Carbon Sink Potential of *Avicennia marina* in the Al-Qurm Nature Reserve, Muscat, Oman

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Abstract. Climate change is a global issue, caused by increased levels of carbon dioxide in the atmosphere resulting in many adverse effects. One of the many responses to the climate change impact is to sequester carbon dioxide from the atmosphere. Al-Qurm Nature Reserve in Muscat city of Oman is a mangrove vegetation protected by law as conservation area. Carbon sequestration was estimated in three distinct zones of this natural mangrove vegetation with *Avicennia marina*. The mean carbon stock in the middle zone was 7.7 ± 0.3 kg C/m^2, and for the seaward zone was 5.3 ± 0.7 kg C/m^2, and for landward 18.8 ± 0.1 kg C/m^2, which is 3.5 times higher than seaward zone and slightly more than 2 times than middle zone. The 0.82 km^2 of Al-Qurm Nature Reserve occupied purely by *Avicennia marina* was estimated to sink about 8692 t C (0.0087 Mt C) equivalent to about 0.032 Mt of $CO_{2e.}$ These estimates suggest a high carbon storage and carbon sequestration potential of *Avicennia marina* in Al-Qurm Nature Reserve despite their relatively small area.

1. Introduction

Mangroves are unique ecosystems that are widely distributed along the coasts of tropical and subtropical regions [1], also survive in a wide range of salinity levels [2]. They provide several benefits to the environment and human beings [3]. Recently mangroves are recognized for their carbon storage and sequestration of carbon dioxide (CO_2) from the atmosphere [2], [4]. The amount of carbon that can be stored by mangrove forest is two to three times higher than that of terrestrial forests [5]. Large amounts of carbon can be stored by mangroves per unit area compared to many terrestrial systems [6]. So that, mangrove forests play a major role in the global carbon budget [7]. There are many species of mangroves, the specie *Avicennia marina* is widely distributed in many regions of the globe [8].

1.1. *Mangroves in the Sultanate of Oman*

Oman has a coast line of about 3165 km, connecting three seas that are the Arabian Gulf, the Sea of Oman and the Arabian Sea. Mangrove forests are located in thirty three sites along the coast of Oman with a total area of about 1,100 ha (11 km^2), or 0.0007 % of the total area of mangrove in the world. One of these sites is Al-Qurm Nature Reserve (QNR) which occupies 171 ha (1.7 km^2) of land within the Muscat capital area which contains about 82 ha (0.82 km^2) of mangrove trees. The Government of Oman designated this reserve area for conservation under Royal Degree No (38/1975). Also this reserve was registered as the first Ramsar site in Oman, and the accession to the Ramsar Convention entered into force on 19/8/2013.There is only one species of mangrove, *Avicennia marina* in Oman. This species can grow successfully in arid and harsh environment with high salinity [9].

1.2.   *Estimation of Carbon Sequestration*

Estimations of forest carbon stocks are dependent on forest biomass [10]. Biomass is defined as the total of all parts of a tree consisting of aboveground biomass and belowground biomass including roots, trunk, leaves, branches, flowers and fruits. Actually, carbon is stored in five pools, called aboveground biomass (AGB), belowground biomass (BGB), dead wood, leaf litter and soil carbon stock in forest ecosystems [11]. The focus of this study was only on the first two pools namely above and below ground biomass. During photosynthesis, vegetation sequesters carbon dioxide (CO_2) from atmosphere and stores it as biomass in their tissues. Carbon stored as biomass is known as carbon stock. Biomass estimation of the forest ecosystems allows us to estimate the amount of carbon dioxide that can be sequestered from the atmosphere by the forest [10]. In order to estimate carbon sequestration we have to calculate the total biomass per hectare or other units of area and then convert this biomass to carbon equivalents using an appropriate conversion factors [12]. Such estimates are significant in modelling the potential consequences of climate change, and also for carbon accounting and monitoring requirements [13].Quantifying the mangrove biomass and structure are very important in order to address climate change adaptation and mitigation [14].The carbon content is calculated from biomass by multiplying by a factor of 0.48 (48 %) for aboveground and 0.39 (39 %) for belowground biomass [15]. Eventually, the amount of carbon dioxide (CO_2) that will be sequestered is estimated by multiplying carbon content of the mangrove ecosystem by 3.6663 [14].

2. Methodology

Studying carbon sequestration requires fieldwork for both aboveground biomass and belowground biomass estimation. Due to surrounding environments, working in mangrove forests is almost inaccessible making fieldwork and sampling a tedious task [14].During the past years, forest ecologists have developed different methods to estimate the biomass of forests [16]. One of these methods is to employ of allometric equations. This method are widely used by researchers as a non-destructive method to estimate mangrove biomass [16],[17]. Also, this estimation depends on measuring trees characteristics such as trunk diameter [18].

2.1.   *Use of Allometric Equations*

The basic theory of allometric relationship is that in many organisms, the growth rate of one part is proportional to that of another. For example, the trunk diameter of a plant is highly correlated with trunk mass. Allometric equations for mangroves have been established for several decades to estimate biomass and subsequent growth [16].They are developed by creating relations between some easily measured individual plant parameter(s) and some variable which is much harder to measure [19]. Diameter at breast height (DBH) (i.e. 1.3 meter above the ground) is commonly and frequently used as predictive variable [13],[17],[20]. These variables are used in models (equations) and input are gathered through forest inventories [6].

Relationships have been developed by many researchers using diameter at breast height (DBH) to predict aboveground biomass of mangroves in many areas in the world [20]-[22]. In the case of multi-stemmed (or branched) mangroves such as *Avicennia marina*, every stem is treated as separate tree [14],[20].The logarithmic model (equation) gives the best explanation of the relationships between biomass (B) and diameter (D) i.e. $B = a \times D^b$ where a and b are constants compared to different forms of regression [17]. Allometric equations are also used to estimate belowground biomass for mangrove trees [14]. Most allometric equations focus on aboveground biomass, while a few belowground biomass functions exist for mangroves due to difficulties extracting mangrove roots and the labor-intensive nature of sampling belowground biomass in intertidal habitats [6],[23].

The study area was stratified in to three zones (i.e. landward- middle-seaward). A non –destructive method (i.e. allometric equations) based on the DBH of stems was used to estimate aboveground biomass and belowground biomass and eventually carbon storage. Table 1 shows the equations which are used in this study to estimate biomass.

Table 1. Allometric equations used to estimate biomass for *Avicennia marina* trees, B= biomass (Kg), D= diameter at breast height (cm).

Avicennia marina size class	Estimate	Equation	source
DBH > 4cm	Aboveground biomass	$B= 0.1776 \times D^{2.299}$	[16]
DBH > 4cm	Belowground biomass	$B= 1.28 \times D^{1.17}$	[10]
DBH < 4cm	Aboveground biomass	$B= 200.4 \times D^{2.1} \times 0.001$	[14]
DBH < 4cm	Belowground biomass	$B=0.92307 \times$ aboveground biomass	[10]

3. Results and Discussion

3.1. Estimation of Aboveground Biomass and Aboveground Carbon

The trunk diameter of the trees were measured and then the equations were used to estimate the aboveground biomass and eventually aboveground carbon .The total aboveground biomass in the study sites was about 218.0 kg/m^2 and the total aboveground carbon was approximately 105.0 kg C/m^2. The average aboveground biomass and aboveground carbon content can be ordered as follows: landward > middle > seaward. The range of overall aboveground biomass was 4.1-28.7 kg/m^2 and aboveground carbon 2.0- 13.8 kg C/m^2. Table 2 shows the summary of estimated aboveground biomass and aboveground carbon of the three zones.

Table 2. Summary of estimated aboveground biomass and aboveground carbon of the three zones.

Zone	Aboveground biomass (kg/m^2)	Aboveground carbon (kg C/m^2)
Average seaward	6.5	3.1
Average middle	9.5	4.6
Average landward	27.6	13.3
Overall average	14.5	7.0

3.2. Estimation of Belowground Biomass and Belowground Carbon

Diameter at breast height of the tree trunk was used as variable to predict the belowground biomass by utilizing the allometric equations .The total belowground biomass in the study sites was estimated to be about 155.0 kg/m^2 and total belowground carbon about 60.0 kg C/m^2. The average belowground biomass and belowground carbon content can be ordered as follows: landward > middle > seaward. The range of overall belowground biomass was 4.2-14.7 kg/m^2 and belowground carbon 1.6-5.7 kg C/m^2. Table 3 shows the summary of estimated belowground biomass and belowground carbon of the three zones.

Table 3. Summary of estimated belowground biomass and belowground carbon of the three zones.

Zone	Belowground biomass (kg/m^2)	Belowground carbon (kg C/m^2)
Average seaward	5.7	2.2
Average middle	8.1	3.1
Average landward	14.3	5.5
Overall average	9.4	3.6

3.3. Total Carbon Stock of Al-Qurm Nature Reserve

The overall total mean carbon stock, including aboveground biomass and belowground of Al-Qurm Nature Reserve was estimated to be 10.6±1.6 kg C/m^2, which is equivalent to 38.9 kg CO_2/m^2.Although, Oman is located in arid and semi-arid region, mangrove trees have high potential to sequester and store higher amount of carbon dioxide from the atmosphere. The mean carbon stock in

landward zone being higher than the seaward zone and middle zone may to be due to accessibility to fresh water facing Wadi(Dry stream) Aday that may supplies nutrients and encourages growth leading to more mature trees that have high circumference. The total area of *Avicennia marina* forest cover in Al-Qurm Nature Reserve is 0.82 km^2. The value of mean stock was extrapolated and estimated that a substantial sink capacity of 8692 t of C (0.0087 Mt), which is equivalent to 0.032 Mt of CO_2. Figure 1 shows carbon stocks of three zones in Al-Qurm Nature Reserve.
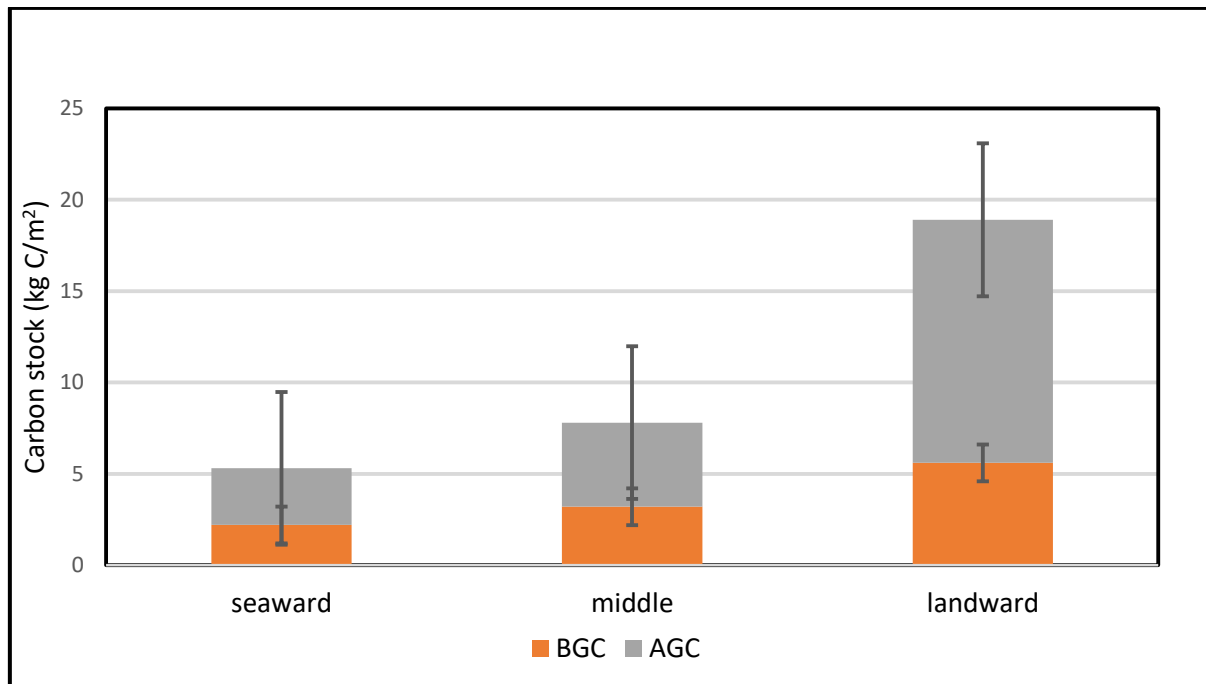

Figure 1. Carbon stocks of three zones in Al-Qurm Nature Reserve.

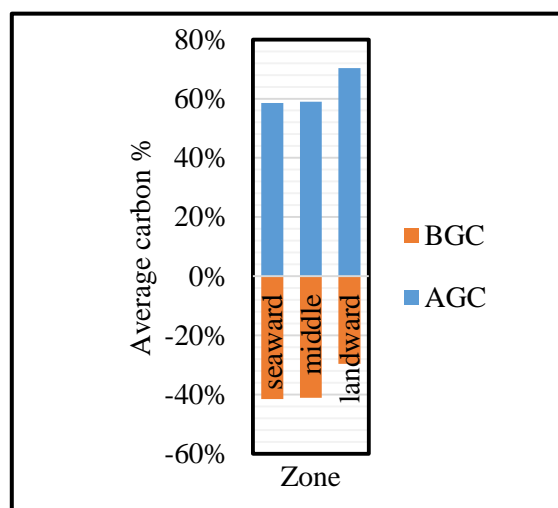3.4.   *Relationship between above and below Ground Biomass*

Figure 2 (a). Percentage of aboveground carbon to belowground carbon. (Note: minus sign here indicates belowground).
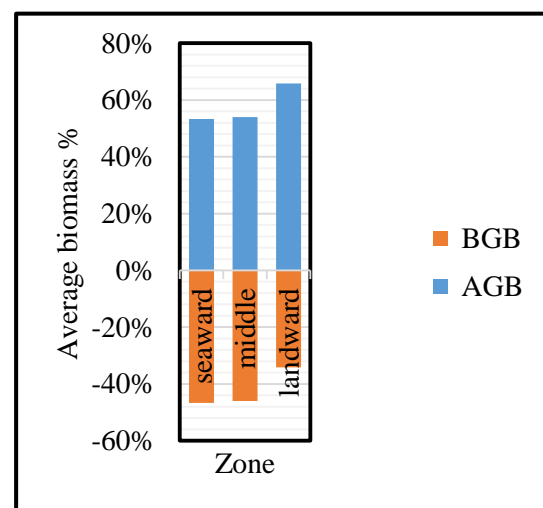

Figure 2 (b). Percentage of aboveground biomass to belowground biomass. (Note: minus sign here indicates belowground.

Figure 2 (a) and figure 2 (b) show the percentage of aboveground carbon to belowground carbon and the percentage of aboveground biomass to belowground biomass respectively. Tree carbon content distributions between aboveground and belowground showed variation between zones. In seaward and middle zones about 40% of the tree carbon and biomass content were in the belowground and about 60% were in the aboveground. However , in the moving to landward zone where larger trees are present with about 70% of tree biomass in the aboveground and only 30% in the belowground. It seems that mangroves in landward side have more matured trees compared to seaward and middle.

4. Conclusion

The three zones showed considerable differences in terms of its productivity to sequester carbon dioxide in their aboveground and belowground biomass. The result from this study concluded that landward zone has the highest value of aboveground carbon and belowground carbon, since more mature trees with high circumference are found in this zone. In contrast, the seaward zone has the lowest value for both aboveground carbon and belowground carbon.

5. References

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