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# Below-ground root yield and distribution in natural and replanted mangrove forests at Gazi bay, Kenya

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ABSTRACT

Estimation of total biomass in woody ecosystems is important because of its relevance to nutrient turnover and the potential to store carbon. Most work on mangrove biomass, particularly in the Western Indian Ocean Region, has concentrated on the above-ground component; comparatively little is known on below-ground biomass. The current study was conducted at Gazi bay on the southern coast of Kenya. The objective was to determine the below-ground biomass of three species of mangrove, *Rhizophora mucronata* Lamarck, *Avicennia marina* (Forsk.) Vierh and *Sonneratia alba* J. Smith, in natural and replanted stands. The effects of distance from the tree base and of soil depth on root biomass and size distributions were also studied using coring. Live below-ground biomass (mean ± S.E.) ranged from 7.5 ± 0.4 t/ha to 35.8 ± 1.1 t/ha, 48.4 ± 0.7 t/ha to 75.5 ± 2.0 t/ha and 39.1 ± 0.7 t/ha to 43.7 ± 1.7 t/ha for *R. mucronata*, *S. alba* and *A. marina*, respectively, depending on the age of the stand. Including dead roots produced total biomass values of 34.9 ± 1.8–111.5 ± 5.6 t/ha, 78.9 ± 3.3–121.5 ± 7.3 t/ha and 49.4 ± 1.1–84.7 ± 5.4 t/ha for *R. mucronata*, *S. alba* and *A. marina*. These values imply carbon contents of live roots ranging between 3.8 ± 0.2 C t/ha and 17.9 ± 0.6 C t/ha, 24.2 ± 0.4 C t/ha and 37.7 ± 1.0 C t/ha and 19.5 ± 0.4 C t/ha and 21.9 ± 0.9 C t/ha for *R. mucronata*, *S. alba* and *A. marina* stands, respectively, and 17.4 ± 0.9 C t/ha and 55.7 ± 2.8 C t/ha, 39.4 ± 1.7 C t/ha and 60.7 ± 3.6 C t/ha and 24.7 ± 0.6 C t/ha and 42.4 ± 2.9 C t/ha for *R. mucronata*, *S. alba* and *A. marina* stands, respectively if dead roots are included. Stand densities were 4650 ± 177 stems/ha, 3800 ± 212 stems/ha and 3567 ± 398 stems/ha for *R. mucronata* 6-year old, 12-year-old and natural stands respectively. Mean stem diameter, and basal area were highest in the 12-year-old plantation while below-ground root biomass increased with age. Stand density for *S. alba*, was highest in the 12-year-old plantation (7900 ± 141 stems/ha) while the 9-year-old stand had trees with the largest diameter (7.7 ± 0.9 cm). Below-ground biomass was highest in the 12-year old (75.5 ± 2.0 t/ha) and lowest in the natural stand (48.4 ± 0.7 t/ha). Stand density for *A. marina* was highest in the 12-year-old plantation (4300 ± 919 stems/ha) while mean stem diameter (7.9 ± 0.7 cm) and basal area (16.2 ± 2.1 $m^2$/ha) were highest in the natural stand. Below-ground biomass in the 12-year-old (43.7 ± 1.7 t/ha) and natural stands (39.1 ± 0.7 t/ha) was similar. Root densities decreased with soil depth and with distance from the base of trees for all species and stands. Fine roots (diameter <5 mm) constituted between 24% and 45% of the total stand live root biomass. The information generated is important in establishing the total biomass and thus the potential amount of carbon sequestered by mangroves in the study area.



## 1. Introduction

Estimation of biomass in woody ecosystems, such as mangroves, is required for a number of reasons. Foresters are interested in the yield of wood as a function of age, stand density and other factors. Ecologists require information about stand biomass for its relevance to nutrient turnover, stand structure and function and competition studies. Ecophysiologists have used biomass as an indicator of atmospheric and soil pollution input and forest health (Komiyama et al., 2002). More recently, there has been much discussion on the potential for woody ecosystems to store carbon and contribute to mitigation strategies to offset carbon emissions (Yanai et al., 2006; Eamus et al., 2002, 2000; Vogt et al., 1998).

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Although mangroves occupy only 0.4% of the forested areas globally, they are important sinks for atmospheric $CO_2$ along tropical coastlines (Bouillon et al., 2008; Komiyama et al., 2002); they are among the most productive ecosystems on earth and account for about 11% of the total input of terrestrial C into the oceans (Jennerjahn and Ittekkot, 2002). Mangroves are estimated to store carbon in excess of 4.0 gigatons (Ong, 1993; Twilley et al., 1992), although this estimate is likely to be too low, given that $\sim$112 Tg C $a^{-1}$, or >50% of all the carbon fixed by mangroves annually, remains unaccounted for (Bouillon et al., 2008). This carbon is stored in both above and below-ground tree components as well as in the sediment (Twilley et al., 1992). In contrast to terrestrial forests, root production may contribute half or more of the total standing biomass in mangroves (Briggs, 1977). Because mangroves grow in saturated, low oxygen soils, much of the carbon stored in roots resists decay and can form long-term sinks as mangrove peat (Middleton and McKee, 2001). Hence understanding the controls on below-ground biomass is essential in determining the carbon dynamics and carbon storage potential of mangrove ecosystems. While there is a substantial literature on the above-ground biomass of mangrove forests (see e.g. Soares and Novelli, 2005; Zianis and Mencuccini, 2003; Komiyama et al., 2002; Clough, 1992), fewer studies have considered below-ground biomass (but see Comley and McGuinness, 2005; Ong et al., 2004; Alongi and Dixon, 2000; Komiyama et al., 2000; Saintilan, 1997a,b), because of the logistical difficulties involved.

Coarse roots generally contribute more to total biomass than fine roots in terrestrial systems (Eamus et al., 2002). However, in mangroves fine roots may contribute up to 66% of the total root biomass (Komiyama et al., 1987). The fine roots of trees such as the mangroves are concentrated on lateral branches that arise from perennial roots. They are important in the acquisition of water and essential nutrients, and at the ecosystem level, they make a significant contribution to biogeochemical cycling. Estimates of root biomass must therefore differentiate between coarse and fine root biomass (Komiyama et al., 2000).

Though distribution of roots with soil depth is difficult to measure in terrestrial forests (Yanai et al., 2006), this is relatively easy in mangroves using coring methods, because mangrove roots and substrate are soft and can be penetrated using a corer (Komiyama et al., 1987). The distribution of root biomass with distance from tree base is not well studied even in terrestrial forests (Yanai et al., 2006). The few relevant studies show that most coarse root biomass is found close to the stems (Millikin and Bledsoe, 1999). Fine roots, however, can extend long distances away from the stem and their spread may reflect the distribution of nutrients in the soil (Yanai et al., 2006) and are less sensitive to distance from tree base (Eamus et al., 2002; Millikin and Bledsoe, 1999).

The present study complements previous work at Gazi bay on above-ground biomass (Slim et al., 1997; Kirui et al., 2006) in arriving at estimates of the total biomass of mangrove species present in the bay. This is among the few studies (Kairo et al., 2008) in eastern Africa to investigate below-ground root biomass of mangroves. The main objectives were to determine the below-ground biomass of mangroves in both replanted and natural stands, exploring the effects of stand age and history (planted or natural) on root biomass. Differences between species, and the effects of soil depth and distance from the tree base on biomass and root size distribution were also examined.

## 2. Materials and methods

### 2.1. Site description

This study was conducted at Gazi bay (4°25′ S and 39°30′ E), on the southern coast of Kenya about 50 km from Mombasa city in Kwale District (Fig. 1). The bay is sheltered from waves by the presence of the Chale peninsula to the east and a fringing coral reef to the south (Bosire et al., 2004). The climate in Gazi bay is principally influenced by monsoon winds. Total annual precipitation varies between 1000 mm and 1600 mm with a bimodal pattern of distribution. The long rains fall from April to August under the influence of the southeast monsoon winds, while the short rains fall between October and November under the influence of the northeast monsoon winds. It is normally hot and humid with an average annual air temperature of about 28 °C with little seasonal variation. Air temperature in Gazi bay varies

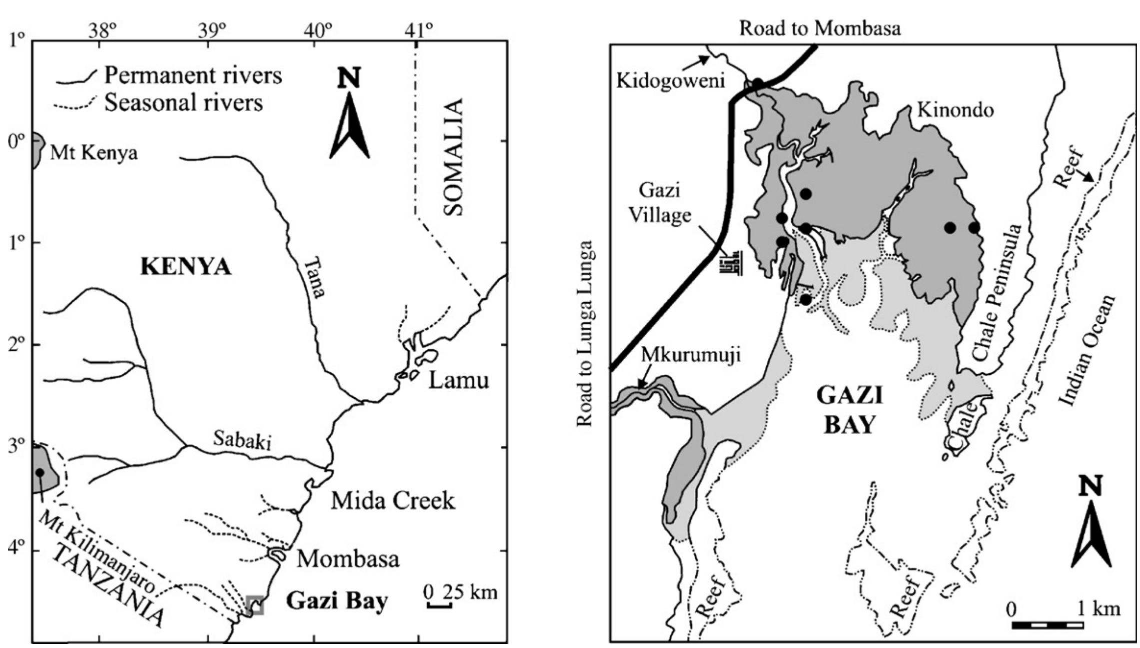


**Fig. 1.** Map of the Kenyan coast showing the study site (Gazi bay) and the locations of sampling. Key: (•) sampling location (Adapted from Bosire et al., 2004).