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Allometric Equations for Estimating Above Ground Biomass of *Rhizophora mucronata* Lamk. (Rhizophoraceae) Mangroves at Gazi Bay, Kenya

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Abstract—Structural characteristics of mangrove forests and stand productivity are a function of management regimes, prevailing environmental conditions and age of the stands. Biomass measurements can be used as proxies of productivity and the potential of stands to sequester carbon. Allometric relationships were developed for estimating above ground biomass of *Rhizophora mucronata* mangrove species at Gazi bay in Kenya. Fifteen trees of diameter range 2.3-23.3 cm were cut, weighed and separated into their different components; stems, prop-roots, branches and leaves. Sub-samples were taken to the laboratory for oven drying at 80°C to determine wet-dry weight ratio. Allometric relations were best estimated from regressing stem diameter at D_{130} cm as the independent variable using the equation of the form $y = ax^b$. Using the developed equation, mean above ground biomass was estimated as 452.02 t/ha. In 1992, Slim *et al.* (1996) found higher above ground biomass of 515 t/ha for the same mangrove species at Gazi, but in a relatively less disturbed location. The variation may be attributed to the differences in sampling design and human pressure over time. It is hoped that this local equation developed will be useful in estimating biomass of this economically important mangrove species at various sites for better management.

INTRODUCTION

Human perception of mangroves as an important resource has improved since the pioneer studies by Heald (1969) and Odum (1971) showed the role of their detritus in the food web of the intertidal zone. In eastern Africa, extensive studies on various aspects of mangrove ecosystems have been carried out. These have mainly focused on ecology and distribution of species (Ruwa, 1997), economic utilization (Kokwaro, 1985; Dahdouh-Guebas *et al*, 2000), tree productivity (Slim *et al.*, 1996), management and conservation (Semesi, 1991), trial mangrove restoration (Kairo, 1995), faunal and flora recolonization (Bosire *et al.*, 2003, 2004) links with marine fisheries (Ngoile & Shunula, 1992; Huxham *et al.*, 2004) among others. However, in spite of this large volume of literature, mangrove habitats continue to be overexploited and degraded.

Sustainable management of mangrove forest requires information necessary to our understanding and prediction of changes in the forest conditions. Aspects that need to be appraised include forest structure and regeneration, this being linked closely to mangrove forest productivity and fisheries production (Fromard *et al.*, 1998). To better understand the dynamics of organic matter cycling in mangroves, it is important to know the amount of biomass present at a given time (Soares & Schaeffer-Novelli, 2005).

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Accurate estimates of biomass are important in describing the status of mangroves, assessing the yield of commercial timber products, development of sound silvicultural practices, modelling potential impacts of climate change and as an essential component of carbon sequestration estimation (Earmus *et al.*, 2000, Comley & McGuiness, 2005; Soares & Schaeffer-Novelli, 2005). Allometric equations are useful tools for estimating tree biomass (Komiyama *et al.*, 2002). In the development of allometric equations, easily measured parameters (e.g. diameter at breast height (DBH) and/or tree height) are regressed against harvested tree component weights. The independent variable (predictor) in this regression is obtained from detailed censusing of study plots (Putz & Chan, 1986).

In many countries of the Western Indian Ocean few allometric equations for mangroves exist. Estimates of 20.25 t/ha in a 5-year old reforested mangroves at Gazi bay Kenya were obtained from an equation of the form $y = -0.1811x^{0.6590}$ (Kairo, 2001), (where y = above ground biomass and x = DBH) while earlier studies by Slim *et al.* (1996) using the equation of the form $y = 0.4049x^{2.20}$ (where y = above ground biomass and X = DBH) in a relatively less disturbed *Rhizophora mucronata* Lamk. stand at the same location estimated biomass values of 515 t/ha. Such stands are currently rare amongst mangroves in south coast of Kenya due to human exploitation. In South Africa, Steinke *et al.* (1995) working in stands dominated by *Bruguiera gymnorrhiza* (L.) Lamk., obtained biomass values of 94.49 t/ha. According to Soares and Schaeffer-Novelli (2005), the variability of environmental conditions, such as climate, geomorphology, edaphic factors, tides, age, and the history of the forest reflect on the structural characteristics of mangrove forests. Temporal variation in structural characteristics makes application of equations constructed from data obtained from the same location difficult.

This study therefore attempts to develop fresh local equations for estimating above ground biomass of *R. mucronata* mangrove species at Gazi bay and compares the biomass findings with that obtained earlier by Slim *et al.* (1996) who worked at the same site 14 years previously.

MATERIALS AND METHODS

Study area

Gazi bay (4° 25'S and 39° 50'E) is situated on the south coast of Kenya about 50 km from Mombasa (Figure 1). The bay is sheltered from strong waves by the presence of Chale Peninsula to the east and

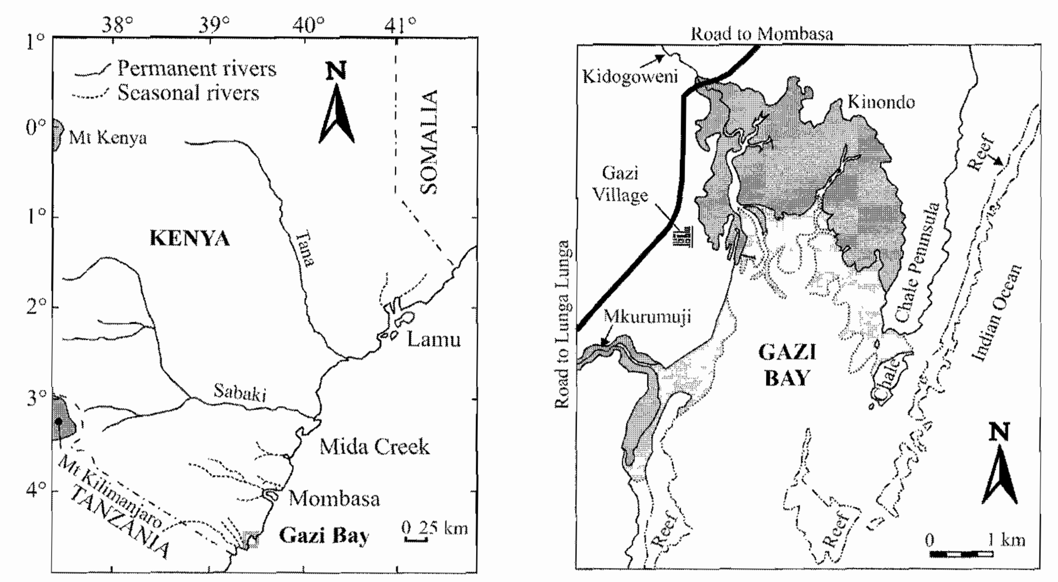

Fig. 1. Map of the Kenyan coast showing the study site at Gazi Bay. (Source: Bosire *et al.* 2003)

a fringing coral reef to the south (Kairo, 2001). The mangroves of Gazi are not continuously under the influence of freshwater, because the two rivers (Kidogoweni in the north and Mkurumuji in the south) that drain into the bay are seasonal and temporal depending on the amount of rainfall inland, while groundwater seepage is restricted to a few points (Tack and Polk, 1999). Generally, freshwater influx via rivers and direct rainfall into the bay accounts for a volume of 305,000 m3 per year of which 20 % is lost due to evaporation, which is also responsible for the salinity maximum zone of 38 ppt in the upper region of the bay covered by mangroves (Kitheka, 1997).

All the nine species of mangroves occurring in Kenya are found in Gazi bay with *R. mucronata* and *Ceriops tagal* (Perr.) C.B. Robinson being the dominant species (Ferguson, 1993). The mangrove forests of Gazi have been exploited for many years especially for industrial fuel and building poles (Kairo, 1995; Dahdouh-Guebas *et al.*, 2000; Bosire *et al.*, 2003). Gazi village has a resident population of 900 people and most of them have strong economic and cultural ties with the coastal resources, which they depend on as fishermen, mangrove cutters and coral collectors among others (Dahdouh-Guebas *et al.*, 2000). The government ban on mangrove harvesting between 1997 and 2004, which was meant to check overexploitation, adversely affected the local community's traditional use of the mangrove forest (Kairo, 2001).

Allometric relations

Mixed stands of naturally growing *R. mucronata* were sampled at Gazi bay. A total of 15 trees were randomly selected and harvested. For the harvested trees, diameter at breast height was measured at 1.3 m above ground (D_{130}, Brokaw and Thompson, 2000) or 30 cm above the highest prop root when this root occurred at height above 1.3 m. Individual trees were felled close to the ground and subdivided into respective components; stems, branches, prop roots, and leaves. The total harvested fresh weight of each component was obtained in the field. Representative samples from each component (about 500 g) were collected and moved to the laboratory where they were oven-dried at 80°C to a constant weight to determine the fresh weight to dry weight ratio. Various allometric regression equations using either tree diameter, or a combination of diameter and height as the independent variables, and the weight of the specific components as the dependent variables were tested.

Determination of standing biomass

In determining standing biomass, thirty-two plots measuring 10 m x 10 m were established. In each plot, tree DBH was obtained for all *R. mucronata* trees. Aboveground biomass of each tree was calculated using the computed regression equation above. Stand above ground biomass was calculated using the stand density of *R. mucronata* of 2570 stems per hectare obtained by Bosire *et al.* (2003) (Table 1)

Table 1 Structural characteristic of the *R. mucronata* stands at Gazi bay

Species	Density	Basal area
R. mucronata	2570 ± 410	34 ± 0.3
Bruguiera gymnorrhiza	1130 ± 410	8 ± 0.3
Xylocarpus granatum	70 ± 61	0

Source: Bosire *et al.*, 2003

Statistical analysis

Correlations were derived between structural parameters and the dry weights for each component of the individual trees. The significance of the regression equation was assessed by a single factor ANOVA at ($p < 0.05$) level. The dry weights of the trees were estimated by power functions, using stem diameter as the independent variable ($y = ab^x$), where, y = biomass, x = stem diameter and, *a* and *b* are the regression constants.

RESULTS

Allometric equations

The regression constants (*a, b*), the correlation coefficient (r^2) and the standard error of the biomass estimate (s.e) for all components of *R. mucronata* are summarized in Table 2. Figure 2 shows linear relationships obtained when dry weights of different components of *R. mucronata* were plotted against stem diameter. The regression equation used for predicting the total above ground biomass for *R. mucronata* at Gazi bay was y = -0.8069DBH$^{2.5154}$, $r^2 = 0.98$, $p < 0.05$.

Table 2. Constants (a and b), coefficients (r^2) and standard errors (s.e) for allometric relationships between dry weight and stem diameter, fore each component of *R. mucronata* at Gazi bay.

Component	a	b	r^2	s.e
Stem	-1.1264	2.5299	0.9703	0.10
Roots	-1.3270	2.5263	0.9649	0.16
Branch	-1.4634	2.4606	0.9860	0.58
Leaf	-1.8069	2.5628	0.8996	0.26
Total	-0.8069	2.5154	0.9799	0.78

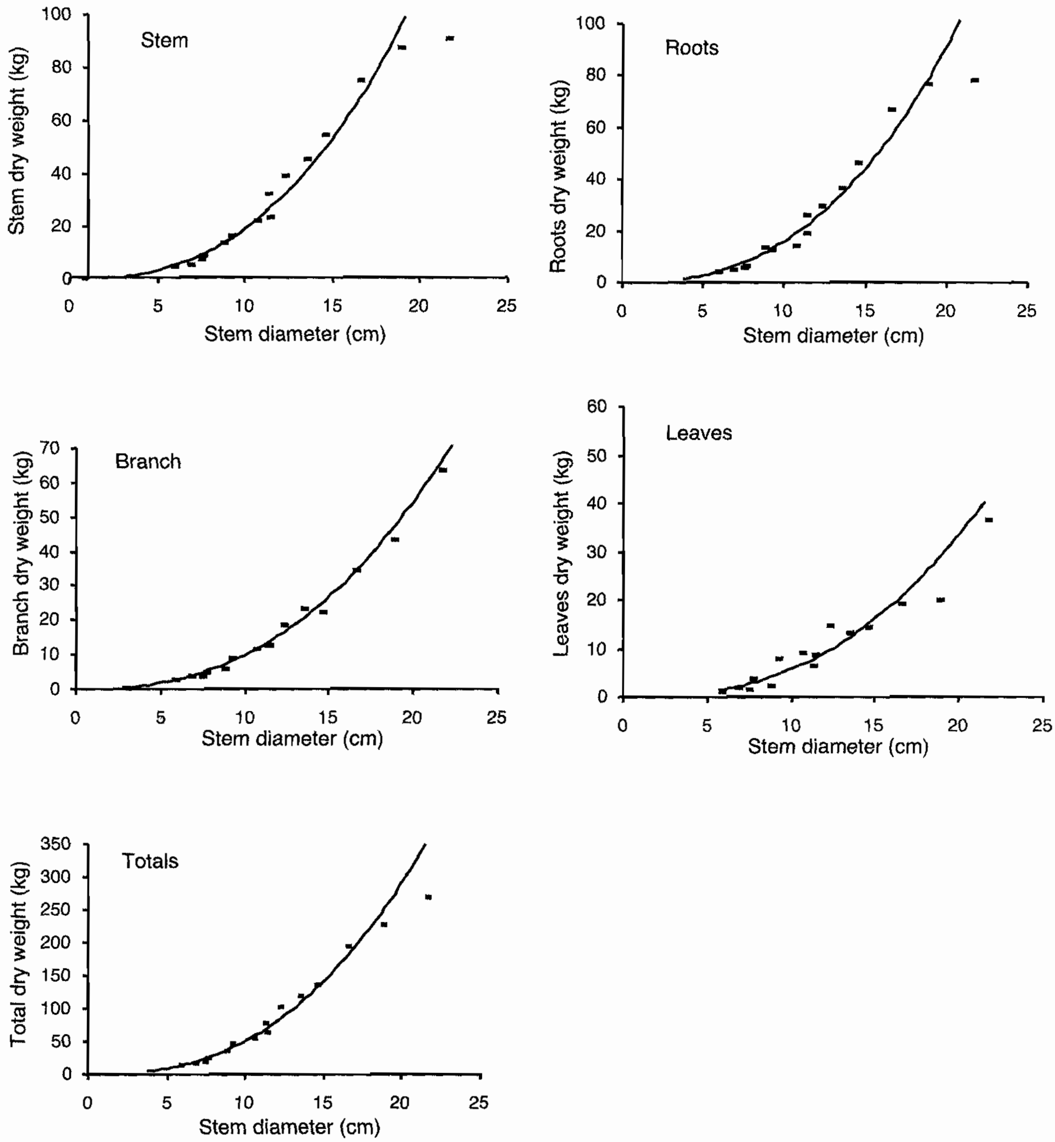

Fig. 2. Plots of dry weight against stem diameter of different components of *R. mucronata*. The corresponding coefficients are given in Table 2

Aboveground biomass

Using the findings of the structural studies carried out at the site by Bosire *et al.* (2003), which gave the stand density of *Rhizophora mucronata* of 2570 stems per hectare, the total stand above ground biomass estimates were estimated to be 452.02 t/ha. Stem diameters ranged from 5.73-21.6 cm (mean: 11.62± 4.57 cm). 80% of the trees were between 5 cm and 15 cm diameter range. Figure 3 shows changes in the proportions of roots, stems, branches and leaves as a function of stem diameter in *R. mucronata* at Gazi bay. Roots had the highest percentage of biomass (38.64 %) while stem, branch, and leaves made up 36.13 %, 16.05 % and 9.19 % respectively. The canopy height ranged from 4.34 m to 11.32 m (mean: 7.34 ± 1.69 m).

in the final equation as it reduced the robustness of the equation.

Clough and Scott (1989) while developing allometric equations for six species in eastern Australia, noted that the use of stem diameter provides an accurate estimate of above ground biomass without the need to include height.

Table 3 shows the estimates of above ground biomasses when the equation developed in this study and equations developed for different areas were applied across different stem diameters. The above ground biomass estimates obtained from the allometric relationship developed in this study between stem diameter and total above ground dry weight for *R. mucronata* were similar to those reported previously for single-stemmed *Rhizophora mangle* L. and *Rhizophora racemosa*

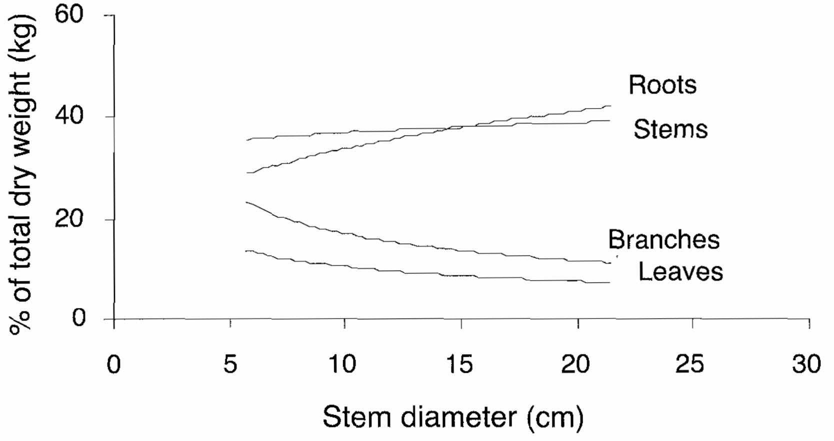

Fig. 3. Changes in the proportions of root, stem, branch and leaves as a function of stem diameter in *R. mucronata* at Gazi bay

DISCUSSION AND CONCLUSION

Allometric equations

Biomass estimates using the equation $y = x^b$ and its linear transformation equation gave a better description of the relationship between above ground biomass and the stem diameter ($r^2 > 0.95$). Other workers (e.g. Woodroffe, 1985; Tam *et al.*, 1995) have used the relationship, which include height as a variable. Whereas height data was collected in this study, the predictive variable used was the stem diameter. Height could not be included

G.F.W.Meyer in French-Guiana for stem diameters between 5 cm and 15 cm (Fromard *et al.*, 1998). However, beyond a stem diameter of 15 cm, our equation gave lower biomass estimates than those reported for Malaysia (Putz & Chan, 1986) and French-Guiana, but gave higher biomass estimates in comparison to the estimates reported in Sri Lanka (Amarasinghe & Balasubramaniam, 1992).

A broad range of allometric equations used in estimating above ground biomass are available. Due to the nonlinearity of the allometric relationship developed in this study for *R. mucronata*, extrapolation of the equation should be done with caution. Also site-specific

Table 3. Comparisons of total tree above ground biomass (kg/ha) of *Rhizophora* spp for various stem diameters, using allometric relationships from different sites

Diameter (cm)	This study		Kenya[1]	Kenya[2]	Malaysia[3]	French-Guiana[4]	Sri-Lanka[5]
	Estimated	Actual					
5	9	8	13	11	10	8	14
10	51	51	64	-	56	51	60
15	141	146	156	-	156	146	138
20	292	306	294	-	321	309	250
25	-	-	-	-	562	552	396

[Sources: [1]Slim *et al.*, (1996) (*R. mucronata*); [2]Kairo (2001) (*R. mucronata*); [3]Putz & Chan (1986) (*R. apiculata*); [4]Fromard *et al.* (1998) (R. mucronata); [5]Amarasinghe and Balasubramaniam (1992) (*R. mucronata*)]

environmental conditions (e.g. climate, geomorphology, edaphic factors, and inundation regimes among others), age, and the history of the forest exert a lot of control on forest structure (Soares and Schaeffer-Novelli, 2005), suggesting that generalizations of these equations may not be appropriate

Aboveground biomass

The percentage contribution by the stem to the total tree biomass was almost constant across the various diameter ranges, whereas the contribution by roots increased with diameter (Figure 3). This presumably reflects the greater support requirements by larger trees since prop roots are the major support structures of *Rhizophora* species (Tomlinson, 1986; Clough and Scott, 1989). Stems and roots in *Rhizophora* are relatively long-lived structures, and accumulation of biomass in each provides an idea on how carbon is partitioned between them as the tree grows. In contrast, leaves and twigs are shed as litter throughout the year (Clough, 1992) and are therefore relatively more transient.

The above ground biomass obtained in this study for *R. mucronata* was 452.02 t/ha. This is lower than that obtained by Slim *et al.* (1996) who conducted above ground biomass estimation study on *R. mucronata* in 1992 at Gazi bay and obtained biomass estimates of 515 t/ha. The differences may be attributed to the differences in sampling design and human pressure over time. Our study randomly selected trees across the whole of the 6.61 km mangrove vegetation while the study by Slim *et al.* (1996) confined itself to a monospecific, undisturbed *R. mucronata* plot measuring 20 m x 20 m and established their equations from harvesting representative trees within the plot.

The biomass values for *R. mucronata* obtained in this study compares well to those of *R. apiculata* Bl. (436 t/ha) in Indonesia (Komiyama *et al.*, 1988) and *R. apiculata* (460 t/ha) in Malaysia (Putz & Chan, 1986). They are however, higher than the values reported for *B. gymnorrhiza* (94.4 t/ha) in South Africa (Steinke *et al.*, 1995) and *R. mucronata* (240 t/ha) in Sri Lanka (Amarasinghe and Balasubramaniam, 1992). These differences may be attributed to longitudinal and latitudinal variations in mangrove biomass. Generally, mangroves yield lower biomass values further away from the equator (Saenger and Snedaker, 1993). As with terrestrial trees, mangrove biomass yields increase with the age of the forest stand. For example, above ground biomass increased from 39 to123 t/ha for a 1 to 5 years old forest to > 664.2 t/ha in forests of 28 years and older (Putz & Chan, 1986). Our estimates of 452.02 t/ha indicate that the *R. mucronata* mangrove forests in Gazi bay may be growing below optimal conditions. Human pressure has been inferred as the possible cause of mangrove degradation at Gazi bay (Dahdouh-Guebas *et al.*, 2004; Obade *et al.*, 2004).

This study has developed allometric equations for *R. mucronata*. It is hoped that the equations developed for the species will aid in estimating the standing biomass of mangrove forests in Kenya and therefore enhance mangrove management. The general equation only applies for trees of the diameter range 2.3-23.3 cm and to mangrove trees in an area with the same environmental conditions as those found at Gazi bay. Complimentary studies of a similar nature should be carried out on all mangrove species along the coastline in order to develop allometric equations that will aid in the effective management of mangroves in the Western Indian Ocean.

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REFERENCES

Amarasinghe, M. D. & Balasubramanian, S. (1992) Net primary productivity of two mangroves stands on the North-western Coast of Sri Lanka. *Hydrobiologia* **247:** 37-47.

Bosire, J. O., Dahdouh-Guebas, F., Kairo. J. G and Koedam, N. (2003) Colonization of non-planted mangrove species into restored mangrove stands in Gazi bay, Kenya. *Aquatic Botany.* **76:** 267-279

Bosire, J. O., Dahdouh-Guebas, F., Kairo, J. G., Cannicci S. and Koedam, N. (2004). Spatial variations in macrobenthic fauna recolonisation in a tropical mangrove bay. *Biodiversity and Conservation* **13**(6): 1059-1074.

Brokaw, N. and Thompson, J. (2000). The H for DBH. *Forest Ecology and Management* **129:** 89-91

Clough, B. F. (1992) Primary productivity and growth of mangrove forests. In: Robertson, A. I and Alongi, D. M (eds), *Tropical Mangrove Ecosystems.* America Geophysical Union, Washington, D.C. 225-249

Clough, B. F and Scott, K. (1989) Allometric relationship for estimating above ground biomass in six mangrove species. *Forest Ecology and Management* **27:** 117-127

Comley, B. W. T and McGuiness, K. A, (2005). Above and belowground biomass, and allometry, of four common northern Australian mangroves. *Australian Journal of Botany:* **53**(5) 431-436

Dahdouh-Guebas, F. R., Mathenge, C., Kairo, J. G., and Koedam, N. (2000) Utilization of mangrove wood products around Mida creek (Kenya) amongst subsistence and commercial users. *Economic Botany* **54:** 508-522.

Dahdouh-Guebas, F., Van Pottelbergh I., Kairo J. G., Cannicci S. and Koedam, N. (2004) Human-impacted mangroves in Gazi (Kenya): predicting future vegetation based on retrospective remote sensing, social surveys, and distribution of trees. *Marine Ecology Progress Series* **272:** 77-92.

Earmus, D. McGuinness, K. and Burrow, S. (2000) Review of allometric relationships for estimating woody biomass for Queensland, the Northern territory and Western Australia. National Carbon Accounting System technical report: No. 5a.

Ferguson, W. (1993) A landscape ecological survey of the mangrove resource of Kenya', Nairobi, Kenya Wildlife Service & Forest Department.

Fromard, F., Puig, H. Mourgin, E. Marty, G. Bettoule J. I. and Cadamuro, L. (1998) Structure, above ground biomass and dynamics of Mangrove ecosystems: New data from French Guiana. *Oecologia,* **115:** 39-53.

Heald, E, J. (1969) *The production of organic detritus in a south Florida estuary.* Unpublished PhD thesis, University of Miami, Florida USA.

Huxham, M., Kimani, E. and Augley, J. (2004). Mangrove fish: a comparison of community structure between forested and cleared habitat. *Estuarine Coastal and Shelf Science,* **60:** 637-647.

Kairo, J. G. (1995) *Community participatory forestry for rehabilitation of deforested mangrove areas of Gazi bay (Kenya).* A first approach. Final technical report. World Wildlife Fund-USA. & University of Nairobi (Kenya).

Kairo, J. G. (2001) *Ecology and restoration of mangrove systems in Kenya.* Unpublished PhD Dissertation, APNA, Belgium. Free University of Brussels.

Kitheka, J. U. (1997) Coastal tidally - driven circulation and the role of water exchange in the linkage between tropical coastal ecosystems. *Estuary and Shelf Science.* **45:** 177-187.

Kokwaro, J. O. (1985). The distribution and economic importance of the mangrove forests in Kenya. *J. E. Afr. Nat. Hist. Soc.*: 75 1-12

Komiyama, A,. Jintana, V., Sangtieran, T and Kato, S. (2002) A common allometric equation for predicting stem weight of mangroves growing in secondary forests. *Ecological Research* **17:** 415-418

Komiyama A., Miriya,. H., Prawiroat, M, S., Toma, T. and Ogino, K. (1988) Primary productivity of mangrove forest. In Ogina, K and Chihara, M. (eds). Ethime University, Ethime.

Ngoile, M. A. K. and Shunula, J. P. (1992). Status and exploitation of the mangrove and associated fishery resources in Zanzibar. *Hydrobiologia,* **247:** 229 - 234.

Obade, P. T., Dahdouh-Guebas, F., Koedam, N., De wulf, R. and Tack, J. (2004) GIS-based Integration of Interdisciplinary Ecological Data to Detect Land-cover Changes in Creek Mangroves at Gazi bay, Kenya. *Western Indian Ocean Journal of Marine Science* Vol. **3:** No 1. 11-27.

Odum, W. E. (1971). *Pathways of Energy Flow in a South Florida Estuary.* Sea Grant Technology Bulletin No 7. University of Miami, Coral Gables, Florida.

Putz, F. E. and Chan, H. T. (1986) Tree growth, dynamics, and productivity in a mature mangrove forest in Malaysia. *Forest Ecology and Management* **17:** 211-230.

Ruwa, R. K. (1997). Zonation of burrowing crabs in the mangroves of the east coast of Kenya. In: Kjerfve B, Drude de Lacerdaand L, Diop HS, (eds). *Mangrove ecosystem studies in Latin America and Africa.* UNESCO Technical Papers in Marine Science, Paris: UNESCO, 316-324.

Saenger, P. and Snedaker, S. C. (1993) Pantropical trends in mangrove above ground biomass and annual litterfall. Oecologia **9:** 293-299.

Semesi, A. K. (1991). *Management plan for the mangrove ecosystem of mainland Tanzania.* Ministry of Natural Resources and Environment, Forest and Beekeeping Division, Tanzania.

Slim, F. J., Gwada, P., Kodjo, M., Hemminga, M. A. (1996) Biomass and litterfall of *Ceriops* and *Rhizophora* in the Mangrove forests of Gazi bay, Kenya. *Marine and Freshwater Resources* **47:** 999-1007.

Soares, M. L. G., Schaeffer-Novelli, Y. S. (2005). Aboveground biomass of mangrove species. I. Analysis of Models. *Estuarine, Coastal and Shelf Science.* **65.** 1-18.

Steinke, T. D., Ward C. J. and Rajh, A. (1995). Forest structure and biomass in Mgeni estuary, South Africa. *Hydrobiologia.* **295:** 159-165.

Tack, J. F., Polk, P. (1999) The influence of tropical catchments upon the coastal zone: modeling the links between groundwater and mangrove losses in Kenya, India and Florida. *In:* Harper, D., Brown, T. (Eds). *Sustainable Management in Tropical Catchments.* Wiley, London, UK.

Tam, N. F. Y., Wong, Y. S., Lang, C. Y. and Chen, G. Z. (1995) Community structure and standing crop biomass of a mangrove forest in Futian Nature Reserve, Shenzhen, China. *Hydrobiologia* **295:** 193-201.

Tomlinson, C. B. (1986) *The Botany of mangroves.* Cambridge Tropical Biology Series, Cambridge, University press, Cambridge, New York, U.S.A.

Woodroffe, C. D. (1985) Studies of a mangrove basin, Tuff Crater, New Zealand: 1. Mangrove biomass and production of detritus, *Estuarine Coastal and Shelf Science.* **20:** 265-280.