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Quantification of above-ground carbon stock and sequestration potential of beach agoho (*Casuarina equisetifolia* L.) forest stand at Barangay Bugtongbato, Ibajay, Aklan, Philippines

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Abstract

This study analyzes the contribution of *Casuarina equisetifolia* L. stands in climate change mitigation efforts. The research aimed to quantify the above-ground biomass, carbon stock, and sequestered carbon dioxide of *C. equisetifolia* L. in a four-hectare stand located in Bugtongbato, Ibajay, Aklan. Non-destructive sampling methods were employed to measure each individual tree in a hundred percent tree inventory, and an allometric equation was used for calculations. A total of 1,380 individuals of *C. equisetifolia* L. were recorded, with estimated above-ground biomass and carbon stock amounts of 334.47Mg and 150.51Mg, respectively. The study revealed that the *C. equisetifolia* potential stand sequestered approximately 552.38Mg of CO_2. Interestingly, the carbon stock sequestration potential of the stand was found to be higher in the 30cm below diameter class than that of the 31cm above diameter class. Based on the study's results and conclusion, it is recommended to develop a carbon accounting methodology specific to the Philippines.

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Introduction

The presence of carbon balance in ecosystems is essential for mitigating climate change. Forest ecosystems play a vital role in carbon storage and sequestration. However, these ecosystems are under threat globally due to the combined impacts of climate change crises and continuous deforestation. Monitoring forest biomass, particularly above-ground carbon stocks, is crucial for understanding the carbon dynamics and global carbon cycle changes. However, in many developing countries, including the Philippines, active monitoring of forest carbon stocks is limited, leading to uncertainties in determining their specific contributions to global carbon emissions (Singh *et al.*, 2022).

One key species that contributes to carbon sequestration in tropical and subtropical regions is *Casuarina equisetifolia* (*C. equisetifolia*), commonly known as Beach Agoho. *C. equisetifolia* is a nitrogen-fixing plant widely employed for windbreaks and coastal stabilization. Coastal forest ecosystems, including *C. equisetifolia* stands, have gained significant attention, particularly after the devastating 2004 Southeast Asian tsunami. These stands have the potential to sequester carbon dioxide (CO2) from the atmosphere and contribute to regional carbon cycling. Previous research on *C. equisetifolia* has primarily focused on its ecological roles, such as land reclamation, windbreaks, erosion control, and wood and fuel production (Hardman *et al.*, 2012; Zoysa, 2008).

In the Philippines, a tropical country with diverse forest ecosystems, there is limited data available on the specific amount of biomass and carbon sequestration and storage capabilities of *C. equisetifolia* (Abino *et al.*, 2013). Understanding the carbon sequestration potential of *C. equisetifolia* is crucial, considering its large actual and potential planting areas in the Philippines and other parts of the country. The Philippines has conducted extensive studies on carbon budgets in forest ecosystems, given the relevance of forests in climate change mitigation. However, there are significant knowledge gaps concerning the carbon sequestration capabilities of various stand species, including *C. equisetifolia* (Racelis *et al.*, 2008).

Bugtongbato, located in the municipality of Ibajay, Aklan, Philippines, is known for its Beach Agoho (*C. equisetifolia*) forest stand. Despite its ecological importance, there is limited information available on the above-ground carbon stock and sequestration potential of the Beach Agoho forest stand in Bugtongbato, Ibajay, Aklan. This knowledge gap hinders effective forest management and the development of targeted strategies for carbon sequestration and climate change mitigation. Therefore, there is a need to conduct a study to address this gap and provide accurate data on the above-ground carbon stock and sequestration potential of the Beach Agoho forest stand in this specific area. In addition, quantifying the amount of carbon stored in the above-ground biomass of *C. equisetifolia* trees in this area is crucial for better management and planning efforts. Furthermore, this data will contribute to the development of a comprehensive database on the current and future carbon stock dynamics of *C. equisetifolia* reforestation efforts in the Philippines.

Material and methods

Materials

The study utilized various materials for data collection and fieldwork. A tree caliper or diameter tape was used to measure the diameter of individual trees at breast height (DBH), providing essential data for biomass estimation. A camera was employed to capture visual documentation of the study area, individual trees, and relevant features. To accurately determine the geographic coordinates of the study area and specific tree locations, a GPS device was utilized. A scientific calculator facilitated calculations related to biomass estimation, carbon stock, and carbon sequestration. The study also relied on a detailed map of the study area, which included the location of individual trees and important landmarks. A record book served as a repository for field observations, measurements, and collected data. Additionally, a laptop was used for data management, analysis, and storing digital records and calculations. Finally, a pencil was employed for taking notes, marking tree measurements in the record book, and making any necessary manual annotations during fieldwork. These materials played a crucial role in collecting accurate and reliable data for the study.

Methods

Study Site Description

This study was carried out in the *Casuarina equisetifolia* forest stand at Bugtongbato, Ibajay, Aklan inside the Seed Production Area (SPA) managed by Biodiversity, Coastal, Wetlands, and Ecotourism Research (BCWERC), Provincial Environment and Natural Resources Office (PENRO) Aklan (Fig. 1).The four (4) ha site is geographically located between 11°48'36.4"N and 122°13'06.4"E. The site is classified as climatic type III, with no apparent maximum rain period. Rain falls throughout the year, with the most precipitation from May to December and the least from January to April. It is relatively dry from November to April, and the rest of the year is wet.

The SPA was established in the year 2013 with a 400 individuals of *Casuarina equisetifolia* categorized as Plus Trees (PT) having six (6) to ten (10) meters spacing, living a stock of 100-200 trees per hectare as prescribed in DENR MEMO 2021-53. Aside from the PT, there are other numbers of the same species of individual trees inside the SPA.

The soil biophysical and chemical properties of the site are 5.72 (pH), 3.21% of Organic Matter, 1.42 ppm of Phosphorus, and the available Potassium is sufficient for Upper Topsoil. The Upper Subsoil is 6.63 (pH), 1.60% of Organic Matter, 0.90 ppm of Phosphorus, and the available Potassium is sufficient. The Middle Topsoil is 5.72 (pH), 1.60% of Organic Matter, 0.90 ppm of Phosphorus, and the available Potassium is sufficient. The Middle Subsoil is 5.77 (pH), 1.74% of Organic Matter, 1.11 ppm of Phosphorus, and the available Potassium is sufficient. The Lower Topsoil is 5.54 (pH), 2.27% of Organic Matter, 1.15 ppm of Phosphorus, and the available Potassium is sufficient. The Lower Subsoil is 5.83 (pH), 1.50% of Organic Matter, 0.64 ppm of Phosphorus, and the available Potassium is sufficient.

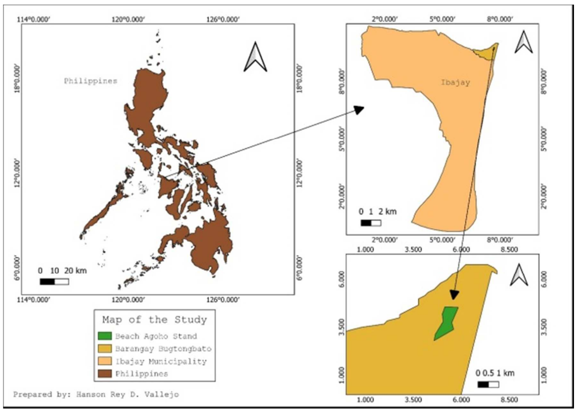

Fig. 1. Map showing the land area of Beach Agohostandprocessed through the Quantum GIS 3.28.

Sampling Procedure

A hundred percent (100%) tree inventory was conducted. All trees with ten (10) centimeters and above were included to determine the above-ground biomass of the area.

Data Collection

In this study, the diameter at breast height (DBH) of every individual tree species was determined. According to Laguiwoy (2010), the DBH of every tree sample was measured at 1.3 m above the ground. For forking trees below breast height, the DBH wastaken and treated individually. The DBH of a leaning tree was taken along its lower side, not the upper as suggested by Condit (2008).

The gathered diameter at breast height (DBH) of trees was in a quantitative approach. The DBH of the trees was measured by using a tree caliper for more than ten (10) centimeters (cm), and Microsoft Excel was used to encode and process this data. Since the study site is in the DENR Agoho Seed Production Area (SPA), a non-destructive sampling method was used to quantify the above-ground biomass of each tree.

Data Analysis

The allometric equation developed by Banaticla *et al.* (2007) was adopted to determine the above-ground biomass (AGB) of the tree species (Equation 1).

The carbon stock of the tree was determined by multiplying the computation AGB by 45% (Equation 2), which is the average carbon content of collection wood samples from secondary forests in several locations in the Philippines (Lasco and Pulhin, 2000), the weight of the CO_2 sequester was determined by multiplying the carbon stock of the tree by 3.67 (Equation 3) which is the ratio of carbon-to-carbon dioxide (Tagupaetal., 2010). The gathered data was analyzed through the following formulae:

Determination of above-ground tree biomass

Equation 1. $Y \text{ (kg)} = 0.342 * (DBH)^{2.073}$

Where:

Y = the above-ground biomass in kg

DBH = the measured diameter at 1.3 m above the ground incm.

Determination of Carbon Stock

Equation 2. C= AGB * 45%

Where:

C = total carbon stock

ABG = computed above-ground tree biomass

45% = carbon content of tree biomass

Determination of CO_2 Sequestered

Equation 3. $CO_2 = C * 3.67$

Where:

CO_2 = total CO_2 sequestered by tree species

C = total carbon stock of tree species

3.67 = ratio of CO_2 to C

The calculated total carbon stock was determined from the 45% of above-ground biomass. Through the

Result and discussion

Result

Casuarina equisetifolia L. Stand Vegetation

Based on the data provided in Table 1, the stand vegetation of *Casuarina equisetifolia* (*C. equisetifolia*) consisted of 1380 individuals of trees categorized based on their diameter classes. The majority of the trees fell under the 21-30cm diameter class, with 696 individuals, while the smallest group was the 51-above class, comprising only three (3) individuals.

Estimated Above-Ground Biomass of C. equisetifolia L.

Table 2 presents the results of the aboveground biomass growth (ABG) analysis for a stand of *C. equisetifolia* trees across different diameter classes. The highest ABG was observed in the 21-30cm diameter class, with a value of 47.78Mg/ha-1. In contrast, the lowest ABG was recorded in the 41-50cm and 51-abovecm diameter classes, with values of 1.32Mg/ha-1 and 1.49Mg/ha-1, respectively. The variation in ABG among the different diameter classes can be attributed to several factors. As trees grow larger, their biomass increases due to the accumulation of stem, branches, and leaves. This explains the overall increase in ABG from the 10-20cm diameter class to the 21-30cm diameter class. However, beyond the 30cm diameter class, the ABG starts to decline. This decline could be attributed to factors such as aging, senescence, and increased mortality of older trees. Additionally, the density and spacing of trees within the stand can also influence the ABG of individual trees.

Table 1. Diameter class distribution of *C. equisetifolia* st and in the study site.

Diameter Classes (cm)	Number of Individual Trees
10-20	557
21-30	696
31-40	118
41-50	6
51-above	3
TOTAL	1380

Table 2. Calculated Above-Ground Biomass (AGB) of *Casuarina equisetifolia* found in four hectares study site.

Diameter Classes (cm)	ABG (Mg/ha^{-1})	TOTAL ABG (Mg)
10-20	17.82	70.82
21-30	47.78	191.14
31-40	15.30	61.23
41-50	1.32	5.29
51-above	1.49	5.98
TOTAL	83.61	334.47

Carbon Stock of C. equisetifolia L. Stand

Table 3 presents the total amount of carbon (C) stocks in the *C. equisetifolia* stand, which was measured to be 150.51Mg. The largest amount of C stock was found in the 21-30 DBH (diameter at breast height) range, with 86.01Mg, followed by 31.87Mg and 27.55Mg in the 10-20 DBH and 31-40 DBH ranges, respectively. The total variation in C stock was observed to be influenced by DBH.

A study conducted by Hoang *et al.* (2021), reported that the ABG of the 21-30cm diameter was the highest, followed by the 31-40cm diameter class. The authors attributed this variation to differences in tree density, stand, age, and site conditions. Similarly, a study by Li *et al.* (2019) in China found that the AGB of *C. equisetifolia* stand increased with tree diameter class, which is consistent with the finding of thepresent study. Furthermore, a study by Rahman *et al.* (2018) in Bangladesh also found that the ABG of *C. equisetifolia* in stand varied significantly among different diameter classes. The study reported that the ABG was highest in the 10-20cm diameter class, followed by the 21-30cm diameter class. However, the authors also reported that the ABG declined beyond the 30cm diameter class, which is consistent with the finding of the present study.

Carbon Stock and CO2 Sequestration

Table 3 contains information on the carbon stock of the *C. equisetifolia* stand with variation across diameter classes. The 21-30cm diameter class has the highest carbon stock. This information is critical for determining the stand's carbon storage potential, which has implications for carbon sequestration and climate change mitigation. The accumulated CO2 sequestration capacity is shown in Table 4, with the highest values found in the 21-30cm diameter class.

Table 3. Calculated carbon stock of *Casuarina equisetifoliast* and at Bugtongbato, Ibajay, Aklan.

Diameter Classes (cm)	Carbon Stock (Mg/ha^{-1})	Total Carbon Stock (Mg)
10-20	7.96	31.87
21-30	21.50	86.01
31-40	6.88	27.55
41-50	0.59	2.38
51-above	0.67	2.69
TOTAL	37.62	150.51

The study conducted at Bugtongbato, Ibajay, Aklan measured a total accumulated carbon dioxide (CO2) of 552.38Mg in a four-hectare *C. equisetifolia* stand. Table 4 shows the CO2 sequestration capacity of the stand at Barangay Bugtongbato, with the highest amount observed in the 21-30cm diameter class at 78.91Mg/ha-1 and the lowest in the 41-50cm diameter class at 2.18Mg/ha-1. The variation in CO2 sequestration and storage within the forest stand is influenced by stand density, total population of trees, area of tree plantations, and their biomass.

Table 4. Accumulated carbon dioxide (CO_2) of *Casuarina equisetifolia* st and.

Diameter Classes (cm)	Accumulated CO_2 (Mg/ha^{-1})	Total Accumulated CO_2 (Mg)
10-20	29.24	116.97
21-30	78.91	315.67
31-40	25.28	101.12
41-50	2.18	8.73
51-above	2.47	9.88
TOTAL	138.09	552.38

Discussion

Stand Vegetation Distribution

The distribution of *C. equisetifolia* trees across different diameter classes is detailed in Table 1. This distribution reveals information about the stand's age and size distribution. The majority of trees are between 21 and 30cm in diameter, indicating a recent surge in regeneration. However, there are fewer trees in the larger diameter classes (41-50 and 51-plus), indicating a possible scarcity of mature trees. It is important to note that the diameter of a tree is an important indicator of its growth and age, and can also provide insight into the tree's overall health and productivity (Waring *et al.*, 1985), supported by the study of Oliver and Larson (1996); Bonan (2008) the larger diameter trees tend to be older and more established, with a larger root system that can access more nutrients and water from the soil. However, it is also important to note that the density of the stand could be an important factor to consider, as overcrowding can lead to competition for resources and reduced productivity (Morin and Lapointe-Garant, 2015). It suggests that the greater number of trees in the 21-30cm diameter class indicates a positive sign for the ecosystem's long-term health, suggesting successful regeneration. This balanced distribution can contribute to the overall stability and diversity of the ecosystem.

Above-Ground Biomass (AGB) Distribution

The calculated above-ground biomass (AGB) for various diameter classes is shown in Table 2.

The AGB is greatest in the 21-30cm diameter class and decreases as diameter increases. This decline could be attributed to aging, senescence, and increased mortality in older trees. AGB variation is also influenced by tree density and spacing. The total C stock amount variation of carbon content was observed to be influenced by DBH. The result of this study showed that the C stock per hectare of *C. equisetifolia* was higher compared to the study conducted by Lumbres *et al.* (2012) with 770.70Mg of C stock in 34.46 ha and lower than the study of Lasco and Cardinoza (2007) with 200Mg C ha^{-1}. As compared to other studies with the same formula of 45% C content from the ABG, the C stock of *C. equisetifolia* data obtained in this study, are generally the results are not far apart. In contrast to the study of Lasco *et al.* (2016), the carbon stock of the dipterocarp forest in Mindanao, Philippines, has 258Mg (C) ha-1. The calculated result of the carbon stock of this study shows a lower amount. The potential explanation for the greater carbon stock amount of the mentioned other study is that, the generic equation overestimated the precision by 10 and 48 percent than the equation using DBH alone with 95 percent accuracy (Kuyah *et al.*, 2013).

Accumulated CO_2 of C. equisetifolia

The total variation in carbon stock was observed to be significantly influenced by the diameter at breast height (DBH) of the Casuarina equisetifolia trees. Our study's results indicate that the carbon stock per hectare of the *C. equisetifolia* stand is comparatively higher than the findings of a study conducted by Lumbres *et al.* (2012), which reported a carbon stock of 770.70Mg in an area of 34.46 hectares. Conversely, our results show a lower carbon stock than the study conducted by Lasco and Cardinoza (2007), which recorded a carbon stock of 200Mg C per hectare.

In terms of methodological alignment, our study employed a formula consistent with other research that considers a standard 45% carbon content derived from the above-ground biomass (ABG). The carbon stock data for *C. equisetifolia* obtained in this study show a general proximity to the results of other studies that utilized similar methodologies.

However, it is noteworthy to contrast our findings with the study conducted by Lasco *et al.* (2016), which investigated carbon stock in a dipterocarp forest in Mindanao, Philippines, revealing a substantially higher value of 258Mg (C) per hectare. One potential explanation for this discrepancy is related to the use of a generic equation that may have led to an overestimation of precision in the mentioned study. The magnitude of this overestimation was found to be as high as 10 to 48 percent compared to the equation that relies solely on DBH, achieving a 95 percent accuracy level according to the research conducted by Kuyah *et al.* (2013).

In conclusion, the observed variation in carbon stock within the *C. equisetifolia* stand is closely linked to the diameter at breast height (DBH) of the trees. Our study's results align with certain research while diverging from others, likely due to differences in methodologies and equations used. It's essential to consider such variations and the precision of equations when interpreting and comparing carbon stock values across different studies and ecosystems.

Conclusion

The *Casuarina equisetifolia* stand has strong C sequestration potential with the potential and significant C in tree biomass. As long as trees are allowed to grow and not subject to cut down for whatever reason, they will continue to act as protective C sinks against the effects of climate change. Furthermore, as long as the stand is properly maintained and handled, they are effective at storing C. However, the biomass density and C stock capabilities vary depending on the size of the diameter. This was illustrated by the lower-diameter class showing more CO_2 accumulation than the high-diameter class.

Recommendation(S)

Based on the presented results, several recommendations can be made in line with international scientific standards. Firstly, it is crucial to prioritize the protection and management of Casuarinaequisetifolia stands, as they have been found to sequester a significant amount of aboveground biomass (ABG) carbon.

This entails implementing measures to prevent deforestation and promote regeneration of these stands. Secondly, selective logging practices should be considered, focusing on smaller diameter trees, to maintain or increase carbon stock within the stand. Additionally, the observed lower carbon stock in larger diameter classes may be attributed to senescence, decay, and biomass decomposition, highlighting the need for further investigation and appropriate management strategies. Regular monitoring for pests and diseases, nutrient management, and suitable silvicultural treatments are recommended to maintain the health and vigor of the trees, thus impacting the overall carbon stock. Moreover, the development and utilization of species-specific allometric equations for estimating biomass and carbon stock in *C. equisetifolia* stands are recommended to enhance the accuracy of carbon stock estimation.

In terms of further research, the establishment of long-term monitoring plots would provide valuable insights into the changes in carbon stock over time. Additionally, investigating soil carbon storage and dynamics, as well as the influence of genetic diversity on carbon sequestration in *C. equisetifolia*, would contribute to a comprehensive understanding of carbon dynamics in these stands. Furthermore, research focusing on developing and refining carbon accounting methodologies specific to *C. equisetifolia* stands would ensure accurate carbon management and trading. Lastly, assessing the economic feasibility of carbon sequestration in these stands would provide valuable information for decision-makers and stakeholders. Overall, following these recommendations and conducting further research would contribute to effective management and conservation strategies, as well as the integration of *C. equisetifolia* stands into climate change mitigation efforts.

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