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Mangrove cover change analysis of Sibuyan Island, Romblon, Philippines

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ABSTRACT. Mangrove forests are one of Earth's most productive and adaptable ecosystems, offering nature-based climate change mitigation and adaptation solutions. However, these forest habitats are experiencing rapid loss, and studies supporting their conservation are still emerging. This study used a geospatial analysis approach to assess the cover change of a critical mangrove reserve: Sibuyan Island, Romblon, Philippines, between 2010 and 2020. Normalized Difference Vegetation Index (NDVI) analysis was performed using radiometrically corrected Landsat 7 and 8 scenes through ArcGIS to determine the island's spatiotemporal changes in mangrove area by vegetation density (bare, sparse, and dense). The accuracy of NDVI images was computed using an error matrix, which showed high accuracy in the classification process. Results showed that over the 10 years, the mangrove area increased by 182.8 ha. The dense vegetation increased by 6.0% yr^{-1}, while bare and sparse vegetation decreased annually by 26.7% and 10.1%, respectively. Rehabilitation programs and the strict implementation of mangrove protection and management policies are the likely drivers of change. Consequently, sustaining these efforts is vital to conserving Sibuyan mangrove forests and preserving its benefits to the global climate and the local community.

Keywords: climate change, geospatial analysis, mangrove vegetation density changes, Normalized Difference Vegetation Index

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INTRODUCTION

Mangroves are salt-tolerant plants that grow within marine intertidal zones of the tropics and subtropics (Long & Giri, 2011). They thrive in both salt and brackish environments. Globally, about 4 to 20 billion tons of carbon (tC) are stored in mangrove forests (Donato *et al*., 2011). This makes them a nature-based and cost-effective means of reducing atmospheric carbon emissions. Moreover, they help maintain ecological balance, providing habitats and spawning grounds for fishes and other marine and terrestrial fauna. For instance, they protect coastal communities from the effects of climate change (*e.g.*, storm surges) and provide income and subsistence to coastal dwellers. However, despite the importance of coastal wetlands, they are among the most endangered ecosystems. They are experiencing significant reduction due to factors like urbanization, poor land use management, and warming oceans (Pulhin *et al*., 2017; The Pew Charitable Trusts, 2019). As a tropical country with abundant rainfall, the Philippines has rich and biodiverse mangrove forests. However, its cover has significantly declined from about 500,000 ha in 1920 (Brown & Fischer, 1920; Chapman, 1976; Garcia *et al*., 2014) to around 300,000 ha in 2015 (FMB, 2020).

One of the country's last remaining gateways of biodiversity and a critical mangrove site is the Sibuyan Island in Romblon Province. Declared as a Mangrove Swamp Forest Reserve in 1981, the island holds a significant potential for contributing to the country's efforts in mitigating climate change. Despite the growing literature on the carbon stocks and changes in Philippine mangroves, there is a dearth of data on Sibuyan, which merits exploration and research for the conservation and management of its mangroves.

This study intended to detect the vegetation cover change of mangroves along the coastlines of Sibuyan Island over time. A NDVI analysis was employed using radiometrically corrected Landsat 7 and 8 scenes through ArcGIS to achieve this objective. While Landsat 7 and 8 and the NDVI have been in the literature for forest cover change detection for quite some time, few studies use them for mangroves in the tropics and the Philippines alone. Hence, their application in this study. Specifically, the paper aimed to 1) assess the change in the mangrove areal extent of Sibuyan Island between 2010 and 2020 using a geospatial analysis approach, 2) describe the mangrove vegetation density changes of Sibuyan Island between 2010 and 2020, and 3) recommend strategies for mangrove conservation of Sibuyan Island.

METHODOLOGY

Study location

Sibuyan Island is located at Romblon Province, Region IV–B, Philippines. The island comprises three municipalities: Magdiwang, Cajidiocan, and San Fernando (**Figure 1**). At its broadest point, it extends 28 km east to west and 24 km north to south, with a land area of 44,500 ha surrounded by deep sea (Verburg & Veldkamp, 2004).

Methodological framework

Changes in the mangrove cover and vegetation density were determined following the methodological framework in **Figure 2**.

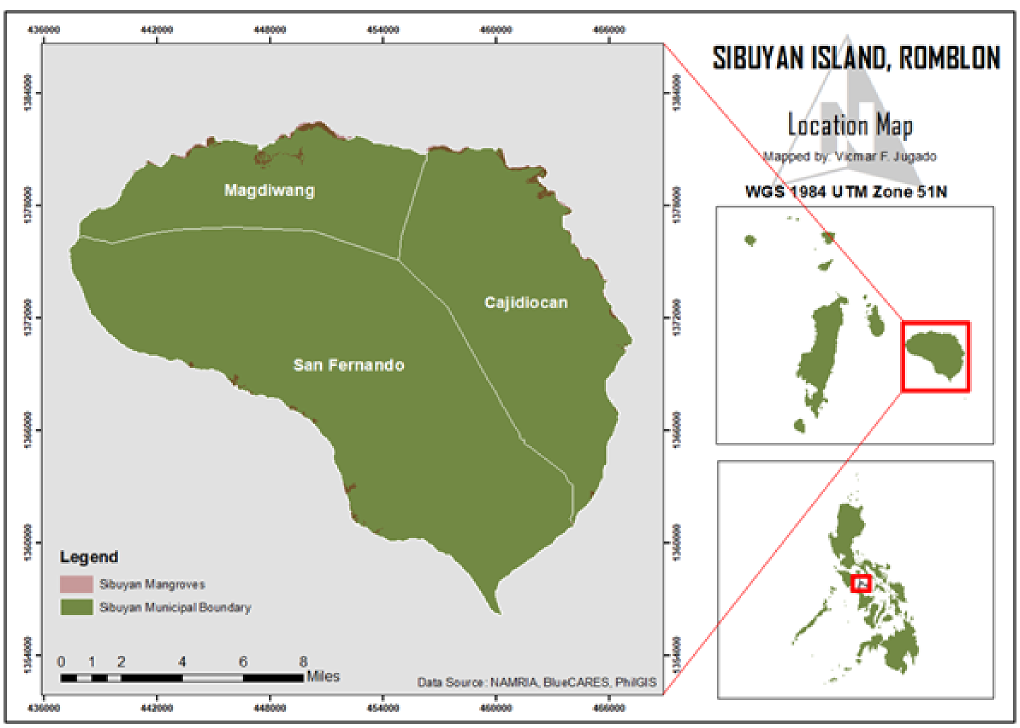

Figure 1. Location map of Sibuyan Island, Romblon (Source: NAMRIA, BlueCARES, and PhilGIS).

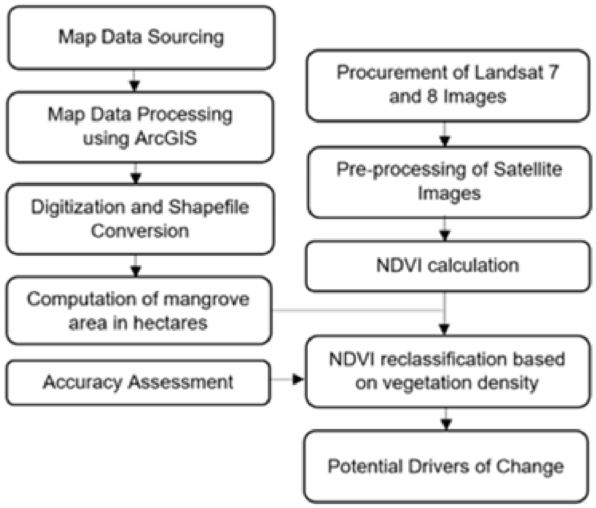

Figure 2. The methodological framework of the study both for 2010 and 2020 (modified from Nesperos *et al*., 2021).

The remote sensing and mapping methodology employed by Nesperos *et al*. (2021) served as the methodological framework for this study. The mangrove area extent was assessed using map data and Google Earth's manual digitization. NDVI analysis was then performed to characterize the vegetation density changes. Lastly, potential drivers of change were identified, which helps recommend possible mangrove conservation strategies.

Data collection

Map data sourcing

Land cover maps were sourced from NAMRIA (2010 and 2020) to identify and validate the locations and areas of mangroves in Sibuyan Island. In addition, map data from the Philippine Mangrove Extent 2019 Layer developed by Baloloy *et al*. (2020) under the Comprehensive Assessment and Conservation of Blue Carbon Ecosystems and their Services in the Coral Triangle (BlueCARES) Project complemented the evaluation. Shapefiles of the provincial and municipal boundary of Romblon were obtained from the PhilGIS website and were clipped to the land cover maps. The maps were processed using ArcGIS (V.10.5) and were projected first to a WGS 1984 geographic coordinate system to achieve a common projection.

Map digitization

Map digitization was performed using Google Earth Pro (version 7.3). The mangrove areas within the study site were extracted from the processed land cover maps and were exported as a KML file to Google Earth Pro to serve as an outline for manual digitization. Vegetation boundaries were traced point by point to form a polygon (see sample digitization in **Figure 3**). The digitized polygons were further converted into shapefiles in ArcGIS and later processed for NDVI analysis. Subsequently, the total mangrove area was computed from the area measurement of the polygons in the attribute table both for 2010 and 2020 using the Calculate Geometry tool of ArcGIS.

Satellite image and meteorological data procurement

Calculation of NDVI requires imagery that contains red and near-infrared bands. For this

Figure 3. Sample digitization of a mangrove area in Sibuyan, Romblon (Image retrieved from Google Earth Pro V.7.3).

purpose, Landsat scenes for Sibuyan Island were acquired from the United States Geological Survey (USGS) Earth Explorer website. Specifically, Landsat 7 Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) images for 2010 and 2020, respectively, were obtained. These raster images were selected based on availability and the least amount of cloudiness to avoid estimation errors in the NDVI analysis. Information and details on these satellite images are summarized in **Tables 1** and **2**.

Table 1. Remotely sensed data used in the study.

Image used	Path/Row	Resolution (m)	Land cloud cover (%)
Landsat 7 ETM+	115/51	30	<10
Landsat 8 OLI/TIRS	115/51	30	<10

Table 2. Comparison of Landsat-7 ETM+ and Landsat-8 OLI/TIRS spectral bands (Li *et al*., 2014).

Landsat–8 OLI and TIRS		Landsat–7 ETM+		Spatial resolution (m)
Band	Wavelength (μm)	Band	Wavelength (μm)	
Band 1–Coastal aerosol	0.43–0.45	NA	--	30
Band 2–Blue	0.45–0.51	Band 1	0.45–0.52	30
Band 3–Green	0.53–0.59	Band 2	0.52–0.60	30
Band 4–Red	0.64–0.67	Band 3	0.63–0.69	30
Band 5–Near–infrared (NIR)	0.85–0.88	Band 4	0.77–0.90	30
Band 6–Short–wave infrared (SWIR 1)	1.57–1.65	Band 5	1.55–1.75	30
Band 7–Short–wave infrared (SWIR 2)	2.11–2.29	Band 7	1.55–1.75	30
Band 8–Panchromatic	0.50–0.68	Band 8	0.52–0.90	15
Band 9–Cirrus	1.36–1.38	NA	--	30
Band 10–Thermal infrared (TIRS) 1	10.60–11.19	Band 6	10.40–12.50	TIRS/ ETM+: 100/60 * (30)
Band 11–Thermal infrared (TIRS) 2	11.50–12.51			

** ETM+ band 6 and TIRS thermal bands are acquired at 60m and 100m resolutions, respectively, but all are resampled to 30 m pixels in the delivered data product.*

Data processing

Pre-processing of satellite images

The acquired satellite images were pre-processed for calculating NDVI values. The pre-processing involved radiometric correction for converting digital number (DN) values to surface reflectance (Patil *et al*., 2015). Converting digital numbers into radiance is a prerequisite in compiling numerous sensory inputs (Chander & Markham, 2003). Additionally, as solar irradiances are modified and improved, radiometric correction via radiance conversion to Top-of-atmosphere (TOA) reflectance renders Landsat scenes relatively more straightforward (Nesperos *et al*., 2021). The conversion of DN values to TOA reflectance was performed using the SCP Plugin of the QGIS software.

NDVI computation

After pre-processing, the output generated is the final surface reflectance Red and Near-infrared (NIR) bands and is ready for NDVI computation (Patil *et al*., 2015). NDVI was calculated in ArcGIS using the standard equation:

$$\mathrm{NDVI} = (\mathrm{NIR}-\mathrm{Red})/(\mathrm{NIR}+\mathrm{Red}) \qquad \text{(Eq. 1)}$$

For the 2010 satellite image from Landsat 7, NDVI was computed using Bands 4 and 3, corresponding to the NIR and Red bands, respectively.

$$\mathrm{NDVI} = (B4-B3)/(B4+B3) \qquad \text{(Eq. 2)}$$

On the other hand, the 2020 satellite image has Bands 5 and 4 used for the calculation of NDVI, and the corresponding formula is as follows:

$$\mathrm{NDVI} = (B5-B4)/(B5+B4) \qquad \text{(Eq. 3)}$$

NDVI reclassification

Processed NDVI images for the Sibuyan mangroves were reclassified into three indices for identifying vegetation densities: bare, sparse, and dense mangrove cover (**Table 3**). These vegetation densities are used in this study to describe the condition of vegetation in mangrove habitats. Hence, bare and sparse covers pertain to open or barren lands and partially vegetated areas. Meanwhile, dense cover refers to vegetated mangrove areas that are either adults or older than the sapling stage and are commonly above the index of 0.5 to a fully vegetated area (Gevaña *et al*., 2015; Nesperos *et al*., 2021).

Table 3. Reclassified NDVI.

Mangrove vegetation density	NDVI range
Bare	0.00–0.10
Sparse	0.11–0.50
Dense	0.51–1.00

The annual rate of change of forest cover between the two time periods was computed using the equation developed by Puyavaud (2003):

$$r = \left(\frac{1}{T2 - T1} \right) * \ln \frac{A2}{A1} \qquad \text{(Eq. 4)}$$

where: A = area (ha) and T = time (year)

Accuracy assessment

Assessing accuracy is necessary to determine the quality of the information derived from remotely sensed data. The accuracy of the reclassified NDVI images was evaluated using an error matrix and was calculated using the overall accuracy percentage and Kappa coefficient. Commission error (User's Accuracy) and Omission error (Producer's Accuracy) were also computed accordingly. Ground truth points representative of each vegetation density class were randomly generated in the ArcGIS software and were validated using Google Earth images.

RESULTS AND DISCUSSION

Sibuyan mangroves

Location and extent

Sibuyan Island, in total, has a land area of 44,500 ha. As per the findings, mangrove forests constitute only a tiny portion of the island, spreading along the coastlines of Magdiwang, Cajidiocan, and San Fernando municipalities.

Using the landcover maps from NAMRIA and manual digitization in Google Earth, the mangrove area of Sibuyan in 2010 is estimated to be 299.8 ha. Interestingly, an increase in coverage was observed in 2020, with Sibuyan mangroves having a total area of 482.6 ha. This is roughly 182.8 ha net increase in ten years, with an annual rate of change of 18.3 ha yr^{-1}. Its mangrove area in 2010 represented only 0.67% of the land, and although it expanded in 2020, the mangrove area is still a meager 1.08% of the island's total land area (**Table 4**).

Table 4. Areal extent of Sibuyan mangroves in 2010 and 2020.

Year	Mangrove area (ha)	Percentage (%)
2010	299.8	0.67
2020	482.6	1.08

Vegetation characteristics (species)

The dominant mangrove species belong to the genera *Avicennia*, *Rhizophora*, and *Sonneratia* (Salmo *et al*., 2017). In total, about 14 species of mangroves are reported in the province. Dominant species include Piapi (*Avicennia lanata*), Bungalon (*Avicennia marina*), Bakawan babae (*Rhizophora mucronata*), Bakawan lalaki (*Rhizophora apiculata*), and, Pagatpat (*Sonneratia alba*). Nipa (*Nypa fruticans*) was common along the mangroves' landward and riverine margins.

Mangrove development programs in Sibuyan in 2010–2020

In general, mangrove planting activities and protection policies and programs have been implemented on the island of Sibuyan from 2010 to 2020.

Mangrove planting programs

In 2017, Salmo *et al*. noted that the various national and local government agencies have conducted massive mangrove planting programs in the province, covering about 493.3 ha since 2009. These mangrove rehabilitation initiatives were under projects like the National Greening Program (NGP), Mangrove Reforestation through Food for Work/Cash for Work, and Plant Now, Pay Later Program, among others. Most of the species planted include: *Avicennia* (Piapi and Bungalon); *Rhizophora* (Bakauan babae, Bakauan lalaki); and *Sonneratia* (Pagatpat). **Table 5** shows the list of planting activities for mangrove rehabilitation programs from national and local initiatives recorded in Sibuyan Island, covering a total land area of about 340 ha.

Considerations in planting, such as choosing suitable species based on mangrove zones and planting materials with long-term survival instead of short-term survival, are essential to ensure success in these planting programs. According to Salmo *et al*. (2017), the overall status of planted mangroves is in good condition, with an average survival rate of 70%. These mangrove planting programs can be seen as one of the possible reasons for the observed expansion of mangrove forest cover, which is highly evident in the municipalities of Magdiwang and Cajidiocan.

Table 5. Planted mangrove area profile of Sibuyan, Romblon, according to Salmo *et al.* (2017).

Date	Municipality/Barangay	Area planted (ha)
2015	Magdiwang and Cajidiocan (Sibuyan Island) along with Odiongan, Ferrol, Looc, Sta. Fe, Calatrava, and Romblon	11
2013	Magdiwang and Cajidiocan (Sibuyan Island) along with Romblon, San Agustin, Looc, Sta. Fe, Ferrol, Alcantara, Corcuera, and Odiongan	329

Mangrove protection and management

Aside from planting activities, mangrove protection and management through well–implemented spatial policies and land tenures are critical in conserving remaining mangrove forests and enhancing natural regrowth. Salmo *et al*. (2017) mentioned policies and programs related to mangrove protection and management at the study site. These include Proclamation 2152 (declaring Sibuyan Island as Mangrove Swamp Forest Reserve), Republic Act (RA) 7161 (prohibition on cutting of mangroves), RA 8550 (Philippine Fisheries Code), PD 705 (Revised Forestry Code), Environment and Natural Resources Office (ENRO) Code, Municipal Fishery Ordinance and Resolutions, and Integrated Coastal Management (ICM)/MPA Plans.

Likewise, various agencies exerted efforts in mangrove protection including the Department of Environment and Natural Resources–Provincial Environment and Natural Resources Office (DENR–PENRO), Department of Agriculture–Bureau of Fisheries and Aquatic Resources–Provincial Fisheries Office (DA–BFAR–PFO), Provincial Government–ENRO and Office of the Provincial Agriculturist (OPAG), Municipal Local Government Units–Municipal Agriculture Office (MLGUs–MAO), Barangay Local Government Units (BLGUs), and People's Organizations (POs). In 2015, the Foundation for Philippine Environment (FPE) also adopted Sibuyan Island as a site-focused area to sustain the gains of its Mainstreaming Indigenous People's Participation in Environmental Governance (MIPPEG) project implemented from 2010 to 2014. The Foundation commits to supporting projects to restore and maintain biodiversity in partnership with different institutions, organizations, and stakeholders. Furthermore, mangrove-protected areas have been declared in Sibuyan Island since the 1980s, according to Salmo *et al*. (2017). These protected areas cover about 430.6 ha (**Table 6**).

In 2004, Verburg & Veldkamp described the near–future land use transitions of Sibuyan Romblon. Based on their projections, the strict implementation of forest conservation will further contribute to the observed increase in mangroves on this island. In support of this, Tumaneng *et al*. (2015) mentioned that the area of mobility of subsistent forest gatherers in Sibuyan has been constrained due to access restrictions imposed by protected areas and forestry laws.

Table 6. List of mangrove protected areas in Sibuyan Island, Romblon.

Municipality	Size (ha)
Magdiwang	233.2
Cajidiocan	197.4
Total	430.6

Mangrove cover change analysis

Regarding vegetation density, the increase in dense mangrove vegetation is evident in Sibuyan mangroves. Results of the study shown in **Table 7** and **Figure 4** revealed that in 2010, about 0.9% (2.6 ha) of the mangrove area of Sibuyan was barely vegetated, while roughly 14% (41.5 ha) was sparsely vegetated. In the same year, most of the mangrove area was densely vegetated, but it only amounted to 255.8 ha. After a decade, the dense cover increased to 467.3 ha or about 97% of the mangrove area of Sibuyan in 2020. While a positive net change in forest cover of dense mangroves of Sibuyan was detected from 2010 to 2020, negative changes in bare and sparse vegetation were observed, having annual rates of change of –26.7% and –10.1%, respectively. This can indicate the transformation of some of the bare and sparse areas to dense cover, possibly due to improvement in the growth and protection of these mangrove patches brought by the different programs discussed in the previous section. The areal extent of Sibuyan mangroves also expanded, indicating the possible conversion of non–vegetated areas to mangrove forests. However, it is important to note that converting dense vegetation to sparse and bare vegetation throughout the 10 years was also possible. Ground validation and ground measurements are still needed to confirm these results.

Table 7. The areal extent and the annual forest cover rate change of Sibuyan mangroves according to vegetation density derived from NDVI analysis.

Vegetation density	NDVI value	Mangrove area and percentage				Annual rate of change of forest cover (%)
		2010		2020		
		ha	%	ha	%	
Bare	0.00–0.10	2.61	0.87	0.18	0.04	–26.75
Sparse	0.11–0.50	41.46	13.83	15.13	3.14	–10.08
Dense	0.51–1.00	255.76	85.30	467.31	96.83	6.03
Total	299.83	100.00	482.63	100.00	–	

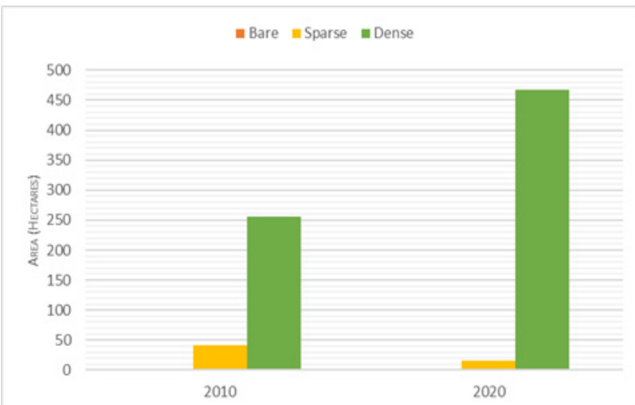

Figure 4. Areal extent of Sibuyan mangrove cover (ha) in terms of vegetation density.

To visualize the changes that occurred in the vegetation and areal extent of Sibuyan mangroves for the two periods, NDVI maps were generated. The reclassified NDVI images were assessed in the ArcGIS software using ground truth points validated via Google Earth. The reclassified 2010 NDVI image obtained an overall accuracy of 90% with an associated Kappa coefficient of 0.85. On the other hand, the reclassified 2020 NDVI image had an overall accuracy of 91.67%, with a Kappa value of 0.85 (**Table 8)**. The accuracy percentages indicate a high classification accuracy rate, and the Kappa values suggest a strong level of agreement between the classified and reference data, with 64–81% of data being reliable, according to McHugh (2012). Sample street and aerial view of the mangroves in terms of vegetation density are presented in **Figures 5 and 6**, respectively.

Table 8. Accuracy of the reclassified NDVI images.

Layer	Overall accuracy (%)	Kappa coefficient
2010	90.00	0.85
2020	91.67	0.85

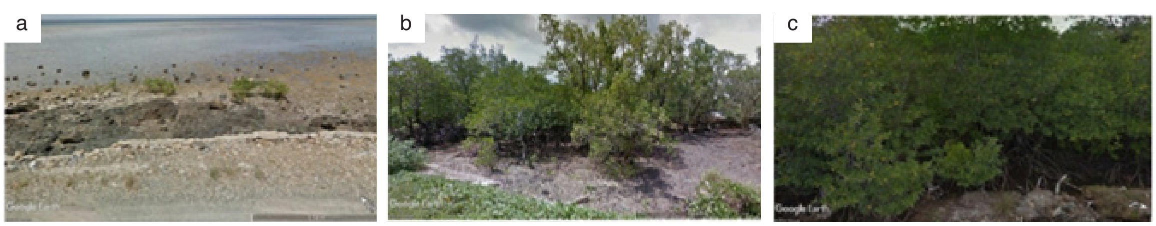

Figure 5. Google Earth Photos of (a) bare, (b) sparse, and (c) dense mangrove vegetation cover of Sibuyan Island (Street View).

Figure 6. Google Earth Photos of (a) bare, (b) sparse, and (c) dense mangrove vegetation covering Sibuyan Island (Aerial View).

The reclassified NDVI maps shown in **Figures 7–9** display dark red for areas with dense vegetation (0.51–1.00), yellow for sparse vegetation (0.11–0.50), and green for bare vegetation (0.00–0.10). The maps visualize the small fraction of the mangrove forests of Sibuyan, which are situated along the coastal boundary of the island. Most of these mangrove areas are in red, representing the high proportion of densely vegetated mangroves. Significant changes can be observed from 2010 (a) to 2020 (b), especially in the municipalities of Magdiwang and Cajidiocan. Specifically, increased mangrove cover was evident along the barangays of (a1 and b1) Ipil, Ambulong, Poblacion, Tampayan; (a2 and b2) Cantagda, Danao, Cambalo; (a3 and b3) Marigondon and Taguilos; as well as in (a4 and b4) España and Taclobo.

CONCLUSIONS AND RECOMMENDATIONS

This study demonstrates the use of Landsat satellite data in detecting and monitoring changes in mangrove cover on an environmentally critical island in the Philippines using NDVI analysis. The findings of this study reveal a significant increase in the mangrove cover and vegetation density on Sibuyan Island over 10 years. This change can be attributed to extensive mangrove planting initiatives carried out by various national and local government agencies in the area, as well as the stringent enforcement of policies related to mangrove protection and management, particularly within designated protection areas. These planting activities and protected areas were concentrated in the municipalities of Magdiwang and Cajidiocan, where significant increases in the mangrove cover were observed.

With these findings, the following are recommended to be undertaken by concerned stakeholders of Sibuyan to conserve and improve its mangrove cover and potential blue carbon:

1. ensure continuity and development of mangrove rehabilitation, protection, and management programs;
2. create long-term sustainable livelihoods for coastal dwellers through nature-based tourism, including fish tourism and marine-based activities;
3. implement effective mechanisms to engage organizations and communities and integrate their efforts toward mangrove protection; and

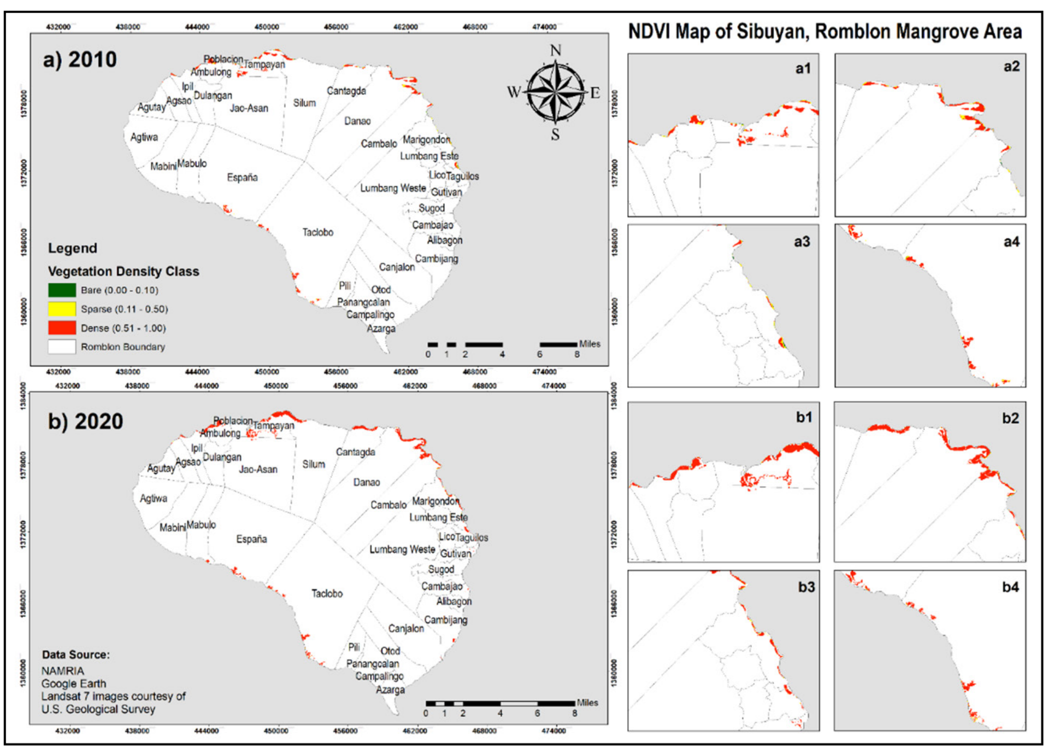

Figure 7. Processed NDVI maps of Sibuyan mangroves with close–up views of vegetation density for the years (a) 2010 and (b) 2020.

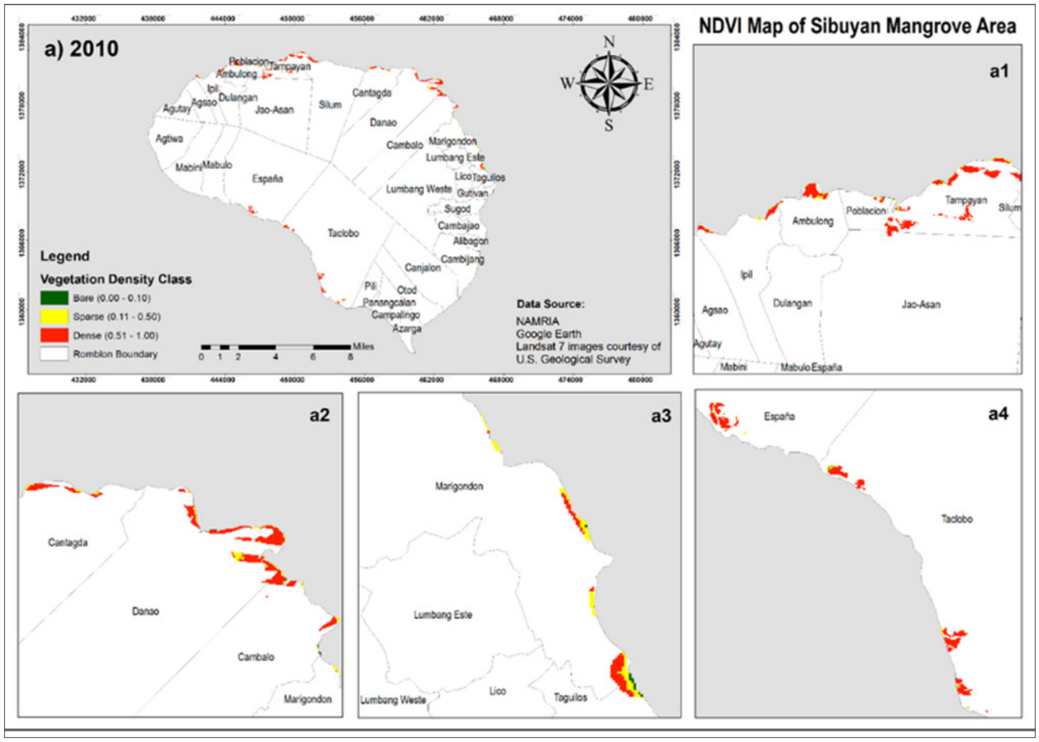

Figure 8. 2010 NDVI map of Sibuyan mangroves with close-up views of vegetation density.

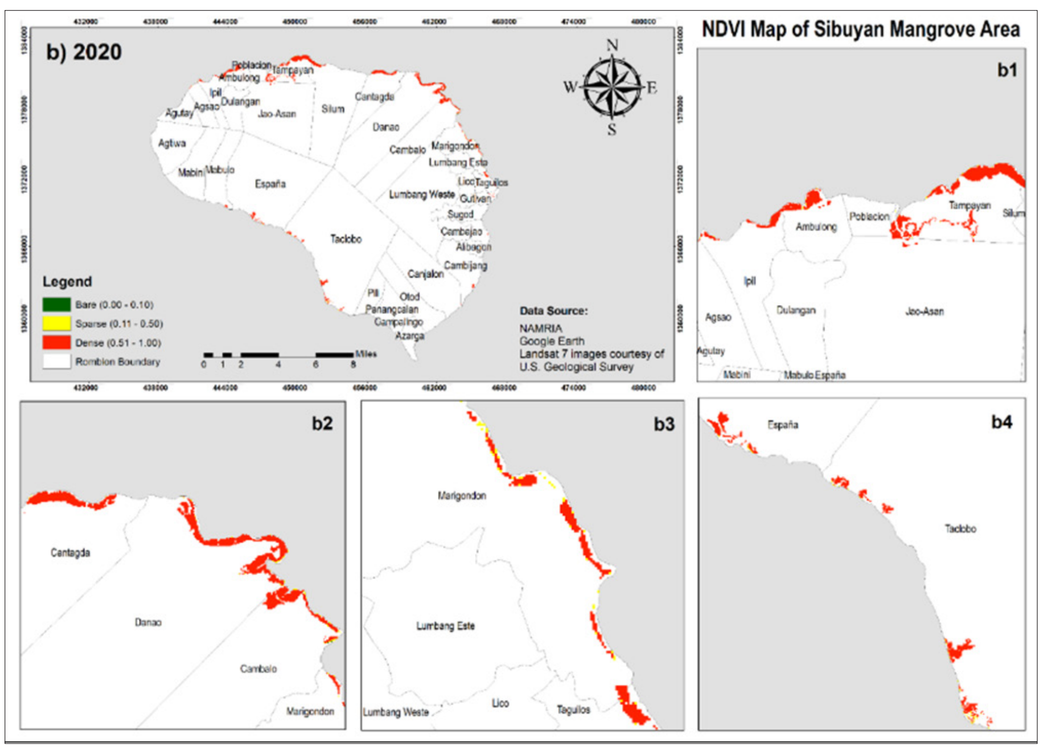

Figure 9. 2020 NDVI map of Sibuyan mangroves with close-up views of vegetation density.

4. boost networks and strengthen financial support for research and extension on the island.

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