Blue Carbon Stock of the Dominant Mangrove Species in Zanzibar - Tanzania

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Abstract: ***This study is aimed at quantifying the above ground and below ground blue carbon stocks of three dominant mangroves namely Avicenia marina, Bruguiera gymnorrhiza and Rhizophora mucronata in the Uzi - Nyeke mangroves forest, Zanzibar, during 2020. It used an allometric method for biomass determination where diameter at breast height (DBH) and tree height (TH) were measured as dependent variables. Biomass were then used to calculate the carbon contents both above ground and below ground tree parties. A. marina contributed highest carbon content of 59.93% of the total average carbon content followed by R. mucronata 20.74% and B. gymnorrhiza 19.33%. Based on carbon parties A. marina contributed the highest average value of carbon content in above ground (AGC) of 3338 Mg C ha $^{-1}$ (70.70%) than the rest sampled mangrove species. The average carbon content of below ground tree part (BGC) had been highly contributed by R. mucronata 700 Mg C ha $^{-1}$ (39.35%) preceded by A. marina 557 Mg C ha $^{-1}$ (31.34%) and B. gymnorrhiza 521 Mg C ha $^{-1}$ (29.34%). We conclude that for rising carbon stock capacity in mangrove ecosystem of Zanzibar, more conservation efforts are needed by the community including shifting to non - destructive forest demands such as bee keeping, eco - tourism, seaweed and fish farming. Implementing above conservation effort could provide better opportunity for carbon stocking as well as improving blue economy.***

Keywords: Blue carbon, allometric method, conservation effort, non - destructive and blue economy

1. Introduction

Blue carbon refers to carbon stored or sequestered in vegetated marine including mangrove forests, salt tidal marshes and sea grass meadows, as well as coral reefs and oceanic that carbon sinks in the form of marine algae (Thomas, 2014[1]; Mcleod *et al*.2011[2]; Mitra and Zaman 2015[3]). Blue carbon now offers the possibility of collecting extra funds and revenue by combining best - practices in coastal management with climate change mitigation goals and needs. Intelligibly dealing with blue carbon ecosystems in climate change mitigation through policy, regulatory, economics, or other performance; the carbon stocks in marine ecosystems need to be recognized and quantified (Howard et. al, 2014[4]).

Mangroves as a blue carbon sink numerous benefits and services that are essential for climate change mitigation along the coasts worldwide, including protection from storms and sea level rise, prevention of shoreline erosion, regulation of coastal water quality, provision of habitat for commercially important fisheries and endangered marine species, and food security for many coastal communities (Mchenga and Ali 2014[5]; Laffoley & Grimsditch 2009[6]).

Despite their benefits and services, blue carbon mangrove ecosystems are some of the most threatened ecosystems on the earth, they are disappearing three to five times faster than overall global forest losses, with serious ecological and socio - economic impacts. It is estimated that every year about 0.15 - 1.02 billion tons of carbon dioxide are being released from deforestation and degradation of blue carbon ecosystems, which account up to 19% of carbon emissions from global tropical deforestation (Pendleton *et al*.2011[7]). The loss of blue carbon ecosystems is caused by land - use change, over exploitation (for salt production, fuel wood supply and building materials) and pollution which reduce their carbon sink capacity and other ecosystem services offered by the blue carbon ecosystems (Chave et al.2005[8]). This is likely to exacerbate the effect of climate change and sea - level rise on blue carbon ecosystem (Lovelock et al.2019[9]).

Like many other parts of the world, the mangroves of Zanzibar are threatened by destruction intimately linked with both climate change (Watkiss et. al., 2012[10]) and human activities such as harvesting for timber and fuel - wood (Hussein, 1995[11]; Semesi, 1998[12]), land reclamation for aquaculture and salt - pond construction (Terchunian et al., 1986[13]; Primavera, 1995[14], SONARECO, 2008[15]). Due to the preceded consequences, this study aimed to quantitatively estimate the blue carbon stocks among the dominant mangrove species of *Avicenia marina*, *Bruguiera gymnorrhiza and Rhizophora mucronata*, while considering friendly and less expensive ways in climate change mitigation.

2. Material and Methods

Study site

Zanzibar is composed of two major islands: Unguja and Pemba located in the Indian Ocean about 25–50 km off the east coast of the Tanzania mainland. This study was conducted in Nyeke - Uzi Mangrove Forest in the Uzi Island

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which lies between 619‟ and 624` S and 39 25` E on southwest coast of main Island of Zanzibar (figure 1) The area is characterized by a tropical climate with a long rainy season (Masika) occurs from March to May and the short rainy season (Vuli) occurs from October to November. The annual average rainfall varies between 1000 mm to 2500 mm. The hot season occurs during the NE monsoon period (Kaskazi) between December and February and a relatively cool, dry season (Kipupwe) occurs between June and September. The temperatures range between 17° and 40°C.

The mangrove forest is found both in sandy and rocky shore in northern tip and southern part of the Island within the Menai Bay Conservation Area close to Jozani Chwaka Bay National Park. The site has eight mangrove species being reported: *R. mucronata*, *B. gymnorrhiza*, *C. tagal*, *A. marina*, *X. granatum*, *L. racemosa*, *S. alba and P. acidula* (Mchenga and Rashid 2011[16]; Mchenga and Ali 2014[5]., 2015[17]).

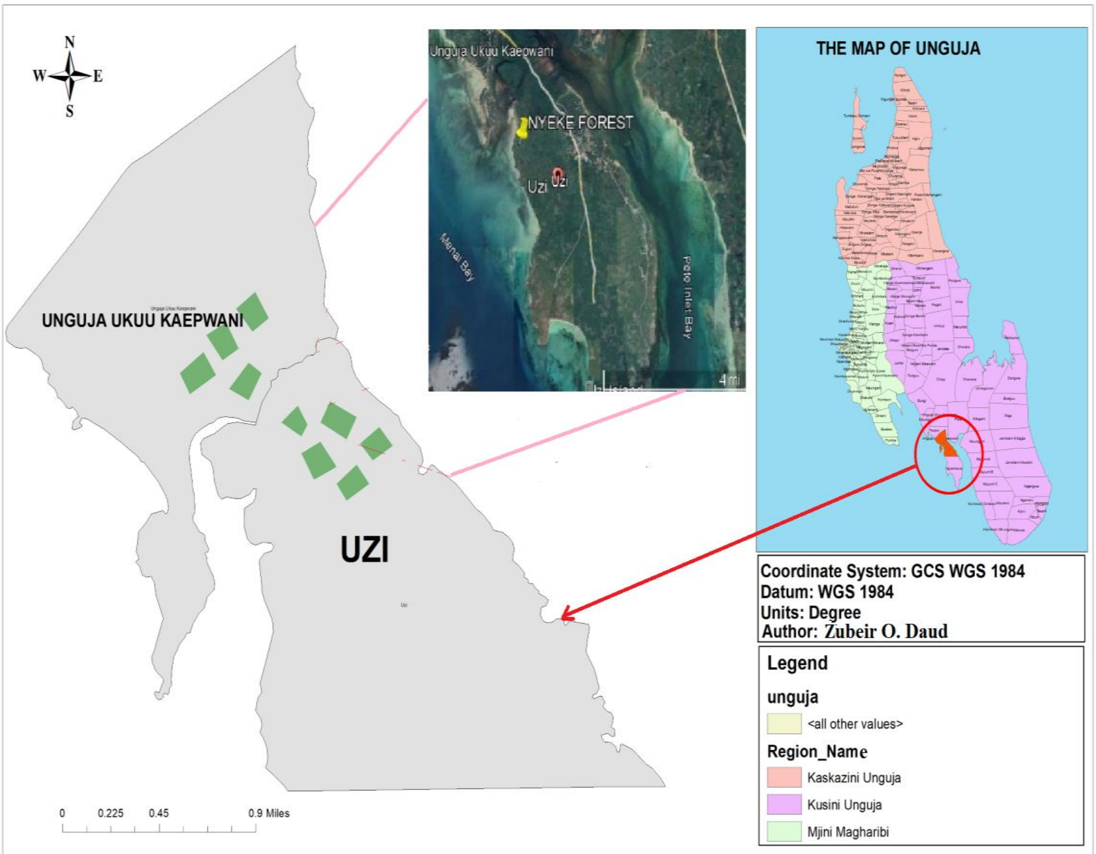

Figure 1: Map of Unguja - Zanzibar showing the study site and sampled field plots

Data collection

Random stratification method was used where 3 strata (zones) were established based on mangrove species dominance of *A. marina*, *B. gymnorrhiza* and *R. mucronata* at the upper, middle and lower zones respectively.9 squared - temporary plots were established along a randomly 100 m transects where the plots were measured 100 m^2.

All mangrove components necessary to determine carbon stocks by allometric method were collected in each of the 9 established temporary plots. These includes the main stem diameters and height of all tree rooted within each plot (Howard *et al*.2014[4]). The diameter of *R. mucronata* trees was measured above the highest prop root while other mangrove species such as *A. marina* and *B. gymnorrhiza* were measured at 1.3 m above the soil surface (DBH). Trees > 3 cm in diameter were measured in a plot of 100 m^2 (Kauffman and Donato 2012[18]). Basic data were recorded in individual mangrove tree in a plot including; species name, main stem diameter at breast height (DBH), tree height and location (Howard *et al*.2014[4]). Simple tools were employed for measurement such as the diameter tape for measuring DBH and field tape for measuring tree height supported by a very long pole.

Data analysis

A two - tailed paired Student's t - test was used to compare difference in total carbon contents contribution between the above and below ground biomass. Variation in carbon content between dominant mangrove species in the upper, middle and lower mangrove zones were tested using a one - way analysis of variance (ANOVA). Post - hoc Tukey (HSD) and Fisher's (LSD) tests were used to detect differences between treatments when significant differences were found. Results were considered significant if $p < 0.05$.

Allometric equations were used for biomass and carbon content estimation where tree diameter (DBH) and tree height were used as dependent variables, with exception of *B. gymnorriza* that used the addition of wood density in its general equation. The equations were used to calculate both the above and below ground tree biomass for the three dominant mangrove species. Species - specific allometric formulas developed by Njana *et al*.2015[19] for the mangrove of Tanzania were applied for the *R. mucronata* and *A. marina* biomass estimation, while the biomass of *B. gymnorrhiza* was estimated using the general mangrove equation by Njana *et al*.2015[19] due to lack of its species - specific allometric equation (table 1). This equation represents average characteristics of mangrove species that were not covered in species - specific equation in the country.

Table 1: Selected allometric equations used in this study to estimate AGB and BGB of sampled mangrove species.

Species	AGB allometric equation (kg)	BGB allometric equation (kg)	Equation type
R. mucronata	$0.19633*dbh^{2.10853}*ht^{0.29654}$	$1.4204*dbh^{1.68979}$	species - specific
A. marina	$0.19633*dbh^{2.08791}*ht^{0.29654}$	$1.4204*dbh^{1.44260}$	species - specific
B. gymnorrhiza	$0.353*p^{1.13}*dbh^{2.08}*ht^{0.29}$	$1.4204*dbh^{1.59666}$	General equation

Where, AGB = above ground biomass (kg), BGB = below ground biomass (kg), p = wood density (gcm^{-3}), DBH = diameter at breast height (cm), and HT = total tree height

Determination of Carbon stocks

Tree carbon was calculated by multiplying biomass by the carbon conversion factor of 0.48 for above ground biomass and 0.39 for below ground biomass as suggested by Howard *et al*.2014[4]. And carbon content per plot was calculated as: -

- Carbon content of AGC per plot (kg C/m^2) = (AGC content of tree #1 + carbon content of tree #2 + carbon content of tree #n) / plot area (m^2).
- Carbon content of BGC per plot (kg C/m^2) = (BGC content of tree #1 + carbon content of tree #2 + carbon content of tree #n) / plot area (m^2) (Kauffman and Donato 2012[18]).

3. Results and Discussion

Total blue carbon contents of mangrove dominant species

The results showed that *R. mucronata* contributed highest value of blue carbon contents of 8, 323Mg C ha^{-1} (41.66%) followed by *A. marina* of 5, 952 Mg C /ha (29.79%) and *B. gymnorrhiza* of 5, 707 Mg C /ha (28.55%) (Figure 2). However, there is no significant difference in total blue carbon contents between reported mangrove species. The observation showed that *R. mucronata* contributed higher amount of carbon contents as they have interconnected prop roots and large leaves that are highly distributed in large area becoming the dominant species among the rest. These results agreed with the previous works in Gazi bay, Kenya where total carbon content of *R. mucronata* was 62% of followed by *A. marina* and *B. gymnorhiza* 25% and 12.8% respectively (Githaiga 2013[20]). Meanwhile, Lupembe (2014[21]) reported that *R. mucronata* stored the highest amount of carbon per unit area (39.87%) followed by *A. marina (*28.06%) and *B. gymnorrhiza (*15.61%) at Rufiji Delta, Tanzania.

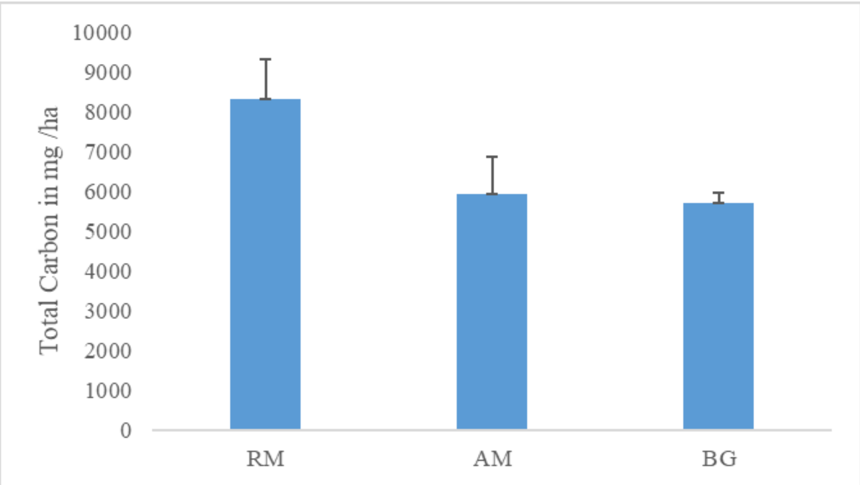

Figure 2: Comparison of total contribution of carbon contents in relation to mangrove dominant Species

Regardless of mangrove species and zonation, contribution of above ground carbon content (AGC) to total carbon stock accounted significant higher 12, 300 Mg C /ha (61.56%) than below ground carbon content (BGC) 7, 681 Mg C /ha (38.44%) (Figure 3, Paired *t - test*, p=<0.05). These results agreed with other studies at Mtimbwani - Tanga, the AGC measured 70% and BGC measured 21.93% (Alavaisha and Mangora 2016[22]) and in Kerala - India, the AGC contributed 68.49% and BGC contributed 31.51% to the total mangrove carbon stocks (Harishma, Sandeep & Sreekumar 2020[23]). In contrast, Kathiresam and Bingham (2001[24]) adopted that BGC was the dominant component in mangrove ecosystem building a sedimentary carbon stock as it fixed carbon from different sources like through root transportation, dead wood and litter decomposition. However, Faridah - Hanum *et al*. (2012[25]) showed that 50% of the total AGC was contributed by *R. mucronata* due to its enormous interconnected prop roots.

Contribution of blue carbon contents by mangrove dominant species in relation to mangrove zonation.

Results of carbon contents among species varied in the upper zone where *A. marina* was significantly higher 4, 941Mg C /ha (73.36%) than *B. gymnorrhiza* 1367 Mg C /ha

(20.30%) and *R. mucronata* 427 Mg C /ha (6.34%) (ANOVA, F=6.7, df=2, $p < 0.05$). This is due to the fact that *A. marina* measured highest DBH value of 36.2 cm and maximum DBH of 128 - 250 cm than other two species. The value of DBH was observed to influence the amount of carbon content per individual tree. Whereas a tree with high value of DBH, also showed to have high amount of carbon contents. In the middle mangrove zone, *R. mucronata* contributed highest carbon contents of about 2, 636 Mg C /ha (44.67%) followed by *B. gymnorrhiza* 2, 253 Mg C /ha (38.18%) and *A. marina* 1, 012 Mg C /ha (17.15%). However, there is no significant different in carbon content between *R. mucronata* and *A. marina* (ANOVA, F=2.9, df=2, $p > 0.05$). Similarly, *R. mucronata* recorded significantly higher in the lower mangrove zone 5, 260 Mg C /ha (71.61%) when compared to *B. gymnorrhiza* 2, 085 Mg C /ha (28, 39%), (ANOVA, F=8.4, df=2, $p > 0.05$), meanwhile *A. marina* measured zero contribution because it was not found in this zone (Table 2).

Table 2: Variation of the carbon contents (Mg C/ha) in sampled mangrove dominant species both above and below ground biomass. Values are mean (±SE), n= 6. Same letter at the top indicates no significant difference at p < 0.05; ANOVA followed by post hoc Turkey (HSD) and Fisher's (LSD) test.

	RM	AM	BG
Upper zone	427 ± 134.11^a	$4, 940\pm999.90^b$	$1, 367\pm347.40^a$
Middle zone	$2, 635\pm525.29^a$	$1, 011\pm303.69^a$	$2, 254\pm127.39^b$
Lower zone	$5, 260\pm1213.16^a$	0.0 ± 0.0^b	2086 ± 181.41^c
Above ground	648.23 ± 13.56^a	$3, 337.69\pm507.36^b$	734.95 ± 35.48^a
Below ground	839.72 ± 22.23^a	557.26 ± 62.40^a	671.84 ± 22.11^b

There is significant higher contribution of the above ground carbon contents at the upper mangrove zone 5, 120 Mg C /ha than the lower and middle mangrove zone 3, 640 Kg C /ha and 3, 540 Mg C /ha respectively (ANOVA, F=21.1, df=2, $p < 0.001$). However, there is no significant difference between the middle and lower mangrove zone. Meanwhile, below ground carbon contents were significantly higher at the lower mangrove zone 3, 705 Kg C /ha than the middle 2, 361 Mg C /ha and the upper mangrove zone 1, 615 Mg C /ha (ANOVA, F=14.3, df=2, $p < 0.001$). Total blue carbon contents were higher in the order of lower zone > upper zone > middle zone (Figure 3).

Based on zonation, the above ground carbon contents of the upper mangrove zone 5, 120 Mg C /ha (76.02%) was significantly higher than the below ground biomass 1, 615 Mg C /ha (23.98) (ANOVA, $F = 6.7$, df = 2, $p < 0.001$). Similarly, above ground contents at the middle mangrove was significantly higher 3540 Mg C /ha (59.99%) when compared with below ground 2, 361 Mg C /ha (40.01%) (ANOVA, $F = 2.91$, df = 2, $p < 0.05$). In contrary, there is no significant difference between below ground carbon contents 3, 705 Mg C /ha (50.44%) and above ground 3, 640 Mg C /ha (49.56%) at the lower mangrove zone (ANOVA, $F = 2.1$, df = 2, $p > 0.05$).

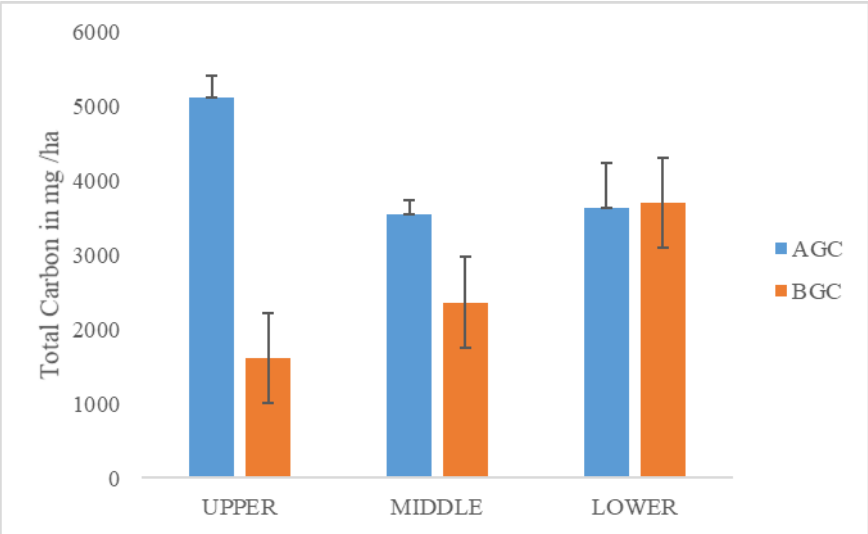

Figure 3: Comparison of total contribution of carbon contents by tree component in relation to mangrove zonation.

Contribution of blue carbon contents by mangrove dominant species in relation to above and below ground biomass.

The results of the average above ground (AGC) blue carbon among dominated mangrove showed that *A. marina* contributed the highest average carbon content of 3, 338 Mg C ha^{-1} (70.70%) compared to *B. gymnorrhiza* 735 Mg C ha^{-1} (15.57%) and *R. mucronata* 648 Mg C ha^{-1} (13.73%). According to Harishma et al. (2020[23]), the AGC value tends to be relatively low in the mangrove ecosystem that is close to the sea. In this study site, *A. marina* and *B. gymnorrhiza* occupied 47.4% and 19.2% of the upper mangrove zone nearby the land, while *R. mucronata* accounted for 66 % of mangrove species distribution in the middle zone (Mchenga & Rashid (2011[16]). In contrast, the average carbon content of below ground (BGC) had been highly contributed by *R. mucronata* 840 Mg C ha^{-1} (39.35%) preceded by *B. gymnorhiza* 672 Mg C ha^{-1} (29.34%) and *A. marina* 557 Mg C ha^{-1} (31.34%). (Table 2). *R. mucronata* contributed the highest BGC due to the presence of massive interconnected prop roots that provide adaptive support against sea surges as they occupied the flooded zone. These results agreed with

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the previous works whose study revealed the average carbon content of 62% of *R. mucronata* followed by 25% of *A. marina* and 12.8% *B. gymnorhiza* Gazi bay in Kenya (Githaiga 2013[20]). It was reported by (Adame et al., 2017[26]) that the highest biomass was found in area where live and dead roots of mangroves are present together.

Conflict of Interest

There is no any kind of engagement interest in this study.

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