SPATIO-TEMPORAL ANALYSIS OF DECADAL MANGROVE COVER AND FRAGMENTATION IN REGION IV-B MIMAROPA, PHILIPPINES

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ABSTRACT:

Mangroves are important vegetation that provides coastal protection and basic life necessities to humans and different marine organisms. Studies have observed that mangrove deforestation is occurring in the Philippines. Thus, monitoring of mangrove extent and fragmentation for rehabilitation planning is necessary to prevent further mangrove cover loss. The utilization of free satellite imagery in mangrove monitoring helps in this enterprise as it reduces the need for expensive field activities. Furthermore, it allows researchers to perform spatio-temporal analyses to observe patterns with respect to time and location. This study analyzed the mangrove loss and growth patterns from 2000 to 2020 in Region IV-B MIMAROPA, Philippines—known to house large amounts of mangrove cover—using Landsat 5, 6, 8. Since fragmentation is associated with deforestation, it was also analyzed using the ZonalMetrics toolbox for ArcGIS Pro 2.8. The results showed that Region IV-B experienced mangrove cover increase with only a few cities/towns that suffered significant deforestation. The change pattern analysis showed that most cities/towns were able to strongly preserve the mangroves, with more mangrove gain than loss. The cities/towns are then categorized for their increasing/decreasing mangrove area and fragmentation in the form of a quadrant. Many of the cities/towns experienced an increase in fragmentation metric values over time. However, the increase in mangrove areas in these cities/towns, especially in areas that previously did not have them, suggests that there is little fragmentation of existing mangrove patches, but rather conversion from non-mangrove land cover to mangrove cover. Still, there are a few towns that do not belong to this category that show signs of deforestation and fragmentation, which needs urgent action.

1. INTRODUCTION

The Philippines holds at least 50% of the world's mangrove species making it one of the most diverse ecosystems (Garcia et. al., 2014). Mangroves provide a source of basic life necessities to different organisms, such as food, shelter, livelihood, and even protection. In the Philippines, mangroves are recognized as a natural mitigating mechanism against storm surge and strong winds due to typhoons (Garcia et. al., 2014). Mangroves are also a source of food, herbal medicines, and other wood and forest products. However, mangrove forest cover in the Philippines has been reduced by almost half from the estimated 500,000 ha. in 1918 (Long and Giri, 2011). There have been practices that have contributed to mangrove deforestation throughout the decade: (1) Aquaculture development wherein ponds were developed for the production of aquatic resources; (2) urbanization caused the replacement of mangrove plantations by fish ponds, settlements, and port infrastructure; (3) cutting mangrove trees were practiced in search for an alternative to fuel and construction. Garcia et.al. (2014) also mentioned that the long-term survival rates of mangroves are low because of the inappropriate species and site selection.

With the availability of satellite images, mangrove cover can easily be extracted with the use of various remote sensing (RS) techniques involving indices, specifically the Mangrove Vegetation Index (MVI). Through these, mangrove information can be quantified and analyzed with respect to time and location. It can also be used to identify what factors affected the growth or decline of forest cover. To this end, it is critical to examine other variables in addition to areal extent. Forest fragmentation is a process in which a large area is subdivided into smaller patches (Rodriguez et. al., 2020). Mangrove fragmentation is often associated with mangrove deforestation, in which land-use change directly affects the loss of mangrove covers (Bryan-Brown, et. al., 2020). In the guidebook written by Spalding et al., (2014) on mangroves for coastal defense, these functions are heavily dependent on properties of mangrove such as structure, density, width, etc.; the book also summarizes which and how specific mangrove cover properties contribute in mitigating damage from waves, storms, storm surges, etc.. For example, fragmentation generally reduces mangrove and/or forest width (Spalding et. al., 2014), thus essentially lowering the forest's ability to combat coastal flooding. It can be concluded that fragmentation of mangrove covers will negatively affect mangroves' ability to reduce the effects of coastal risks. In line with this, fragmentation can be used in mangrove forest analysis such as health and temporal changes, ecological relationship analysis, and other studies. Blanco-Libreros & Ramírez-Ruiz (2021) used mangrove fragmentation in determining the relationship between urbanization and the spatial configuration of mangroves, where it was found that stronger urban intensity (urbanization) shows higher mangrove fragmentation. Additionally, Kanniah et al. (2021) assessed how fragmentation affects the Leaf Area Index (LAI) in relation with the Gross Primary Productivity (GPP) of mangrove forest in determining mangrove cover change. The study illustrated mangrove cover change from 2000-2019, where they found to have been caused by urbanization, transformation to aquaculture, and mangrove erosion. Nevertheless, mapping accurate mangrove fragmentation creates better monitoring on mangrove health towards implementation of conservation policies.

As such, this study relates change patterns extracted from decadal mangrove cover from 2000, 2010, and 2020 through the use of RS and mapping techniques, and incorporates mangrove

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fragmentation in the analysis of mangrove cover growth or loss with respect to the spatio-temporal condition of Region IV-B that may be used to lay out suitable policies towards mangrove forest monitoring, conservation, and management.

2. DATA AND METHODS

2.1 Study Area

Shown in Figure 1 is Region IV-B or MIMAROPA, which is an acronym from its provinces (Mindoro, Marinduque, Romblon, and Palawan), located southwest of the Philippine Archipelago. Surrounded by the Sulu Sea and West Philippine Sea, southeast and west of the region respectively. MIMAROPA has a total land area of 27,457.20 sq.km, covering 9% of the total land area of the Philippines. As of 2010, the total forested area recorded is 9,156.64 sq.km. (DENR-FMB, 2010). Palawan, one of the region's provinces, houses the largest remaining mangrove cover in the Philippines (UNESCO, 2018).

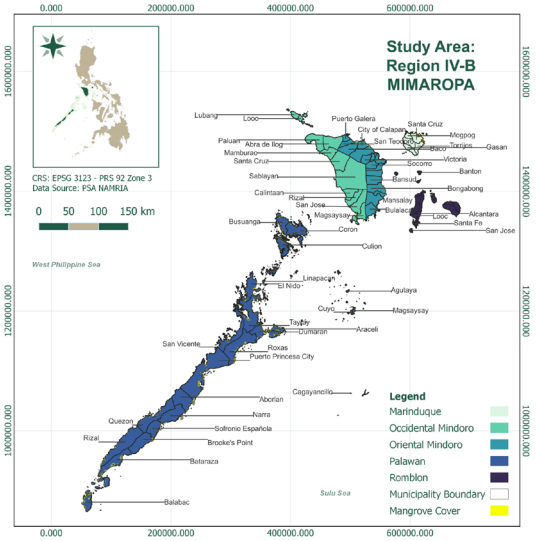


Figure 1. Region IV-B Administrative Boundaries

2.2 Data

Mangrove mapping is possible with remotely sensed images. In this study, cloud-free Landsat 8, 7, and 5 images were mainly used. The images were queried and processed in Google Earth Engine—a cloud computing platform that allows the processing and analysis of large geospatial datasets (Gorelick et al., 2017)—for rapid generation of mangrove extent data.

2.3 Methodology

2.3.1 Decadal Mangrove Extent Mapping

Mangrove extents of the Philippines for 2000, 2010, and 2020 were extracted from yearly composites of Landsat images available in Google Earth Engine (GEE) (Gorelick et al., 2017). The Mangrove Vegetation Index (MVI) is the technique used to separate mangroves from other vegetation, allowing fast and accurate mapping of mangroves from satellite imagery, i.e., from Sentinel-2 and Landsat.

$$MVI = \frac{NIR - Green}{SWIR1 - Green} \quad (1)$$

The index requires thresholding to accurately extract extents. Afterward, the results were exported for data cleaning and area calculation in ArcGIS™. The area covered by mangroves are analyzed up to the city/town level.

2.3.2 Change Pattern Analysis

The Change Detection Wizard tool of ArcGIS Pro 2.8 was employed to analyze the patterns of mangrove loss and gain throughout each decade. First, categorical change detection from 2000 to 2010 mangrove extent rasters was applied. Afterwards, change detection was applied again with the 2000-2010 change and 2020 mangrove extent raster.

2.3.3 Mangrove Cover Fragmentation

To analyze the city/town-level mangrove cover fragmentation, ZonalMetrics—an open-source Python toolbox for ArcGIS Pro for calculating landscape metrics on user-defined zones—was employed (Adamczyk & Tiede, 2017). Liu et al. (2022) categorized thirteen landscape metrics to their specific applications and their type (if positive—the higher value, the better the landscape health—or negative—the lower the value, the better the landscape health). Patch Density (PD), Number of Patches (NP), and Edge Density (ED) are in the fragmentation category. NP and PD are considered the most important metrics for landscape fragmentation (Echeverria et al., 2006; Kammerbauer and Ardon, 1999; Southworth et al., 2004; as cited in Encisa-Garcia, 2020). On the other hand, area landscape metrics, from its name, provide insights of the area covered by a certain class (Adamczyk & Tiede, 2017). Among the area metrics, Percentage of Zone (PZ) and Largest Patch Index (LPI) provide insight if the increase in mangrove patches is a result of land conversion to mangroves and not fragmentation of an original plot of mangrove. Table 1 shows the landscape metrics selected in this study, their definitions, category, and relationship with landscape health or fragmentation (denoted by type) for studying the mangrove landscape health and fragmentation. The computed metrics of each town/city is mapped.

Metric	Definition	Type
	Area Metrics	
PZ	Total Area of the patches over zonal area.	Positive
LPI	Area of the largest patch divided by the total zonal area in percentage.	Positive
	Fragmentation Metrics	
NP	Number of mangrove patches.	Negative
PD	Number of Mangrove patches per 100 hectares of zonal area.	Negative
ED	Length of the edge (or perimeter) per 1000 hectares of zonal area.	Negative

Table 1. Selected landscape Metrics for fragmentation analysis. PZ = Percentage of Zone. NP = Number of Patches. PD = Patch Density. ED = Edge Density. LPI = Largest Patch Index

2.3.4 Landscape Health

The cities/towns are categorized in four quadrants and mapped based on the average of the decadal percent change in area metric (i.e., PZ and LPI) vs fragmentation metrics (i.e., NP and ED). Cities/towns with:

1. decrease in area and in fragmentation indicate deforestation;
2. a decrease in area but an increase in fragmentation indicate true fragmentation;
3. an increase in area but a decrease in fragmentation indicate original mangrove forest expansion;

4. increase in area and fragmentation indicate land cover conversion from non-mangroves to mangroves.

3. RESULTS AND DISCUSSION

3.1 Analysis of Decadal Mangrove Cover

Table 2-6 shows the area estimate of the extracted mangroves (in ha) of the towns/cities of Region IV-B from the years 2000, 2010, and 2020 along with the cover change in percent from 2000-2010, 2000-2020, and 2010-2020.

Region IV-B	Decadal Mangrove Cover (in ha) and Cover Change (in %) in Marinduque					
	Mangrove Cover (ha)			Cover Change (%)		
City/Town	2000	2010	2020	2000-2010	2000-2020	2010-2020
Boac	42.05	28.15	55.61	-33.06	97.53	97.53
Buenavista	0.00	0.00	0.00	**	**	**
Gasan	0.00	0.16	0.00	*	-100.00	-100.00
Mogpog	91.05	87.22	104.64	-4.20	19.97	19.97
Santa Cruz	2018.73	2016.42	2267.86	-0.11	12.47	12.47
Torrijos	254.41	256.15	277.43	0.68	8.31	8.31
Total	2406.24	2388.10	2705.53	-0.75	13.29	13.29

Table 2. Extracted Mangrove area (in ha) estimates in Marinduque.
Note: *percent change from 0 to a value. **percent change from 0 to 0.

Region IV-B	Decadal Mangrove Cover (in ha) and Cover Change (in %) in Occidental Mindoro					
	Mangrove Cover (ha)			Cover Change (%)		
City/Town	2000	2010	2020	2000-2010	2000-2020	2010-2020
Abra De Ilog	11.00	22.49	23.09	104.50	109.89	2.64
Calintaan	2.62	1.21	3.52	-53.99	34.09	191.44
Looc	0.00	38.43	71.36	*	*	85.68
Lubang	0.00	7.22	47.03	*	*	551.00
Magsaysay	157.60	115.29	354.05	-26.85	124.66	207.11
Mamburao	88.05	78.38	182.24	-10.98	106.98	132.50
Paluan	0.00	0.17	0.00	*	**	-100.00
Rizal	14.32	2.53	32.14	-82.32	124.40	1169.08
Sablayan	39.85	44.85	77.41	12.52	94.24	72.62
San Jose	186.38	181.71	362.25	-2.50	94.36	99.35
Santa Cruz	137.25	140.36	306.25	2.27	123.14	118.18
Total	626.07	632.65	1495.33	1.05	133.09	130.67

Table 3. Extracted Mangrove area (in ha) estimates in Occidental Mindoro.
Note: *percent change from 0 to a value. **percent change from 0 to 0.

Region IV-B	Decadal Mangrove Cover (in ha) and Cover Change (in %) in Oriental Mindoro					
	Mangrove Cover (ha)			Cover Change (%)		
City/Town	2000	2010	2020	2000-2010	2000-2020	2010-2020
Baco	325.31	275.87	633.37	-15.20	94.70	129.59
Bansud	18.05	8.29	50.91	-54.10	182.03	514.50
Bongabong	194.02	198.81	578.27	2.47	198.05	190.87
Bulalacao	156.56	154.11	164.00	-1.57	4.75	6.42
Calapan City	398.14	398.65	891.97	0.13	124.03	123.75
Gloria	5.37	4.72	18.84	-12.06	251.09	299.24
Mansalay	40.55	37.09	71.25	-8.53	75.73	92.11
Naujan	398.37	402.86	514.55	1.13	29.16	27.72
Pinamalayan	27.43	34.07	47.21	24.18	72.11	38.59
Pola	206.95	220.00	308.08	6.30	48.87	40.04
Puerto Galera	17.35	15.85	37.75	-8.66	117.57	138.20
Roxas	54.08	47.03	167.54	-13.04	209.79	256.22
San Teodoro	22.44	16.29	130.43	-27.44	481.13	700.93
Socorro	0.00	0.10	0.00	*	**	-100.00
Victoria	0.00	6.67	0.00	*	**	-100.00
Total	1864.63	1820.39	3614.17	-2.37	93.83	98.54

Table 4. Extracted Mangrove area (in ha) estimates in Oriental Mindoro.
Note: *percent change from 0 to a value. **percent change from 0 to 0.

Region IV-B	Decadal Mangrove Cover (in ha) and Cover Change (in %) in Palawan					
	Mangrove Cover (ha)			Cover Change (%)		
City/Town	2000	2010	2020	2000-2010	2000-2020	2010-2020
Aborlan	1204.21	1236.05	1289.64	2.64	7.09	4.34
Agutaya	0.00	0.44	0.00	*	0.00	-100.00
Araceli	1492.53	2157.13	2344.28	44.53	57.07	8.68

Balabac	3837.89	3965.05	5122.96	3.31	33.48	29.20
Bataraza	3441.35	4435.37	4624.37	28.88	34.38	4.26
Brooke's Point	515.38	474.69	548.98	-7.90	6.52	15.65
Busuanga	1300.15	1295.11	1462.38	-0.39	12.48	12.92
Cagayancillo	0.00	0.00	0.00	**	**	**
Coron	1743.56	1757.54	2332.27	0.80	33.76	32.70
Cuilion	1950.01	1959.78	116.91	0.50	-94.00	-94.03
Cuyo	50.78	67.63	4157.35	33.19	8087.23	6046.87
Dumaran	3302.13	3743.84	2069.30	13.38	-37.33	-44.73
El Nido	1628.79	1717.99	2332.27	5.48	43.19	35.76
Kalayaan	0.00	0.00	0.00	**	**	**
Linapacan	118.25	457.09	526.88	286.53	345.55	15.27
Magsaysay	73.00	73.60	116.99	0.83	60.26	58.94
Narra	1038.42	1044.58	1122.45	0.59	8.09	7.46
Puerto Princesa City	4562.91	4577.48	5272.17	0.32	15.54	15.18
Quezon	1314.15	1261.84	1671.16	-3.98	27.17	32.44
Rizal	1610.50	1591.62	2382.26	-1.17	47.92	49.68
Roxas	2828.41	2866.66	3349.05	1.35	18.41	16.83
San Vicente	556.45	659.74	834.48	18.56	49.96	26.49
Sofronio Espanola	894.52	834.94	859.95	-6.66	-3.87	2.99
Taytay	3429.95	4138.60	5103.91	20.66	48.80	23.32
Total	36893.35	40316.79	47290.31	9.28	28.18	17.30

Table 5. Extracted Mangrove area (in ha) estimates in Palawan.
Note: *percent change from 0 to a value. **percent change from 0 to 0.

Region IV-B	**Decadal Mangrove Cover (in ha) and Cover Change (in %) in Romblon**					
	Mangrove Cover (ha)			**Cover Change (%)**		
City/Town	**2000**	**2010**	**2020**	**2000-2010**	**2000-2020**	**2010-2020**
Alcantara	12.42	11.79	25.09	-5.07	102.05	112.85
Banton	0.00	9.30	0.00	*	**	-100.00
Cajidiocan	128.94	113.12	197.24	-12.27	52.97	74.37
Calatrava	22.11	31.91	31.33	44.36	41.70	-1.84
Concepcion	0.00	3.91	0.00	*	**	-100.00
Corcuera	0.00	11.26	13.43	*	*	19.29
Ferrol	53.64	58.56	107.17	9.18	99.80	83.01
Looc	51.05	68.10	126.36	33.38	147.52	85.57
Magdiwang	106.26	140.29	190.40	32.02	79.18	35.72
Odiongan	81.18	85.44	85.18	5.24	4.93	-0.30
Romblon	49.15	46.20	36.44	-6.01	-25.86	-21.12
San Agustin	4.28	13.55	0.53	216.89	-87.71	-96.12
San Andres	80.69	78.08	72.17	-3.24	-10.57	-7.57
San Fernando	13.62	24.69	49.87	81.34	266.22	101.95
San Jose	0.00	0.00	1.73	**	*	*
Santa Fe	81.67	62.70	97.38	-23.24	19.23	55.33
Santa Maria	2.72	0.00	0.00	-100.00	-100.00	**
Total	687.74	758.89	1034.32	10.35	50.39	36.29

Table 6. Extracted Mangrove area (in ha) estimates in Romblon.
Note: *percent change from 0 to a value. **percent change from 0 to 0.

Throughout the years, Palawan province contains the largest mangrove cover in 20 years, covering 84 to 88% of the total mangrove in the region (Figure 2). The time epoch in which mangrove fragments have experienced negative cover change was from 2000 to 2010 indicating weak implementation of existing and/or new mangrove conservation policies on provinces except for Palawan where it was declared as swamp forest reserves under Proclamation No. 2152, series of 1981. Marinduque province’s mangrove forest shows minimal loss in the first decade, and the mangrove growth in the span of 20 years was from the last ten years (2010-2020) similar to Occidental and (266.22%). Municipalities of Gasan, Paluan, Socorro, Victoria, Agutaya, Banton, and Concepcion showed an attempt to grow mangrove trees between 2000 and 2010, although they were not maintained and were eventually lost by 2020, reason may be unsuitable environment and/or human-driven practices. Successful efforts on mangrove reforestation (natural or man-induced) can be observed in municipalities of Looc, Lubang, Corcuera, and San Jose wherein no records of mangrove cover exist in the first decade. In general, most towns/cities of Region IV-B displays a positive growth rate of mangrove covers, nevertheless, municipalities such as Romblon (-21.12%), San Agustin (-96.12%), and San Andres (-7.57%) of Romblon displayed a downward trend or loss of mangrove forest throughout the decades thus the local and national government should investigate the causes of deforestation in the said areas. Overall, from the year 2010 to 2020, efforts in reforestation of Oriental Mindoro. Numerous municipalities were also found to have no mangrove cover which are Buenavista, Marinduque, Cagayancillo and Kalayaan, Palawan. The said municipalities are surrounded by ocean water and are mostly small islands. Majority of the towns/cities of Region IV-B have an upward trend in cover change signifying the continuous growth of mangrove forests. San Teodoro, Oriental Mindoro has the largest mangrove growth in the last two decades with 481.13% growth from 22.44 ha of mangrove area, followed by Linapacan, Palawan (345.55%), and San Fernando, Romblon

mangrove in Region IV-B have shown to be successful with an increased growth rate from 8.10% (2000-2010) to 22.19% (2010-2020).

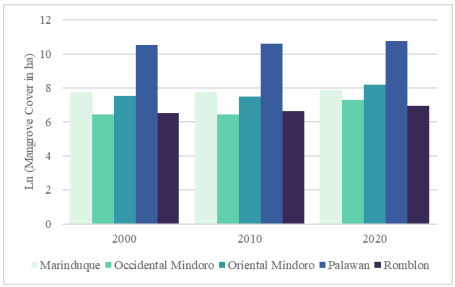


Figure 2. Mangrove cover of Region IV-B provinces of 2000, 2010, and 2020 on an ln scale and in hectares.

3.2 Mangrove Cover Change Pattern

Tables 7-11 shows the mangrove cover change pattern from 2000 to 2020 categorized into: (1) consistently mangrove; (2) Persistent Mangrove Gain; (3) Mangrove Loss then Gain; (4) New Mangrove; (5) Recent Mangrove Loss; (6) Mangrove Gain then Loss; and (7) Persistent Mangrove Loss. Consistent with Tables 2-6, the province of Palawan has the largest area of consistent mangrove cover (52.98%) and new mangrove cover (72.70% of the total new mangrove) within the region, but it also has the largest area of lost mangroves, this shows that despite being a protected reserve, practices leading to deforestation are still prevalent. While, in terms of each province, 80.51% of Marinduque's mangrove forest is consistently mangrove, which may indicate that mangroves in this area are preserved and/or maintained throughout the years. In Occidental and Oriental Mindoro, more than 50% of its mangrove forest are new mangroves; this is consistent with the sudden emergence of mangrove cover from 2010 to 2020 in Table 3 and 4, signifying reforestation during the same timeframe. The province of Romblon has a considerably large portion of mangroves that was lost by 2020. In relation to the highest percentage change, the municipality of Cuyo, Palawan has a relatively small area of mangroves lost, additionally, new mangroves from reforestation are greater than the consistent mangroves. Thus, relationship between the change pattern and overall temporal trend of mangrove covers can be drawn out from quantifying the cover area; from the data of San Agustin, Romblon, in Table 6, cover changes has a negative slope which reflected in the cover change pattern data (Table 11) wherein the total sum of lost and failed mangroves is significantly greater than the first four categories that contributes to the growth of mangrove cover.

Region IV-B	**Decadal Mangrove Cover Change Pattern (in ha) in Marinduque**						
City/Town	Consistently Mangrove (M)	Persistent Mangrove Gain (NM->M->M)	Mangrove Loss then Gain (M->NM->M)	New Mangrove (NM->NM->M)	Recent Mangrove Loss (M->M->NM)	Mangrove Gain then Loss (NM->M->NM)	Persistent Loss (M->NM->NM)
Boac	18.55	3.51	2.07	33.37	5.87	1.2	17.02
Buenavista	0	0	0	0	0	0	0
Gasan	0	0	0	0	0	0.16	0
Mogpog	73.04	0.82	0.98	32.96	15.03	0.97	5.1
Santa Cruz	2014.16	7.31	5.63	318.92	60.27	4.44	8.46
Torrijos	253.27	0.27	0.54	32.9	7.42	3.96	1.89
Total	2359.02	11.91	9.22	418.15	88.59	10.73	32.47

Table 7. Decadal Mangrove cover change pattern (in ha) in Marinduque.
Note: M symbolizes the existence of mangroves, NM otherwise.

Region IV-B	**Decadal Mangrove Cover Change Pattern (in ha) in Occidental Mindoro**						
City/Town	Consistently Mangrove (M)	Persistent Mangrove Gain (NM->M->M)	Mangrove Loss then Gain (M->NM->M)	New Mangrove (NM->NM->M)	Recent Mangrove Loss (M->M->NM)	Mangrove Gain then Loss (NM->M->NM)	Persistent Loss (M->NM->NM)
Abra De Ilog	0	11	0	12.87	0	12.28	0
Calintaan	0	0.14	0.27	3.25	0	1.1	2.43
Looc	0	29.84	0	43.62	0	9.81	0
Lubang	0	6.99	0	41.29	0	0.37	0
Magsaysay	56.26	3.06	13.34	291.9	41.42	17.93	51.22
Mamburao	60.66	1.62	4.65	121.42	15.48	3.22	10.18
Paluan	0	0	0	0	0	0.18	0
Rizal	0.9	0	4.41	27.81	1.62	0.09	7.83
Sablayan	10.94	0.67	4.44	63.77	19.61	15.05	6.13
San Jose	118.28	6.63	10.71	237.48	46.05	16.19	16.94
Santa Cruz	107.59	3.42	1.35	203.9	30.54	3.4	2.25
Total	354.63	63.37	39.17	1047.31	154.72	79.62	96.98

Table 8. Decadal Mangrove cover change pattern (in ha) in Occidental Mindoro.
Note: M symbolizes the existence of mangroves, NM otherwise.

Region IV-B	**Decadal Mangrove Cover Change Pattern (in ha) in Occidental Mindoro**						
City/Town	Consistently Mangrove (M)	Persistent Mangrove Gain (NM->M->M)	Mangrove Loss then Gain (M->NM->M)	New Mangrove (NM->NM->M)	Recent Mangrove Loss (M->M->NM)	Mangrove Gain then Loss (NM->M->NM)	Persistent Loss (M->NM->NM)
Baco	252.14	0.63	19.53	382.71	31.2	1.34	33.54
Bansud	6.3	0.09	7.11	39.03	2.07	0.09	3.15
Bongabong	151.43	15.39	11.52	417.98	26.45	11.82	10.72
Bulalacao	97	0.9	3.12	67.93	54.27	6.64	6.93

Calapan City	308.59	29.1	9.25	575.41	58.35	16.21	35.56
Gloria	0.99	3.15	2.51	12.76	0.1	0.63	1.95
Mansalay	28.31	0.09	1.65	43.46	8.73	1.16	3.16
Naujan	328.78	2.37	5.04	195.75	67.5	17.79	10.44
Pinamalayan	16.11	1.26	1.28	30.08	9.67	8.14	1.25
Pola	148.98	2.62	0	166.61	64.78	10.89	0
Puerto Galera	5.84	0.5	0.55	32.18	8.74	1.3	2.77
Roxas	36.03	2.07	4.68	129.88	7.2	3.17	7.82
San Teodoro	14.04	0	2.88	117.94	2.39	0.42	3.87
Socorro	0	0	0	0	0	0.09	0
Victoria	0	0	0	0	0	6.89	0
Total	1394.54	58.17	69.12	2211.72	341.45	86.58	121.16

Table 9. Decadal Mangrove cover change pattern (in ha) in Occidental Mindoro.
Note: M symbolizes the existence of mangroves, NM otherwise.

Region IV-B	**Decadal Mangrove Cover Change Pattern (in ha) in Palawan**						
City/Town	Consistently Mangrove (M)	Persistent Mangrove Gain (NM->M->M)	Mangrove Loss then Gain (M->NM->M)	New Mangrove (NM->NM->M)	Recent Mangrove Loss (M->M->NM)	Mangrove Gain then Loss (NM->M->NM)	Persistent Loss (M->NM->NM)
Aborlan	1137.63	21.57	0.09	156.63	88.59	13.52	2.47
Agutaya	0	0	0	0	0	0.42	0
Areceli	1473.26	648.13	0	278.77	54.94	32.29	0
Balabac	3469.38	90.71	25.99	1622.4	371.16	98.22	35.6
Bataraza	2522.6	609.84	0.02	1573.67	979.74	402.04	0
Brooke's Point	440.03	0.09	28.86	90.28	42.3	1.19	13.88
Busuanga	1259.13	2.37	9.01	235.01	60.76	11.13	9.73
Cagayancillo	0	0	0	0	0	0	0
Coron	1662.83	12.27	4.96	360.46	122.58	11.56	4.49
Cuilion	1901.61	6.02	3.53	487.96	97.76	10.56	3.1
Cuyo	49.2	14.74	0.07	55.86	2.61	2.83	0.19
Dumaran	3306.18	368.37	0.45	580.16	73.22	84.43	0.1
El Nido	1543.27	65.44	4.6	509.59	115.04	38.65	8.02
Kalayaan	0	0	0	0	0	0	0
Linapacan	117.59	319.06	0.09	104.38	3.48	29.47	0.25
Magsaysay	70.55	0.49	0.6	48.29	3.23	1.21	0.5
Narra	968.4	9.85	2.28	164.36	79.18	8.06	9.36
Puerto Princesa City	4406.05	25.12	23.14	931.55	206.6	38.43	25.41
Quezon	1044.93	9.27	70.75	579.39	210.8	22.11	13.83
Rizal	1395.89	3.26	12.07	1014.68	214.49	7.14	17.61
Roxas	2676.13	9.13	29.88	709.91	152.5	94.12	34.19
San Vicente	506.88	62.65	0	284.73	62.16	43.78	0.72
Sofronio Espanola	675.35	2.56	47.93	150.63	168.08	4.9	20.22
Taytay	3074.68	562.35	0.94	1593.28	438.5	166.97	2.14
Total	33701.57	2843.29	265.26	11531.99	3547.72	1123.03	201.81

Table 10. Decadal Mangrove cover change pattern (in ha) in Palawan.
Note: M symbolizes the existence of mangroves, NM otherwise.

Region IV-B	**Decadal Mangrove Cover Change Pattern (in ha) in Occidental Mindoro**						
City/Town	Consistently Mangrove (M)	Persistent Mangrove Gain (NM->M->M)	Mangrove Loss then Gain (M->NM->M)	New Mangrove (NM->NM->M)	Recent Mangrove Loss (M->M->NM)	Mangrove Gain then Loss (NM->M->NM)	Persistent Loss (M->NM->NM)
Alcantara	11.43	0	0.21	14.2	0.72	0	0.44
Banton	0	0	0	0	0	9.6	0
Cajidiocan	103.46	1.26	0.63	43.34	9.03	2.83	3.54
Calatrava	17.52	0	0.44	14.36	4.25	11.16	0.6
Concepcion	0	0	0	0	0	4.06	0
Corcuera	0	11.09	0	2.86	0	0.6	0
Ferrol	48.38	2.2	0	59.81	6.91	2.88	0
Looc	35.58	17.62	2.34	74.66	12.08	5.02	2.72
Magdiwang	99.9	28.36	0.63	67.11	7.36	8.8	1.53
Odiongan	54.42	1.26	0.09	32.05	27.45	4.94	1.72
Romblon	9.8	1.71	1.46	24.63	28.05	8.02	11.34
San Agustin	0	0.18	0	0.37	0.62	13.18	3.81
San Andres	40.61	0.11	0.89	32.84	23.92	15.91	17.82
San Fernando	5.72	0.18	2.61	42.85	1.62	17.91	4.07
San Jose	0	0	0	1.78	0	0	0
Santa Fe	29.08	4.71	5.33	61.33	23.58	7.21	26.24

Santa Maria	0	0	0	0	0	0	2.8
Total	1394.54	58.17	69.12	2211.72	341.45	86.58	121.16

Table 11. Decadal Mangrove cover change pattern (in ha) in Occidental Mindoro.
Note: M symbolizes the existence of mangroves, NM otherwise.

The maps in Figure 3 show notable change patterns. Most areas are maintaining or increasing their mangrove cover as seen in clusters of green pixels. The clusters of yellow pixels among the green pixels show strong efforts in expanding the existing mangrove forests. Furthermore, there are also several areas that have yellow pixel clusters signifying attempts to create new mangrove forest patches. However, on index/page 71, it can be observed that the Municipality of Bataraza experienced a vital amount of mangrove loss denoted by the clusters of red and orange pixels. Nevertheless, green and yellow pixels are still predominant in that area.

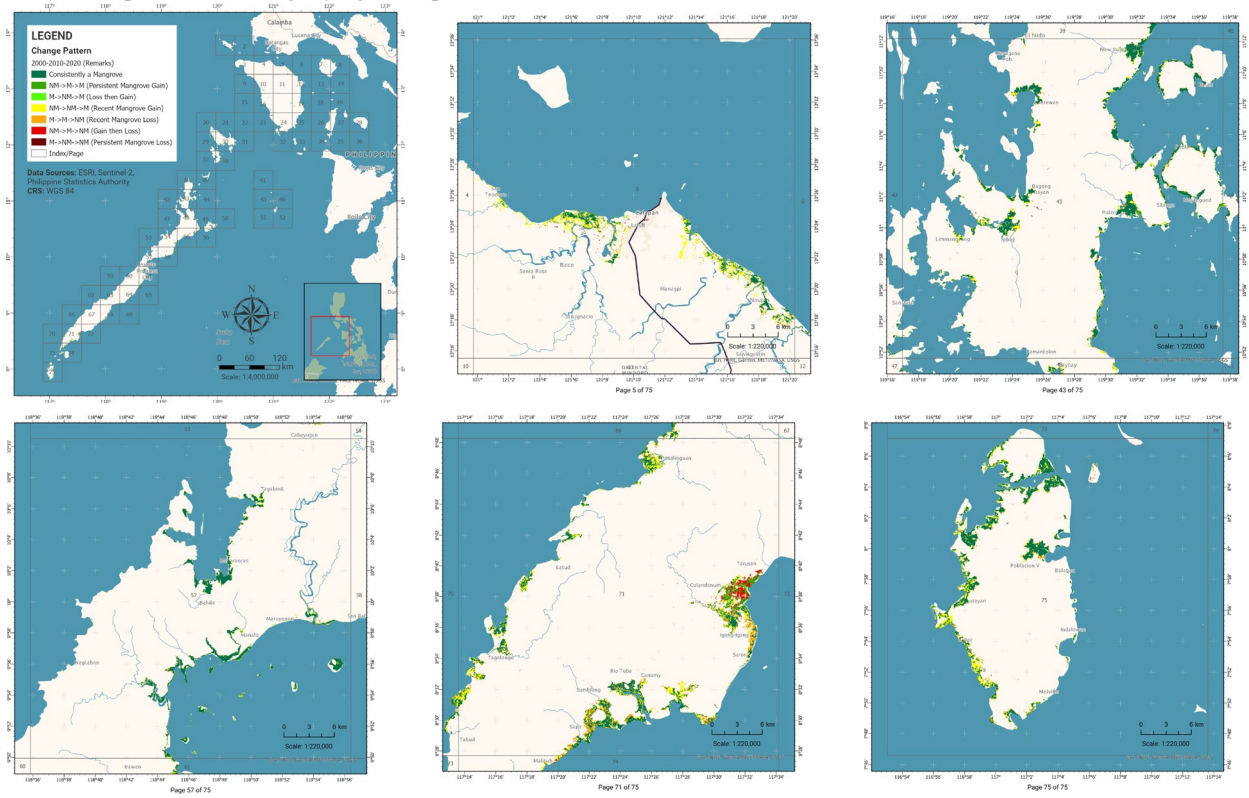


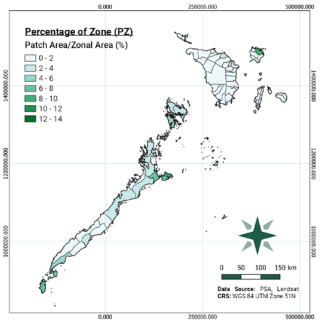
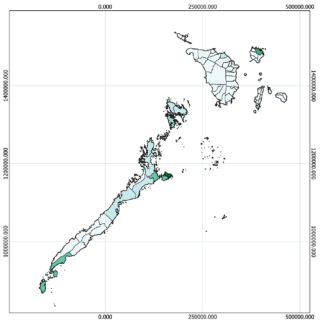
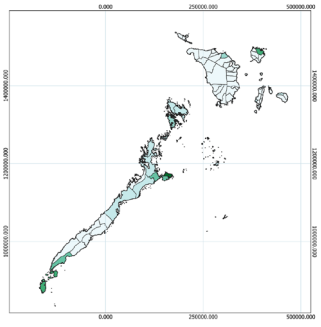
Figure 3. Region IV-B Decadal Mangrove Cover Change Pattern Map Series and select indices/pages with notable change patterns.

3.3 Mangrove Cover Fragmentation

Table 12 shows the decadal and zonal values of metrics PZ, NP, PD, ED, and LPI. Only a few cities/towns experienced a significant increase in mangrove cover percentage. However, cities across the whole region have signs of fragmentation with the increase of NP, PD, and ED values. Nevertheless, the LPI of most cities remains almost constant indicating that their largest patches of mangroves are not fragmenting. This suggests that the increase in patches may be a result of new mangrove forests that initially did not have mangroves.

3.4 Mangrove Cover Fragmentation

Table 12 shows the decadal and zonal values of metrics PZ, NP, PD, ED, and LPI. Only a few cities/towns experienced a significant increase in mangrove cover percentage. However, cities across the whole region have signs of fragmentation with the increase of NP, PD, and ED values. Nevertheless, the LPI of most cities remains almost constant indicating that their largest patches of mangroves are not fragmenting. This suggests that the increase in patches may be a result of new mangrove forests that initially did not have mangroves.

Metric	2000	2010	2020
PZ			

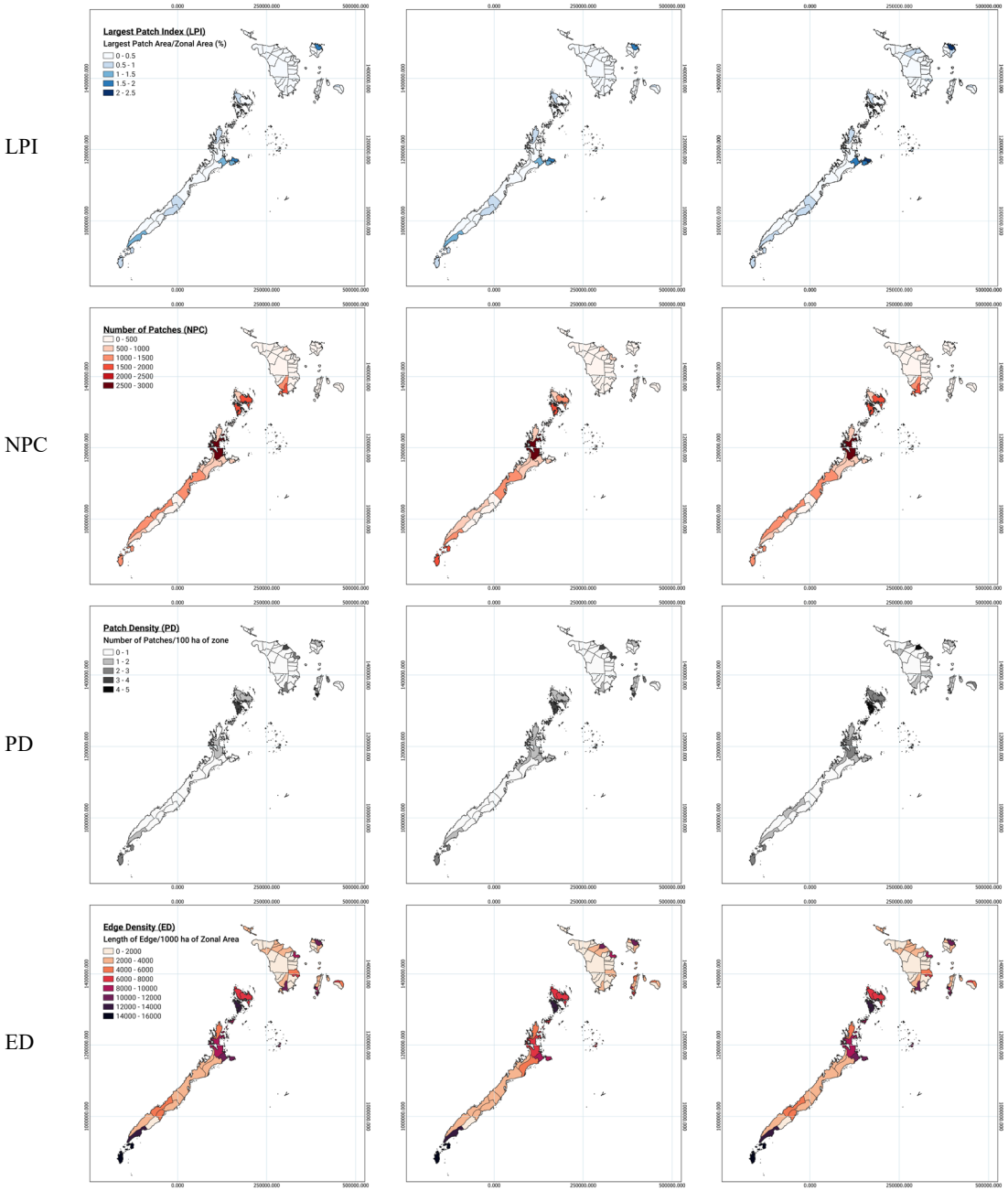


Table 12. Decadal City/Town-Level Landscape Metric Maps of Region IV-B. PZ = Percentage of Zone. LPI = Largest Patch Index. NP = Number of Patches. PD = Patch Density. ED = Edge Density

Region IV-B	**Area Metric Change (%)**				**Fragmentation Metric Change (%)**			
Province	Percentage of Zone (PZ)		Largest Patch Index (LPI)		Number of Patches (NPC)		Edge Density (ED)	
Town/City	2000-2010	2010-2020	2000-2010	2010-2020	2000-2010	2010-2020	2000-2010	2010-2020
				Marinduque				
Boac	-32.97	97.54	0	111.11	-33.67	36.92	-35.67	60.3
Buenavista	**	**	**	**	**	**	**	**
Gasan	*	-100	*	-100	*	-100	*	-100
Mogpog	-4.14	19.91	0	0.85	-27.03	36.11	-11.42	13.21
Santa Cruz	-0.11	12.46	0	27.6	-8.67	40.36	-1.54	5.08
Torrijos	0.68	8.27	0	28.84	-22.92	72.97	-0.74	6.78
				Occidental Mindoro				
Abra de Ilog	*	2.7	*	380	*	-56.38	*	-33.63
Calintaan	-55.56	200	-50	100	-40	100	-58.06	182.74
Looc	*	85.86	*	76.92	*	20.88	*	38.4
Lubang	*	546.55	*	100	*	617.65	*	754
Magsaysay	-26.78	207	0	24.44	-51.96	396.41	-38.65	264.1
Mamburao	-11.27	132.79	0	96	-27.18	103.56	-17.77	100.92

Paluan	**	**	**	**	*	-100	*	-100
Rizal	-82.98	1225	-57.14	300	-85.54	1316.67	-83.13	1197.87
Sablayan	10.53	76.19	0	50	18.23	-0.83	14.55	27.07
San Jose	-2.3	98.99	0	-34.69	-12.73	155.5	-11.01	135.72
Santa Cruz	2.51	118.14	0	231.82	5.69	3.97	3.41	34.4
Oriental Mindoro								
Baco	-15.24	129.65	0	116.67	-45.53	53.62	-27.92	66.45
Bansud	-53.85	512.5	0	150	-80.65	483.33	-66.14	473.1
Bongabong	2.45	190.84	0	387.18	1.96	29.32	1.54	96.39
Bulalacao	-1.58	6.41	0	-37.25	-18.08	71.03	-6.25	14.46
City of Calapan	0.14	123.72	0	126.79	-5.45	22.6	-1.77	49.34
Gloria	-14.29	311.11	300	8.33	-63.33	336.36	-48.31	330.05
Mansalay	-7.87	91.46	0	137.5	-37.14	175	-17.41	97.46
Naujan	1.15	27.67	0	26.83	11.45	-4.61	2.09	12.95
Pinamalayan	24.54	38.42	0	221.05	42.57	-22.22	29.74	5.05
Pola	6.27	40.05	0	65.38	21.27	-22.93	10.76	14.06
Puerto Galera	-8.81	137.93	0	80.77	-30.84	140.54	-16.2	134.39
Roxas	-13.05	256.07	0	1014.55	-12.35	7.04	-14.62	101.62
San Teodoro	-27.78	703.85	0	890	-45.36	218.87	-34.42	411.26
Socorro	**	**	**	**	*	-100	*	-100
Victoria	*	-100	*	-100	*	-100	*	-100
Palawan								
Aborlan	2.63	4.37	0	1.72	92.93	-3.1	13.51	-4.05
Agutaya	*	-100	*	-100	*	-100	*	-100
Araceli	44.53	8.67	0	50	384.13	-17.05	58.24	-11.34
Balabac	3.32	29.18	0	9.63	35.65	-9.86	9.08	-4.15
Bataraza	28.87	4.25	0	-26.3	55.54	-27.02	28.56	-5.79
Brooke's Point	-7.85	15.58	0	9.78	-75.18	500	-31.49	70.6
Busuanga	-0.37	12.9	0	6.63	0.31	37.5	-0.95	16.73
Cagayancillo	**	**	**	**	**	**	**	**
Coron	0.8	12.8	0	41.36	16.26	20.97	2.84	14.43
Culion	0.51	19.01	0	40.3	18.1	8.92	2.47	4.92
Cuyo	33.19	72.8	0	214.59	76.4	35.67	43.75	44.53
Dumaran	13.37	11.03	0	12.18	254.36	23.11	30.29	4.72
El Nido	5.49	20.44	0	11.82	60.24	16.2	15.29	3.3
Kalayaan	**	**	**	**	**	**	**	**
Linapacan	286.76	15.27	33.16	-4.02	1316	39.83	449.9	13.91
Magsaysay	0.85	58.88	0	91.36	5.88	12.96	2.1	24.02
Narra	0.58	7.43	0	5.26	7.12	37.97	1.15	4.14
Puerto Princesa City	0.33	15.16	0	92.34	25.36	4.32	2.36	-0.35
Quezon	-3.98	32.37	0	2.08	28.43	39.8	2.35	38.16
Rizal	-1.18	49.64	0	167.89	-20.42	45.61	-4.25	6.35
Roxas	1.36	16.83	0	21.03	11.38	8.4	3.25	-8.92
San Vicente	18.57	26.47	0	48.64	132.55	-2.48	48.58	7.08
Sofronio Española	-6.67	3.02	0	-3.88	-4.92	51.03	-7.92	14.07
Taytay	20.64	23.33	0	27.83	85.37	7.81	33.27	13.91
Romblon								
Alcantara	-5.11	113.17	0	15.7	-47.37	590	-15.59	212.88
Banton	*	-100	*	-100	*	-100	*	-100
Cajidiocan	-12.27	74.41	0	-24.01	-55.17	561.54	-24.48	132.12
Calatrava	44.41	-1.79	0	60.78	130	-24.64	84.94	-18.05
Concepcion	*	-100	*	-100	*	-100	*	-100
Corcuera	*	19.27	*	36.36	*	10	*	4.87
Ferrol	9.18	83	0	56.66	37.61	22	17.02	42.01
Looc	33.33	85.53	178.18	33.99	1.96	55.29	15.71	61.28
Magdiwang	32.02	35.68	0	-3.59	126.32	170.93	73.75	69.17
Odiongan	5.22	-0.16	0	36.51	13.95	-3.4	8.51	-13.2
Romblon	-6.12	-21.07	0	60.36	-14.29	-47.47	-8.48	-46.28
San Agustin	216.67	-96.24	800	-96.3	2.33	-79.55	92.89	-92.28
San Andres	-3.3	-7.62	0	14.38	0.64	-29.3	-1.66	-18.54
San Fernando	80.36	101.98	-35.71	77.78	43.48	146.97	76.72	94.84
San Jose	**	*	**	*	**	*	**	*
Santa Fe	-23.25	55.37	0	-38.89	-32.14	50.53	-31.35	57.1
Santa Maria	-100	**	-100	**	-100	**	-100	**

Table 13. Decadal Landscape Metric changes of each town/city from 2000. Area metric percent change highlighted in light green, green, light red, and red have values ≥ 25%, ≥ 100%, ≤ -25%, and ≤ -100%, respectively. Fragmentation metric percent change highlighted in light red, red, light green, and green have values ≥ 25%, ≥ 100%, ≤ -25%, and ≤ -100%, respectively. ***Note.*** *percent change from 0 to a positive value. **percent change from 0 to 0.

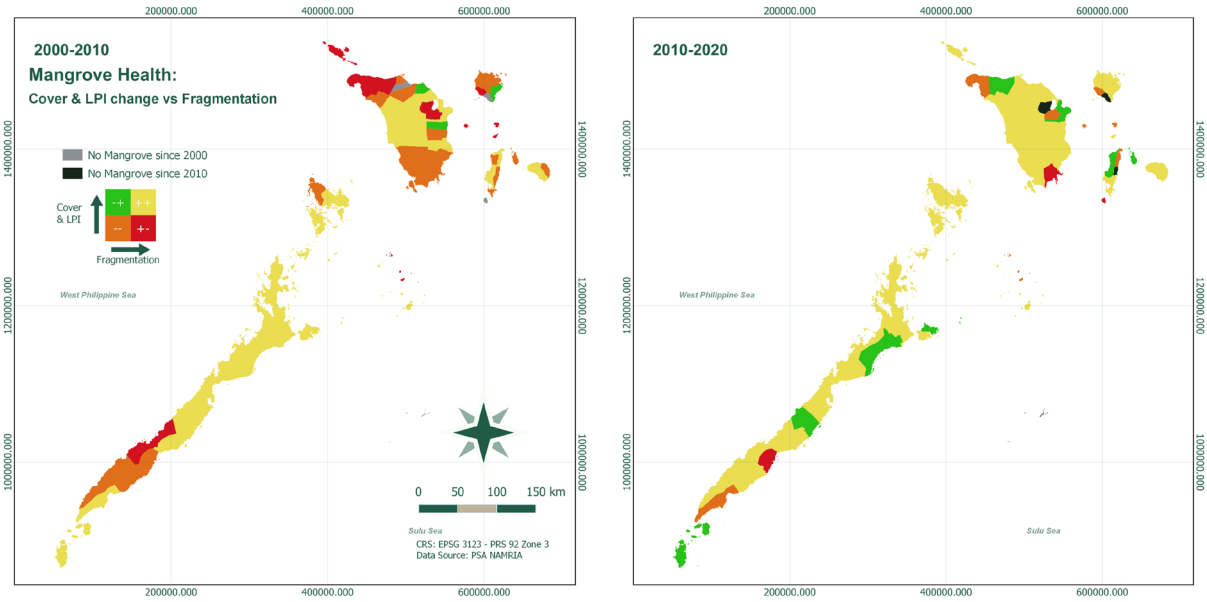


Figure 4. Decadal Mangrove landscape health quadrant maps of cities/towns in terms of area vs fragmentation metrics.

To further inspect if fragmentation occurs for each city/town, Table 13 shows the percent changes of each metric value of each city/town across the decades. Looking at the PZ column, majorities of the cities/towns, especially in Occidental Mindoro and Oriental Mindoro show significant (≥ 25%) area metric increase from 2010-2020. Boac, Calintaan, Magsaysay, Rizal, Bansud, and San Teodoro whose mangrove loss is significant in 2000-2010 were able to come back in the next decade, except for Santa Maria. However, San Agustin lost a significant amount of mangrove cover, almost fully deforested like Gasan, Victoria, Agutaya, Banton, and Concepcion, after an increase in mangrove cover.

The LPI values show that only Calintaan, Rizal, and San Fernando’s largest patch suffered mangrove loss in 2000-2010, but all three were able to recover in the next decade. However, San Jose, Bulalacao, Bataraza, San Agustin, and Santa Fe lost a significant amount of mangroves in their largest patch in 2010-2020. San Jose’s and Santa Fe’s have high fragmentation metric values in 2010-2020. While the municipalities’ increase in mangrove cover (possibly in areas far from the original patches) may have influenced the high fragmentation metric values, their LPI decrease suggests fragmentation. On the other hand, Bulalacao’s weak mangrove cover percent gain, decrease in LPI, and increase in fragmentation metrics indicate fragmentation. The mangrove cover increased in 2000-2010 but total deforestation in 2010-2020 of Gasan, Victoria, Agutaya, Banton, and Concepcion denote that these are the towns/cities that failed in mangrove conservation.

Figure 4 summarizes and positions each city/town regarding the landscape health according to area vs fragmentation metrics quadrant. The first quadrant (--) contains cities/towns with a decrease in fragmentation and cover, which can be characterized by deforestation in many of its mangrove forest lands. The second (-+) contains cities/towns with a decrease in cover but an increase in fragmentation, which can be characterized by fragmentation of original mangrove patches. The third (+-) contains cities/towns with an increase in cover but a decrease in fragmentation, which can be characterized by the expansion of original mangrove patches. The fourth (++) contains cities/towns with an increase in cover and fragmentation, which can be characterized by the increase of mangrove forest lands in areas that had or did not have mangroves previously. Many of the towns/cities in 2000-2010 identify with the fourth quadrant and first quadrant. This means that in that decade, deforestation was rampant but mangrove expansion was also prevalent. However, many of the towns/cities of the first quadrant in 2000-2010 changed to the fourth quadrant, which indicates that these towns/cities noticed the deforestation of mangrove forests and decided to recover the lost mangroves. Many of the towns/cities also continue to have an increase in mangrove as they either identify with the second and fourth quadrant. Overall, the results imply that Region IV-B experienced mangrove cover increase from expansion of initial forests to land cover conversion to mangroves in the past two decades. Deforestation was also significantly reduced after 2010.

4. CONCLUSION

The Philippines is currently suffering from mangrove deforestation while its people and its marine organisms rely on them for many of their basic life needs. Researchers have developed methodologies to prevent further mangrove cover loss and one technique is the use of remote sensing (RS) technology in the form of satellite imagery. With the advent of remote sensing technology, mangrove extent can be extracted from remotely sensed data, e.g., satellite imagery. Moreover, the availability of multitemporal imagery across the globe allows analysis of patterns of certain locations across time towards better understanding and monitoring of the environment. This study utilized this technology to perform a spatiotemporal analysis of the decadal mangrove cover in Region IV-B MIMAROPA—a region in the Philippines that is abundant with mangroves—and its fragmentation from 2000 to 2020.

This research found that the majority of the cities in Region IV-B have increasing mangrove cover over time. Palawan Province maintained the largest percent share across the region in two decades. It also has the largest area of consistent mangroves in the region but has the largest area of lost mangroves indicating that deforestation is still prevalent. Romblon also has strong deforestation rates, but contrary to Palawan, it struggled in preserving mangroves and countering deforestation through rehabilitation. On the other hand, 80.51% of Marinduque’s mangroves were preserved in two decades while Occidental and Oriental Mindoro have started mangrove planting efforts as there

is an emergence of large amounts of new mangrove cover from 2010 to 2020. Each province is left with individual challenges regarding mangroves maintenance and rehabilitation in the upcoming years (e.g., Palawan should strengthen mangrove preservation, Marinduque should venture in creating more mangrove forest patches, Occidental and Oriental Mindoro should maintain the new mangroves, and Romblon should take lessons from its neighboring provinces with regards to taking care of the mangrove forests).

Analysis of fragmentation found that the majority of the cities had increasing trends of fragmentation metrics through time but their increase in mangrove cover suggests that the increase in mangrove patches is a result of the conversion of land for new mangrove forest areas. There are notably several cities/towns that suffered mangrove loss from 2000 to 2010 but they were able to rehabilitate and increase the mangrove cover from 2010 to 2020. However, there are cities/towns that suffered significant deforestation by 2020 (e.g., San Agustin, Gasan, Victoria, Gatuya, Banton, and Concepcion), and cities/towns that experienced fragmentation and deforestation (e.g., Bulalacao, Sofronio Espanola, and Santa Fe).

Overall, Region IV-B seems to be safe from deforestation and fragmentation. However, there are still cities that need attending. Furthermore, since studies found that the Philippines does experience mangrove deforestation, this means other regions may require more tending to.

RECOMMENDATIONS

The researchers recommend that LGUs of other regions take lessons from Region IV-B regarding their mangrove monitoring and rehabilitation activities. Furthermore, barangay-level analysis is also recommended for cities/towns that showed significant fragmentation metric changes for a more precise spatio-temporal analysis of mangrove cover growth and/or loss and fragmentation.

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