Mindanao Journal of Science and Technology Vol. 24 (2) (2026) 180-198

Aboveground Biomass Estimation of Canarem Lake Bird Sanctuary in the Municipality of Victoria, Tarlac, Philippines

Kyle Joseph G. Quijano*, Jan Joseph V. Dida, Analyn L. Codilan, and Diomedes A. Racelis
Institute of Renewable Natural Resources
University of the Philippines Los Baños
College, Laguna 4031 Philippines
**kgquijano@up.edu.ph*

Date received: May 8, 2025
Revision accepted: August 17, 2026

Abstract

The Canarem Lake Bird Sanctuary in Victoria, Tarlac, is a 116-hectare wetland that serves as a critical refuge for endemic, resident, and migratory avian species throughout the year. Aside from providing shelter, its trees and other vegetation store carbon within their biomass. However, human activities such as land conversion and development may have a negative impact on this bird sanctuary. This study estimated the aboveground biomass (AGB) of the sanctuary using a combination of field inventory and allometric equations to provide a baseline for responsive conservation policies and management strategies. The tree inventory identified 478 individual trees across 14 species and seven families, with the exotic/naturalized species Leucaena leucocephala and Samanea saman exhibiting the highest frequencies. Oryza sativa L. was the only crop planted while the bamboo stands consisted of Bambusa vulgaris and Bambusa blumeana. Total AGB was estimated at 687.19 to 1,263.2 tonnes, corresponding to approximately 5.90 to 10.89 tonnes/hectare. The findings reveal a landscape where the majority of the AGB (584.65 tonnes) is maintained by naturalized tree species, while the tree size distribution indicates a relatively young to mid-aged stand. Annual crops (576.01 tonnes) and bamboo (102.54 tonnes) account for smaller, seasonal shares of the total pool. Ultimately, these results highlight the Canarem Lake Bird Sanctuary's critical role as a vegetated wildlife habitat. Implementing management strategies to promote native biodiversity and climate change mitigation will support long-term ecosystem and community resilience.

Keywords: allometric equation, bird sanctuary, carbon storage, carbon sink, climate mitigation

1. Introduction

Wetland ecosystems play a measurable role in the global carbon cycle and in climate change responses through both mitigation and adaptation pathways (Potschin *et al*., 2016). As ecosystems, wetlands contribute to climate change mitigation by removing carbon dioxide from the atmosphere and storing it in biomass and soils, while also supporting adaptation by providing ecosystem services that enhance the capacity of human and ecological systems to cope with climate variability and change (Potschin *et al*., 2016). Among wetland types, freshwater wetlands, including lakes, marshes, and swamps, are increasingly recognized for their capacity to function as carbon sinks, particularly through vegetation growth and organic matter accumulation (Moomaw *et al*., 2018; Intergovernmental Panel on Climate Change [IPCC], 2023).

Understanding ecosystem structure and dynamics is fundamental to effective management and conservation, as it underpins the protection of biodiversity, ecosystem processes, and the services ecosystems provide. In this context, carbon sequestration has become a key focus of ecosystem assessment, especially for climate change mitigation strategies. Aboveground biomass (AGB) is a major component of ecosystem carbon pools, encompassing all living vegetation above the soil surface, including stems, branches, bark, foliage, and stumps (IPCC, 2019). Quantifying AGB provides an empirical basis for estimating aboveground carbon stocks and for comparing carbon storage capacity across ecosystems and land-use types (Vashum, 2012; IPCC, 2019). In Cebu City, quantifying urban tree AGB and carbon sequestration potential provided baseline information on the benefits of trees in urban areas (Pansit, 2019).

Researchers have developed a range of methods to estimate AGB, broadly classified into field-based approaches using destructive or non-destructive measurements and remote sensing techniques that employ optical imagery, radar, and light detection and ranging (LiDAR) (Tadese, 2019; Chave *et al*., 2019). While total ecosystem carbon stocks also include belowground biomass and soil organic carbon, AGB estimation remains a widely applied and practical indicator of vegetation carbon storage, particularly in sites dominated by woody or emergent vegetation and where baseline data are limited (IPCC, 2019). Establishing AGB estimates is therefore often a necessary first step toward more comprehensive carbon accounting in freshwater wetland ecosystems.

The Philippines stands out as one of the 18 megadiverse countries globally, hosting approximately two-thirds of the Earth's biodiversity. The country ranks fifth in plant species diversity and houses 5 % of the world's flora (Department of Environment and Natural Resources-Protected Areas and Wildlife Bureau [DENR-PAWB], 2009). Given this abundance of biodiversity, the Philippines has established a network of protected areas under the National Integrated Protected Areas System (NIPAS) Act of 1992 (Republic Act No. 7586) and the Expanded National Integrated Protected Areas System (E-NIPAS) Act of 2018 (Republic Act No. 11038). Currently, 244 protected areas exist, comprising 172 terrestrial areas totaling 4.68 million hectares and 72 marine areas totaling 3.08 million hectares. These collectively encompass 7.76 million hectares of marine nationwide. In addition to proclaimed protected areas, Republic Act No. 7586 also provides for the designation of critical habitats—areas outside formally declared protected areas that are essential for conserving threatened species (DENR-BMB, 2019). However, ecologically significant areas are not always encompassed within formally declared protected areas. Many wetlands of high ecological value remain outside formal protection, underscoring the importance of scientific assessments that can support evidence-based conservation and management.

One such wetland ecosystem is the Canarem Lake Bird Sanctuary, a natural freshwater wetland located in the Municipality of Victoria, Tarlac Province, Philippines. This natural wetland supports migratory and resident bird populations and lies along the East Asian-Australasian Flyway, which is recognized as one of the Earth's paramount migratory routes. The Philippine government has identified Canarem Lake Bird Sanctuary as a potential Ramsar wetland and recognized it as an important habitat for migratory birds, underscoring its ecological significance (DENR-BMB, 2016; Sapnu, 2018).

Existing knowledge on Canarem Lake Bird Sanctuary is largely derived from local government records, agency reports, and site-level assessments, with very limited coverage in peer-reviewed scientific literature. Available sources primarily emphasize avian diversity and the site’s role as a bird sanctuary (Lacadin *et al*., 2024; Municipality of Victoria, 2026), while other ecosystem attributes such as vegetation structure, biomass, and carbon storage remain poorly quantified. Recent assessments indicate that Canarem Lake Bird Sanctuary faces multiple anthropogenic pressures, including recreational activities, fishing, and farming, which directly impact its avifauna and overall ecological integrity (Lacadin *et al*., 2024).

Given these knowledge gaps, this study focuses on estimating the aboveground biomass of vegetation within Canarem Lake Bird Sanctuary. To our knowledge, this is the first baseline study to quantify the area's aboveground biomass using a combination of field measurements and imagery techniques. By providing site-specific AGB estimates, the study contributes baseline empirical data on the carbon storage potential of a freshwater wetland that is primarily recognized for its biodiversity value. The findings are intended to support a more integrated understanding of the ecological functions of Canarem Lake Bird Sanctuary and to inform future assessments that link wetland conservation, biodiversity management, and ecosystem-based climate change mitigation.

2. Methodology

2.1 Description of the Study Site

Canarem Lake Bird Sanctuary is a freshwater wetland situated within the geographical confines of Barangays of Canarem, San Agustin, San Vicente, and Bantog in the Municipality of Victoria, Tarlac Province, Philippines. It covers approximately 116 hectares. The study site features a mix of natural vegetation, bamboo stands, and cultivated areas (primarily rice paddies). Canarem Lake Bird Sanctuary lies within the geographic extent of the East Asian–Australasian Flyway, a major migratory route for waterbirds, and bird observations at the site include species characteristic of this flyway, indicating its ecological relevance to migratory waterbird movements (Lacadin *et al*., 2024).

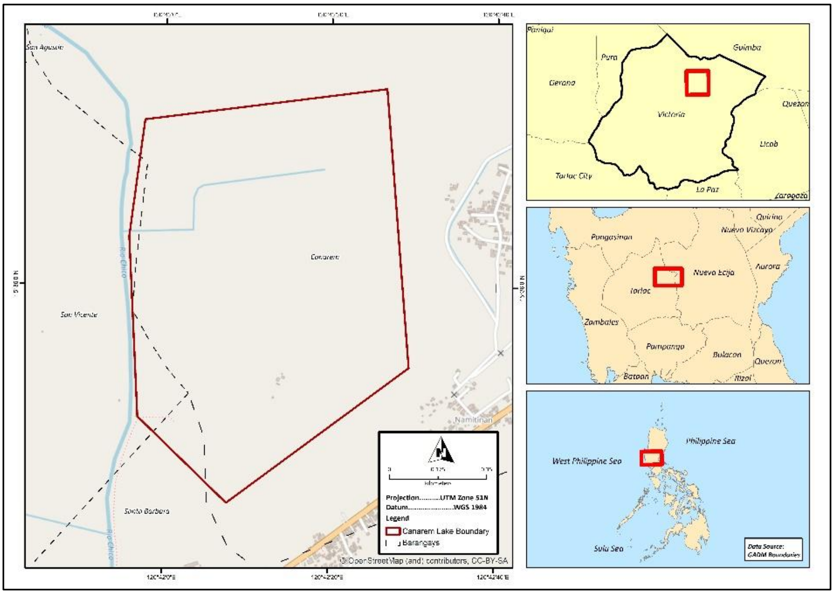

Figure 1. Map of the Boundary of the Canarem Lake Bird Sanctuary

2.2 Data Collection

2.2.1 Tree Inventory

All trees within the sanctuary boundary, which consists largely of agricultural areas and inland water bodies, were inventoried during a field survey. Before the field survey, reconnaissance and site inspection supported the strategic implementation of the tree inventory. Because most of the sanctuary consists of open water and rice paddies with sparse tree distribution, a complete tree census was feasible within the allotted survey period. A total of two days (6th and 7th of April 2024) were allocated for two surveyors to complete the full tree census. Bamboo stands, areas under annual crops, and inland water bodies were excluded from the inventory unless individual trees were present. Individual trees were measured for diameter at breast height (DBH, 1.3 meters above ground) using a diameter tape. Only individual trees with DBH above 5 centimeters were included in the inventory as recommended in the allometric equation evaluation guidance (Walker *et al*., 2016). Standing dead trees and other dead woody stems were excluded from biomass estimation because the allometric equations used in this study were developed for living trees, and decay class assessments were not conducted during the field inventory. Individuals were identified to species level through local expert validation.

Tree locations were recorded using GPS handheld Global Positioning System (GPS) navigation devices (Li *et al*., 2023). The biogeographic classification of tree species was obtained from the Co's Digital Flora of the Philippines (Pelser *et al.*, 2011). Although palm species were present in the area, they were excluded from biomass estimation because the study's allometric models are not applicable to palms.

2.2.2 Bamboo and Annual Crop Assessment

The total area occupied by bamboo stands was determined using Google Earth Pro following established GIS-based delineation procedures (Venkatappa *et al*., 2020). The total area of annual crops was extracted from the 2020 land cover shapefile of the Department of Environment and Natural Resource (DENR) - National Mapping and Resources Information Authority (NAMRIA). Field inspection and GPS mapping were conducted to validate bamboo species and spatial extent.

2.3 Data Analysis

2.3.1 Aboveground Biomass Estimation for Trees

Aboveground biomass (AGB) of trees was estimated using the allometric model of Chave *et al*. (2005). Although newer allometric models have been developed, the Chave *et al*. (2005) model was selected because our inventory included DBH and wood density but lacked consistent tree height measurements for all individuals. This allometric equation incorporates wood density, which has been validated for tropical species in conditions similar to the Canarem Lake Bird Sanctuary and was previously applied in a study at the Mount Makiling Forest Reserve (Dida & Tiburan, 2020). The use of an allometric equation that incorporates wood density was also previously demonstrated for the Mangium species in Claveria, Misamis Oriental (Palma, 2014). Tree DBH and species-specific wood density (ρ) were used as input parameters:

$$Y = \rho \times exp(-1.499 + 2.148 \times ln(D) + 0.207 \times (\ln(D))^2 - 0.0281 \times (ln(D))^3 \quad (1)$$

where

Y = Tree aboveground biomass or AGB (in kilograms)
D = Diameter at breast height or DBH (in centimeters)

ρ = Specific wood density (in grams per cubic centimeter)

For this study, the wood density values of the observed species (Table 1) were gathered from the Food and Agriculture Organization (FAO) of the United Nations (Brown, 1997), International Tropical Timber Organization (ITTO), and Climate Action Reserve.

Table 1. Specific wood density of tree species in the study area

Family Name	Scientific Name	Common Name	Specific Wood Density (g/cm^3 or t/m^3)
Fabaceae	*Leucaena leucocephala*	Ipil-Ipil	0.65
Fabaceae	*Samanea saman*	Rain Tree	0.46
Meliaceae	*Swietenia macrophylla*	Big Leaf Mahogany	0.52
Fabaceae	*Pithecellobium dulce*	Camachile	0.52
Fabaceae	*Pterocarpus indicus*	Narra	0.52
Rubiaceae	*Nauclea orientalis*	Bangkal	0.49
Myrtaceae	*Syzygium cumini*	Duhat	0.70
Fabaceae	*Tamarindus indica*	Sampaloc	0.75
Meliaceae	*Azadirachta indica*	Neem	0.69
Anacardiaceae	*Mangifera indica*	Carabao Mango	0.59
Myrtaceae	*Eucalyptus deglupta*	Bagras	0.34
Boraginaceae	*Cordia dichotoma*	Anonang	0.43
Fabaceae	*Acacia mangium*	Mangium	0.58
Sapotaceae	*Chrysophyllum cainito*	Caimito	0.80

The total tree biomass per plot was summed and converted from kilograms to tonnes.

2.3.2 Aboveground Biomass Estimation for Bamboo and Annual Crops

Given terrain limitations for field sampling, mean AGB values for bamboo species (97.5 tonnes/hectare for *Bambusa blumeana* and 72.2 tonnes/hectare for *Bambusa vulgaris*) were obtained from secondary sources (Patricio & Dumago, 2014). Allometric models for bamboo can complement AGB estimation in inventories (Camargo Garcia *et al.*, 2024). For rice paddies, a mean AGB of 8.85 tonnes/hectare was used, based on a multi-site study by Nakajima *et al*. (2023), which reported AGB values ranging from 0.007 tonnes/hectare (0.7 grams/square meter) to 17.7 tonnes/hectare (1770 grams/square meter) across diverse rice cultivars. A mean value of 8.85 tonnes/hectare was adopted from was adopted from Nakajima *et al*. (2023) and applied uniformly across rice paddies. Since rice paddies are classified as annual crops, their total aboveground biomass was assumed to be seasonal. Total AGB for each vegetation type was calculated by multiplying the mean AGB by the mapped area of each species or crop.

2.3.3 Estimation of Total Aboveground Biomass

The total aboveground biomass (AGB) of the sanctuary was calculated by aggregating biomass estimates from trees and bamboo, while treating rice paddies as seasonal biomass. This aggregation follows standard biomass accounting practices consistent with international guidance on greenhouse gas inventories (IPCC, 2019). All values were expressed in tonnes to represent the total AGB of Canarem Lake Bird Sanctuary.

3. Results and Discussion

3.1 Tree Composition and Structure

A total of 478 individual trees representing 14 species across seven families were recorded within Canarem Lake Bird Sanctuary (Table 2 and Figure 2). Tree density was estimated at approximately five trees per hectare, indicating a relatively open woody vegetation structure compared with densely forested tropical systems.

Leucaena leucocephala was the most abundant species, followed by *Samanea saman*, while several species (*Acacia mangium*, *Cordia dichotoma*, *Chrysophyllum cainito*, and *Eucalyptus deglupta*) were observed only rarely. *Leucaena leucocephala* and *Samanea saman* are both classified as non-native and naturalized in the Philippines based on Co's Digital Flora of the Philippines, suggesting that portions of the sanctuary reflect anthropogenic influence or historical planting rather than purely native vegetation assemblages.

The prevalence of naturalized species may have important ecological implications. Fast-growing exotics often accumulate biomass rapidly, thereby enhancing short- to medium-term carbon storage through increased plant and soil carbon (He *et al*., 2025). Once these species become invasive, they can substantially alter plant species composition, reduce native diversity and ecological function, and fundamentally change habitat quality and ecosystem processes (Wu *et al*., 2025). Notably, Lacadin *et al*. (2024) identified invasive species as a significant threat to Canarem Lake Bird Sanctuary, highlighting how the dominance of non-native plants can pose direct risks to wetland biodiversity and ecosystem integrity.

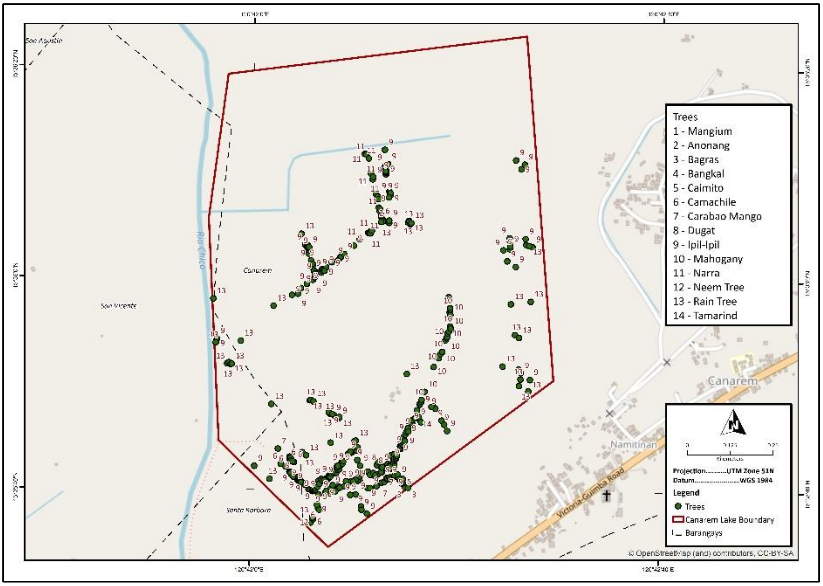

Figure 2. Distribution of trees in Canarem Lake Bird Sanctuary

Table 2. Abundance, conservation status, and classification of the tree species identified in Canarem Lake Bird Sanctuary

Family Name	Scientific Name	Frequency	Conservation Status DAO 2017-11	IUCN 2025-2	Classification
Anacardiaceae	*Mangifera indica*	3	Other	Data Deficient	Naturalized
Boraginaceae	*Cordia dichotoma*	2	Wildlife Species	Least Concern	Native
Fabaceae	*Acacia mangium*	2	Other Wildlife Species	Least Concern	Naturalized
Fabaceae	*Leucaena leucocephala*	209	Other Wildlife Species	Not Assessed	Exotic/ Naturalized
Fabaceae	*Pithecellobium dulce*	35	Other Wildlife Species	Least Concern	Naturalized

Fabaceae	*Pterocarpus indicus*	33	Other Wildlife Species	Endangered	Native
Fabaceae	*Samanea saman*	126	Vulnerable	Least Concern	Exotic/
Fabaceae	*Tamarindus indica*	6	Other Wildlife Species	Least Concern	Naturalized
Meliaceae	*Azadirachta indica*	6	Other Wildlife Species	Least Concern	Exotic/ Naturalized
Myrtaceae	*Swietenia macrophylla*	39	Other Wildlife Species	Endangered	Naturalized
Myrtaceae	*Eucalyptus deglupta*	2	Other Wildlife Species	Vulnerable	Exotic/
Myrtaceae	*Syzygium cumini*	6	Other Wildlife Species	Least Concern	Naturalized
Rubiaceae	*Nauclea orientalis*	7	Other Wildlife Species	Least Concern	Native
Sapotaceae	*Chrysophyllum cainito*	2	Other Wildlife Species	Least Concern	Naturalized

3.2 Aboveground Biomass of Trees

Aboveground tree biomass in Canarem Lake Bird Sanctuary was strongly influenced by both species' composition and size structure. The total AGB of trees was estimated at 584.65 tonnes, corresponding to approximately 5.04 tonnes/hectare across the 116-hectare sanctuary (Table 3). While larger-statured species such as *Samanea saman*, *Leucaena leucocephala*, and *Tamarindus indica* dominated the upper DBH classes, the majority of trees were concentrated in the 20 to 40 centimeters DBH class. This size distribution suggests that most of the forest structure is composed of relatively young to mid-aged trees, with fewer large, old-growth individuals contributing disproportionately to total biomass.

Notably, the dominance of exotic and naturalized species such as *Leucaena leucocephala* and *Samanea saman* enhances short- to medium-term potential carbon storage but may compromise long-term ecosystem resilience by altering species composition, suppressing native regeneration, and potentially reducing habitat quality for wetland biodiversity (He *et al*., 2025). This is consistent with Lacadin *et al*. (2024) who identified invasive species as a potential threat to Canarem Lake Bird Sanctuary. A similar pattern has been observed in other Philippine tree studies. For instance, Parilla (2018) reported that older *Swietenia macrophylla* trees had higher AGB compared to younger *Vitex parviflora* trees, highlighting how age and size structure can strongly influence forest carbon stocks. In a study in Baungon, Bukidnon, tree patches and trees along riparian strips contributed to aboveground biomass and carbon sequestration potential in agroforestry and grassland areas (Canencia *et al.*, 2015).

This observation illustrates what may be described as a carbon-biodiversity paradox in Canarem Lake Bird Sanctuary. The species contributing most to aboveground biomass and carbon storage are predominantly exotic and naturalized, whereas the sanctuary's primary ecological objective is conserving native wetland biodiversity and maintaining high-quality bird habitat. Invasive species accounted for nearly half of the total carbon stock in the tropical wetlands of Barak Valley, Assam, Northeast India (Borbhuyan *et al.*, 2026). In this context, maximizing carbon storage does not necessarily align with maximizing biodiversity conservation, highlighting the need for management strategies that balance these potentially competing objectives.

Table 3. Estimated AGB of trees in Canarem Lake Bird Sanctuary

Family	Scientific Name	Total AGB (tonnes)
Fabaceae	*Samanea saman*	343.88
Fabaceae	*Leucaena leucocephala*	86.67
Fabaceae	*Tamarindus indica*	72.43
Fabaceae	*Pterocarpus indicus*	33.55
Meliaceae	*Swietenia macrophylla*	31.22
Fabaceae	*Pithecellobium dulce*	6.65
Meliaceae	*Azadirachta indica*	6.12
Myrtaceae	*Syzygium cumini*	1.39
Rubiaceae	*Nauclea orientalis*	1.01
Anacardiaceae	*Mangifera indica*	0.67
Myrtaceae	*Eucalyptus deglupta*	0.28
Boraginaceae	*Cordia dichotoma*	0.27
Sapotaceae	*Chrysophyllum cainito*	0.26
Fabaceae	*Acacia mangium*	0.26
TOTAL		584.65

3.3 Aboveground Biomass of Annual Crops

In the study site, only one type of crop, *Oryza sativa*, was cultivated throughout the year. Based on the DENR-NAMRIA land cover, the total area planted with rice was approximately 65.08 hectares. Applying the mean aboveground biomass (AGB) for rice reported by Nakajima *et al*. (2023), the total AGB of rice in Canarem Lake Bird Sanctuary was estimated at 576.01 tonnes, indicating that annual crops contribute a relatively small but notable portion (45.60 %) of the sanctuary's overall biomass. Previous studies have successfully combined remote sensing-based land cover data with published biomass values, such as de los Santos *et al*. (2024), who used satellite-derived vegetation indices to estimate AGB and carbon stocks across rice croplands in the Philippines.

This estimate is approximate. The method relied on secondary values rather than direct field measurements and did not incorporate advanced remote sensing techniques, such as canopy spectral reflectance or unmanned aerial vehicle (UAV)-based RGB imagery, which have been used effectively to estimate rice AGB in agroecosystems (Wang *et al*., 2022). Furthermore, these annual crops are assumed to be harvested later in the year and are therefore not treated as permanent aboveground biomass. Nevertheless, these results provide a useful first-order assessment of carbon stocks in the agricultural component of the Canarem Lake Bird Sanctuary. Annual crops also provide food and economic benefits alongside their biomass carbon sequestration potential (Funes *et al*., 2022).

3.4 Aboveground Biomass of Bamboo

Two bamboo species were present in the study area: *Bambusa vulgaris* and *Bambusa blumeana*. *Bambusa vulgaris* occurred in a total area of around 0.3145 hectares, while *Bambusa blumeana* occurred in an area of 0.9956 hectares. Using species-specific mean AGB values reported by Patricio and Dumago (2014), the total aboveground biomass was estimated at 30.66 tonnes for *Bambusa vulgaris* and 71.88 tonnes for *Bambusa blumeana*, yielding a combined bamboo AGB of 102.54 tonnes.

When compared to other bamboo studies in the Philippines, the AGB values of *Bambusa vulgaris* and *Bambusa blumeana* correspond to a lower biomass density than the AGB reported for *Schizostachyum lumampao* in Cuyambay, Tanay, Rizal, where a mean AGB of 74.19 tonnes/hectare was observed (De Guzman *et al*., 2021). The difference reflects both the smaller total area and lower density of bamboo stands in Canarem Lake, as well as species-specific growth characteristics. Further, De Guzman *et al*. (2021) demonstrated that the culms were the dominant contributor to AGB in bamboo, followed by branches and leaves, showing how clumping bamboo species can achieve high carbon storage even in relatively small areas.

3.5 Estimation of Total AGB *of the Canarem Lake Bird Sanctuary*

Using the allometric model of Chave *et al*. (2005), the total aboveground biomass (AGB) of Canarem Lake Bird Sanctuary was estimated at 1,263.2 tonnes, of which 584.65 tonnes are from trees, 576.01 tonnes from annual crops (rice), and 102.54 tonnes from bamboo (Table 4 and Figure 3). Without annual crops, the total AGB was estimated at 687.19 tonnes.

Table 4. Estimated AGB of trees, annual crops, and bamboos in Canarem Lake Bird Sanctuary

Vegetation Type	AGB (tonnes)	%Total AGB
Trees	584.65	46.28
Annual Crop (seasonal)	576.01	45.60
Bamboo	102.54	8.12
TOTAL	1,263.2	100.00

With an area of around 116 hectares, the total AGB corresponds to 5.90 tonnes/hectare to 10.89 tonnes/hectare. Compared with other Philippine wetland ecosystems, Canarem Lake Bird Sanctuary exhibits moderate biomass density. For comparison, the disturbed Bambanin peatland has an estimated total AGB of 1,093 tonnes, corresponding to approximately 2.00 tonnes/hectare (Orella *et al*., 2022). In contrast, the AGB of the relatively undisturbed Caimpugan peatland was estimated at 201,514 tonnes, or 35.80 tonnes/hectare (Orella *et al*., 2022). Although the total AGB in Canarem Lake is smaller due to its limited area, its AGB density (5.90 tonnes/hectare to 10.89 tonnes/hectare) exceeds that of the disturbed peatland. An important source of uncertainty in the total AGB estimate is the use of literature-derived biomass values for bamboo and rice rather than site-specific field measurements. Therefore, the total AGB estimate should be considered a baseline estimate.

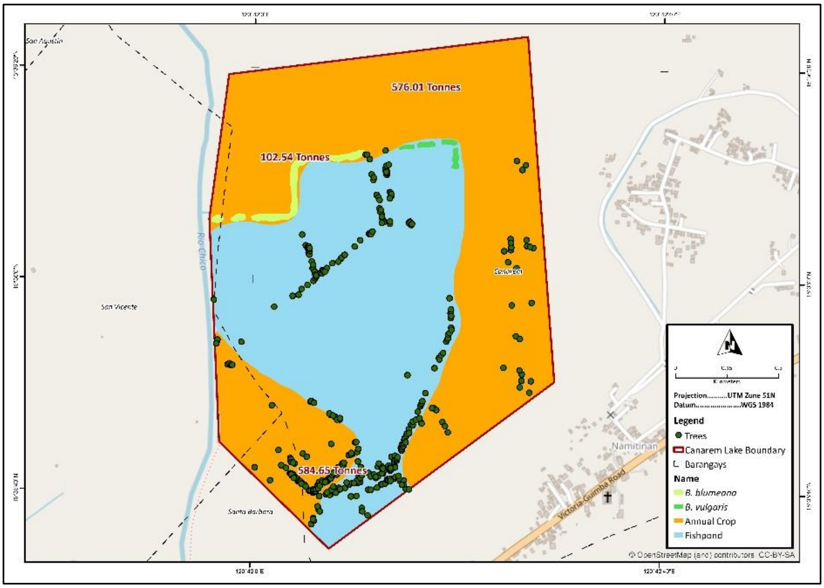

Figure 3. Aboveground biomass map of Canarem Lake Bird Sanctuary (Annual Crop and Fishpond extracted from NAMRIA 2020 land cover)

4. Conclusion and Recommendation

The assessment of the Canarem Lake Bird Sanctuary reveals a total aboveground biomass (AGB) of 687.19 tonnes to 1,263.2 tonnes, corresponding to around 5.90 tonnes/hectare to 10.89 tonnes/hectare. This estimate reflects a complex mosaic of naturalized timber, bamboo stands, and seasonal agriculture. While the sanctuary has potential for tree biomass accumulation, its current composition reinforces the carbon-biodiversity paradox identified in the discussion, given the dominance of exotic species such as *Leucaena leucocephala* and *Samanea saman*. These species contribute the bulk of the tree biomass (584.65 tonnes), but their dominance as non-native species may influence the ecosystem necessary for a specialized bird sanctuary. Hence, conservation efforts at the Canarem Lake Bird Sanctuary must simultaneously address climate mitigation and biodiversity objectives through targeted interventions, including buffer zone implementation, the use of native tree species, and more educational campaigns. The involvement of local government and civil society organizations may also help sustain these efforts.

It is important to note that some uncertainty remains in AGB estimation, as allometric equations may not fully capture local variations in tree architecture, species-specific growth, or stand structure. Similarly, using secondary AGB values for bamboo or rice paddies may over or underestimate biomass relative to actual field conditions. These limitations point to the need for primary data collection of all key parameters, destructive sampling, and more extensive studies across different wetland types. Addressing these gaps will improve the accuracy of biomass and carbon assessments that inform conservation efforts. Future research is also recommended to build on this study by expanding the scope of carbon accounting and technological integration. While this study focused on AGB, subsequent investigations should include belowground biomass (BGB) and soil organic carbon (SOC), which often represent the largest carbon pools in wetland ecosystems. The use of multi-temporal satellite imagery or high-resolution UAV-based LiDAR can be used to capture spatial variability and detailed profile of vegetation in wetland rice systems. Overall, Canarem Lake Bird Sanctuary has the potential to support a meaningful aboveground carbon stock, underscoring the importance of management strategies that mitigate invasive species impacts, promote native biodiversity, and support long-term ecosystem resilience.

5. Acknowledgement

The authors would like to thank the Municipality of Victoria, Tarlac for their support in the conduct of the study.

6. References

Borbhuyan, S., Das, N., Chakraborty, K., Bhattacharyya, D., & Das, T. (2026). The paradox of carbon sequestration in tropical wetlands: High contributions from invasive species demand control and native plant promotion. *Environmental Management, 76*(2), 37. https://doi.org/10.1007/s00267-025-02342-8

Brown, S. (1997). Estimating biomass and biomass change of tropical forests: A primer (FAO Forestry Paper 134). *Food and Agriculture Organization of the United Nations*. https://www.fao.org/4/w4447e/w4447e00.htm

Canencia, O. P., Palma, R.A., Ansigbat, V., Lacang, G., Osio, A., Tulang, R., Enguito, R., Tamang, R., & Arnejo, B. (2015). Carbon sequestration potentials for agro-forestry system and grasslands in Bukidnon and Cagayan de Oro landscape. *Mindanao Journal of Science and Technology, 13,* 152–169.

Camargo García, J.C., Arango Arango, A.M., & Trinh, L. (2024). The potential of bamboo forests as a carbon sink and allometric equations for estimating their aboveground biomass. *Environment, Development and Sustainability, 26,* 20159–20187. https://doi.org/10.1007/s10668-023-03460-1

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F… & Yamakura, T. (2005). Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia, 145*(1), 87–99. https://doi.org/10.1007/s00442-005-0100-x

Chave, J., Davies, S.J., Phillips, O.L., Lewis, S.L., Sist, P., Schepaschenko, D., Armston, J., Baker, T.R., … & Saatchi, S. (2019). Ground data are essential for biomass remote sensing missions. *Surveys in Geophysics, 40*(4), 863–880. https://doi.org/10.1007/s10712-019-09528-w

De Guzman, H.A., Vallesteros, S.F., Vallesteros, A.P., Caranza, J.Q., & Castaneto, Y.T. (2021). Aboveground biomass and carbon stock of Buho (*Schizostachyum lumampao* (*Blanco Merrill*) in Cuyambay, Tanay, Rizal. *Journal of Agricultural Research, Development, Extension and Technology, 3*(1), 60-70. https://doi.org/10.5281/zenodo.8296484

De los Santos, A.S., Guzman, M.A.L.G., Vicente, M.C.T.M., Mijares, J.M.J., del Castillo, M.F.P., & Estiva, J.A.N. (2024). Application of Remotely Sensed Data in Estimating Aboveground Biomass and Carbon Stocks. *Philippine Journal of Science, 153*(6B), 2399-2414.

Department of Environment and Natural Resources–Biodiversity Management Bureau [DENR-BMB]. (2019). Protected Areas Philippine Clearing House Mechanism. Philippine Clearing House Mechanism. https://www.philchm.ph/terrestrial/

Department of Environment and Natural Resources–Biodiversity Management Bureau [DENR-BMB]. (2016). Philippine biodiversity strategy and action plan (2015–2028): Bringing resilience to Filipino communities. BMB-DENR, United Nations Development Programme–Global Environment Facility, & Foundation for the Philippine Environment. https://www.cbd.int/doc/world/ph/ph-nbsap-v3-en.pdf

Department of Environment and Natural Resources-Protected Areas and Wildlife Bureau [DENR-PAWB]. (2009). Assessing progress towards the 2010 biodiversity target: The 4th National Report to the Convention on Biological Diversity. Quezon City, Philippines: PAWB-DENR, UNDP, ACB, & ASOG. https://www.cbd.int/doc/world/ph/ph-nr-04-en.pdf

Dida, J.J.V., & Tiburan, C.L. Jr. (2020). Above ground biomass estimation of trees in the University of the Philippines Los Banos Campus, Philippines. *Sylvatrop, 30*(2), 91-105.

Funes, I., Molowny-Horas, R., Savé, R., De Herralde, F., Aranda, X., & Vayreda, J. (2022). Carbon stocks and changes in biomass of Mediterranean woody crops over a six-year period in NE Spain. *Agronomy for Sustainable Development, 42*, 98. https://doi.org/10.1007/s13593-022-00827-y

He, Y., Li, J., Siemann, E., Li, B., Xu, Y., & Wang, Y. (2025). Plant Invasion Increases Soil Microbial Biomass Carbon: Meta-Analysis and Empirical Tests. *Global Change Biology, 31*(3), e70109. https://doi.org/10.1111/gcb.70109

Intergovernmental Panel on Climate Change [IPCC]. (2023). Climate Change 2021 – The Physical Science Basis: Working Group I Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge: Cambridge University Press.

Intergovernmental Panel on Climate Change [IPCC] (2019). 2019 Refinement to the 2006 IPCC guidelines for national greenhouse gas inventories. https://www.ipcc.ch/report/2019-refinement-to-the-2006-ipcc-guidelines-for-national-greenhouse-gas-inventories/

International Tropical Timber Organization [ITTO] (n.d.). Tropical Timber Information System. https://www.tropicaltimber.info

Lacadin, E.B., Gagarin, W.S. & Baoanan, Z.G. (2024). Identifying Direct Threats to an Inland Wetland and Its Avifauna: The Case of Canarem Lake, Central Luzon, Philippines. *Journal of Nature Studies, 23*(2), 22-41.

Li, S., Chen, X., Sun, Y., Lv, C., Yuan, F., & Fang, L. (2023). Method and Device for Measuring the Diameter at Breast Height and Location of Trees in Sample Plots. Forests, 14(9), 1723. https://doi.org/10.3390/f14091723

Nakajima, K., Tanaka, Y., Katsura, K., Yamaguchi, T., Watanabe, T., & Tatsuhiko Shiraiwa. (2023). Biomass estimation of World rice (*Oryza sativa* L.) core collection based on the convolutional neural network and digital images of canopy. *Plant Production Science, 26*(2), 187–196. https://doi.org/10.1080/1343943x.2023.2210767

Moomaw, W.R., Chmura, G.L., Davies, G.T., Finlayson, C.M., Middleton, B.A., Natali, S.M., Perry, J.E., Roulet, N., & Sutton-Grier, A.E. (2018). Wetlands in a changing climate: Science, policy and management. *Wetlands, 38*(2), 183–205. https://doi.org/10.1007/s13157-018-1023-8

Municipality of Victoria. (2026). Asian Waterbird Census (AWC) 2026 at Canarem Lake Bird Sanctuary. https://www.victoriatarlac.gov.ph/asian-waterbird-census-2026-canarem-lake-bird-sanctuary/

Orella, J., Africa, D. R., Bustillo, C. H., Pascua, N., Marquez, C., Adornado, H., & Aguilos, M. (2022). Above-and-belowground carbon stocks in two contrasting peatlands in the Philippines. *Forests, 13*(2), 303. https://doi.org/10.3390/f13020303

Palma, R.A. (2014). Determination of Aboveground Carbon Density of Mangium (*Acacia mangium* Willd.) using Biomass Expansion Factor. *Mindanao Journal of Science and Technology, 12*, 39-50.

Pansit, N.R. (2019). Carbon Storage and Sequestration Potential of Urban Trees in Cebu City, Philippines. *Mindanao Journal of Science and Technology, 17*, 98-111.

Parilla, R. (2018). Carbon Storage and Sequestration by Selected Tree Species in the University of San Carlos – Talamban Campus' (USC-TC) Nature Park, Cebu City, Philippines. CNU. *Journal of Higher Education, 12*, 15–20. https://jhe.cnu.edu.ph/index.php/ojs3/article/view/20

Patricio, J.H.P., & Dumago, S.W.L. (2014). Comparing Aboveground Carbon Sequestration of Three Economically Important Bamboo Species Grown in Bukidnon, Philippines. *Journal of Multidisciplinary Studies, 3*(1). https://doi.org/10.7828/jmds.v3i1.622

Pelser, P.B., Barcelona, J.F., & Nickrent, D.L. (Eds.). (2011). Co's digital flora of the Philippines. https://www.philippineplants.org

Potschin, M., Haines-Young, R., Fish, R., & R. Kerry Turner. (2016). Routledge Handbook of Ecosystem Services. Routledge. https://www.routledge.com/Routledge-Handbook-of-Ecosystem-Services/Potschin-Haines-Young-Fish-Turner/p/book/9781138025080

Sapnu, R. (2018, February 7). DENR urges public to protect, conserve Central Luzon wetlands. Philippine News Agency. https://www.pna.gov.ph/articles/1024380

Tadese, S. (2019). Above Ground Biomass Estimation Methods and Challenges: A Review. *Journal of Energy Technologies and Policy, 9*(8). https://doi.org/10.7176/jetp/9-8-02

Vashum, K. (2012). Methods to Estimate Above-Ground Biomass and Carbon Stock in Natural Forests - A Review. *Journal of Ecosystem & Ecography, 02*(04). https://doi.org/10.4172/2157-7625.1000116

Venkatappa, M., Anantsuksomsri, S., Castillo, J. A., Smith, B., & Sasaki, N. (2020). Mapping the Natural Distribution of Bamboo and Related Carbon Stocks in the Tropics Using Google Earth Engine, Phenological Behavior, Landsat 8, and Sentinel-2. *Remote Sensing, 12*(18), 3109. https://doi.org/10.3390/rs12183109

Walker, S., Murray, L., & Tepe, T. (2016). Allometric Equation Evaluation Guidance Document. https://winrock.org/wp-content/uploads/2018/08/Winrock-AllometricEquationGuidance-2016.pdf

Wang, Z., Ma, Y., Chen, P., Yang, Y., Fu, H., Yang, F., Raza, M.A., Guo, C., … & Ma, J. (2022). Estimation of Rice Aboveground Biomass by Combining Canopy Spectral Reflectance and Unmanned Aerial Vehicle-Based Red Green Blue Imagery Data. *Frontiers in Plant Science, 13*. https://doi.org/10.3389/fpls.2022.903643

Wu, J., Liu, C., Peng, C., Xie, B., & Liu, Z. (2025). Impacts of Anthropogenic Disturbances on the Functional Traits of Wetland Plants: A Retrospective Review of Studies Conducted Globally over the Past Two Decades. *Ecologies, 6*(4), 85.