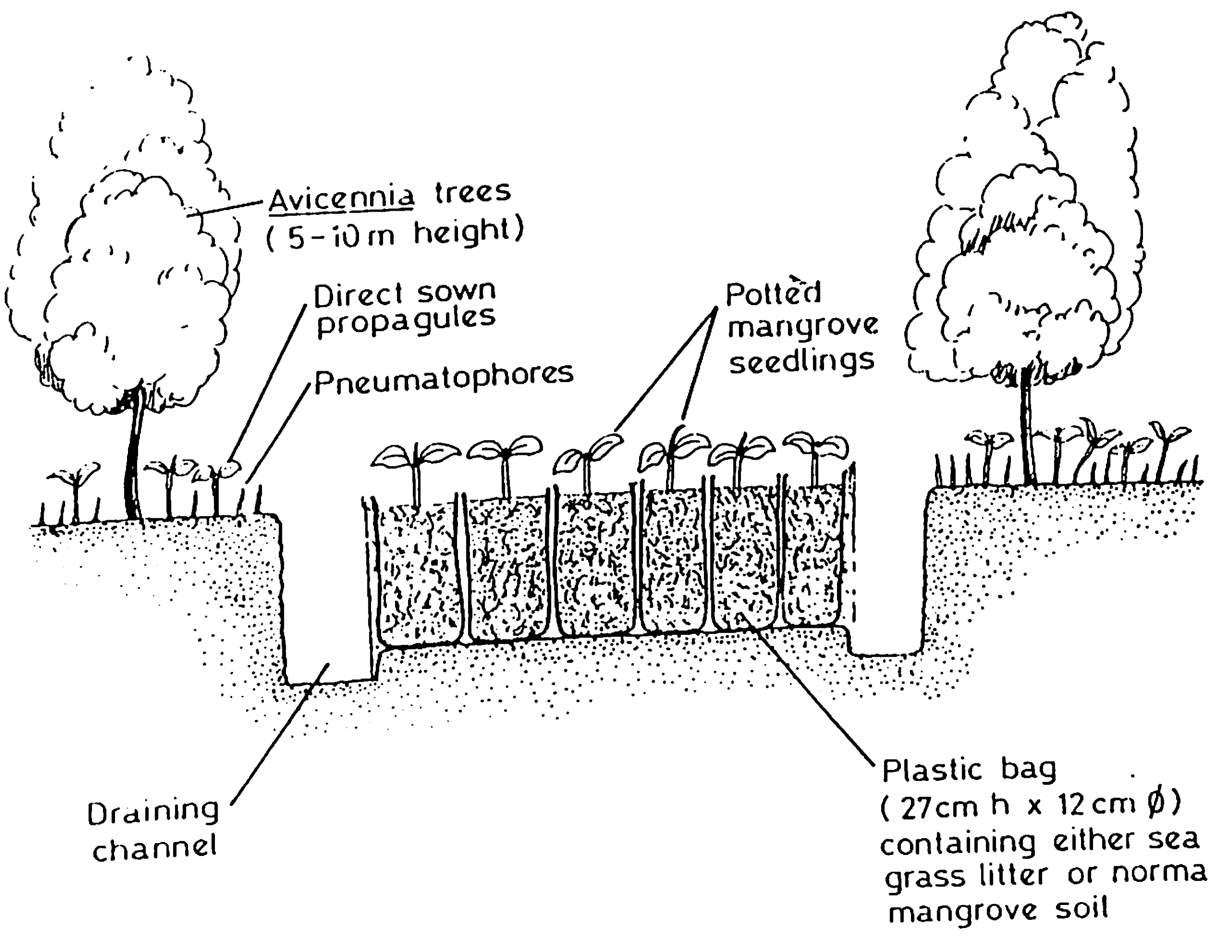


Fig. 5. Structure of the nursery bed in cross-section at Gazi bay showing 'pot-cultured' and 'direct sown' propagules under tidal conditions.

Fig. 6 Schematic representation of a belt transect over which mangroves were cultivated. Some edapho-physiographic characteristics exhibited by each of the plots (G-i, K-i and M-i) are presented in the table. G-i: Low lying mangrove stands on the seaward side of Gazi, M-i: Mkurumuji riverine nurseries; K-i: elevated Kinondo plots on the most land-ward side.

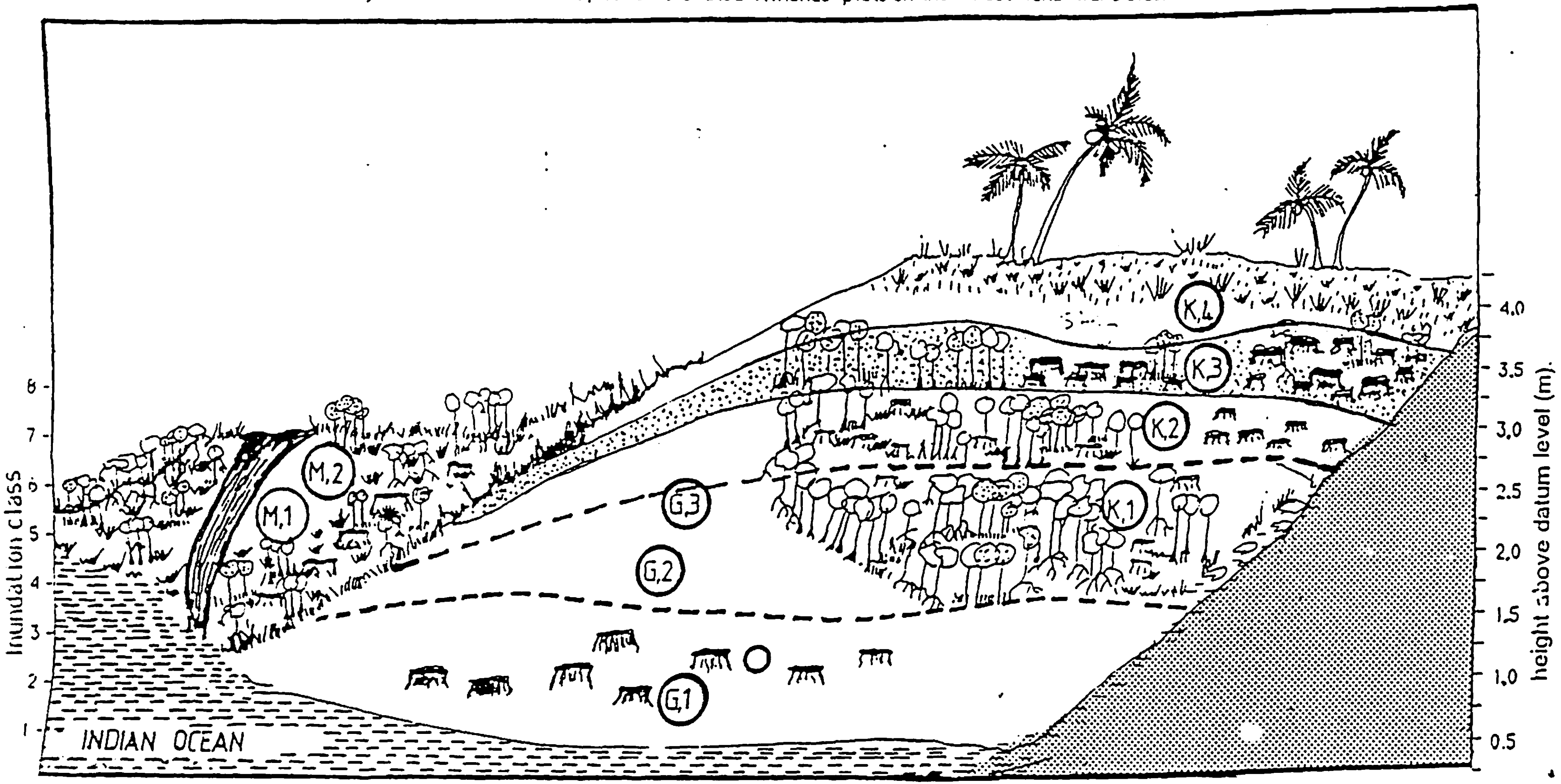


Table for fig. 6 (above)

Plot	mangrove edge (m)	Inundation class	Soil texture	*soil salinity (mmhos/cm*	Species planted	sample size P	sample size S	Tested items	Comments
G-1	0.5 - 1.0	1	- loamy sand	*14.64*	R. mucronata C. tagal B. gymnorrhiza S. alba A. marina	380 600 180	303 240 240 530 300	- Ground level - Shade - species selection	- all B.g. C.t. & A.m died in the first 4 months. Probably the best zone for S.a., maximum growth for S.a. = 1.18 m/year.
G-2	1.2 - 1.7	3	- loamy sand - sand	*20.50*	R. mucronata C. tagal B. gymnorrhiza	60	122 100 100	- transplanting method	- nurseried saplings performed better than the wildings
G-3	1.5 - 2.6	4	- sand -loamy sand	*15.44*	R. mucronata C. tagal B. gymnorrhiza A. marina	240 280 180 400	 91	- method of germination - potting method - transplanting method - sowing method	- B.g. grown in sea grass litter attained a height of 53.17 cm/yr (c.f. 27.10 cm/yr for B.g. grown in 'normal' mangrove soil
K-1	1.7 - 2.6	3	- sandy clay	*11.25*	R. mucronata C. tagal B. gymnorrhiza A. marina	100 200 80	84 180 70 30	- Ground level - shade - salinity	- Probably the best zone for planting R.m. Survival of R.m after 1 year was greater than 90%
K-2	2.5 - 2.9	4	- sandy clay	*9.83*	R. mucronata C. tagal B. gymnorrhiza	60 60 200	80 40 150	- Ground level -soil	....
K-3	2.8 - 3.0	5 & 6	- sand clay loam - sand	*8.83*	R. mucronata C. tagal B. gymnorrhiza X. granatum	60 200 80	80 80 50 30	- Ground level - shade - salinity - soil	- Probably the best zone for planting C. t. Survival after a year was more than 80%
K-4	3.1 - 3.2	7	- sand - sand loam	*6.0*	C. tagal A. marina X. granatum	150	88 50 30	- Ground level - shade - salinity - soil	- X.g. suffered from a great degree of defoliation and mortality (80%) and extremely poor growth
M-1	2.4 - 3.0	6 & 7	- loamy sand	....	X. granatum	300	.....	- method of germination	.. ..
M-2	3.0 - 3.8	7 & 8	- sandy loam	....	H. littoralis	250	.....	- method of germination	....
					TOTAL	4060	3068		

Tree names are abbreviated as R.m. = *Rhizophora mucronata* e.t.c, P- Propagules, S- saplings

CHAPTER 4

RESULTS

4.1 The mangrove environment

4.1.1 Zonation

Existing accounts of mangrove zonation and structure over some parts of the Kenyan coast include publications by Walter and Steiner (1936); Gallin (1988); Beeckman et al., (1990) and Van Speybroeck (1992a). Additional information for Gazi bay is given by Ruwa (1993) and Van Speybroeck et al., (1993). The following summarizes the results: Eight mangrove species were found in the mangrove area of Gazi bay these are *S. alba, R. mucronata, C. tagal, B. gymnorrhiza, L. racemosa, X. granatum* and *H. littoralis.* The total parent cover and the tree height differed along the transect with *Ceriops, Avicennia* and *Rhizophora* showing the most dense cover. The tallest trees were the seaward *Avicennia* and *Rhizophora* that attained 15 - 18m height and a percentage cover of 75 - 100% (fig. 7(a) and (b)). Based simply on the density of propagules and saplings, *Avicennia, Rhizophora* and *Ceriops* stands, have a high regeneration potential (fig.7 (d), (e), (f)). All these stands have been under concessions for many years, thereby opening up the canopy and allowing light to reach the seedlings. The density of saplings and propagules was much lower in the sea-facing *Sonneratia* zone (fig.7(c)) and in the most landward *Heritiera* zone (fig 7(h)). Small-scale clearing in mangrove appears not to be a recent occurrence in most areas of Gazi bay, and it must be considered as a factor which may have played some role in determining the present tree density, regeneration and percentage cover.

4.1.2 Soil characteristics

The soil properties for Kinondo (Ki) and Gazi (Gi) plots are summarized in table 2. In Gazi the soils were characterized by medium to high salinity (13.78 - 22.50

mmhos/cm), along the whole length of the transect, and relatively small amount of clay (4 - 26%). Soils in Kinondo (Ki) had a much lower surface salinity; (7.0 - 12 mmhos/cm); silt (0 - 8%); organic carbon (0.80 - 2.90%) and nitrogen (0.07 - 0.21%). Lower figures for above parameters may be due to recent clear-felling of the forest with a consequential washing out of the loose top soil by the tidal actions and land runoff.

In terms of % sand and pH, there was no significant difference ($p > 0.05$) between the two blocks. The cation exchange capacity (CEC) in most of the Kinondo soils were low to medium: 14.05 ± 2.41 meq/100g dry soil (range: 6.0 - 29.0 meq/100g dry soil.) while in Gazi the soils had medium to very high CEC: 33.40 ± 5.25 meq/100g dry soil (range: 22.13 - 95.50 meq/100g dry soil). In both Kinondo and Gazi plots, Mg^{++} was found to be the chief cation associated with the exchange sites, followed by Na^{+}, Ca^{++} and K^{+}.

4.1.3 Phenology

Data collected on fruiting period of different species between October 1991 and September 1992 are of qualitative nature (not quantified) - fig.8.

In *Rhizophora, Ceriops* and *Bruguiera* propagules are available all the year round with peak seasons in April-July (*Rhizophora* and *Bruguiera*) and February to May in *Ceriops*.. Mature fruits of *Avicennia* are available from April to June. Out of season *Avicennia* 'stragglers' could not be found between September and February. In *Xylocarpus* and *Heritiera* peak fruit dropping was seen to occur in May to July, off season 'stragglers' were difficult to find all the year round.

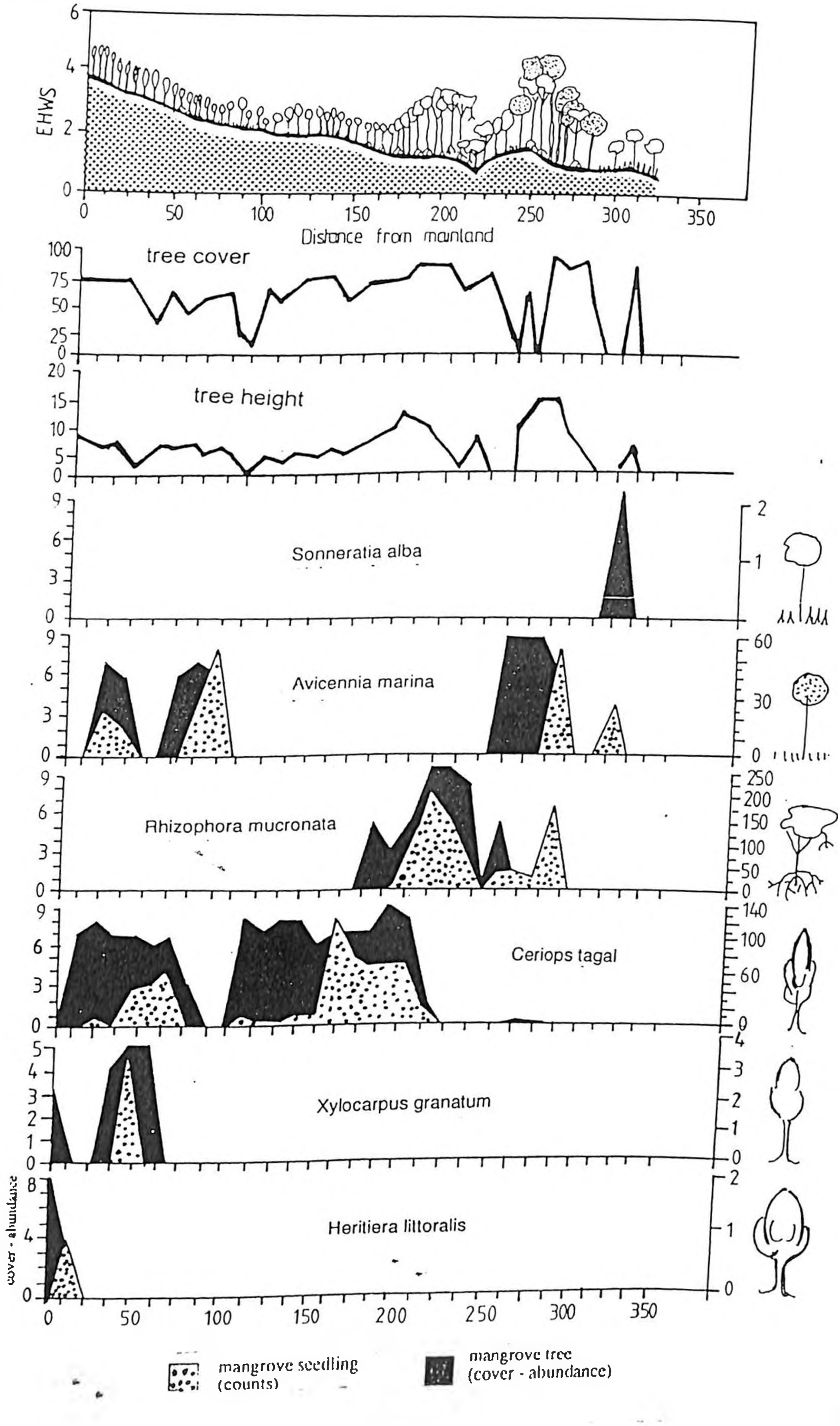


Fig. 7. **Distribution of mangroves along the intertidal area of Gazi bay.** Illustrating: a) tree density/cover (%), b) tree height (m), (c - h) specific zonation of the species.

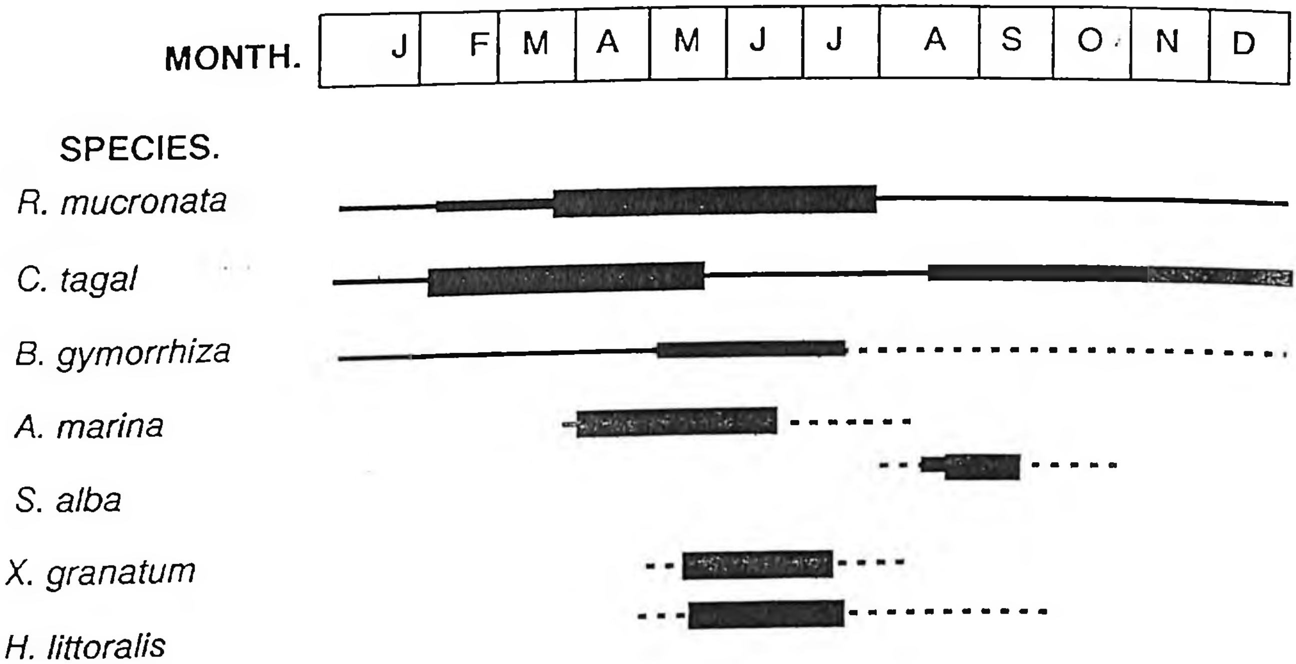


Fig. 8 Availability of mangrove propagules at Gazi bay. Relative abundance of the propagules of each species in the plant community is presented by the width of the bar:

Plots	sample	% sand	% silt	% clay	Texture	pH 1:2.5 H2O	Ec mmhos/cm 1:2.5	C%	N%	CEC meq./100 dry soil	meq/ 100 g dry soil Ca	Mg	K	Na
G1	S-1	90	6	4	sand	5.20	15.50	3.02	0.10	32.00	4.70	29.20	1.10	10.50
	S-2	78	10	12	sand clay loam	6.80	13.78	2.64	0.18	37.42	13.77	26.68	1.15	8.42
G2	S-3	64	10	26	clay loam	5.80	22.50	7.41	0.86	94.30	8.90	79.80	4.50	25.60
	S-4	76	12	12	sand loam	6.40	18.50	8.03	0.85	95.50	8.70	76.80	3.20	23.50
G3	S-5	79	13	8	loamy sand	5.93	16.33	3.92	0.29	30.08	5.18	27.60	1.13	9.18
	S-6	86	9	6	sand	6.15	16.25	3.39	0.26	22.13	6.20	7.78	1.04	3.97
	S-7	82	10	8	sand	5.80	13.75	2.25	0.11	23.50	3.50	24.00	0.88	7.25
K1	S-8	74	6	20	sand clay loam	6.20	12.00	2.90	0.21	29.00	5.90	29.20	7.90	8.20
	S-9	80	4	16	loamy sand	6.20	10.50	2.17	0.18	18.00	3.30	21.20	1.10	5.70
K2	S-10	95	1	5	sand clay loam	5.80	11.00	1.51	0.06	11.50	2.70	13.20	2.90	3.70
	S-11	84	4	12	sand	6.40	9.00	1.62	0.11	9.00	2.50	14.00	0.81	3.20
	S-12	84	0	16	sand loam	6.20	9.50	1.45	0.11	9.00	2.10	14.00	0.79	2.90
K3	S-13	74	8	18	sand loam	6.20	11.00	2.82	0.20	24.50	5.90	30.80	7.20	7.20
	S-14	76	8	16	loamy sand	6.40	8.50	1.82	0.14	13.00	2.70	16.00	5.30	4.20
	S-15	84	4	12	sand	6.40	7.00	0.99	0.07	7.00	1.30	8.00	0.61	2.20
K4	S-16	76	6	18	sand loam	6.40	9.50	1.57	0.12	13.50	2.70	14.40	1.00	3.50
	S-17	82	4	14	sand	6.40	8.50	0.80	0.08	6.00	0.90	7.60	0.59	2.10

4.2 NURSERIES

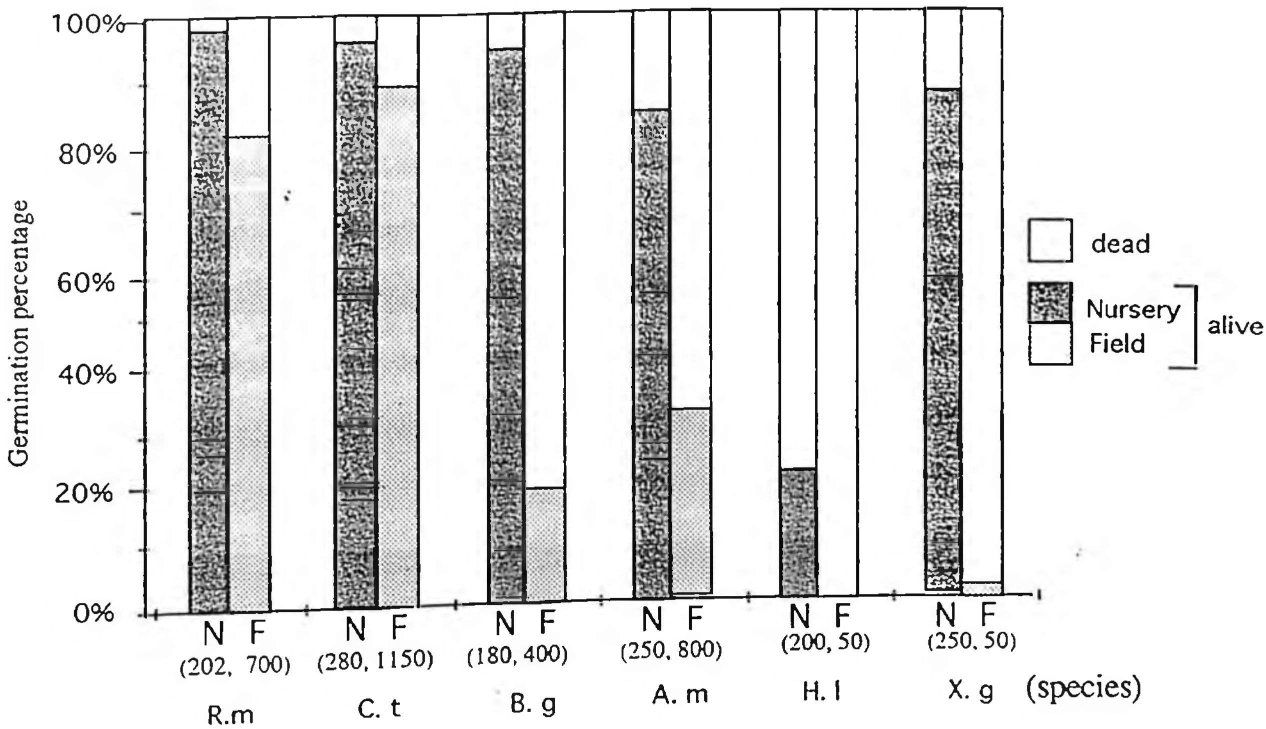
4.2.1 Germination

Germination percentage for mangrove propagules in nursery and field conditions are shown in fig 9(a). All the 6 species tried in the nursery germinated. In *R. mucronata,* germination (sprouting) started within 7 days of sowing, and almost 90% of the propagules had germinated within 20 days. In *X. granatum* germination commenced 20 days after sowing. By the 7th week of sowing 80% germination had occurred. While in *B. gymnorrhiza* germination was completed in 16 days after sowing (fig 9 (b)).

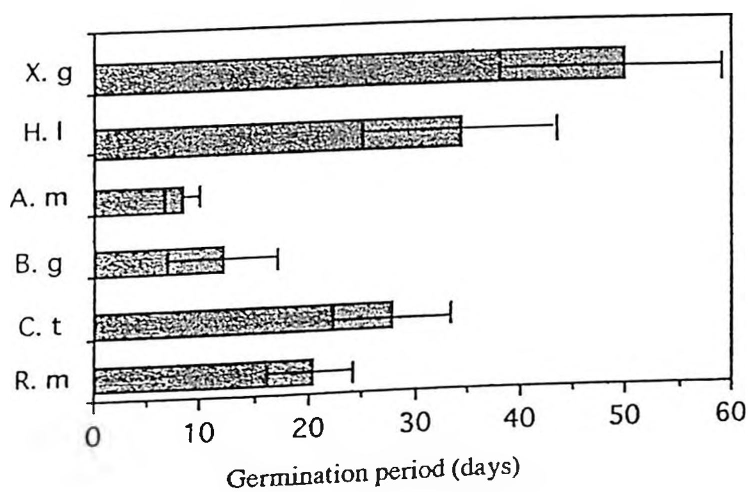
Looking at fig. 9(a), two contrasting patterns of germination/ sprouting emerge: one for propagules sown in the nursery, and the other for those sown in the field. It is obvious that germination percentage of all the species in which the propagules were sown in the field were worse than those sown in the nursery. Most species e.g. *Bruguiera, Avicennia, Xylocarpus* and *Heritiera* recorded a nursery to field germination difference of more than 20%. Differences were less than 20% for *R. mucronata* and *C. tagal.* These species are estimated to have enough tolerance to salinity and insolation in Gazi bay.

Lower germination percentage in the field for *A. marina* (31.2%), *X. granatum* (0%) and *H. littoralis* (2%) is explained by the fact that the propagules were washed away by wave/tidal actions, and that propagules (especially for *Heritiera* and *Xylocarpus*) were in bad conditions due to insects and crabs predation.

(a)



(b)



R. m = *R. mucronata* C. t = *C. tagal* B. g = *B. gymnorrhiza*
H. l = *H. littoralis* X. g = *X. granatum* A. m = *A. marina*

(the numbers in brackets refers to the sample size, error bar indicate (± std.)

Fig 9 (a) Comparison in germination percentage of mangrove propagules (after 12 months), under nursery (N) and field (F) conditions

(b) Average number of days between planting (sowing) and sprouting of mangrove propagules under nursery conditions.

4.2.2 Seedling growth in the nursery

Growth performance of 12 months old seedlings of some mangrove species raised under various cultural conditions is presented in table 3. In almost all the observed parameters, *C. tagal* showed the lowest growth rate.

After 49 weeks (11.4 months) of growth *C. tagal* attained an average shoot height of 11.50 ± 9.6 cm with a stem diameter of 0.52 ± 0.08 cm while *Rhizophora* recorded a net height of 36.90 ± 9.6 cm and 0.60 ± 0.10 cm stem diameter (fig 10). Compared to *C. tagal*, growth of other species: *R. mucronata, A. marina, B. gymnorrhiza, H. littoralis*, and *X. granatum* were substantially faster. Growth in terms of stem elongation was of quite a higher order in *X. granatum* (111.9 ± 24.8 cm) followed by *A. marina* (41.01 ± 13.2 cm), *R. mucronata* (36.9 ± 9.6 cm), *B. gymnorrhiza* (27.10 ± 4.80 cm) and *H. littoralis* (24.9 ± 5 cm) - table 3. On the basis of total height (above ground height of the propagule included) *R. mucronata* was however much taller than *A. marina*..

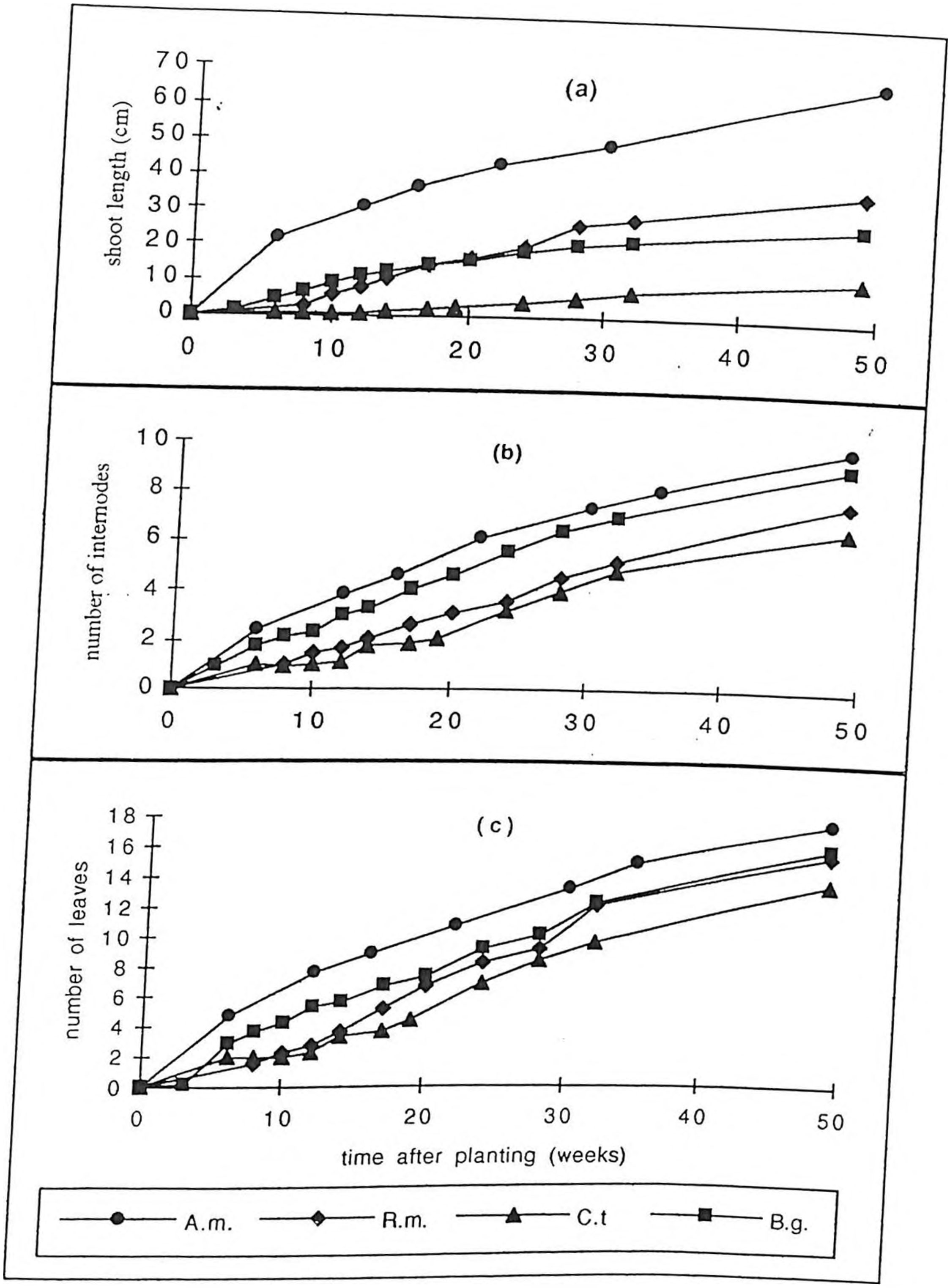
a) Effects of potting medium on seedling performance

The effects of potting medium on seedling performance was only investigated in *B. gymnorrhiza* and *C. tagal*, by sowing 70 propagules each of *Bruguiera* and *Ceriops* in polythene plastic pots using either normal mangrove forest soil or sea grass litter as potting media. The pots were placed under partially shaded area of *Avicennia* trees. Germination percentage obtained was excellent (100%) for both species.

On subsequent seedling performance there was a significant difference in growth between the propagules sown in 'normal mangrove soil' and the 'litter'. Almost all growth parameters indicated that seedling performance was improved by growing the propagules in sea grass 'litter' rather than in the 'normal mangrove soil'. Such a tendency was however more conspicuous in the average height increment, numbers of internode and leaves of *Bruguiera* (fig. 11)

Bruguiera sown in litter after four months had attained a net height of 22.09 ± 3.66 cm (range: 12 to 25.7 cm), with 4.93 ± 0.70 (range: 4 to 6) internodes and 15.40 ± 6.25 (range: 10 to 34) leaves; improving significantly to a height of 53.17 ± 8.72 cm (range: 36 to 67 cm), with 19.47 ± 6.68 (range: 14 to 36) internodes and 29.80 ± 9.84 (range: 20 to 50) leaves. By the 12th month after planting, *Bruguiera* potted in the 'normal soil' had attained a net height of 27.10 ± 4.80 cm (range: 19 to 39 cm), with 12.35 ± 2.50 leaves and 9.12 ± 1.54 (range: 7 to 12) internodes. Survival, 12 months after planting was however not significantly affected by the type of soil media used.

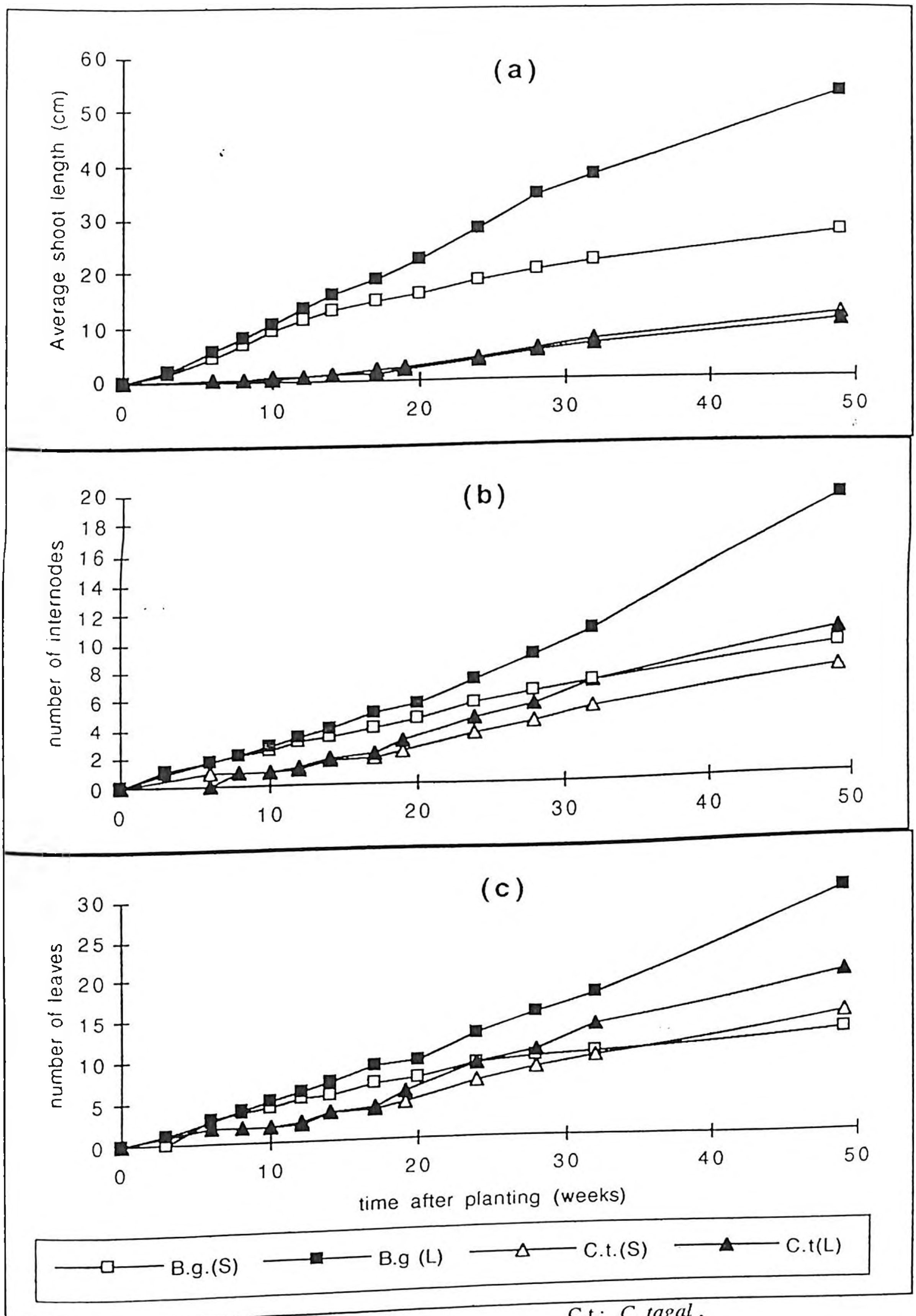
Ceriops sown in litter had a mean height of 10.39 ± 3.34 cm which is not significantly different ($p > 0.05$) in magnitude to the average height attained by *Ceriops* sown in the normal mangrove soils: 11.51 ± 3.82 cm, (fig 11(a). In terms of the average leave number, litter potted *Ceriops* propagules attained 19.59 ± 6.57 leaves. This is statistically ($p < 0.01$) different to the number of leaves achieved by *Ceriops* propagules potted in 'normal' mangrove soils: 14.67 ± 5.69 (fig. 11(c))



R.m.: *R. mucronata* A.m.: *A. marina*

C.t .: *C. tagal* B. g.: *B. gymnorrhiza*

Fig 10: Growth performance of four mangrove species under nursery conditions.



B.g.: *B. gymnorrhiza*,
(S):= Normal mangrove soil;

C.t.: *C. tagal* ,
(L)= Sea-grass litter.

Fig 11 Growth performance of two mangrove species under different potting conditions.

4.3 PLANTING OF MANGROVES IN THE FIELD

4.3.1 The effects of inundation level on seedling performance

The growth performance of *R. mucronata*, *C. tagal* and *B. gymnorrhiza* in different inundation levels is described below:

(i) Rhizophora mucronata

Rhizophora growing in the low lying muddy area of Gazi (plot G-1, inundation class 1) developed characteristically long and narrow stem. This was probably for a need to be contained above or near the water surface during high tides. Barnacle infestation was profusely present at this plot covering tightly on the stem of the plants upto 3rd or 4th internode (i.e. circ. 35 cm from the soil), and the underside of the leaves. On the lowest part of the plot the saplings were seen heavily covered by drifted green algae that formed a mat, this contributed to mortality due to physical and/or physiological stress such as breaking of the tender shoot, hindrance in gaseous exchange, reduced photosythesis owing to leaf cover causing reduced illumination.

After 4 months *Rhizophora* saplings growing in plot G-1 (inundation class 1) had attained a shoot height of 12.00 to 69.50 cm ($\bar{X}$ = 35.11 ± 3.86) with 3 to 23 internodes ($\bar{X}$ = 7.29 ± 3.78), 2 to 20 leaves ($\bar{X}$ = 6.17 ± 3.86), and 0 to 5 lateral branches ($\bar{X}$ = 0.63 ± 1.27). These growth parameters are comparable in magnitude to the 4 month old *Rhizophora* saplings transplanted at K-1, K-2 and K-3 (representing inundation classes 3, 5 and 6 respectively) - fig.12 (a - c).

In 10 months (44 weeks) of growing the shoot height of *Rhizophora* saplings in plot G1: 49.17 ± 15.69 cm (range: 23 - 86.70 cm) was significantly different ($p < 0.001$) to that recorded for *Rhizophora* in K-1: 34.20 ± 9.06 cm (range: 23.50 ± 64.50 cm), K-2: 29.46 ± 7.19 cm (range: 9 - 40.50 cm) and K-3: 20.72 ± 7.86 cm (range: 7.50 - 34.00 cm) - fig 12(a). In terms of average leaf number per plant, *Rhizophora* in G-1 recorded a significantly lower value: 9.82 ± 5.83 (range: 1 - 24) than in plot K-1: 26.89 ± 9.64 (range: 10 - 50) and K-2: 16.55 ± 6.83 (range: 6 - 31) - fig. 12(c). In plot G-1, the frequency of bearing 15 to 20 internodes, (inclusive of the lateral branches), was 13.0%, while the frequency of bearing 30 to 35 internodes was around 11.0%. In plot K-1 the frequency of bearing 15 - 20 internodes was around 53.0%.

By the 12th month (52 weeks) of growing all *Rhizophora* saplings growing in plot K-3 (area of low fertility that was relatively less frequently inundated) had died. Probably the saplings died of excessive drought.

At 18 months (72 weeks) saplings transplanted in plot G-1 had attained a net height of 57.66 ± 15.63 cm ranging from 28.40 to 94.00 cm which was not significantly different ($P > 0.05$) to the height attained by 18 months old *Rhizophora* saplings at K-1: 53.20 ± 6.89 cm (range: 43 to 67 cm)- fig 12(a). The number of leaves in G-1 ranged from 2 to 31 ($\bar{X}$ = 10.38 ± 7.43), this was significantly lower ($P < 0.01$) to the average number of leaves attained by saplings growing in plots, K-1: 74.37 ± 26.65 (range: 26 - 136) and K-2: 46.14 ± 13.70 (range: 25 - 66)-fig. 12(c). The proportion of the saplings bearing more than 50 internodes in plot G-1 was 2% as compared to 36.8% in K-1 (see plates 5 and 6).

Plants in plot G-1 had generally fewer and narrow leaves, these leaves were often young and very localized in the new internodes at the top of the plant. At 18 months after planting *Rhizophora* saplings in G-1 (inundation level 1) had gained only 0.694 ± 3.74 new leaves (range: -5 to 12), compared to the equally aged saplings in plot K-1 which had gained 14 to 97 new leaves ($\bar{X}$ = 46.95 ± 20) and in plot K-2: 29.10 ± 10.25 leaves (range:13 to 50)

Some survival values of *R. mucronata* saplings after 12 months of growth may, with respect to the intertidal positions, be visualized as in fig 13. The highest survival performance along the transect was recorded in inundation class 3 and 4 followed by class 5, then class 1, 6 and lastly inundation class 7.

(ii) Ceriops tagal

Plot G-1 (inundation class 1) which remained submerged for relatively long hours could not support the growth of *Ceriops*.. Almost all the transplanted propagules and saplings, had stunted growth that was accompanied by a great degree of leave abscission, reduction in foliar expansion and a characteristic sootened shoot tip; that culminated to their death, 2-3 months after planting. The highest survival values for propagules and saplings after a year were observed in plot K-3 (inundation class 5) - fig 13.

Looking at the growth performance in *Ceriops* propagules and saplings (fig. 14 and 15), two tendencies were clear: a) there was less growth performance in the first 10 months (44 weeks) after planting b) a significant improved growth after 14 weeks.

At 10 months of planting, *Ceriops* saplings in plot K-3 had an average shoot height of 11.88 ± 3.41 cm (range: 7.5 - 20.1 cm), with 5 to 36 ($\bar{X}$ = 14.26 ± 6.93) leaves. Around 59% of the seedlings had more than 5 internodes, and the proportion of saplings bearing 10 to 13 internodes was 29.4%. The number of lateral branches varied from 0 to 4 ($\bar{X}$ = 1.16 ± 1.46).

On reaching the age of about 18 months (72 weeks), *Ceriops* saplings in plot K-3 attained a net height of 28.32 ± 8.02 cm, ranging from 14.5 to 73 cm which was significantly higher than the height attained by equally aged *Ceriops* saplings transplanted in plot K-2: 16.97 ± 5.70 cm (range: 5 to 33 cm) and K-4: 11.97 ± 4.37 cm (range: 4.5 to 25 cm) (fig 14(a)). The number of internodes per plant in K-3 ranged from 9 to 54 ($\bar{X}$ = 28.26 ± 11.86) which also differed significantly ($P < 0.05$), from saplings growing in K-1: 15.23 ± 6.19 (range: 6 to 27); K-2: 18.73 ± 6.31 (range: 7 to 34) and K-4: 13.13 ± 5.57 (range: 5 to 25) (fig. 14(b)) - see plate 7.

Ceriops tagal propagules:

The plots where *Ceriops* saplings performed best were the same plots where the propagules performed well (fig. 13 and 15). The maximum annual height increment in *Ceriops* propagules growing in plot K-3 (inundation class 5) was 27.1 cm with 37 internodes and 68 leaves (see plate 8).

(iii) **Bruguiera gymnorrhiza**

Growth of *Bruguiera* saplings was largely equal from plot to plot, except in the low-lying plot G-1 where planting was unsuccessful (fig. 16)

In plot K-3, only some few trees planted as either saplings or propagules could be detected after 12 months. Out of the 150 saplings planted, 49 (32.6%) survived, and out of 180 propagules, 12.2% survived upto the 12th month. The generally low survival rate of the planted propagules and saplings was observed to be due to various factors among which was attack by crabs which might have accounted for 30% mortality. Another factor was excessive exposure to sunshine indicated by the fact that as many as 40% of the dead propagules and saplings were strongly blackened and shrivelled at their upper halves.

After 4 months (c. 17 weeks) *Bruguiera* saplings transplanted in plot K-1 (inundation class 3) had a height of 25.80 ± 12.20 cm (range: 12.50 to 55.5 cm), with 5 to 15 leaves ($\bar{X}$ = 7.6 ± 2.8) and 5 to 21 internodes ($\bar{X}$ = 10.9 ± 5.1).

At 16 months (70 weeks) *Bruguiera* saplings in K-1 attained a height of 49.70 ± 12.20 cm (range: 34 to 69), with 16.60 ± 7.10 (range: 6 to 31) internodes and 55.40 ± 19.80 (range: 26 to 84) leaves. These figures are similar to those obtained by equally aged saplings in plots G-3, K-2 and K-3 (fig. 16). The maximum annual height increment for *Bruguiera* grown in the field was 38.16 cm with 55 internodes and 70 leaves (table 6)

4.3.2 To establish an efficient method of sowing *Avicennia* propagules in the field.

In broadcast condition, *Avicennia* after 3 months of experiment showed 26% (n = 200) germination, as compared to 84% (n = 200) germination in direct-hand sown propagules. Further assessment carried out 6 months after sowing showed that out of the 200 broadcasted propagules 20 (10%) survived and out of 200 hand-sown propagules 84 (42%) survived. The reason for high mortality among the broadcast propagules was estimated to be due to tidal flushing which might have accounted for upto 45% mortality. The pattern shown by the parameters such as mean leaf area per plant, number of internodes and branches was remarkably similar (see table 3).

4.3.3 Effects of propagule length on subsequent seedling performance

There was no outright correlation between propagule size at time of planting and height increment ($R^2 = 0.037$, $p > 0.05$) or between propagule size and leave number ($R^2 = 0.028$, $p > 0.05$). The average plant height increment, number of internodes, branches and leaves was not significantly different ($p < 0.05$). The pattern shown by the parameters such as mean leaf area per plant, number of internodes and branches was remarkably similar (table 4)

4.3.4 Effects of transplanting method on seedling performance

On reaching an approximate age of 12 months (49 weeks) the nurseried *Rhizophora* plants attained a net height of 42.00 ± 7.68 cm (range: 24 to 56 cm), (inclusive of the propagules above the ground height it was around 72 cm). This height was significantly ($P<0.05$) higher than the average shoot height recorded in naturally raised saplings: 38.00 ± 8.20 cm (range: 16 - 47 cm). The total leave area/plant in nurseried saplings: 986.5 ± 63.6 cm^2 (range: 379.9 - 1416.6 cm^2) was significantly higher ($P < 0.05$) than the total leave area/plant of the naturally raised saplings: 893.1 ± 71.3 cm^2 (table 5).

In *Ceriops*, apart from the average leave number/plant, other parameters like plant height. internodes and lateral branches were statistically similar.

4.3.5 *Sonneratia alba*

The major objective of planting *S. alba* was to provide a natural barrier that would prevent un-anchored free floating logs and boats from getting access to (and breaking) the artificial oyster ranks. The work was commissioned by the managing director of the K. B. P, Oyster project (Mr. J. F. TacK) in understanding that the current artificial erecting of a fence by use of mangrove poles was awkward, expensive and annoying especially when the dry mangrove poles are susceptible to firewood collectors from the village. But a natural fence erected through mangrove planting, control coastal erosion, provide rich environment for oysters and obviously improve the aesthetic value of the area. The work was funded by the E. E. C project. The results were quite encouraging (see Plates 9).

Irrespective of the age of the sapling transplanted, the species showed satisfactory survival performance. Out of 530 saplings transplanted, 420 (79.2%) survived. Of this 195 (46.4%) were the "small" sized saplings while 157 (37.4%) were "medium" and 68 (16.2%) were "large".

This species showed the highest growth rate among all the transplanted species with a maximum annual diameter increment of 1.9 cm and height increment of 1.18 m (table 6). This is satisfactory for a mangrove species considering that the fast growing terrestrial Eucalyptus species show a maximum of 2.4 m height growth per year (Davidson. *et al.*, 1985).

4.3.6 Restoration by use of 'Small trees'

Survival after 12 months was high (100%) in *Rhizophora* and 85.8% in *Avicennia*. The maximum annual height increment in *Rhizophora* was 1.16 m and a diameter increment of 1.13 cm. In *Avicennia* the maximum annual height increment attained was 1.46 m, and a diameter increment of 1.3 cm (table 6). In about 1.5 years after transplanting *Rhizophora* 'small trees' recorded a maximum height of 3.0 m, with a diameter at breast height (dbh) of 2.7 cm. At this age 8 *Rhizophora* plants (36.4%) had developed flower buds.

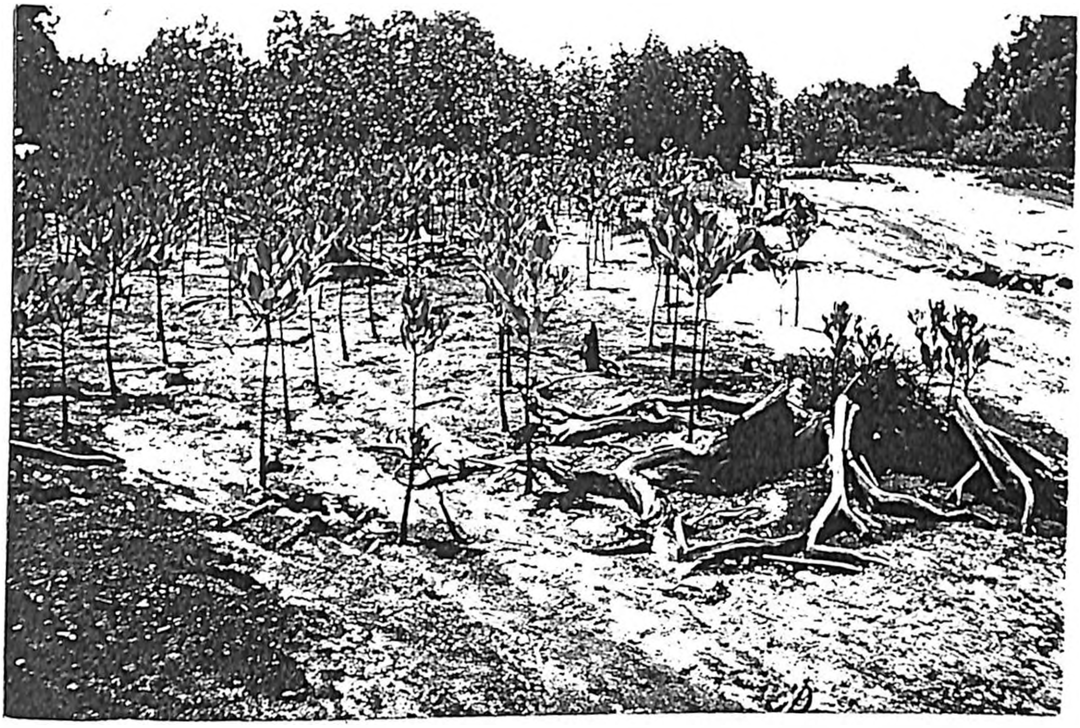


Plate 5: 18 months old plantation of *R. mucronata* at Gazi bay, Kinondo (plot K-3), inundation class 5. The plot is most suitable for *C. tagal* (see plate 7). (Photo Kairo)

Plate 6: An 18 months old plantation of *R. mucronata* at Gazi bay, Kinondo (plot K-1), inundation class 3 showing good height growth and moderate root development. The planting was carried out at a proper elevation for the species. (photo Kairo)

Plate 7: An 18 months old plantation of *C. tagal* at Gazi bay , Kinondo (plot K-3), inundation class 5 & 6, showing good height growth and elaborate branching of the main stem. The plot elevation is best for the species. (Photo Kairo)

Plate 8: A plantation of *C. tagal* (Gazi bay) in the more elevated plot K-4, 18 months after transplanting. Note the slowed growth rate when incorrect site selection is done. The stand was originally occupied by *X. granatum*. (Photo Kairo)

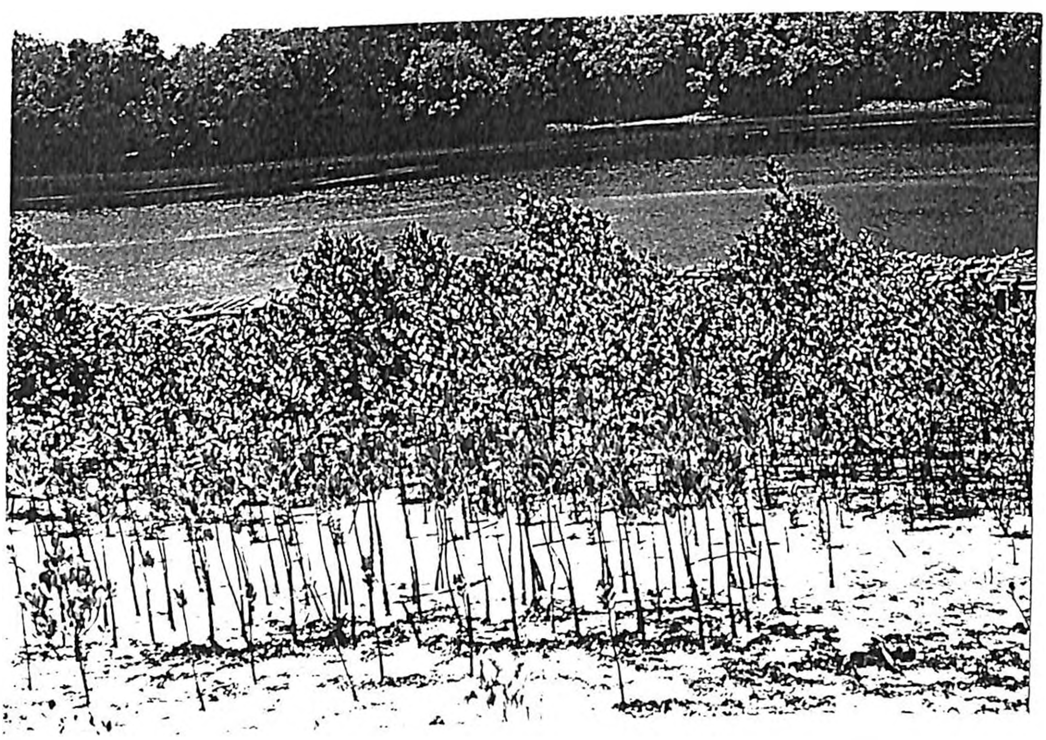


Plate 9: (*above*)
A mangrove plantation establishment at the Oyster's plot (Gazi bay, Plot G - 1) during low tide. Note the Oysters beds at the sea shore, and the bareness of the area where planting was done. Species zonation is represented as *S. alba* on the sea-ward side followed by *R. mucronata*, *B. gymnorrhiza* and *C. tagal* to the land-ward side

Below: The same plantation, 18 months after planting, note the fast growing *S. alba* that borders the Oyster beds. (Photo: Kairo, *Gazi, August, 1993*)

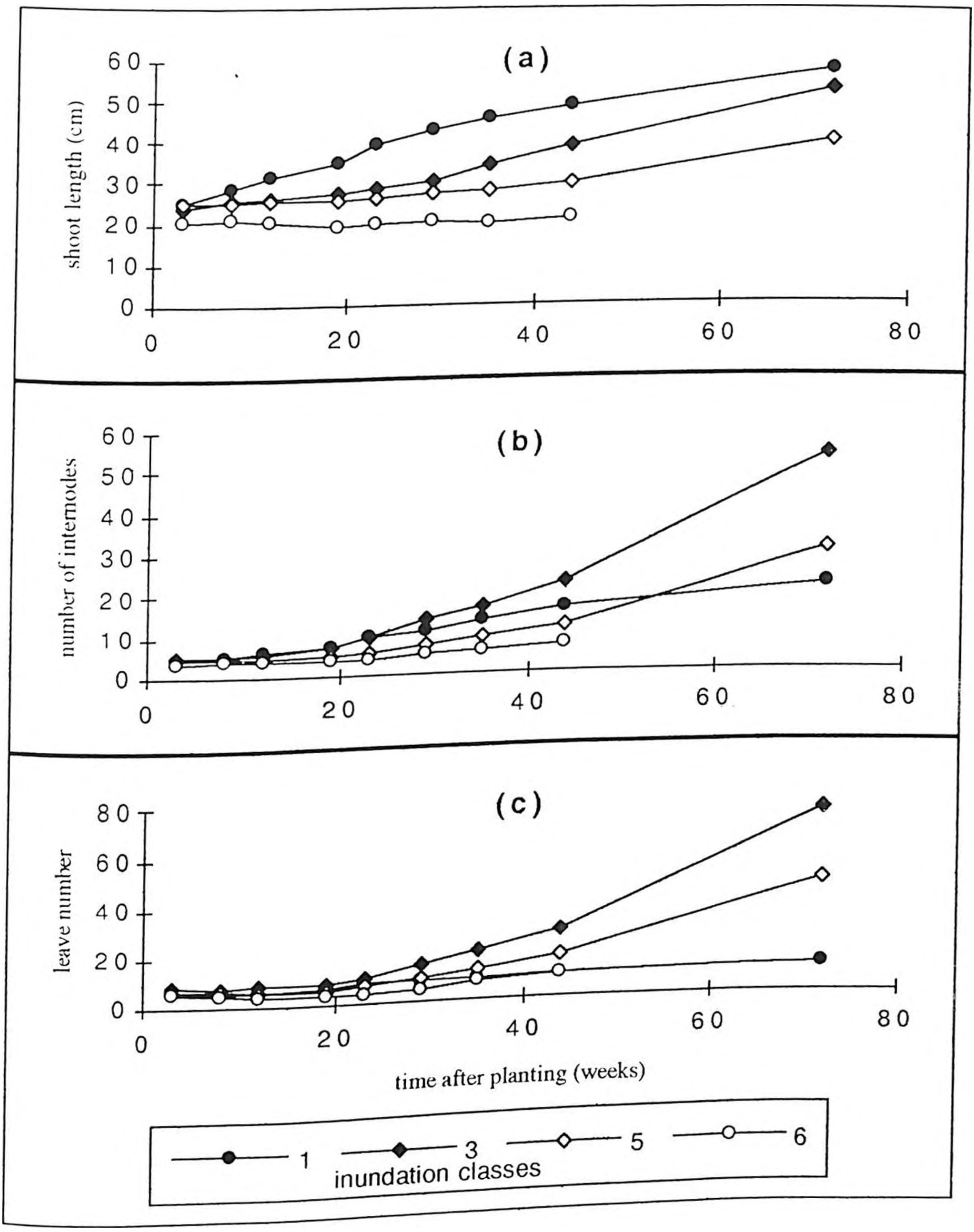


Fig. 12: *Rhizophora* **saplings:** Average shoot height (a); average number of internodes (b) and average number of leaves (c) in four inundation classes (1, 3, 5 and 6)

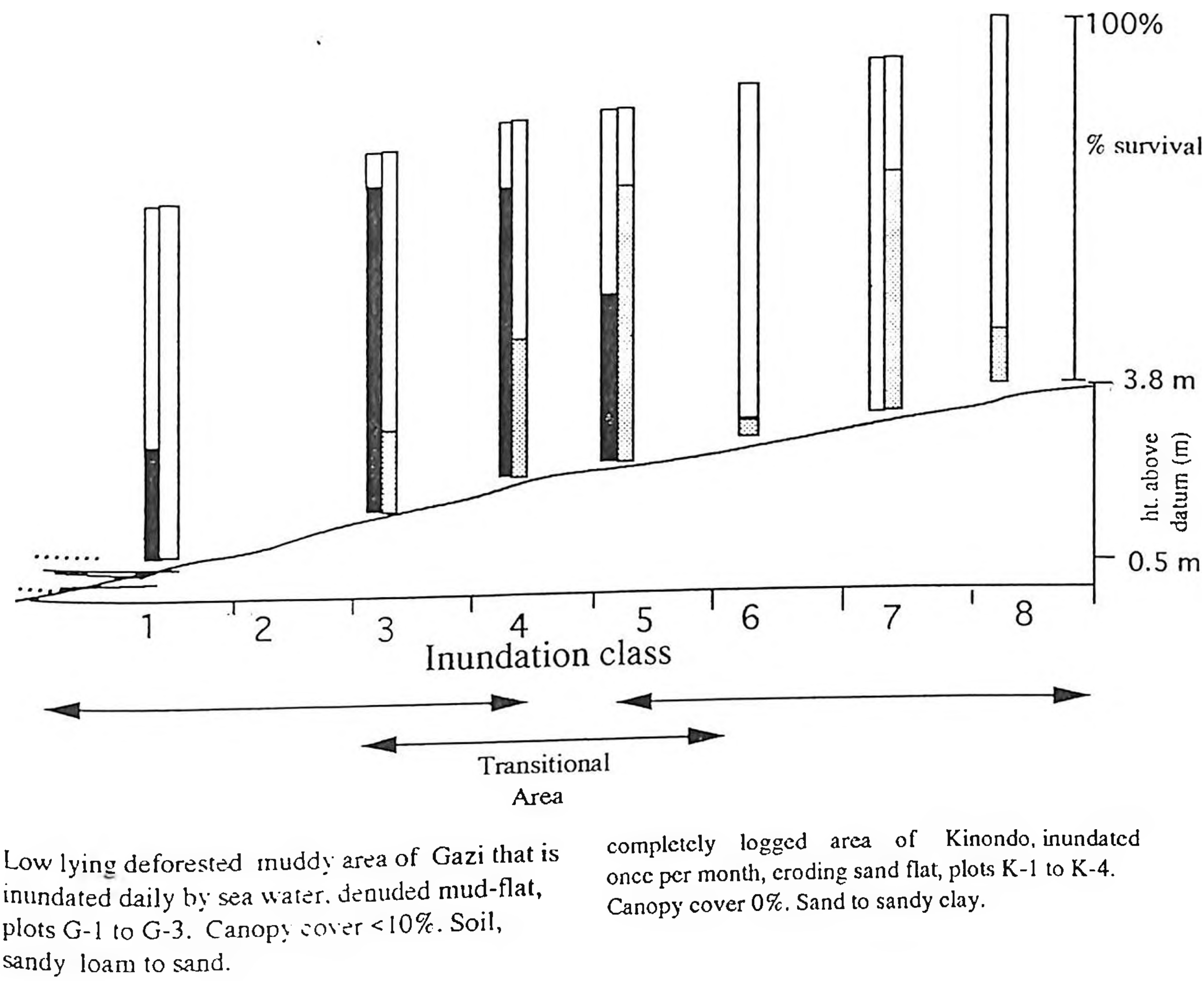


Fig. 13: Survival of *R. mucronata* ■ and *C. tagal* □ saplings along a belt transect laid across Gazi bay from barren highly sandy area (of Kinondo) to lowlying muddy area (of Gazi) colonized by *S. alba* (*circa* 1 year after transplanting)

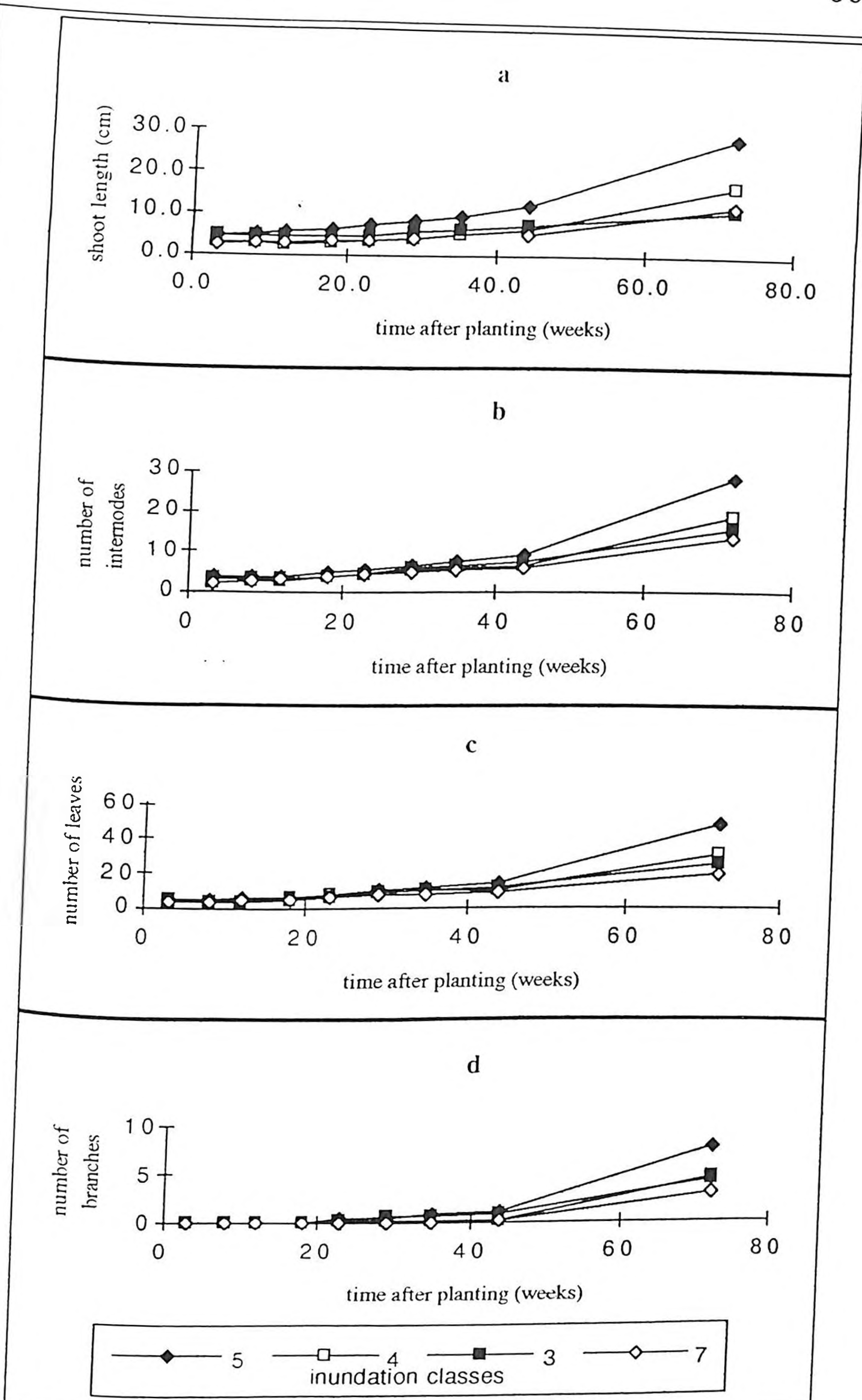


Fig. 14: *Ceriops* saplings: Average shoot height (a), average number of internodes (b), average number of leaves (c), and average number of branches (d), in four inundation classes, (3, 4, 5 and 7)

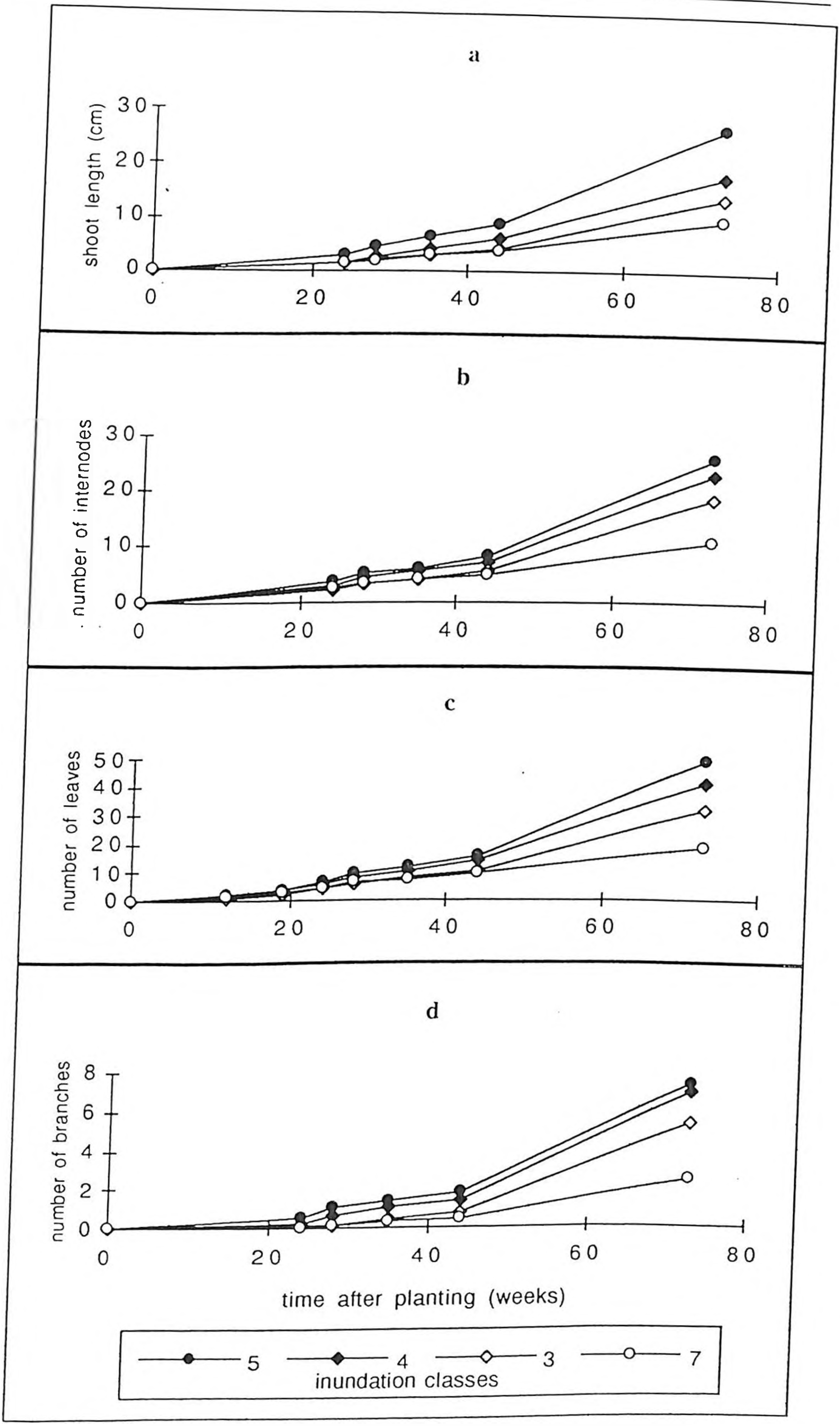


Fig. 15 *Ceriops* propagules: Average shoot height (a); average number of internodes (b); average number of leaves (c) and average number of branches (d), in four inundation classes (3, 4, 5 and 7)

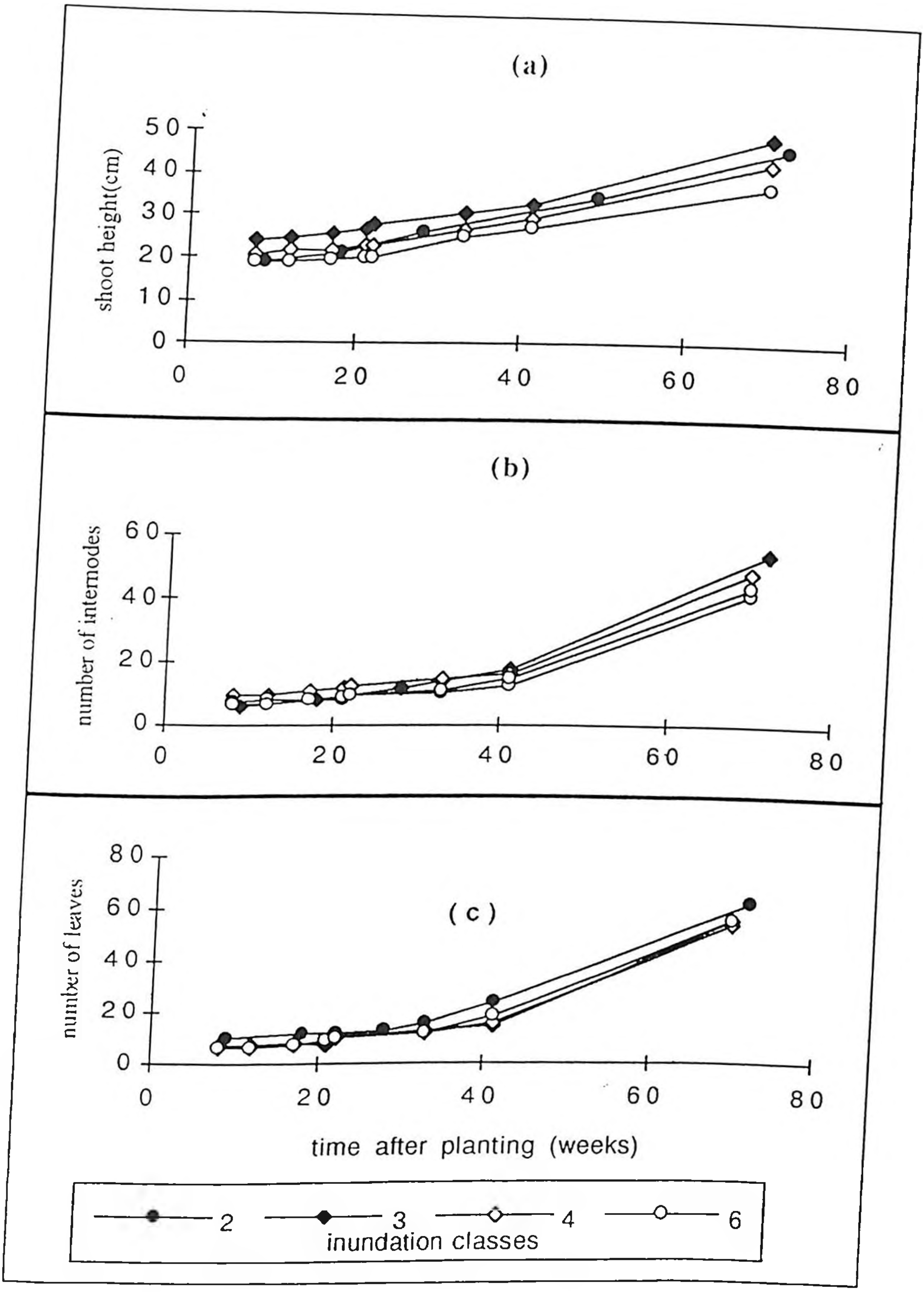


Fig. 16 *Bruguiera* saplings: Average shoot height (a), average number of internodes (b) and average number of leaves (c) in four inundation classes (2, 3, 4, 6).

Table 3. Growth performance of saplings of some mangrove species at ca.12 months of age grown under various cultural conditions

Treatment	Species	Net growth in height (cm)	Number of leaves/plant	Number of internode/plant	Number of branches/plant	Diameter at first internode(cm)
Nursery using 'normal' mangrove soil	*X. granatum* n=150	111.9 ± 24.8 (70 - 169)	20.3 ± 15.2 (3 -62)	–	0.83 ± 1.45 0 - 6	–
	A. marina n=100	41.01 ± 13.2 (20 - 68)	12. ± 4.01 (6 - 23)	6.80 ± 2.21 (3 - 12)	0.70 ± 0.07 (0 - 4)	–
	R. mucronata n =30[c]	36.9 ± 9.6[a] (19.5-53.5)[b]	11.1 ± 3.7 (6 - 19)	6.3 ± 1.8 (4 - 11)	0.4 ± 0.8 (0 - 2)	0.6 ± 0.1 (0.4 - 0.8)
	B. gymnorrhiza n=60	27.10 ± 4.8[d] (19 - 39)	12.4 0± 2.5 (8 - 17)	9.12 ± 1.04 (7 - 12)	0.24 ±0.56 (0 - 2)	0.55 ± 0.09 (0.38 - 0.7)
	H. littoralis n=100	24.9 ± 5.0 (14 - 32)	5.96 ± 1.88 (2 -9)	–	0.08 + 0.28 (0 - 2)	–
	C. tagal n=60	11.5 ± 3.8 (1 - 18.5)	14.66 ± 5.7 (6 - 28)	7.57 ± 2.9 (4 - 15)	1.83 ± 1.32 (0 - 4)	0.52 ± 0.08 (0.32 - 68)
Nursery in 'sea-grass' litter	*B. gymnorrhiza* n=30	53.2 ± 8.7 36 - 67.2	29.8 ± 9.8 (20 - 50)	19.5 ± 6.4 (14 - 36)	3.6 ± 2.1 (1 - 8)	0.7 ± 0.1 (0.6 - 0.9)
	C. tagal n=30	6.52 ± 2.11 (2.5 - 10)	13.5 ± 4.71 (4 - 22)	7.01 ± 2.22 (3 - 11)	1.92 ± 1.23 (0 — 4)	0.40 ± 0.10 (0.3 - 0.6)
Mangrove propagules sown in the field	*A. marina* (broadcast) n=200	43.9 ± 14.7 (12 - 74.5)	15.24.± 3.5 (8 - 26)	9.51 ± 3.24 (6 - 13)	0.85± 0.15 (0 - 5)	–
	A. marina (direct sowing) n=200	47.11 ± 17.6 (19 - 83)	14.21. ± 3.71 (5 - 25)	10.12 ± 4.21 (7 - 12)	0.77 ± 0.20 (0 - 6)	–
	R. mucronata n=75	37.89 ± 8.8 (19 - 54)	42.06 ± 17.3 (7 - 128)	23.35 ± 9.37 (5 - 45)	4.7 ± 2.6 (0 - 12)	–
	C. tagal n=490	10.7 ± 5.35 (1.9 - 27)	22.71 ± 12.05 (4 - 66.5)	12.33 ± 6.8 (3 - 37)	3.15 ± 2.15 (0 - 11)	–

[a] Does not include the above ground height of Rhizophora, Ceriops and Bruguiera propagules.

[b] Range. [c] sample size. [d] Mean ± std.

Table. 4. Relationship between propagule size and sapling performance of *Rhizophora mucronata* under field conditions. Data collected at the sapling age c. 14 months after sowing.

Growth parameter	Average length of propagules (cm)			Remarks
	< 41cm	>41 < 45 cm	> 45 cm	
Average shoot * height (cm)	36.71 ± 10.49 (19 - 54)	39.69 ± 7.27 (25 - 51)	37.38 ± 8.84 (21 - 51)	Date of planting: 23/1/92
Number of internodes/plant	22.43 ± 9.81 (5 - 36)	24.44 ± 9.58 (7 - 39)	23.17 ± 9.31 (6 - 45)	
Number of leaves/ plant	40.00 ± 18.77 (7 - 68)	43.13 ± 19.39 (10 - 78)	42.54 ±15.51 (8 - 17)	date of observation 8/4/93
number of branches / plant	4.86 ± 2.98 (0 - 10)	5.06 ± 2.89 (0 - 12)	4.58 ± 2.36 (0 - 10)	

* The parameter does not include the above ground height of the propagule.
The sample size in each case of the treatment was 25 propagules.

Linear Correlation and Regression analysis

Average height increment (cm) = 12.686 - 0.106X
(r = 0.184, P > 0.05)

Average number of internodes (cm) = 15.602 - 0.082X
(r = 0.135, P> 0.05)

Number of leaves = 37.00 - 0.169X
(r = 0.137, P> 0.05)

(X = propagule length (cm))

Table 5. Growth performance of saplings of two mangrove species one year after transplanting, as either '**wildings**' or '**nurseried**' saplings.

	shoot length(cm)	number of internodes	number of leaves	number of branches	leave area/plant (cm^2)
R. mucronata wildings (21)[a]	38.00 ± 8.20* (16 - 47)[b]	24.00 ± 6.60 (12 - 37)	44.10 ± 11.85 (19 - 68)	6.10 ± 1.80 (2 - 10)	893.10 ± 71.30* (195.20 - 1615.50)
R. mucronata nurseried (38)	42.00 ± 7.68* (24 - 56)	25.00 ± 7.02 (10 - 40)	40.53 ± 11.15 (12 - 62)	5.60 ± 2.20 (2 - 10)	986.50 ± 63.60* (379.90 - 1416.60)
C. tagal wildings (22)	37.00 ± 4.00 (28 - 45)	33.00 ± 12.00 (13 - 56)	61.45 ± 26.79* (20 - 112)	9.00 ± 3.00 (4 - 18)	___
C. tagal nurseried (48)	38.00 ± 5.50 (24 - 49)	27.00 ± 10.00 (10 - 61)	43.71 ± 19.94* (8 - 80)	8.10 ± 3.70 (3 - 22)	___

* 95% significant difference between 'wildings' and 'nurseried' saplings

Date of transplanting = 20/2/92

Date of observation = 3/4/93

[a] sample size

[b] range

Table 6: Maximum annual increment in : height(ht); diameter at first internode; number of internodes and leaves for five mangrove species transplanted under field conditions.

Plant material type	Species	height (cm)	diameter at first internode (cm)	number of internodes/year	number of leaves/year	Plot	inundation class of the plot
saplings	*S.alba*	118	1.90	----	----	Oyster	1
	R. mucronata	30.9	0.95	102	93	K-1	3
	B. gymnorrhiza	38.2	0.84	55	70	K-2	4
	C. tagal	26.2	0.30	38	87	K-3	5
propagules	*A. marina*	98	1.12	12	26	G-3	4
	B. gymnorrhiza	71.6	0.93	38	53	G-3	4
	R. mucronata	45.3	1.01	38	65	K-1	3
	C. tagal	27.1	0.39	37	68	K-3	5
small trees*	*R. mucronata*	149	2.25	----	----	G-2	3
	A. marina	146	1.30	-----	---	G-3	4

For sample size in each case refer to fig. 7.

---- data was not taken.

* the labour input over-rules this method for general use (see section 3.3.2 (f).

4.4 AIR LAYERING

Root growth was observed from late September, 1992 to early November 1992, 3 - 4 months after the plants were layered. Not all the experimental specimens had roots, but swelling on many unrooted branches indicated possible root formation.

Rooting success $\left\{\frac{\text{number of roots per species}}{\text{total number of roots in all the species}}\right\}$ differed significantly between species ($P < 0.001$). The highest rooting success was recorded in *S. alba* (58.8%), followed by *L. racemosa* (36.8%) and *X. granatum* (4.4%). *Sonneratia* roots appeared firm, with good colour and often with short secondary roots, extending from the main roots. 95% of the *Sonneratia* specimens layered with moss had 26 to 36 ($\bar{X} = 32.60 \pm 2.27$) roots followed by *Lumnitzera*:: 17 to 25 ($\bar{X} = 20.89 \pm 1.41$), and *Xylocarpus* : 0 - 5 ($\bar{X} = 2.33 \pm 0.57$), fig. 17. Mean root number and length per species differed significantly between the rooting media ($P < 0.001$). Rooting success was highest in material layered with moss (62.8%) followed by the rooting hormone (28.5%) and forest litter (8.6%). *Sonneratia* layered with moss had the highest mean root length of 5.3 ± 0.5 cm, fig. 18. Roots produced in specimens layered with forest litter were few, short and often very weak.

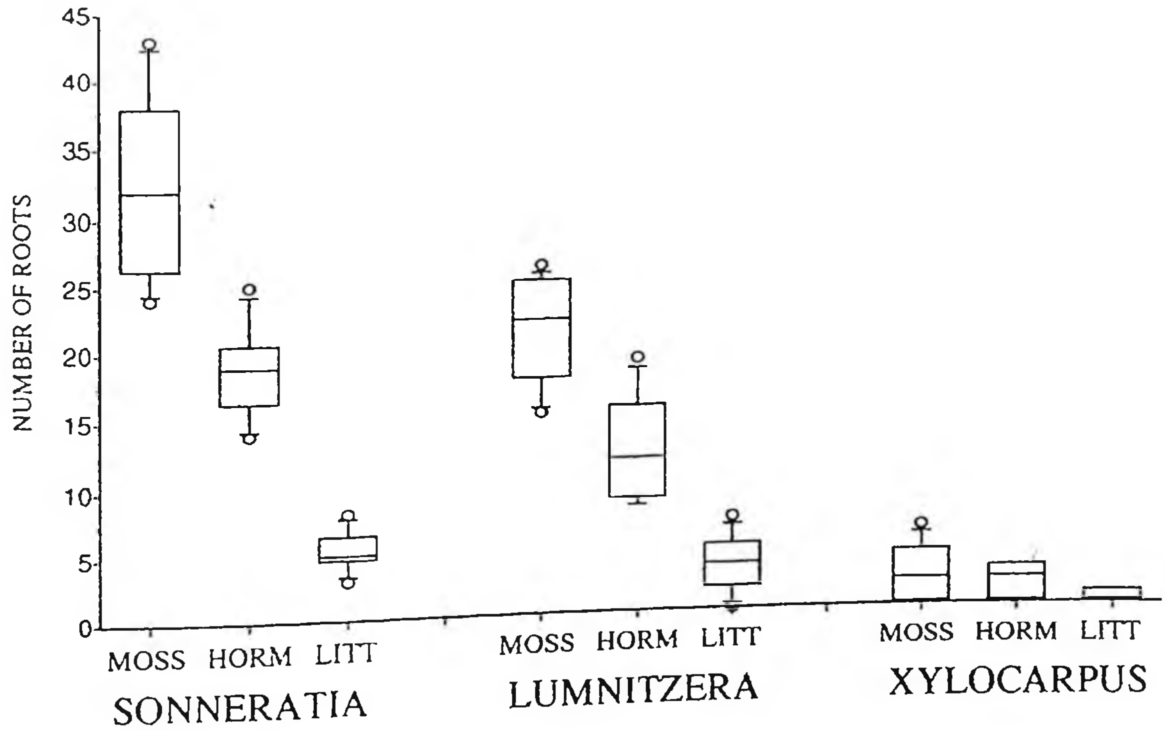


Fig. 17 Number of roots after 5 months, for three mangrove species air-layered in three rooting media

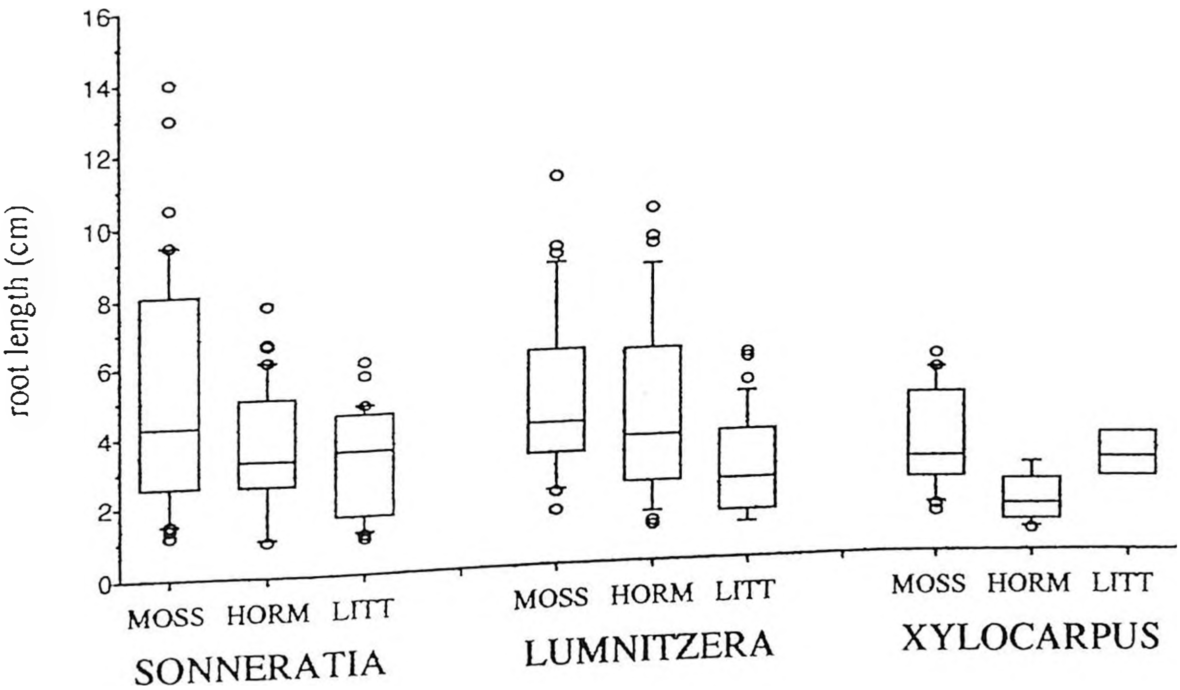


Fig.18 Root length after 5 months for 3 mangrove species air-layered in three rooting media

(MOSS: Sphagnum moss HOMM: Rooting hormone, Soradix-3 powder
LITT: mangrove forest litter)

CHAPTER 5

5.0 DISCUSSION

The protection, restoration, creation and enhancement of mangrove forests has received a lot of attention. (Teas,1977; 1981; Goforth and Thomas, 1980). The primary reason for this is that the long ignored ecological values of mangrove forests as habitat and detrital food sources have scientifically been documented for many mangrove areas in the world (e.g. Odum and Heald, 1972). In addition to their ecological values mangroves have been used for centuries as sources of firewood, construction, timber, salt, tannins, dyes and even food (Macnae,1968; Walsh,1974; Hamilton and Snedaker,1984). Because of these many uses mangroves have been planted for silviculture, erosion control, restoration of damaged areas or for mangrove biology (Watson,1928; Noakes,1955; Banijbatana, 1958; Rabinowitz, 1975; Lewis and Dunstan, 1976; Qureshi, 1990). Mangrove forestry in Kenya suffers from inadequate knowledge: of silviculture, denial of multiple use potential of resources and lack of economies and techniques of natural and artificial regeneration. Consequently this project has an important role to play in gathering basic informations based on field trials as the necessary technical input towards present and future mangrove afforestation.

From the view point of rehabilitating degraded mangrove areas, restoring the denuded mudflats and transforming disturbed forests into uniform stands of higher productivity, a pilot afforestation project was launched in October 1991 at Gazi bay. Data obtained from the preliminary study (section 4.1.1) conform with other studies carried out in the same area (Gallin. 1988; Beeckman et al., 1990; Van Speybroeck, 1992a; Ruwa, 1993) and indicate that the trees within mangroves swamps show marked zonation (fig. 7). Some species (e.g. *Sonneratia*) are found predominantly in the lower more seaward portions of the swamp, while other species (e.g. *Heritiera* and *Lumnitzera*) are to be found on the higher more elevated portions of the swamp. The results obtained here compares well with those discussed by Walter and Steiner (1936) for the East African coast. When tidal range is small, *S. alba* may be absent and its pioneer role being taken by *Rhizophora* (Macnae and Kalk, 1962; Macnae, 1968, 1971). In a creek mangrove of Gazi bay Ruwa (1993) found that *R. mucronata* formed the outmost seaward zone, while *C. tagal* occurs in the intermediate zone and *A. marina* the landward zone.

A number of investigators (e.g. Rabinowitz, 1978a) are to the idea that the seral successional stages (zonation) in mangroves is due to: the species environmental tolerance, physiological preference and competition hierachy. Under an hypothesis of environmental tolerance, each species of mangrove has a narrow range of tolerance of environmental variables (e.g. salinities, tidal flooding, shading, elevation of the land) that restricts it to the zones in which it customarily resides. If inversion through another zone occurs, the colonist may fail to survive because the physical conditions are 'toxic' for some reasons (such as too high or too fluctuating salinities). For instance *Sonneratia alba* is found in the seaward fringe because it cannot tolerate wide fluctuations in salt concentrations (fig. 7(c)).

On physiological preference hypothesis, each mangrove species has a distinct preferred portion of the swamp where it grows best. Under these circumstances each mangrove species is superior in its home swamp and excludes invaders where solid stands exists. For instance *Heritiera littoralis* prefer brackish water medium with more fresh water elements in it (Pers. Observ.). It does not grow in admixed sea water or more saline sea water. *Heritiera* is therefore more restricted to the more elevated sites on the landward fringe (fig 7 (h)), where tidal flushing is limited and surface soil salinities is very low (Van Speybroeck, et. al., 1993).

If a single site is optimal for all mangrove species, competition hierachy may determine the succession/zonation pattern. For example in the seaward side *Sonneratia* and *Avicennia* are most encountered as the pioneer species. Once established the species cause accretion by impeding water movement ("nurse" and/or "faciliation" effects), the soil level rises. and other species of *Rhizophora* and *Bruguiera* germinate from stranded seeds (Van Speybroeck, 1992a) and become established. The successors, tend to grow taller than the pioneers (fig. 7(b)), over top them and these then die off. Hence it was difficult in our transect to find well grown *Sonneratia* and *Avicennia* trees in *Rhizophora - Bruguiera* community.

An extension of these hypothesis may fail to explain some of the vagaries in distribution of *S. alba*, *X. granatum* and *A. marina* in Kenya. In marginal areas of Kinondo (appendix 1) solitary trees of *S. alba* are seen growing very far away (inundation class 5) from their common seaward zone (inundation class 1). It seems possible that the colonization of bare areas (either primary or secondary) depend on which species happen to be producing seedlings when the areas forms. The species developing on the available mud bank will depend on the seeds which become grounded, but why one or sometimes another of this species develop in a pure stand is difficult to account. While investigating dispersibility and the ability for establishment of mangrove propagules Rabinowitz (1978a) maintained that, "propagule weight affects ecological distribution of the mangroves". Large dispersal units like those of *Rhizophora* are supposed to be more resistant to tidal buffeting than the small units in *Avicennia* that are dispersed all over the intertidal area.

The mangrove area is unique not in any single feature, but as a complex of factors, so that it has proved difficult to assign zonational patterns to a single factor. Lind and Morrison (1974) maintain that: "each species of the mangrove forest grows best under slightly different conditions which depend on factors such as the amount of water in the mud, salinity, and the ability of the plant to tolerate shade". This means that the various species are not mingled together in a haphazard way, but occur in fairly distinct zonation...........". Chapman (1976) states that tidal factors, salinity, drainage, currents, and soil composition are the most important environmental factors operative in mangrove swamps. Related factors thought to be critical are the length of the submersion period, daily and seasonal fluctuations in salinity (Schnell, 1971), soil consistency or texture, admixture of fresh water, competitive ability (Walter, 1971) and the dispersal ability of the propagules (Van Speybroeck, 1992a).

It is most probable that zonation or succession pattern in mangroves is closely associated with elevation above mean sea level, seasonal fluctuations in soil salinity, and small differences in microtopography. Also light and water logging of the soil are important to species distribution. The sharpness of zonation depends upon the intensity of species interaction at the ecotones. Slight environmental changes related to topography produce intense competition which makes significant factors that are normally of secondary importance.

The importance of understanding the natural succession/ zonation in mangrove forestry and the factors driving it, is that each mangrove stand has its own unique characteristics that may indicate (1) natural recovery will be sufficient to provide revegetation and that manual planting is unnecessary, (2) a 'nurse' species may be the best species to use in revegetation or (3) problems of exclusion by other plant species or slash may require large-scale clearing of the site before planting. Heavy emphasis on planting an area with a species that will naturally flood the site with propagules and revegatate quickly is obviously a waste of time and money. Knowing which species will not return quickly by themselves gives a direction to any wetland rehabilitation or restoration efforts.

5.1 Phenology

The seasonal availability of propagules need to be closely monitored by anyone anticipating their need for mangrove propagules. Unfortunately no work on mangrove study has been directed on propagule availability in Kenya. Some work by Slim and Gwada (1993) emphasizes more on primary productivity of *Rhizophora* and *Ceriops*, using litter baskets, with very little on propagule abscission. I personally observed that sporadic fruiting of mangrove species at Gazi bay occurs during most months of the year (section 4.1.3). It is obvious that anyone planning to use propagules for reafforestation should also schedule their installation during peak availability of propagules otherwise there will be none at all. Such information will allow foresters to plan their annual planting programmes in advance if the months of heavy propagule fall are known. Similarly, pollination experiments are important in determining the breeding systems. Such information is a prerequisite to planning tree breeding programmes through the establishment of nurseries. Work of (Gill and Tomlinson, 1969) shows that flowering in *Rhizophoraceae* is precocious with the first flowering occuring 3 - 4 years of age. Chan et al; (1987) reported that several saplings of *R. mucronata* started flowering 3 years after planting. At Gazi flowering of *R. mucronata, C. tagal* and *B. gymnorrhiza* occur all the year round (pers. observ.). More work need to be carried out to determine the duration of a complete reproductive cycles for the commercial mangrove species in Kenya.

5.2 NURSERY EXPERIMENTS

In our nursery experiments, most of the species tried Viz. *A. marina, C. tagal, B. gymnorrhiza, R. mucronata,* and *X. granatum*, irrespective of locality of collection, elevation of the nursery and the type of potting media used, exhibited a high germination percentage (83-98.2%). When directly sown in the field a substantial reduction in germination occured in *X. granatum, H. littoralis, B. gymnorrhiza* and

A. marina (fig. 9(a)). This reduction is expained by: (a) the propagules were being washed away by the incoming tides (*A. marina*, *X. granatum* and *H. littoralis*), (b) immaturity and non-viability (due to insect and crab predation) of the propagules at the time of planting (*X. granatum* and *H. littoralis*), (c) excessive exposure to sunshine that led upto 40% mortality in *B. gymnorrhiza* (see section 4.3.1(iii)).

Undoubtedly lack of 'nursing' or 'facilitation' effect of the propagules in the clearfelled areas of Gazi and Kinondo (see map) has led to poor regeneration of the forest. The clearfelled condition has caused several microhabitat alterations including: (a) break-down of the canopy cover, thus more light hitting the ground per unit of time, (b) the exposed areas exhibit a high soil evaporation and the salt concentration may built up to a 'toxic' level during drought, (c) the removal of cover crop leaves the area susceptible to erosional activities as a result of tidal flushing and land run-off. The direct consequent of this is poor soil nutrients. disproportionately high sand fraction and low Carbon:Nitrogen (C/N) ratio (see table 2). Poor germination of *B. gymnorrhiza* sown in the field (fig 9(a)) is therefore deserved, since the species is a shade lover (Macnae and Kalk, 1962; Ferguson, 1993) and it responds favourably to high nutrient levels (see section 4.2.2(a)). And although the stump density showed the Kinondo block to have originally been covered by a *Rhizophora - Bruguiera - Xylocarpus* community, the edapho - physiographic changes (e.g. soil salinity, soil nutrients. tidal regime, shade) for the c. 20 years after clearfelling (pers. enquiry), has made the area to be recolonized by a non-climax community. In almost all the situations the species that was seen to colonize the clearfelled area of the forest (i.e. *Ceriops*), was not the dominant species of the mature forest. In deed this is the classic case of several seres leading to climax community (Detweiler, et. al.,1976, McCuster, 1977). Revegatation of such an area like Kinondo, will obviously demand some techniques to prevent loss of propagule by insolation and tidal currents. The first technique would be to plant a light loving species with a wide nutrient tolerant range e.g. *Ceriops* and *Avicennia* (Watson, 1928; Semesi, 1986). After the environment has been changed by 'light loving' species then *Bruguiera* can be planted. The results obtained from transplantation of *C. tagal* in Kinondo plots K-4 and K-5 (section 4.3.1 (ii)) is quite encouraging in that 68 - 77% of the saplings survived in the one year they were under observation (see plates 7 and 8).

Since mere germination of a species in a hostile environment does not guarantee the subsequent growth of the plants, measurements related to sapling performance of the species became essentially important. On the basis of growth performance, the conditions of the elongation in the nursery could be divided into three groups as follows:

(a) Slow elongation (less than 12 cm/year): *C. tagal* (the species is known to have a slow growth in the early stage (Qureshi, 1990).

(b) Medium elongation (20-40 cm/year): *R. mucronata, B. gymnorrhiza* and *H. l ittoralis*.

(c) Fast elongation (greater than 50 cm/year); *A. marina* and *X. granatm.*

The type of soil media used in the nursery significantly affected growth performance of *B. gymnorrhiza*, but not of *C. tagal*. *B. gymnorrhiza* that were sown in polythene plastic pots using sea grass litter as potting media and placed under partially shaded area of *Avicennia* trees had a higher diameter and height increment 12 months after potting: O.7 ± 0.1 cm and 53.2 ± 8.7 cm respectively, (fig.11 and table 3). Such results might be explained by the fact that *B. gymnorrhiza* respond favourably to a high nutrient availability.

5.3 TRANSPLANTING FIELD EXPERIMENTS

Apart from the preliminary trials of mangroves at the nursery, emphasis was placed on planting of the most commercial mangrove species: *Rhizophora*, *Ceriops, Bruguiera, Avicennia* and *Sonneratia*, on some denuded mud-flats, degraded and disturbed mangrove forests of Gazi bay (see appendix 1). Emphasis was laid on investigating the plant material type (either to use propagules, saplings or 'small trees' in mangrove rehabilitation) and the proper elevation within the intertidal area where maximum growth performance could be attained. Data collected on subsequent growth performance and saplings mortality indicated that, in addition to the method of transplanting and plant material type, soil topography, its texture and chemistry, "elevation with respect to tidal level was a significant factor in mangrove establishment". *A. marina, C. tagal* and *B. gymnorrhiza* propagules and saplings did not naturally or artificially establish among the planted *S. alba* below 0.5m above datum. It is evident from the results (Section 4.3) that there is no common habitat site in which saplings show maximum growth for all mangroves species. In most of the cases however, mangrove saplings will tend to show growth superiority in habitats of their own parents. Each tree regardless of species should be planted at an elevation similar to which it originally grew (fig. 7). The easiest way to determine proper elevations of plantings is simply to survey the elevations of existing mangroves at the closest location to the proposed planting site. In general *Sonneratia* and *Rhizophora* can be planted in zones of greater inundation than species found in the upper intertidal (e.g. *Heritiera* and *Avicennia*). Rabinowitz (1975) utilizing transplant experiment tested the survival of four mangrove species at elevation different from where they are normally found. *Luguncularia racemosa* did not do well in the lower elevations normally occupied by *Rhizophora* species, but *Avicennia* spp. did appear to do well in all zones. In Tanzania, trial experiments which were intended to replace the less useful *Avicennia* with *Rhizophora* were not successful after the 10th year because of incorrect site selection (Semesi, 1992)

Regarding what method to use: broadcast or direct hand sowing of *Avicennia* propagules, it is evident from the results that direct hand sowing method is relatively more useful than the broadcasting of its small propagules which in each case of methods are swept away by the tidal currents (section 4.3.2). Because the propagules of *Avicennia* always float, this species has an absolute requirement for a stranding period in order to establish. That is, the propagules must have freedom from tidal disturbance in order to take hold in the soil. The only alternative mode of *Avicennia* propagule establishment is snagging on objects such as coral rubble, slash or tree stumps, so that the propagules are held in a 'fixed' condition (see Van Speybroeck, 1992a) when the tides enter. Tidal flushing of the establishing *Avicennia* propagules might also explain the low natural regeneration of the species in deforested areas of Kinondo and Gazi. This situation really demands some techniques to prevent loss of *Avicennia* propagules by tidal currents. As far as the transplantion of the already established small mangrove trees is concerned, the results obtained in Gazi plot G-3 (see map in appendix 1) are quite encouraging. Transplanted small *Avicennia* trees (average height at the time of transplanting: 1.15 ± 0.38 m), showed 85.8% (n=91) survival after one year. The trees attained an average annual height increment of 68.6 ± 10.2 cm with an average stem diameter increment of 1.34 ± 0.3 cm. The annual maximum height increment attained was 1.49 m with a diameter increment of 2.25 cm (table 6). Figures obtained by CSSRI (1985), supports further the idea of using saplings instead of propagules in *Avicennia* afforestation. 30-40 day old saplings of *A. marina* were transplanted in a non tidal highly saline soil. The saplings attained an average height of 93.58 cm with a stem girth of 2 cm and 275 leaves after 13 months of transplanting.

It should be stressed here that the regeneration of *A. marina* in the elevated Kinondo plots is strongly disturbed by grazing by goats. The data presented in this discussion was purely obtained from the 'small trees' *Avicennia* plantation set in the seaward Gazi plots. Without solving the problem of grazing at Kinondo (which is expected to increase), reafforestation by *Avicennia* will be useless. I understand how difficult it is to stop the goats from invading the mangrove areas due to the fact that mangrove ecosystem is a 'no man's land'. In recommendations therefore there are two choices: (a) to make fence to protect against herbivory of the tender saplings or (b) to intensify plantation of mangrove species which are not grazed by goats (e.g *Ceriops*)

When nurseried (root-ball) and wildings (soil-free) transplanting techniques for planting *Rhizophora* saplings are compared (section 4.3.4) the nurseried saplings yields higher survival rate than the soil-free wildings (90.7 (n=43) Vs 78 (n=50)) after 49 weeks. Apart from the height increment and the total leave area, the pattern shown by other parameters e.g. number of leaf, internodes and branches was remarkably similar (table 5). The period to acclimatize the physiological shock is estimated to be the cause of initial low growth rate and high mortality among the transplanted soil free saplings.

An experiment under field conditions to investigate the relationship between growth and propagular size was conducted (section 4.3.3) to test the hypothesis raised by Qureshi (1990) that " under nursery conditions there is a direct correlation between propagule size and sapling vigour". Under field conditions however there was no outright correlation between propagule size and sapling performance (table 4). The slight correlation ($r = 0.106$) still supports the practical implication of utilizing larger propagules for plantation. The larger propagules will definitely allow for a plant to grow linearly more rapidly and cross the level of mean flooding by tidal water in minimum span of time; this in turn should reduce the chance and extend of barnacle infestation in the foliar region of the plant.

If its determined that a damaged or clearfelled forest need to be put back to its original form immediately, then small mangrove trees (5 to more years old, 1-1.8 m height) may be used. Planting trees of these size may be desirable where propagules and young saplings may be washed away. *Rhizophora* and *Avicennia* transplanted as small trees (section 4.3.6) gave quite good results. Survival after 1 year was 100% (n=22) for *Rhizophora* and 85.8% (n=91) for *Avicennia*.. The practical implication of this is that larger size of the trees and their more extensive root systems offer promise of greater and faster shore protection than can be achieved by using propagules and young saplings. Teas (1977) reports no success in transplanting large trees (upto 6m) of *A. germinans* and *Laguncularia racemosa*. These trees had been root pruned five to six months before transplantation and were top pruned $\frac{1}{4}$ to $\frac{1}{3}$ of their height at the time of transplanting. Moving the trees rather than pruning caused the mortality.

5.4 Air layering.

Mangrove reafforestation has historically dependent upon four techniques as follows: direct planting of propagule; transplanting of saplings or 'small trees' and aerial planting of propagules (Watson, 1928; Teas, 1977; Goforth and Thomas, 1979). Most results (e.g. Teas, 1977), indicate incurring problems associated with the techniques: a) a high seedling loss even though the plantings are surrounded by a protective structure, b) it takes two to four years for surviving propagules to establish themselves c) removing mangrove from a stocking area may damage the remaining stock by extensive disturbance and d) the costs for any of the above technique may be prohibitive. The results reported by Pulver (1976), Carlton and Moffler (1978) and our findings, suggests air-layering to be a promising technique of providing stock plants of transplanting without removing mangroves from the source area. Propagule production in *Sonneratia, Xylocarpus* and *Lumnitzera* is small and seasonal (Pers. observ.) and is often faced with extremely high mortality rates. Air layering allows layers to be transplanted 4-6 months after layering thus avoiding the seasonal production and predispersal mortality of the propagules.

It is apparent from the mean values of the box plots that the rooting success depend on the species (fig. 17) and the type of the rooting media (fig. 18) used. Low rooting success in specimens layered with mangrove forest litter, could be attributed to a high salinity of the litter, which inhibits root production.

CHAPTER 6

Conclusion and Recommendations

At the opening session of the First National Workshop for the Improved Management and Conservation of the Kenya Mangroves (July 24th - 29th 1993), Mr Kioko, J. M., Deputy Director, Kenya Wildlife Services (KWS), proposed the establishment of a national mangrove information network to facilitate effective exchange of information on mangrove as well as co-operation in mangrove research and development. What the director was basically pointing at was a need to establish a **National Mangrove Committee** (or Technical Advisory Committee). The national mangrove committee once formed would:

(1) examine *inter-alia* sustainable uses of mangroves,

(2) define areas for genetic preservation of species threatened with extinctions and over exploitation.

(3) recommend strategy for regeneration and afforestation of mangrove bordered coastline with advantageous species.

(4) educate the local population on the importance of mangroves and make them understand environmental and social impacts of large scale exploitation operation of mangroves on their land.

If our mangrove programme is to succeed it must be fully understood, accepted and supported first and foremost by the inhabitants of the area. As noted earlier in sections 1.5.2 and 1.5.3, over-exploitation of mangrove forests in Kenya occur due to a lack of **awareness of the problems**, than to a lack of economic alternatives. Policy makers, developers and the general public generally no not understand the need or the urgency to protect these resources. Decisions makers must become aware along with citizens, that protecting mangroves is in their own best interests. The attitude that the benefits derived from protection are minimal when compared to the benefits of the activities which degrade these ecosystems must be changed. Community education contributes to public involvement and greater public participation in issues related to mangrove conservation. When management decisions incorporate local inputs they will succeed, and political support will be greater when public is satisfied that it has been heard and has the opportunity to become involved. Any development must represent the needs, aspirations and well-being of the people who have the most intimate relationship with the resource and (habitats).

To win public acceptance and support for forestry programmes *in situ* pilot projects are required to demonstrate the economic viability, sustainability and manageability of planting mangroves, and sound forest management practice.

From the foregoing results and discussions one may make a conclusion that it is possible to implement mangrove plantation artificially in Kenyan coast, and thereby enhance the afforestation work in this region for achieving socioeconomic objectives both tangible and intangible as well as e.g. control of soil erosion, supply of fuel, creation of employment opportunities and improvement of environmental conditions. Some fast growing mangrove species e.g. *Sonneratia, Avicennia, Xylocarpus, Rhizophora* (investments returning high rates of 'interests') can sustainably be planted for charcoal, or firewood or timber as well as supplying fish and wildlife to nearby human populations. For slower growing species e.g. *Ceriops* and *Heritiera* exploitation must be slow. This management strategy has the advantage that it retains as many resource use options as possible open for future use.

I realize that this is a contentious statement and it is not meant to detract conservation efforts, it must be pointed clearly that presently large scale artificial regeneration is not feasible due to lack of manpower. fund and experience in propagule collection. storage and transport and species-site matching. Trial plantations are required before commercial plantations are contemplated. During the period 1994-1998 it is suggested that 50 ha/yr of environmental plantations be established on a trial basis. Commercial plantations at the rate of 75 - 100 ha/yr should be established later. It is encouraging to note here that the first phase of trial mangrove plantation covering approximately 50 ha is to be initiated at the end of the year 1993. This first phase is to cover part of the deforested mangrove areas of Gazi bay, Shimoni and the species rich river Ramisi estuary. The program is being supported by the Biodiversity Support Program (USAID) and the Belgium government through the Kenya Belgium Project - Mombasa. The programme is basically on community base. An important objective of the project will be to **transfer knowledge** on the procedures and methodology which has been developed in experimental plots at Gazi bay (this thesis), to the traditional people living around the mangroves.

The experience obtained from this work show that **it is not possible to devise any single technique** that will satisfy the planting requirements of all types of mangroves. It is however recommended that mangrove species should be planted at an elevation similar to that it originally grew (section 4.3). The use of propagules and saplings is a more appropriate method of revegatation. they are readily available and easy to install than the 'small trees' (section 3.2.1, 3.3.2(f)). The use of 'small trees' to restore *Rhizophora* and *Avicennia* gave quite encouraging results - 80-100% survival (section 4.3.6.), but two factors over-rule this method for general use. The first is the cost and labour input (as yet undetermined) and the second is the availability of donor sites. This method should only be used if a damaged or clear forest needs to be put back in its original form immediately.

Its considered that future studies on mangrove reforestation in Kenya should concentrate on:

a) studies concerned with seeds/propagules: seasons and areas of collection, collection method, maturity, preservation,

b) studies concerned with nursery and transplantation : type of nursery, season and method of transplantation,

c) studies concerned with afforestation methods: technical aspect, economic aspects, co-operation of villagers.

d) phenological studies: Growth, flowering, seeding, development of roots,

e) studies in management and utilization: role of mangrove forests, felling period, thinning, human stress etc.

On the international level, there should be effective linkages among countries, institutions, and professional groups and individuals working or concerned with mangroves to:

(a) have better and faster exchange of information and technology on the management and protection of mangrove areas;

(b) undertake cooperative research and development program; and

(c) generate additional financial support for research and development programs notably reforestation of denuded and disturbed mangrove areas.

Now with the formulation of a Memorandum of Understanding (MoU) between the Forest Department and Kenya Wildlife Services (KWS) it is hoped that there will be more collaboration in the enhancement of the management of mangrove biodiversity. It is therefore considered desirable to allow the joint subordinate staff (Forest Dept. and KWS) a good deal of discretion in the control of the felling and to train them to enforce simple rules which though by no means perfect, should ensure sufficient natural regeneration. A fine (e.g. withdrawing of licenses or being made to plant the cut areas) can be introduced for non-observance or breachers of rules.

For the adequate enforcement of harvesting rules it is of course essential for the supervising guards to live in the immediate vicinity of the forest, and it may be necessary to increase the subordinate staff and physical management tools (e.g. vehicles and boats) to enable closer supervision.

Just as the backbone of the army is the non - commissioned man, so the mainstay of the Memorandum of Understanding (MoU) between the Forest Department and the Kenya Wildlife Services, is the trained forest guards and game rangers. No inspection on the part of the mangrove cutters or fines inflicted on licensees will result in thorough work and satisfactory regeneration unless the supervising guards and rangers have reasonably definite ideas of the silvicultural requirements of the trees and are able to command respect of the cutters.

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APPENDIX 1

REAFFORESTATION SITES OF MANGROVE FOREST AT GAZI BAY - KENYA

KEY TO LEGEND (Ref. Map)

Br - Mixed stands of mainly **secondary forest** which are vigorously growing and subjected to periodic harvest or more frequent prunning, height 8 - 15 m, cover 50 - 100%. Due to cutting Rhizophora is often freakishly formed, whereas Bruguiera and Avicennia are truncated. Monospecific stands of Rhizophora (> 80% cover) occur on the seaward side. Towards mainland of Kinondo mangrove area have been disturbed extensively and are either eroding or being, 'excluded' by an 'inferior' mangrove species. This is the main source of 'boriti', 'mazio' and 'pau' being used locally or for sale.

Cm - Isolated monospecific stands of C. tagal, with dense to sparse thinly tall trees/shrubs. height 2 - 8 m, cover 50 - 75 %.

Pi - S. alba, A. marina, R. mucronata and C. tagal. On the seaward side a fringing vegetation of Sonneratia (2 - 5) rows of trees, occasionally mixed with Avicennia and Rhizophora. Height 4 - 8m, cover < 30%. Severely denuded mud-flats due to over-cut. Most of the older trees of S. alba and A. marina are truncated and have coppiced side branches.

Wm - A. marina, C. tagal, H. littoralis, X. granatum. height 3 - 8m. C. tagal found as continous fringing vegetation on the mainland side and in isolated stands, cover 50 - 75%.

Fi - Isolated trees of H. littoralis, X. granatum, L. racemasa on the mainland edge; cover upto 30%, height 2 - 10m, on the seaward side Avicennia mixed with Rhizophora; height 10 - 20m, cover > 50%.

Mr - Creek fringing vegetation of several (2 - 5) rows of mixed Avicennia (60%) Rhizophora (20%) and Bruguiera. Cover 60 - 80%, height 5 - 15m.

Ng - A well zoned mangrove stand. monospecific stands of R. mucronata on the seaward, height 15 - 20m cover > 80%; toward the mainland is Ceriops, height 2 - 8m, cover > 75%. Towards the the most landward side is a monospecific Avicennia shrubs, height 2 - 6m cover > 75%.

Ht - **Over-exploited mangrove areas** that are either idly eroding or being recolonized by an 'inferior', mangrove species as compared to the original clear-felled climax (see plate 1).

Vm - Monospecific stands of A. marina shrubs, height 2 - 8m, cover 30 - 60%, thinly trees/shrubs with trunks branching on low level above ground.

Li - **Disturbed mangroves** stands of A. marina, L. racemosa and X. granatum, height < 50%, constantly cut for 'fitos'

REAFFORESTATION SITES OF MANGROVE FOREST AT GAZI BAY, KENYA