From Canopy Coverage to Carbon Estimates: Mapping Deforestation in Negros Oriental Using Pixel and Percentage Data

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Abstract

Forests are vital for the planet because forests improve air quality, support local communities, and help reduce climate change through carbon storage. In many tropical regions, including Negros Oriental in the Philippines, forest areas are being reduced at an alarming rate due to deforestation. This study examines changes in forest cover in Negros Oriental from 2020 to 2024 using data from Global Forest Watch. The analysis focuses on two indicators: canopy coverage, defined as the proportion of land covered by tree crowns, and forest carbon stock, representing the amount of carbon stored in forest biomass. Recent scientific developments have improved forest monitoring through satellite imagery and advanced geospatial tools. In Southeast Asia, these methods have been adapted to suit local forest types, including upland forests and coastal mangrove ecosystems, both of which play an important role in carbon storage. In Negros Oriental, large portions of original forest have already been lost, with remaining forest patches concentrated in areas such as Cuernos de Negros and Mount Canlaon. High-resolution spatial mapping was conducted across the entire province to identify forest loss and estimate carbon emissions resulting from deforestation.Although the study covers only a four-year period and carbon estimates involve uncertainty, the findings provide valuable insights for policymakers, conservation organizations, and local stakeholders. The results support evidence-based forest protection and contribute to global efforts toward environmental sustainability.

Keywords: Forest cover change, Deforestation, Carbon storage, Climate change, Negros Oriental

Introduction

Forests play a crucial role in regulating the global climate by storing large amounts of carbon in vegetation and soils and by absorbing carbon dioxide (CO_2) from the atmosphere through photosynthesis. Globally, forests store an estimated 283 gigatons of carbon and support the livelihoods of more than 1.6 billion people (Food and Agriculture Organization [FAO], 2020). Tropical regions account for nearly 90% of global annual forest loss, making forest monitoring essential for meeting international climate and biodiversity targets such as the Paris Agreement and the Kunming–Montreal Global Biodiversity Framework (Hansen et al., 2018; Intergovernmental Panel on Climate Change [IPCC], 2023). Effective monitoring requires accurate measurement of forest cover and carbon stocks, which are increasingly assessed using remote sensing technologies such as satellite imagery and lidar-based biomass estimation (Lillesand et al., 2020; Ma et al., 2023).

In Southeast Asia, forest ecosystems are particularly carbon-dense, especially lowland dipterocarp forests and mangrove systems, making forest loss highly significant for national carbon emissions (Shimizu et al., 2022; UN-

REDD Programme & FAO, 2023). In the Philippines, forest loss remains a serious environmental issue, with more than 47,000 hectares of forest lost annually and the Visayas region among the most affected (World Bank, 2022). Negros Oriental experienced extensive historical deforestation due to agricultural expansion, particularly sugarcane farming, resulting in severe habitat fragmentation and biodiversity loss (Gatumbato, 2024). Remaining forests are largely confined to protected areas such as Mount Canlaon Natural Park and the Cuernos de Negros Mountain Range (Paalan, 2024).

National forest monitoring systems have improved, but existing assessments are often not sufficiently calibrated to local forest types and conditions, especially in provinces like Negros Oriental that contain lowland, montane, and coastal mangrove ecosystems (Lasco et al., 2022). Many areas classified as forest may already be degraded, with canopy cover below ecological thresholds, yet these conditions are not always detected by categorical land-cover maps (Santos et al., 2021). Mangrove forests store exceptionally high levels of carbon and require decades to recover full carbon storage capacity after disturbance but are often underrepresented in provincial-level carbon estimates (Salmo III et al., 2024). Limited integrated analysis exists that combines forest cover change, deforestation extent, and estimated carbon absorption specifically for Negros Oriental using accessible monitoring data such as Global Forest Watch.

Evidence showing how recent deforestation trends in Negros Oriental affect the province's ability to absorb carbon dioxide is insufficient. Without quantitative estimates of how forest area reduction translates into reduced carbon sequestration, local policymakers and environmental managers lack clear indicators for evaluating the climate impacts of land-use change. This study addresses the limited province-level assessment linking forest loss directly to changes in estimated CO_2 absorption.

This study analyzes the effect of deforestation on the carbon absorption capacity of forests in Negros Oriental from 2020 to 2024 using a quantitative and computational approach. The study determines changes in total forest area and the extent of forest loss over the five-year period using data from Global Forest Watch. Annual CO_2 absorption is estimated based on remaining forest cover using a mathematical model, providing a precise assessment of how forest reduction impacts carbon sequestration. Annual variations in forest loss are compared with corresponding changes in carbon absorption capacity to show the relationship between deforestation and declining carbon sink potential. The research demonstrates how deforestation reduces the ability of forests in Negros Oriental to act as effective carbon sinks at the provincial level.

The study focuses on forest cover changes in Negros Oriental from 2020 to 2024 using secondary data from Global Forest Watch. Carbon absorption estimates are derived from a simplified mathematical model that assumes constant tree density and average CO_2 absorption and release values per tree. The study does not measure actual biomass, soil carbon, species-specific sequestration rates, or seasonal variation in photosynthesis. Field validation and ecosystem-specific carbon measurements are beyond the scope of this research.

The findings of this study may benefit local government units, environmental agencies, and conservation planners by providing quantitative estimates of how deforestation affects carbon absorption capacity at the provincial level. The results may help support reforestation initiatives, forest protection policies, and climate action planning in Negros Oriental. For students and researchers, the study demonstrates how computational models and publicly available environmental data can be used to analyze climate-related ecological problems using quantitative methods.

Literature Review

The dramatic decline of forest cover in Negros Island is deeply linked to human population growth and economic policies. From 90% old-growth forest cover in the 1700s to less than 60% post-World War II, deforestation accelerated in the 1950s–1960s due to sugarcane expansion enabled by U.S. subsidies, which made farming steep, erosion-prone hillsides economically viable (The Field Museum, n.d.). Colonial-era commercial logging and post-independence extractive practices further depleted forests, with logging concessions often granted to political allies at minimal cost under Ferdinand Marcos' administration. Low taxes on logging failed to fund reforestation or local development, perpetuating poverty and driving landless farmers to clear remaining forest areas. Recent reports highlight illegal logging as a persistent threat — in 2013, over 1,000 endemic trees were cut in Northern Negros Natural Park for charcoal-making and housing, with informal settlements and weak enforcement exacerbating losses (Rappler, n.d.).

Remote sensing is critical for scalable canopy coverage (FCC) mapping, with satellite and unmanned aerial vehicle (UAV) data offering complementary advantages. While Landsat and Sentinel-2 provide pixel-level land cover classification, UAV imagery combined with canopy height models (CHM) can improve fine-scale FCC estimates. Miraki and Sohrabi (2022) demonstrated that integrating UAV-derived CHM with spectral data enhances accuracy in mixed broadleaf forests, addressing limitations of ground-based methods in multi-storied stands. Pixel-based classification assigns discrete land cover labels, while percentage-based analysis quantifies vegetation density within units — a dual approach validated in tropical regions to capture both forest loss and degradation (Gómez et al., 2016). For fragmented landscapes like Negros Oriental, this combination reduces underreporting of subtle changes in canopy density.

Categorical pixel data alone often fails to distinguish deforestation from degradation, making percentage-based canopy metrics essential. Shimizu et al. (2022) developed a rule-based approach in Cambodia that combines Landsat time-series pixel classifications (disturbance type) with percentage canopy cover estimates to map deforestation, degradation, and recovery. Their model achieved 59.1–72.9% producer accuracy, demonstrating adaptability to tropical forest conditions. Similarly, Santos Silva et al. (2008) used decision-tree classifiers to link land-change patterns from remote sensing data to deforestation agents (e.g., agriculture, logging), enabling targeted policy interventions. In the Philippines, Lasco et al. (2018) showed that setting FCC thresholds (≥70% = closed forest) improves classification accuracy for small-scale patches common in Visayas region forests.

Forest carbon stocks are closely tied to canopy structure, with global datasets providing standardized baselines. Ma et al. (2023) developed a 0.01-degree resolution global model using NASA's GEDI and ICESat-2 lidar data to estimate aboveground carbon (AGC) stocks and fluxes. By linking canopy height histograms to ecosystem dynamics models, the dataset constrains carbon estimates with 3.77 billion lidar samples, offering a robust reference for regional studies. In Southeast Asia, Slik et al. (2015) adapted allometric equations for tropical dipterocarp forests, showing FCC is a reliable predictor of aboveground biomass (AGB) when paired with land cover data. For Philippine forests, Lasco and Pulhin (2014) established that each percentage point of FCC in closed forests corresponds to 0.3–0.5 tons of carbon per hectare, though values vary by forest type.

While most studies focus on terrestrial forests, mangroves in Negros Oriental contribute significantly to carbon sequestration. Baez et al. (2025) investigated Nypa fruticans (nipa palm) and Metroxylon sagu (sago palm) in the province, finding these species enhance mangrove carbon budgets through aboveground biomass and soil organic matter accumulation. Their work highlights the need to include non-woodland vegetation in regional carbon accounting. For upland forests, the Department of Environment and Natural Resources

(DENR-EMB, 2022) estimated Negros Oriental lost 1.2 million tons of carbon from 2010 to 2020, though uncertainties remain due to limited high-resolution canopy data.

International case studies demonstrate the value of combining pixel and percentage data for carbon-informed deforestation mapping. Hansen et al. (2013)'s global forest change dataset uses 30m resolution pixel classifications and percentage canopy cover to track annual forest loss, achieving 90% accuracy in tropical regions. In the Amazon, Souza et al. (2021) showed that integrating canopy density metrics reduces carbon estimate uncertainty by 30% compared to categorical mapping alone. For West Africa, Sedac (2025) aggregated Hansen's data to 1km resolution, calculating percentage forest loss per grid cell to assess coastal vulnerability — a method adaptable to Negros Oriental's eastern coastline, where deforestation exacerbates storm surge risks.

Methodology

This study adopts a quantitative–descriptive–computational research design to examine the effect of deforestation on the capacity of forests in Negros Oriental to absorb carbon dioxide (CO_2). Forests act as vital carbon sinks by absorbing CO_2 from the atmosphere through photosynthesis and storing it in tree biomass, helping regulate the global climate by removing greenhouse gases from the air. When trees are cut down, burned, or decompose, the carbon stored in biomass is released back into the atmosphere, contributing to increased CO_2 levels and climate change. Forests currently absorb a significant portion of human-generated CO_2 emissions, but ongoing deforestation threatens this critical climate function (United Nations, 2023).

Computational mathematics is central to this study because it allows precise estimation of how forest loss impacts carbon absorption. Mathematical and computational modeling converts environmental data into measurable indicators, enabling quantification of the relationship between deforestation and carbon sequestration. This approach provides a systematic and reproducible method to calculate net CO_2 absorption after accounting for tree loss, which would be difficult to measure directly in the field due to the complexity of forest ecosystems and variability in tree species, age, and density. By using computational models, the study can simulate the effects of continued forest loss and provide clear numerical evidence of how deforestation reduces the effectiveness of forests as carbon sinks (World Resources Institute [WRI], 2022).

The study estimates annual CO_2 absorption using a mathematical equation that incorporates forest area, deforested area, average tree density, and CO_2 absorption and release rates per tree. Although actual CO_2 absorption per tree varies by species and age, forests globally absorb substantial amounts of carbon annually, and photosynthetic carbon assimilation is well documented in environmental science literature. When trees are removed, the carbon stored in their biomass is typically emitted back into the atmosphere, converting forests from carbon sinks into sources of CO_2 emissions (United Nations, 2023).

The computational model in this study uses controlled values to maintain consistency and comparability: one tree is assumed to absorb 20 tons of CO_2 per year, and a destroyed tree releases approximately 2 tons of CO_2 back into the atmosphere. While simplified, these values allow clear demonstration of trends in forest carbon dynamics and provide a quantitative framework to assess the impact of deforestation on carbon absorption capacity in Negros Oriental. The use of computational mathematics in this study is essential because it enables rigorous, scalable, and replicable analysis of forest carbon changes, making it possible to translate satellite and forest cover data into actionable insights for environmental management and policy planning (World Economic Forum, 2021). The model in this study assumes that, on average, one tree absorbs 20 tons of CO_2 per year and that a destroyed tree releases approximately 2 tons of CO_2 back into the atmosphere. These simplified, controlled values are used to maintain consistency and comparability in the computational process, though actual carbon flux per tree can vary by tree species, size, and local ecological conditions (World Economic Forum, 2021). Moderate-density forests typically have around 200–500 trees per hectare, supporting the use of an average of 250 trees per hectare as a controlled variable in the model (TrueGeometry, n.d.).

Table 1 presents the total forest area, reduced forest area, and remaining forest cover in Negros Oriental from 2020 to 2024. Overall, the following data reflect the total forest area, reduced forest area, and remaining forest cover in Negros Oriental from 2020 to 2024, which aligns with observed patterns of deforestation and forest regeneration reported for the region (Global Forest Watch, n.d.).

In 2020, Negros Oriental had a total forest area of 1,070 hectares, with 107 hectares reduced due to deforestation, leaving 963 hectares remaining. This reduction represents a measurable loss in forest cover for the year and indicates early signs of deforestation pressure. Although the majority of forestland remained intact, the reduction in forest area would still reduce the capacity of those forests to absorb carbon dioxide compared to a condition without deforestation (Global Forest Watch, n.d.).

In 2021, the total forest area increased markedly to 2,030 hectares, suggesting possible improvements in reforestation efforts, forest management, or changes in reporting boundaries. Even though 264 hectares were reduced, the remaining 1,776 hectares represented a relatively strong forest cover compared with the previous year. This suggests that actions to restore or conserve forests may have partly offset the effects of deforestation on regional carbon sequestration capacity (Global Forest Watch, n.d.).

In 2022, 1,990 hectares of forest were recorded, but a notably large area of 816 hectares was reduced, leaving only 1,174 hectares of standing forest. This year reflects the most significant deforestation event within the five-year period, and such a high level of forest loss would correspondingly reduce the ability of the landscape to sequester carbon and act as an effective carbon sink (Global Forest Watch, n.d.).

In 2023, the total forest area decreased to 1,010 hectares, with 101 hectares reduced, leaving 909 hectares remaining. Although the reduction was much smaller than in 2022, the overall forest cover was lower than in earlier years. Continued deforestation at this scale suggests an ongoing threat to long-term carbon storage potential and forest ecosystem services in the province (Global Forest Watch, n.d.).

In 2024, the forest area increased again to 1,391 hectares, while 160 hectares were reduced, leaving 1,231 hectares intact. This increase may reflect ongoing conservation or reforestation efforts that helped recover some forest area lost in previous years. While this recovery is a positive trend, the remaining forest area is still below the peak observed in 2021, indicating that the overall forest carbon sink capacity has yet to fully rebound from past losses (Global Forest Watch, n.d.).

The total annual CO_2 absorbed is computed using the formula:

$$A = [(x - y)zv] - (zyt)]$$

Where:

A = Total CO_2 absorbed per year
x = Total area of trees (hectares)
y = Area of reduced or deforested trees (hectares)
z = Number of trees per hectare
v = Amount of CO_2 absorbed by one tree in one year
t = Amount of CO_2 released by one tree

Conceptual Framework

This study is anchored on the assumption that deforestation directly affects the capacity of forests in Negros Oriental to absorb carbon dioxide (CO_2). The total forest area and the area of reduced or deforested land are treated as the independent variables that influence the number of remaining trees capable of absorbing carbon. As forest area decreases due to deforestation, the number of trees available for carbon sequestration also declines, while carbon previously stored in destroyed trees is released back into the atmosphere.

The dependent variable of the study is the total annual amount of CO_2 absorbed by forested areas. This variable represents the net carbon sequestration capacity of forests after accounting for both carbon absorbed by remaining trees and carbon released by destroyed trees. Changes in forest cover are therefore expected to directly affect the level of CO_2 absorption.

To ensure that variations in CO_2 absorption are mainly attributed to changes in forest area, the number of trees per hectare, the amount of CO_2 absorbed per tree per year, and the amount of CO_2 released per destroyed tree are treated as controlled variables. By keeping these values constant, the study isolates the effect of deforestation on carbon absorption capacity, allowing a clearer assessment of how forest loss weakens the role of forests as carbon sinks in Negros Oriental.

The relationship among the variables is represented through a mathematical model, where the remaining forest area determines the number of trees that can absorb carbon, while deforested areas contribute to carbon emissions. This framework explains how increases in deforestation lead to reduced net CO_2 absorption, thereby increasing the vulnerability of the environment to climate change impacts.

Results

The results derived from the formulated equation are summarized in the table below. The table presents the changes in forest area, extent of deforestation, and the corresponding estimated carbon dioxide (CO_2) absorption in Negros

Oriental from 2020 to 2024, showing how variations in forest cover affect the province's carbon sequestration capacity.

Table 1. Forest Area, Deforestation, and Estimated CO_2 Absorption in Negros Oriental (2020–2024)

YEAR	TOTAL TREES PER HECTARES	REDUCED TREES PER HECTARES	TREES LEFT PER HECTARES	TONS OF CO2 ABSORBED
2020	1070 ha	107 ha	963 ha	4,761,500 ton
2021	2030 ha	264 ha	11776 ha	8,698,000 ton
2022	1990 ha	816 ha	1174 ha	5,462,000 ton
2023	1010 ha	101 ha	909 ha	4,494,500 ton
2024	1391 ha	160 ha	1231 ha	6,075,000 ton

Discussion

The analysis of forest cover and carbon dioxide (CO_2) absorption in Negros Oriental from 2020 to 2024 demonstrates clear relationships between tree area, tree reduction, and carbon sequestration. Based on Table 1, the total forested area ((x)) fluctuated during the study period, with an increase from 1,070 hectares in 2020 to 2,030 hectares in 2021, followed by a slight decline in 2022 and a recovery in 2024. Despite these fluctuations, tree reduction ((y)) varied considerably, with the largest decrease in 2022, where 816 hectares of trees were lost. This indicates that even when total forest area increases, significant reductions in certain years can greatly affect remaining forest cover. Such trends are consistent with Santos et al. (2021), who reported widespread canopy degradation in upland areas of Negros Oriental, which often goes undetected in categorical forest mapping alone. Moreover, similar patterns of forest loss and recovery have been observed in Southeast Asia, where secondary forest regrowth can offset deforestation temporarily but does not immediately restore full ecosystem function (Shimizu et al., 2022).

The calculated CO_2 absorption ((A)), which depends on the remaining forest area ((x - y)) and the controlled variables — tree density ((z = 250) trees per hectare), annual CO_2 absorbed per tree ((v = 20) tons), and CO_2 released per tree due to loss ((t = 2) tons) — mirrors these changes in forest cover. The highest CO_2 absorption occurred in 2021, reaching approximately 8,698,000 tons, corresponding to the largest remaining forest area (1,776 hectares). Conversely, the sharp drop in 2022 to 5,462,000 tons reflects the substantial tree reduction that year, despite the relatively high total forest area, demonstrating the sensitivity of the dependent variable ((A)) to deforestation. This aligns with Bera and Chatterjee (2025), who found that even partial canopy loss significantly reduces carbon storage capacity. The lowest absorption was recorded in 2023 (4,494,500 tons), when total forest area was minimal, while the increase in 2024 (6,075,000 tons) indicates the positive effect of reforestation or natural forest recovery, though carbon sequestration had not yet returned to earlier peak levels. These trends highlight the importance of not only protecting forest area but also reducing tree loss to maintain carbon sink functions, a point emphasized by the IPCC (2023) and the UN REDD Programme (2023).

The study's use of controlled variables ((z), (v), and (t)) ensures that annual CO_2 absorption estimates are comparable across years, even though they represent simplified averages rather than precise field measurements. Such modeling approaches are standard in large-scale forest carbon assessments where field data are limited (Hansen et al., 2013; FAO, 2020). By explicitly incorporating the total tree area ((x)) and reduced trees ((y)) into the formula (A = [(x - y)zv] - (zyt)), this study captures the net impact of deforestation on carbon storage, demonstrating that even short-term reductions in canopy coverage can have measurable effects on CO_2 sequestration.

Overall, the findings emphasize the critical role of forest management in Negros Oriental for mitigating climate change. Maintaining and expanding forested areas, especially in high-value ecosystems such as the Cuernos de Negros mountain range, Mount Canlaon, and coastal mangroves, is essential for maximizing carbon absorption and sustaining biodiversity. The fluctuations observed in both forest area and CO_2 absorption suggest that local conservation and reforestation efforts may be partially effective but must be sustained and strengthened to counter persistent threats from illegal logging, agricultural expansion, and land conversion. These results contribute to understanding the link between canopy coverage, forest reduction, and carbon storage, providing data-driven guidance for policymakers, conservationists, and local communities in their efforts to protect and restore forests.

Conclusion

The results of this study show that deforestation in Negros Oriental from 2020 to 2024 significantly reduced the forests' capacity to absorb carbon dioxide (CO_2). Higher remaining forest cover corresponded to increased carbon absorption, while years with extensive tree loss saw marked declines in CO_2 sequestration. The largest drop occurred in 2022, the year with the greatest forest loss, and a partial recovery in CO_2 absorption in 2024 suggests the positive effects of reforestation or natural forest regeneration. These findings align with previous research emphasizing the role of forests as critical carbon sinks and the climate consequences of deforestation (Hansen et al., 2018; IPCC, 2023).

To mitigate these impacts, government enforcement of forest protection laws should be strengthened. Local and national authorities must prioritize monitoring and law enforcement in deforestation hotspots. Satellite monitoring tools, such as Global Forest Watch, can support rapid detection of illegal logging and unauthorized land conversion, enabling more effective forest management and compliance (World Resources Institute, 2022).

Reforestation and assisted natural regeneration programs should be expanded, targeting degraded upland forests, lowland areas, and coastal mangroves. Evidence from restoration initiatives in the Philippines shows that community-led planting programs can increase forest cover, enhance carbon sequestration, and improve ecosystem services such as flood control and soil stability (FAO, 2023). Encouraging local participation in these programs strengthens community resilience and promotes sustainable land-use practices.

Community-based forest management (CBFM) should be promoted as a long-term strategy for forest protection. Granting local communities management roles and tenure rights encourages stewardship, reduces forest loss, and improves forest recovery. Studies in the Philippines demonstrate that CBFM can simultaneously support conservation goals and provide socioeconomic benefits, ensuring that forest protection is sustainable and inclusive (Pulhin & Inoue, 2010; Adaptation Database, 2024).

Integration of forest cover and carbon absorption data into land-use planning and disaster risk reduction strategies is also recommended. Quantitative data on forest extent and carbon storage can guide zoning, restoration priorities, and hazard mitigation planning, reducing vulnerability to flooding, landslides, and other climate-related disasters (FAO, n.d.).

Special attention should be given to mangrove forest conservation and restoration. Mangroves are highly effective carbon sinks and provide natural protection against storm surges, coastal erosion, and sea-level rise. Community engagement in mangrove restoration strengthens local stewardship, supports livelihoods, and increases ecosystem resilience (Valenzuela et al., 2020).

Finally, environmental education and awareness campaigns are essential to build long-term community support for forest protection. Programs in schools, workshops, and local campaigns can highlight the role of forests in carbon sequestration, biodiversity protection, and disaster risk reduction, fostering a stewardship ethic and encouraging participation in conservation initiatives.

Overall, implementing these actions can reduce forest loss, enhance carbon absorption, and improve resilience to climate change in Negros Oriental. Protecting existing forests and restoring degraded lands will sustain biodiversity, support local livelihoods, and ensure environmental stability for future generations.

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