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Community structure and carbon sequestration potential of mangroves in Maasim, Sarangani Province, Philippines

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Abstract. The capacity of mangrove forests to act both as a source and sink of carbon makes them key ecosystems on the mitigation strategies against climate change. We evaluated the community structure and carbon sequestration potential of mangroves in Maasim, Sarangani Province using distribution and diversity indices and allometric equations. A total of 1129 mangrove individuals growing in different habits were inventoried. Five species were identified, namely: *Sonneratia alba*, *Rhizophora mucronata*, *Rhizophora apiculata*, *Avicennia marina*, and *Bruguiera gymnorrhiza*. *R. mucronata* was the most dense (RD = 76.88%) and most frequent (RF = 44.53%) species in the area, but *S. alba* dominated (RO = 91.36%) in terms of basal area and was also the most important species (IV = 49.08%). The forest has low to moderate diversity (H' = 0.715) and evenness (E = 0.444) with only two equally abundant species (ENS = 2.044). In terms of aboveground carbon density, *S. alba* was significantly greater in amount (446.275 Mg C ha^{-1}) compared to the other species. Zone-wise, seaward stored most of the carbon mass amounting to 241.527 Mg C ha^{-1}. Overall, the total aboveground carbon stock in the mangrove forest was 15.130 Gg, which is equivalent to 55.526 Gt of CO_2. In conclusion, *S. alba* showed high potential of sequestering atmospheric carbon among the mangrove species identified. Meanwhile, the high forest aboveground carbon density implies high carbon sequestration activity. However, this could also mean huge amounts of carbon to be released back to the atmosphere if the forest is disturbed by human activities.
Key Words: allometric equation, carbon sequestration, climate change, diversity index, mangrove.

Introduction. Recent anomalies in the global climatic patterns have been widely correlated with the increasing concentration of greenhouse gases (GHGs) in the atmosphere (Hitz & Smith 2004; CO2Now.org 2011). Of the GHGs reported, carbon dioxide (CO_2) is observed to exert the greatest impact to climate change in the coming years. Apparently, the high levels of CO_2 in the atmosphere is strongly linked to various anthropogenic activities including the excessive use of fossil fuels, industrialization activities, large-scale deforestation, and the conversion of forest ecosystems into agricultural, residential and commercial lands (Alongi 2002; NEFA 2002; Fearnside & Laurance 2004; Hegerl et al 2007). In a report by the International Energy Agency (2012), CO_2 emissions from the use of fossil fuels contributed 61% of the global GHG emissions by gas/source in 2010.

Given the serious implications of climatic change throughout the biosphere, mitigating factors have been aggressively looked into by the scientific community. Essentially, knowledge from these factors were used to formulate and develop strategies to combat climate change or, at the very least, minimize its disastrous effects. One of such strategies involves the carbon sequestration potentials of forest ecosystems. This looks into how trees, understory plants and the soil are able to act as carbon sinks and serve in reducing excessive CO_2 levels in the atmosphere (Newell & Stavins 2000).

According to Gibbs et al (2007), the high carbon removal and storage activities in forest ecosystems may provide a crucial "brake" on the climate change phenomenon.

Being one of the more established forest stands along the tropical and subtropical coastlines, mangroves are thought to be a major player in the global carbon sequestration process. Accordingly, mangrove stands have the capacity to remove and store carbon from the atmosphere in a manner that is comparable to, and even better than, other forest types (Alongi 2002; Fatoyinbo & Armstrong 2010; Donato et al 2011). This is not to exclude the fact that mangrove communities create habitats for diverse communities of organisms, protect coastal communities from the destructive impacts of storm surges and tsunamis, and provide an indispensable support to coastal development and economic growth by stabilizing the shorelines (Feller & Sitnik 2002; Primavera et al 2004; Bouillon et al 2008). However, mangrove stands, like any other terrestrial forests, are now becoming vulnerable to deforestation, aquaculture and land conversion activities (Alongi 2002; Sitoe et al 2014).

The shoreline of Maasim is an important part of Sarangani Bay, a declared protected seascape in southern Mindanao under the National Integrated Protected Areas System (NIPAS) Act of 1992, otherwise known as Republic Act No. 7586, and as stipulated in the Presidential Proclamation No. 756. It is one of the few remaining wide stretches of mangrove stands along Sarangani Bay. To date, there are few available and accessible data on the population dynamics and carbon stocking capacities of the mangrove forest in the area. Considering that the mangrove community is part of a protected seascape, understanding its structure and potentials is necessary to properly implement conservation programs in the Bay and to maximize, as well, the forest's role in developing better climate change mitigation strategies in the region.

It is in the aforesaid premise that this study was anchored to. Purposively, it assessed the distribution, diversity and carbon stocks of mangrove species in the forest. Ultimately, the data gathered could serve as a basis for more relevant, responsive and sustainable approaches to protect and manage Sarangani Bay while maximizing its potentials to address climate change.

Material and Method

Study area. Maasim, Sarangani Province is a community located south of Sarangani Bay in Southeastern Mindanao, Philippines. It covers about 28.94 hectares of mangrove forest, and is considered to be the second largest area along the Bay with a more or less intact mangrove forest (Environmental Conservation and Protection Center, n.d.). The area is under reforestation activities. Global Positioning System (GPS) was used to mark the sampling points (Figure 1).

Establishment of the sampling plots. Eleven belt transects were laid down perpendicular to the shore in a seaward to landward direction. Each belt transect was divided into six 10 m x 10 m nested plots which are 10 meters apart. Plot 1 was at least 15 meters away from the mangrove-seagrass ecotone.

Mangrove distribution and diversity. Mangroves were classified based on their habit. All mangrove trees with at least 50% of their trunk within the plots were counted. Their individual girth was determined using a measuring tape, from which, the diameter-at-breast height (DBH) was computed. Mangrove saplings and seedlings within a 5 m x 5 m subplot were also counted and recorded. DBH measurements were taken for saplings, but not for seedlings. Mangrove distribution was described using density, frequency, dominance in terms of the basal area, and importance value. Diversity, on the other hand, was evaluated using Shannon's diversity index, evenness index and the effective number of species.

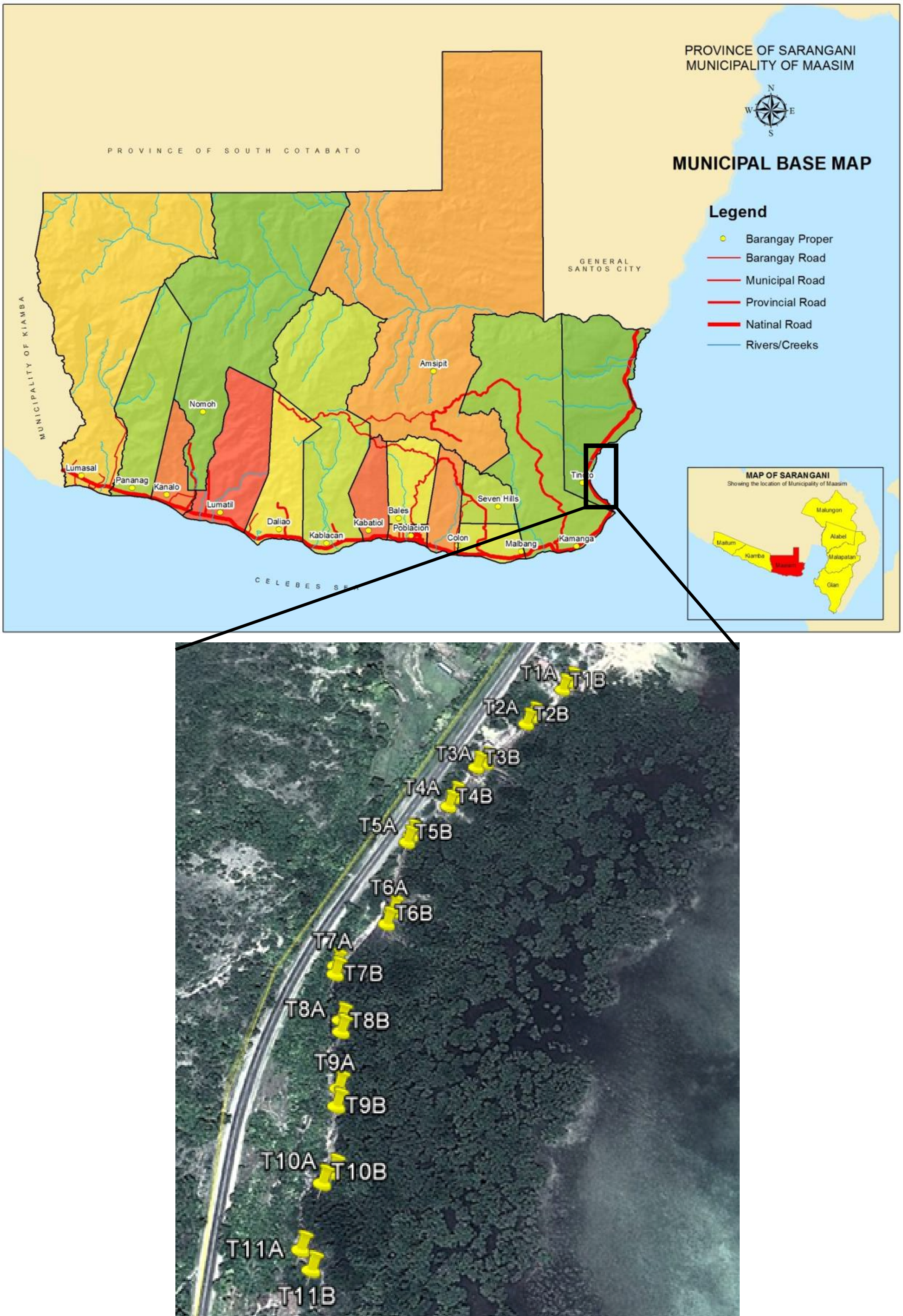

Figure 1. Location of the sampling points (yellow pins) in the mangrove forest.

Biomass and aboveground carbon stock. Individual mangrove aboveground biomass (AGB) was quantified using allometric equations as recommended by Kauffman & Donato (2012) and Kauffman et al (2011) and the aboveground carbon (AGC) mass per mangrove individual was determined as follows:

$$AGC = AGB * \%C$$

where: AGC - aboveground carbon mass (Mg)
AGB - aboveground biomass (Mg)
%C - % carbon in mangrove trees (0.5; SAARC 2011)

The total tree AGC per plot and total sapling AGC per subplot were then computed by summing up all the tree AGCs per plot and sapling AGCs per subplot, respectively. The value was scaled to tree AGC per hectare. The total aboveground carbon density was then determined by summing up all the mean carbon densities of each carbon pool considered. From the total carbon Density, the total carbon stock in the forest and its CO_2 equivalents were computed.

Results and Discussion. A total of 1129 mangrove individuals were recorded. These were identified to belong to five mangrove species, namely: *Sonneratia alba* (Pagatpat), *Rhizophora mucronata* (Bakauan-babae), *Rhizophora apiculata* (Bakauan-lalaki), *Avicennia marina* (Bungalon), and *Bruguiera gymnorrhiza* (Busain). There were a total of 282 (24.98%) mangrove trees, 288 (25.51%) saplings, and 559 (49.51%) seedlings recorded (Table 1).

Table 1

Species, habit and abundance of mangroves

Mangrove species	*Abundance by habit*			*Total*
	Tree (DBH ≥ 10 cm)	*Sapling (DBH < 10 cm)*	*Seedling (H < 1.3 m)*	
S. alba	140	17	4	161
R. mucronata	104	250	514	868
R. apiculata	34	21	40	95
A. marina	2	-	1	3
B. gymnorrhiza	2	-	-	2
Total	282	288	559	1129

Note: DBH – diameter-at-breast height; H - height.

In terms of total abundance, *R. mucronata* dominated the area with 868 (76.88%) individuals resolved into 104 trees, 250 saplings, and 514 seedlings. *S. alba* followed with 161 (14.26%) individuals resolved into 140 trees, 17 saplings, and 4 seedlings. *R. apiculata* came in third with 95 (8.41%) individuals resolved into 34 trees, 21 saplings, and 40 seedlings. *A. marina* and *B. gymnorrhiza* were the least in count with 3 (0.27%) and 2 (0.18%) individuals, respectively. Among the three (3) *A. marina*, two (2) are trees and one (1) is seedling while all *B. gymnorrhiza* individuals are trees.

As defined, density is the number of individuals of a mangrove species over a given sampling area while relative density (RD) reflects the density of a certain species in relation to the density values of other species. Based on the results, the mangrove species could be arranged from the most dense to least dense in the forest as follows: *R. mucronata* > *S. alba* > *R. apiculata* > *A. marina* > *B. gymnorrhiza* as reflected by their respective RD values equal to 76.88% > 14.26% > 8.41% > 0.27% > 0.18% (Table 2).

Table 2

Distribution of different mangrove species

Mangrove species	*Relative density (%)*	*Relative frequency (%)*	*Relative dominance (%)*	*Importance value (%)*
S. alba	14.26	41.61	91.36	49.08
R. mucronata	76.88	44.53	6.94	42.78
R. apiculata	8.41	10.95	1.15	6.84
A. marina	0.27	2.19	0.51	0.99
B. gymnorrhiza	0.18	0.73	0.04	0.32

Results on frequency also followed the same trend as the density, that is, *R. mucronata* was the most frequent species with relative frequency (RF) = 44.53%, followed by *S. alba* with RF = 41.61%, followed by *R. apiculata* with RF = 10.95%, then by *A. marina* with RF = 2.19%, and finally by *B. gymnorrhiza* with RF = 0.73%. Frequency refers to the number of times a mangrove species occur in the plots considered for the study. Relative frequency, on the one hand, describes the frequency of a mangrove species relative to the frequencies of the other mangrove species.

On basal area, however, another trend was observed. Basal area was used to describe the dominance of one mangrove species over the other, that is, the extent of the influence of a mangrove species exerted over the other mangrove species. In a sequence from the most dominant to the least dominant, the following trend was observed: *S. alba* > *R. mucronata* > *R. apiculata* > *A. marina* > *B. gymnorrhiza* as reflected by their respective relative dominance (RO) values equal to 91.36% > 6.94% > 1.15% > 0.51% > 0.04%. Results further revealed that of the five identified mangrove species, *S. alba* had the greatest importance value with 49.08%, followed by *R. mucronata* with a value of 42.78%, then by *R. apiculata* with a value of 6.84%. *A. marina* came in fourth with an importance value of 0.99% while *B. gymnorrhiza* was found to be relatively less important than the other mangroves having an importance value of 0.32%.

Species diversity was appreciated using Shannon's diversity index (H') and equitability index (E). Accordingly, H' = 0.715 and E = 0.444. Species diversity takes into account the species richness, which is basically the number of species in the area being considered, and the species equitability, which considers the relative number of the individuals belonging to each species in the community (Huy 2004; Wilsey & Stirling 2007). Such observation, however, is better explained by the effective number of species (ENS) value. ENS is, in a way, a real measure of the number of species in a certain community that would be considered equally abundant (Jost 2010). It should be realized that Shannon's index only gives a range of values and that depending on how close the values are to the extremes, the interpretation varies with ambiguity. ENS resolves this concern by interpreting more clearly the values of Shannon's diversity and equitability indices. In this study, with the value s of H' = 0.715 and E = 0.444 taken into account, the ENS had a value equal to 2.044. This value can be translated into two species. In other words, of the five mangrove species identified in the area, only two species were equally abundant in the forest and essentially, define the diversity in the study area. Based on the distribution parameters (i.e. density, frequency, dominance and importance value), the two species could be *S. alba* and *R. mucronata*.

On the one hand, the mean aboveground carbon density (ACD) in the area was 522.793 Mg C ha^{-1}. This amount of carbon was divided between two carbon pools, namely: tree aboveground carbon pool and sapling aboveground carbon pool. It can be observed that a greater portion of the carbon density was shared by the tree aboveground carbon density having a total mean of 516.220 Mg C ha^{-1}while the sapling ACD had only a total mean of 6.572 Mg C ha^{-1}. Such results could be attributed to the larger trunks, and thus greater DBH, of mangrove trees than saplings. This agrees with the research findings of Tulod (2015) wherein he noted that aboveground biomass, and essentially the aboveground carbon mass, is shared in bulk by the tree component such that greater biomass means greater amount of stored carbon. Moreover, much of the

ACD was shared in large part by *S. alba* (85.36%) with a mean value of 446.275 Mg C ha^{-1}and *R. mucronata* (13.02%) with a mean value of 68.085 Mg C ha^{-1}. *A. marina* (0.80%), *R. apiculata* (0.79%) and *B. gymnorrhiza* (0.02%) shared the least with a mean value of 4.176 Mg C ha^{-1}, 4.126 Mg C ha^{-1}, and 0.130 Mg C ha^{-1}, respectively (Table 3). This result supports the findings of Almulqu & Kleruk (2015) where *S. alba* showed the highest carbon sequestration potential (about 20-51% higher than the other mangroves).

Table 3

Mean aboveground carbon density (Mg C ha^{-1}) by species and habit

Mangrove species	*Mangrove habit*		*Total*
	Tree	*Sapling*	
S. alba	445.317	0.958	446.275
R. mucronata	63.021	5.064	68.085
R. apiculata	3.576	0.550	4.126
A. marina	4.176	-	4.176
B. gymnorrhiza	0.130	-	0.130
TOTAL	516.220	6.572	522.792

It can be noted that the trend of aboveground carbon density by zone is in the following sequence: seaward > middle > landward. The seaward zone had the greatest mean ACD value with a total of 241.527 Mg C ha^{-1} followed by the middle zone with 169.060 Mg C ha^{-1} and finally the landward zone with a value of 112.205 Mg C ha^{-1} (Table 4).

Table 4

Mean aboveground carbon density (Mg C ha^{-1}) by species and zone

Mangrove species	*Mangrove zone*			*Total*
	Seaward	*Middle*	*Landward*	
S. alba	208.909	143.517	93.849	446.275
R. mucronata	32.618	24.539	10.928	68.085
R. apiculata	-	0.649	3.477	4.126
A. marina	-	0.355	3.821	4.176
B. gymnorrhiza	-	-	0.130	0.130
Total	241.527	169.060	112.205	522.792

Overall, the total aboveground carbon density summed up to 522.792 Mg C ha^{-1} which is equal to 15.130 Gg of carbon stock. This is high carbon content as most carbon-poor mangrove forests usually have approximately 272 Mg C ha^{-1} while most carbon-rich mangrove forests have 703 Mg C ha^{-1} (Jardine & Siikamaki 2014). In terms of CO_2 equivalents, this much aboveground carbon density amounted to 55.526 gigatons of carbon dioxide. It means that, if the mangrove forest will be exposed to deforestation or any other disturbance from human activities, it can release this much of CO_2 back to the atmosphere, increasing the already high level of atmospheric GHGs. Consequently, it may aggravate the worsening impact of climate change.

Conclusions. Five mangrove species thrived in the forest. *R. mucronata* was the most dense and most frequent but *S. alba* was the most dominant and most important species. The forest was low to moderate in diversity and evenness with only two equally abundant species. *S. alba* had the greatest aboveground carbon densities compared to other species. This may provide guidance in the implementation of reforestation activities in the mangrove forest as to what species have to be selected for planting without compromising the diversity of species and stability of the mangrove stand. The seaward zone stored most of the carbon mass. The mangrove forest has high carbon stocks implying high carbon sequestration potential. Conversely, such high values also imply release of huge amounts of carbon if the forest is disturbed, deforested and mismanaged.

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