

Assessment of Spatial and Temporal Fragmentation Dynamics of Various Land Covers and Their Implications for the Mangroves of San Juan, Batangas

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Abstract— As vital intertidal ecosystems, mangroves not only buffer coastal communities and support local livelihoods but also play a crucial role in mitigating climate change. In this context, this study examines landscape fragmentation driven by changes in land cover and its implications on mangrove ecosystems in San Juan, Batangas, Philippines, a coastal municipality increasingly affected by anthropogenic pressures. Using satellite data from 2010, 2015, and 2020 obtained from DENR-NAMRIA, land cover classification and landscape metrics were analyzed through QGIS and the LecoS plugin to assess fragmentation patterns across eight land cover types. Five key fragmentation metrics —Number of Patches, Mean Patch Size, Large Patch Index, Patch Cohesion Index, and Edge Density —were assessed to quantify and characterize spatial changes. Results revealed increasing fragmentation in built-up and agricultural areas, while mangrove patchiness remained relatively stable in number but diminished in spatial cohesion and edge complexity over time. Statistical analyses (ANOVA and Kruskal-Wallis) confirmed significant differences in fragmentation metrics across land cover classes, emphasizing the structural vulnerability of mangroves amid expanding urbanization and agriculture. Ground validation and field interviews highlighted the impact of sea-level rise, plastic pollution, fishpond expansion, and non-evidence-based mangrove planting initiatives. However, a growing mismatch between conservation efforts and the changing landscape threatens their sustainability. While local government-led mangrove conservation exists, these efforts are undermined by a lack of integration with broader land use dynamics. Thus, underscoring the need for spatially informed, evidence-based management strategies that incorporate landscape ecology principles and design holistic, adaptive, and scientifically sound management frameworks.

Keywords— Mangrove fragmentation; landscape ecology; GIS; land cover change; San Juan Batangas; coastal ecosystems; spatial analysis; landscape metrics.

I. INTRODUCTION

Mangrove forests are vital ecosystems found in intertidal zones, providing critical habitats for marine biodiversity and serving as some of the most efficient natural carbon sinks. They sequester large amounts of carbon, potentially the highest among forest ecosystems, and enable long-term storage, contributing significantly to the global reduction of atmospheric carbon (Choudhary et al., 2024). Beyond their climate function, mangroves support a wide range of biodiversity. Their complex root systems offer ideal spawning grounds and shelter for fish and other macrobenthos, while their trunks and canopies provide essential habitat for birds, mammals, and reptiles (Climate Change Commission, 2022). Wetlands, including mangroves, are well known for supporting

high bird diversity and often serve as critical stopovers for migratory species. In addition to biodiversity conservation, mangroves play a crucial role in disaster risk reduction. They act as natural buffers against storm surges and stabilize shorelines by trapping sediments and reducing coastal erosion (Schoonees et al., 2019, as cited in Sunkur et al., 2023). These functions are vital in protecting coastal communities and sustaining their livelihoods. Frontline mangrove species such as those in the genera *Avicennia* and *Sonneratia* are especially adapted to withstand harsh coastal conditions, offering strong resistance to typhoons and storm surges (Carlos, 2015). Furthermore, mangroves are integral to the subsistence and economy of coastal communities. They serve as nurseries for fish, provide food, and supply materials for construction and firewood (Carrasquilla-Henao et al., 2019). Over the years, however, mangrove cover in the Philippines has drastically declined. As of 2024, only 311,400 hectares of mangroves remain, down from approximately 450,000 hectares in the 1920s (Gevana et al., 2013, as cited in World Economic Forum, 2025). Large, intact mangrove forests are now limited to a few provinces, including Palawan (22.2%), Sulu (8%), Zamboanga del Norte and Sur (9.86%), Surigao del Norte and Sur (6.8%), Eastern and Western Samar (6.1%), Quezon (5.5%), Tawi-Tawi (4.4%), Bohol (3.69%), and Basilan (2.97%) (Viray-Mendoza, 2017). Although around 80% of the provinces still have some mangrove forests, many of them remain fragmented and in degraded conditions. The decline has been largely attributed to anthropogenic pressures, especially the overexploitation of resources by coastal communities and widespread conversion of mangrove areas into aquaculture ponds, salt beds, settlements, ports, agricultural land, and charcoal production sites. Among these, fishpond conversion is recognized as the primary cause of mangrove loss (Loma et al., 2017; Primavera, 2000). This is further exacerbated by the impacts of climate change, including sea level rise, increased typhoon intensity, changes in salinity, rainfall patterns, and ocean currents (Ward et al, 2016) that threaten the survival of the existing mangrove forests, and render planting interventions futile. This has resulted in significant damage and loss of livelihoods in the coastal areas due to massive flooding events. Studies have shown that benefits received from coastal protection of mangroves are valued at \$3,200/ha/year in flood reduction (Waves Policy Brief Philippines, 2017). Despite this alarming trend, interest in mangrove rehabilitation and reforestation has grown in recent years, particularly as part of the country's climate adaptation and mitigation efforts. Several

policy interventions have been introduced to support these initiatives. In the Philippines, several policies are being enacted to conserve the remaining mangroves and to institutionalize national funding to mobilize large-scale efforts, including the reversion of abandoned fishponds, and blended financing mechanisms for the rehabilitation of degraded mangroves. While political willingness remains strong, in effect, the majority of restoration efforts are. Mangrove rehabilitation initiatives yielded only 10-20% survival due to inappropriate species planting and improper site selection (Primavera & Esteban, 2008). *Rhizophora* species, one of the most common species to propagate and use in planting activities, are planted on seafront zones during periods of low inundation, without considering species zonation (Primavera et al., 2014). Furthermore, planting of mangroves in contiguous ecosystems, such as seagrass ecosystems, is a common practice causing ecological disruption in other ecosystems (Mendoza et al., 2019). Lastly, the lack of community participation in management planning, monoculture plantations, and planting efforts without science-based principles backing and unsustained funding play a large role in these failures. Particularly, if coastal communities are largely dependent on aquaculture (Wetlands International, 2017). However, many studies have merely focused on reporting the rate of mangrove cover loss, and while it is beneficial in conservation efforts, it remains insufficient. Another ecological degradation that remains vague is the occurrence of mangrove fragmentation as a result of. Fragmentation refers to the breaking up or disintegration of large tracts of mangrove forests into smaller, isolated patches. The disintegration of these connective ecosystems undermines the functions of an otherwise healthy mangrove. Fragmented mangroves are shown to exhibit lower resilience and ecological functionality and reduced capacity to buffer waves and thereby increasing soil erosion and sediment accretion (Bryan-Brown et al., 2019; Jaramillo et al., 2023). Fragmented mangroves are found to have diminished aboveground and soil carbon storage capacity compared to intact forests due to increased salinity fluctuations and reduced organic matter inputs (López-Portillo et al., 2022; Friess et al., 2020). These disturbed forest covers are also found to harbor less biodiversity, reporting 20% less in macrobenthic diversity, and may cause species migration disruption, and are less resistant to species invasion (Zhang et al., 2021; Carugati et al., 2017). Isolation of mangroves also results in limited gene flow and general reduction of genetic diversity (Amade et al., 2021). Critically, mangrove fragmentation undermines the social-ecological resilience of coastal communities. Fragmented mangrove forests provide fewer and less reliable ecosystem services per unit area compared to larger, contiguous stands. Smaller patches are often ecologically degraded, offer limited storm protection, and are less capable of supporting fisheries and biodiversity. Moreover, fragmented mangrove areas are less likely to be prioritized for legal protection or integrated into long-term conservation planning. The persistent issue of anthropogenically driven fragmentation, compounded by unsustainable land use practices and ineffective and weak science-backed governance, places additional strain on the already declining mangrove cover in the Philippines. Although

various policy and restoration interventions have been implemented, many reforestation efforts continue to suffer from low survival rates and limited ecological success. This is largely due to their failure to consider the biological requirements of mangrove species, hydrological connectivity, and the need for a landscape-scale intervention planning. Current programs often rely on isolated, site-based initiatives that do not consider the broader spatial dynamics of mangrove ecosystems, resulting in disconnected, myopic, and often unsustainable rehabilitation plans. This study aims to assess the spatio-temporal fragmentation dynamics of various land cover types in San Juan, Batangas, using appropriate landscape metrics and geospatial analysis. It also seeks to examine how these fragmentation trends potentially influence the extent, distribution, and connectivity of mangrove forests over time.

II. MATERIAL AND METHODS

Study Area

This study was carried out in San Juan, Batangas, a coastal municipality at the southeast end of Batangas Province in the Philippines. The site includes a number of coastal habitats, such as the estuarine domains and intertidal zone, suitable for the growth of mangroves. The mangrove ecosystem in San Juan is a critical coastline guardian for people living in the coastal community, a sustainer of fisheries, and a carbon sequester. Nevertheless, the region continues to experience growing anthropogenic activities, including coastal development, aquaculture, and increased tourism, which lead to habitat fragmentation (Primavera & Esteban, 2008).

Identification of the spatial limits of mangrove patches was done using remote sensing and GIS methods. Field validation was made where possible to qualify the presence of mangroves and the condition of the patches. This in-ground-truthing was of vital importance to confirm the correctness of the satellite-based classification as well as to notice the possible inconsistencies in the data.

Source of Data and Data Classification

The main space data used in the current research involved 2010, 2015, and 2020 geospatial data obtained from the Department of Environment and Natural Resources – National Mapping and Resource Information Authority (DENR-NAMRIA). Mangrove cover information was classified using a binary raster format with mangrove coverage (value = 1) and other land cover (value = 2,3,4,5,6,7,8,9) respectively. To achieve spatial consistency in analysis, all datasets were transformed to a common projection in EPSG: 3123-PRS92/Philippines zone 3. Fragmentation metrics were computed in QGIS, an open-source tool for ecological spatial analysis, with the help of the Landscape Ecology Statistics (LecoS) plugin (Jung, 2016). This plugin enables computing landscape-level metrics. Subsequently, statistical analyses were performed to determine patterns of fragmentation across land covers and to determine the significance of metrics and individual LCs in impacting fragmentation at a landscape level.

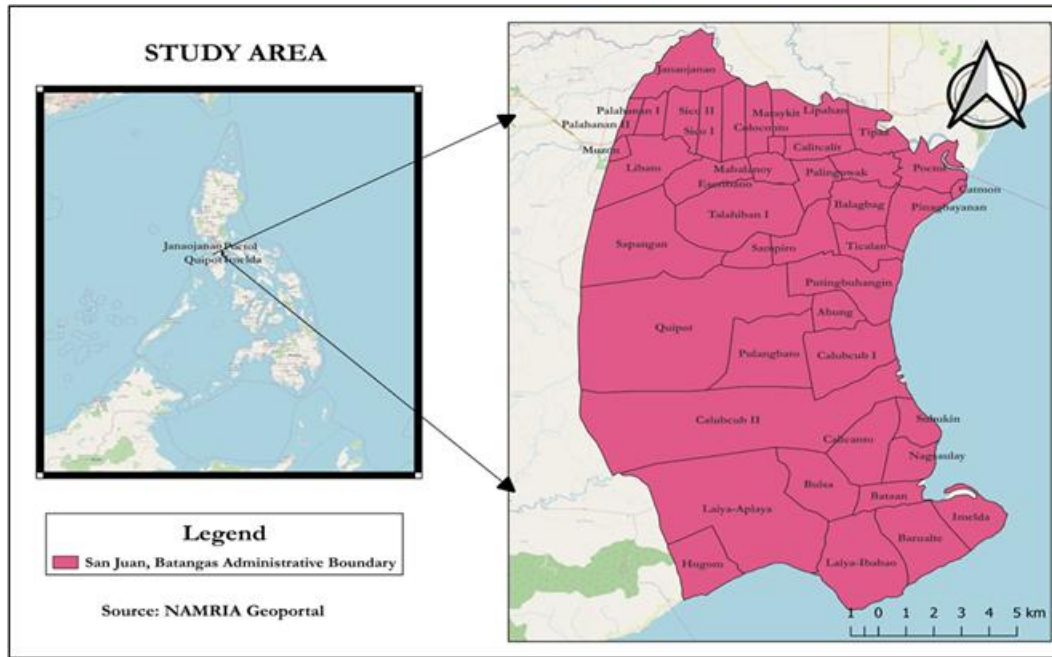


Figure 1. Administrative Map of San Juan, Batangas

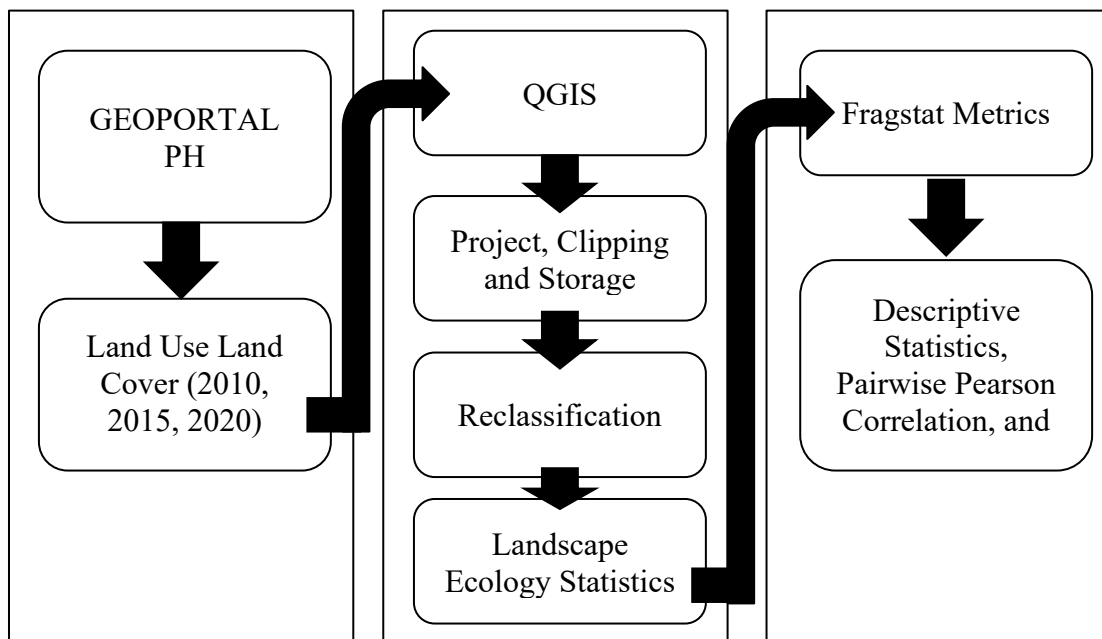


Figure 2. Methodological Framework

III. RESULTS AND DISCUSSION

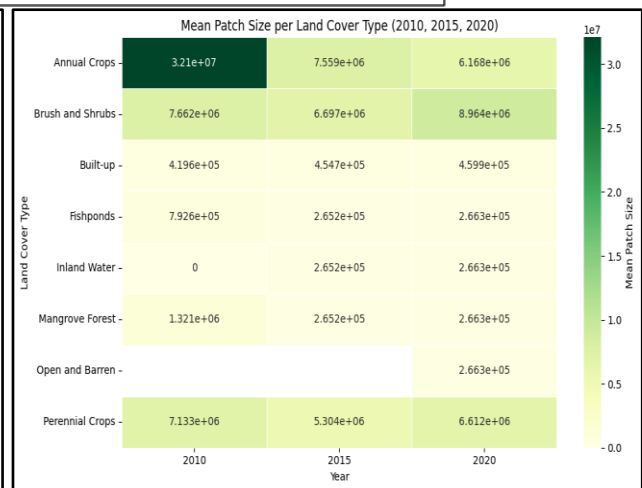
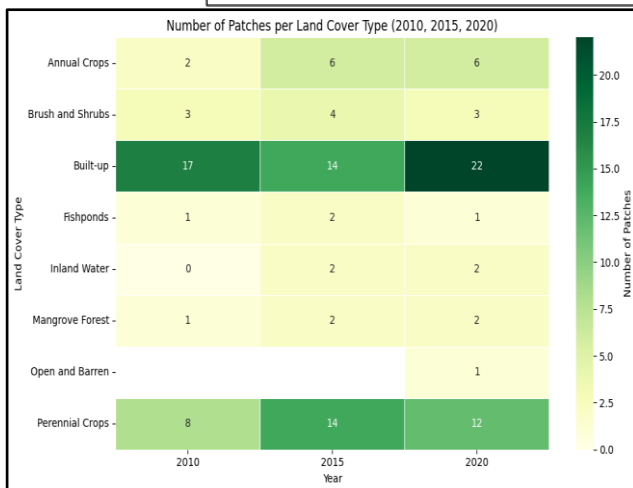
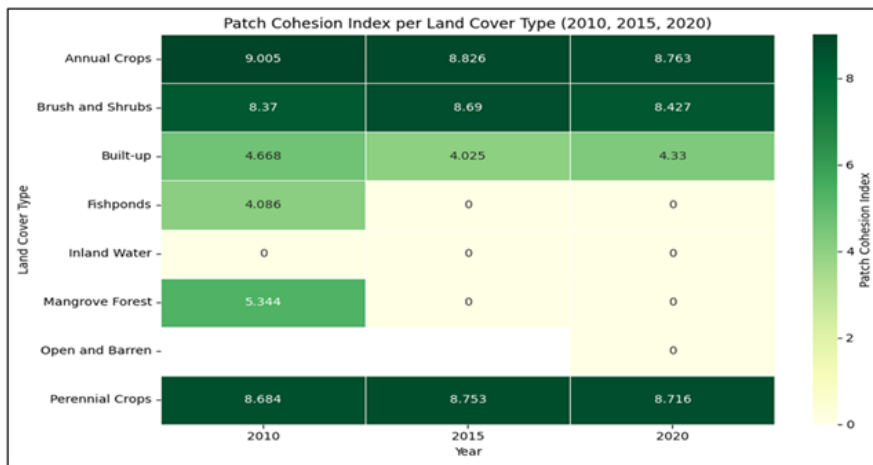
Changes in Land Cover per Fragmentation Metric over the years

Fragmentation across eight (8) land covers exhibited distinct spatio-temporal patterns from 2010-2020. The number of patches (NP) increased over the years, with built-up (from 17-22) and perennial crops (8-12) exhibiting the most evident changes, suggesting urban and agricultural encroachment. Meanwhile, the patchiness of mangrove forests remains relatively stable, suggesting minimal quantitative

fragmentation. Mean Patch Size (MPS) declined over the decade, with annual crops' patch size 3.2×10^7 m² in 2010 to 6.1×10^6 m² in 2020. The same trend has been observed in perennial crops, suggesting fragmentation of agricultural areas into smaller land parcels, potentially suggesting conversion to another land cover. However, mangroves and built-ups showed minimal variation, implying structural stability and uniformity, which suggests consistent land use practices and slowdown of urban sprawl. Fishponds, likewise, exhibited a sharp decline in mean patch size from 7.92×10^5 to 2.66×10^5 , suggesting a decline in structural stability of aquaculture land use. Large

Patch Index (LPI), a measure of the existence of patch dominance, likewise yielded the same results in annual crops (38.9 to 21.48), indicating increasing fragmentation and reduced dominance of single large patches. Conversely, perennial crops that initially exhibited a decline in mean patch size showed an increase in the size of dominant patches, which may hint at land shift in land use between the two land covers. Brush and shrub areas fluctuated, exhibiting peaking in 2015 before declining in 2020. Meanwhile, coastal land covers such as mangrove forests, inland water, and fishponds consistently showed low LPI values (~0.17%), reflecting diminishing or limited spatial extent of dominant patches. Built-up areas also maintained low LPI, indicating dispersed urban development with minimal expansive patches. Patch Cohesion Index (PCI) among land covers revealed patterns of landscape connectivity, particularly among agricultural and urban land uses. High PCI values exhibited by perennial crops, brush and shrubs, and annual crops indicate sustained spatial connectivity within the decade, and imply fairly stable or contiguous patch structures, among which, perennial crops displayed the highest structural cohesiveness, which likewise coincided with dominant and stable patch structures. In contrast, built-ups recorded the lowest but likewise stable PCI values among the land covers, suggesting that they maintained structural stability over the years despite an increase in fragmentation. Mangrove forests showed a moderate PCI in 2010 (5.344) but were absent in

subsequent years, suggesting a drastic loss of mangrove, or possible re-classification of cover. Inland waters and open and barren land covers exhibited 0 PCI in the succeeding years due to a lack of geospatial data. Edge Density (ED) remains largely stable and minimal across all land covers, except coastal-related land uses. Mangrove forests and fishponds exhibited the highest ED values in 2010 (4.018 and 3.349, respectively), a stark contrast to the values exhibited by agricultural and built-up areas, which were revealed at levels below 0.0005, indicating more highly fragmented or irregular patches. Despite the significant difference, both showed a steady decline over time, converging at 2.664 by 2020, suggesting a reduction in edge complexity, possibly due to consolidation or loss of these land cover types. In contrast, inland water, initially absent in 2010, appeared with a consistent ED value of 2.66 in later years, potentially reflecting classification changes or hydrological shifts. Agricultural and built-up land cover ED values suggest more compact, homogenous patches and less edge complexity, thereby suggesting less vulnerability to edge effects. However, despite their low values, perennial crops revealed an increase in edge, suggesting potential expansion or intensification of land cover changes resulting in encroachment on connected LCs. The land cover changes, visible at a landscape level, reveal notable shifts in dynamics that potentially result in changes in surrounding habitats over the years.



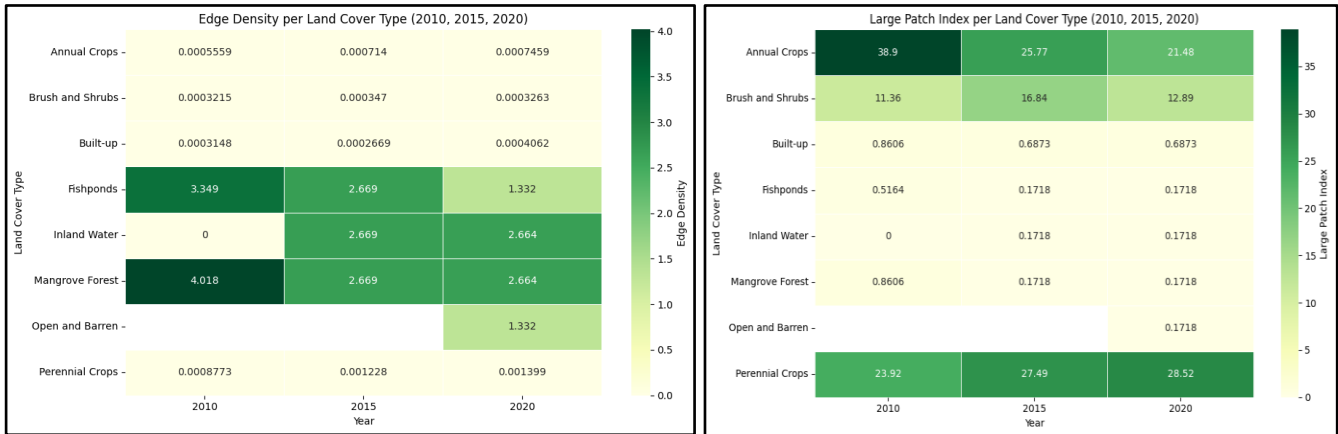


Figure 3. Changes in Fragmentation Metrics per Land Cover in 2010, 2015, and 2020

Spatial Patterns in Fragmentation by Land Cover

Analyzing the spatial separation of land cover classes enhances understanding of how various land uses shape landscapes and influence ecological processes. Visual patterns show that urbanized areas contain many small patches with high edge density and low patch cohesion. These characteristics indicate that patches are small and widely dispersed, likely resulting from urban expansion and the construction of roads and other infrastructure. Urban fragmentation can restrict the movement of species, decrease species interaction, lower habitat quality, and make habitats more prone to invasion by invasive species (Seto et al., 2012). The noticeable patchiness in urban land use reveals patterns of disbursement as a result of ongoing development that alters natural land covers. Agricultural land use, predominantly composed of annual and perennial crops, appears as large, contiguous patches in spatial

analyses, reflected in high values for both LPI and MPS. The low edge density observed in these areas indicates minimal fragmentation and a relatively uniform landscape structure. Intensified agricultural production can alter ecosystem functions, contribute to the introduction of fertilizers and pesticides, and, in some cases, affect adjacent ecosystems such as mangroves, particularly if these patches are among the most dominant within the landscape which could signify greater chances of affecting the connected ecosystems (Foley et al., 2005). These patterns reveal that fragmentation across different land cover types manifests in distinct and characteristic spatial configurations. Each land cover classification—such as urban, agricultural, or coastal land use—exhibits unique fragmentation dynamics shaped by a suite of anthropogenic activities that consequently influence the structure, form, and quality of connected ecosystems.

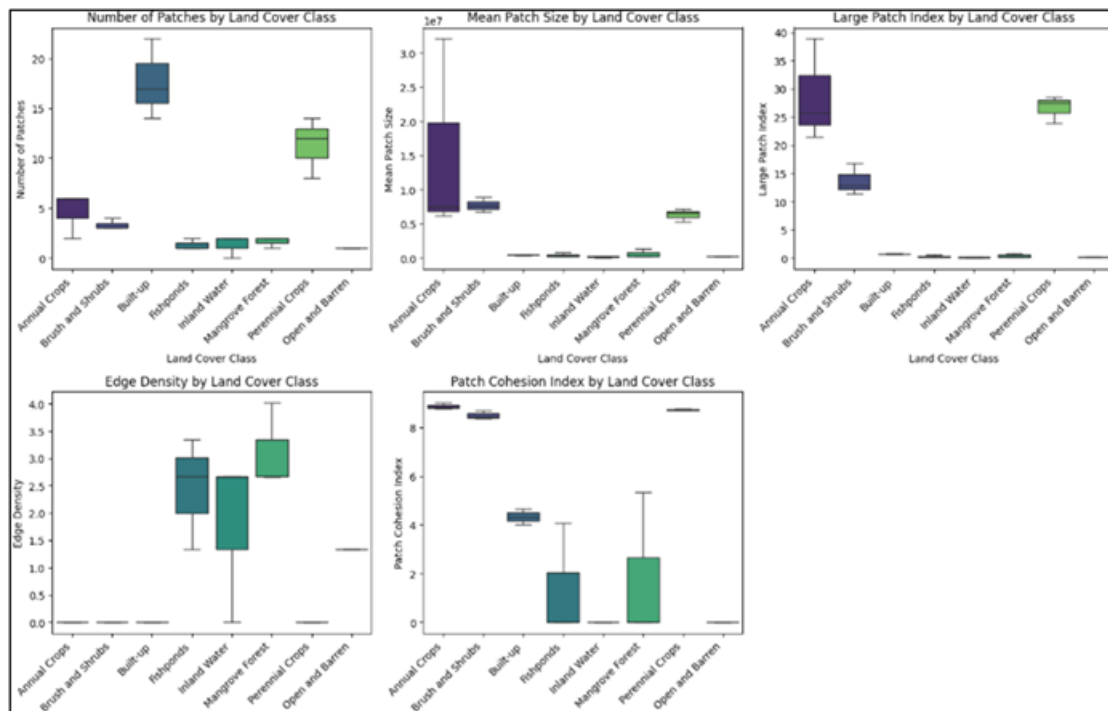


Figure 4. Variation in Landscape Fragmentation Metrics Across Land Cover Classes

These impacts on contiguous land covers or ecosystems may also vary in scale and intensity, depending on the nature of the fragmentation and the ecological sensitivity of the surrounding landscape. The use of classified spatial maps highlights the value of applying targeted landscape metrics in coastal resource management. While urban and agricultural expansion is often assessed for its socioeconomic benefits, its impact on mangroves, an ecosystem that is highly sensitive to disturbance such as aquaculture expansion, deforestation, among many anthropogenic and climatic factors, remains underemphasized (Akram et al., 2023). Fragmentation disrupts ecological connectivity, limiting the movement, interaction, and organization essential for coastal protection, carbon sequestration, and biodiversity support (Barbier et al., 2011). Sustainable coastal landscapes will depend on integrating landscape ecology principles into land use planning to minimize fragmentation and its effects.

Correlation and Assumption Test

To guide the selection of appropriate statistical tests, a two-pronged assumption testing approach was conducted. First, correlation analysis among the five fragmentation metrics was performed to assess interdependence and determine whether the variables should be analyzed collectively or individually. Second, tests for normality and homogeneity of variances were applied to evaluate the distributional characteristics of each metric, informing whether parametric or non-parametric analyses were appropriate. The correlation matrix reveals strong interrelationships among several fragmentation metrics. MPS is highly correlated with LPI ($r = 0.81$) and moderately correlated with PCI ($r = 0.63$), while LPI and PCI exhibit a strong correlation ($r = 0.83$). These patterns suggest that landscapes with larger patches tend to be more cohesive and structurally dominant, traits commonly associated with intact or recovering mangrove systems (Zhao et al., 2018).

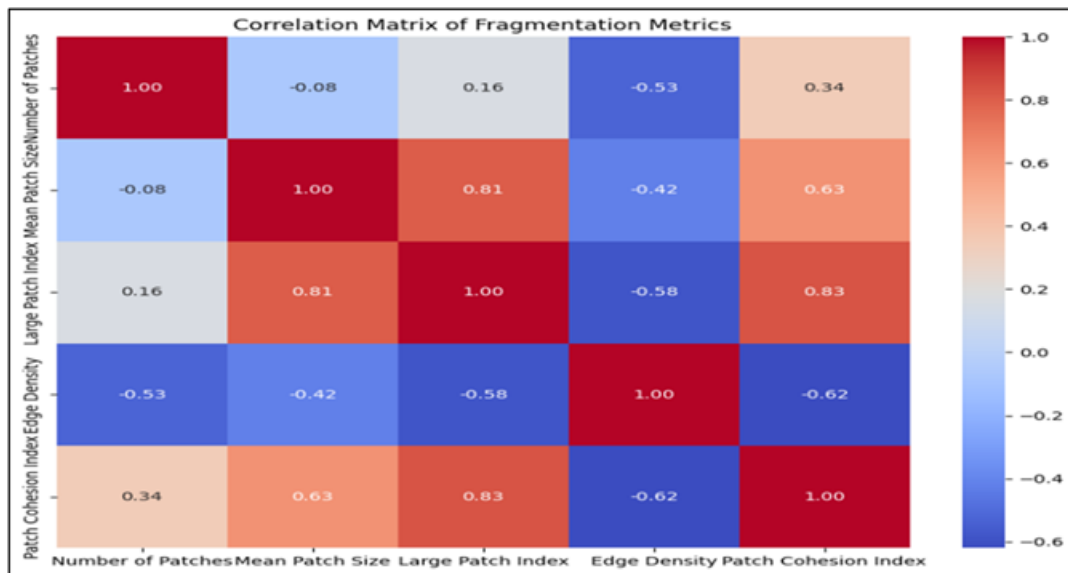


Figure 5. Correlation Matrix of Landscape Fragmentation Metrics

TABLE 1. Summary of Normality and Homogeneity of Variance Tests with Test Statistics and P-values ($\alpha=0.05$).

Metric	Test Name	Test Statistic	P-value	Result ($\alpha=0.05$)
Assumption Test: Normality				
NP	Shapiro-Wilk (Residuals)	0.93345922	0.144834872	Normal distribution
MPS	Shapiro-Wilk (Residuals)	0.585126414	9.22E-07	Non-normal distribution
LPI	Shapiro-Wilk (Residuals)	0.765653234	0.000152101	Non-normal distribution
ED	Shapiro-Wilk (Residuals)	0.798257673	0.00046995	Non-normal distribution
PCI	Shapiro-Wilk (Residuals)	0.747924996	8.51E-05	Non-normal distribution
Assumption Test: Homogeneity of Variance				
NP	Levene	0.941919192	0.50604279	Equal variances
MPS	Levene	0.94651639	0.503167862	Equal variances
LPI	Levene	1.538595623	0.233048357	Equal variances
ED	Levene	0.786235048	0.610100174	Equal variances
PCI	Levene	0.664759679	0.698344244	Equal variances

Although some fragmentation metrics are more correlated than others, each captures a distinct aspect of landscape structure. For instance, Mean Patch Size (MPS) reflects average patch dimensions, while Patch Cohesion Index (PCI) measures spatial connectivity, both offering unique insights into how landscapes are configured (McGarigal et al., 2012). While redundancy can be addressed through methods like dimensionality reduction, such approaches may obscure the ecological meaning of individual metrics. As McGarigal et al. (2012) emphasize, each metric contributes specific information about landscape patterns; thus, this analysis proceeds with a univariate approach to preserve the integrity and interpretability of each measure when evaluating differences across land cover classes.

The results of the normality tests (Shapiro-Wilk) indicate that only the residuals for the Number of Patches variable meet the assumption of normality ($p > 0.05$), while all other metrics significantly deviate from normal distribution ($p < 0.05$).

Meanwhile, Levene's test shows homogeneity of variances across all variables ($p > 0.05$). Based on these findings, a parametric approach using ANOVA will be applied for the Number of Patches variable, where normality is satisfied. For the remaining metrics that violate normality assumptions, nonparametric testing using the Kruskal-Wallis test will be employed to ensure robust and valid statistical inference.

Univariate Statistical Test

TABLE 2. Summary of Univariate Tests Showing Significant Metrics with Test Statistics and P-values ($\alpha=0.05$).

Metric	Test Name	Test Statistic	P-value	Result ($\alpha=0.05$)
NP	ANOVA	21.90	1.61E-06	Significant
MPS	Kruskal-Wallis	17.37848606	0.015112069	Significant
LPI	Kruskal-Wallis	19.01809691	0.008130839	Significant
ED	Kruskal-Wallis	15.11048159	0.034608984	Significant
PCI	Kruskal-Wallis	18.90041494	0.008505091	Significant

ANOVA and Kruskal-Wallis tests were used to determine whether there are statistically significant differences between land cover classes for each metric. This approach aligns with standard practices in landscape ecology, which recommend including all correlated metrics for comprehensive analysis (Li et al., 2020). The statistical tests indicate that all five landscape metrics differ significantly across the eight land cover classes. This confirms that fragmentation patterns and landscape structure vary notably depending on land use type. Notably, NP differed significantly across land cover classes (ANOVA, $F = 21.90$, $p < 0.001$), indicating that fragmentation intensity, measured by patch count, varies depending on land use type. MPS (Kruskal-Wallis, $\chi^2 = 17.38$, $p = 0.015$) and LPI (Kruskal-Wallis, $\chi^2 = 19.02$, $p = 0.008$) also differed significantly across land cover classes, suggesting that patch size and dominance vary according to land cover. These results align with Fahrig (2003), who noted that fragmented landscapes generally have smaller and more isolated patches, affecting species movement and ecological dynamics. The PCI showed significant variation across land cover classes as well (Kruskal-Wallis, $\chi^2 = 18.90$, $p = 0.009$), reflecting differences in habitat connectivity that are critical for biodiversity conservation (Primavera & Esteban, 2008). ED also differed significantly across land cover classes (Kruskal-Wallis, $\chi^2 = 15.11$, $p = 0.035$), highlighting how exposure to edge effects such as erosion and saltwater intrusion varies among ecosystems, particularly impacting mangrove vulnerability (Alongi, 2002). The results show that habitat fragmentation occurs at broad spatial scales, with each land cover class forming a distinct component of the fragmentation pattern. These differences underscore the value of integrating land cover data into spatial planning. Identifying areas that exhibit fragmentation and influence surrounding habitats can support conservation strategies aligned with local management priorities (McGarigal et al., 2012)

The Status of Mangroves in San Juan

The Local Government Unit (LGU) of San Juan, Batangas, has actively pursued initiatives to conserve the municipality's

remaining mangrove cover. In 2010, a municipal resolution was enacted to support activities that enhance coastal protection and resilience. In line with this, the Municipal Environment and Natural Resources Office (MENRO) has facilitated mangrove planting efforts, particularly those initiated by the private sector, along coastlines, beaches, and eroded riverbanks. While these efforts have led to the successful reforestation of some mangrove patches, particularly within the large river delta, many of these efforts remain largely fragmented and lack scientific grounding. As a result, many of these initiatives suffer from high seedling mortality. The lack of evidence-based planting approaches leads to poor site-species matching, and with the evident fragmentation of various land covers, and consequently affects mangrove habitat degradation, further lowering the chances of mangroves surviving in already vulnerable habitats.

Field interviews also strengthened the findings on drastic landscape changes that occurred within the last two decades. Sea level rise has consumed long stretches of coastline, eroded the sediments where seafront species used to thrive, causing massive die-offs. Natural and planted mangrove forests have become more fragmented into smaller, isolated patches. Urbanization of coastal areas and expansion of production zones have resulted in the alteration of natural hydrologic flow, causing *Rhizophora* species to be subjected to long periods without tidal inundation. Built-ups have also resulted in massive plastic pollution that degrades the sediments and root systems of remaining mangrove forests. The river delta has been subjected to large-scale quarrying that lasted for decades, altering the structure of riparian ecosystems and weakening the riverbanks where planting efforts are being held annually. Fishpond conversions are almost irreversible, as large-scale aquaculture production shifted the dynamics within the lands due to decades-long intensified use and expansion. Field observations pointed out that mangrove conservation in these zones is largely driven by the privatization of fish ponds, by which the owners value mangroves as areas to spawn oysters for production. Ecotourism has significantly affected the survival of *Avicennia* and *Sonneratia* species along the coasts, with only a few individuals remaining in these areas. This decline further compromises the resilience of an already vulnerable ecosystem against natural disasters such as typhoons and storm surges. Despite these challenges, coastal communities continue to remain vigilant and cautious about cutting down mangroves, recognizing their crucial role in protecting the shoreline and riverbanks. The ongoing protection of coastal resources, including mangroves, has benefited greatly from the deputation of coastal patrols, which has fostered a shared and united commitment to maintaining and conserving the remaining mangrove cover. However, while the local government is proactive in implementing conservation strategies, it is evident that without a landscape-wide view of fragmentation and land change dynamics, particularly their cascading effects on surrounding habitats, efforts are at risk of being undermined. Mangroves, as highly sensitive and interconnected ecosystems, cannot be effectively conserved in isolation from the broader landscape context. A failure to adopt an integrated spatial approach not only weakens ecological

outcomes but also compromises long-term climate resilience and coastal protection for local communities.

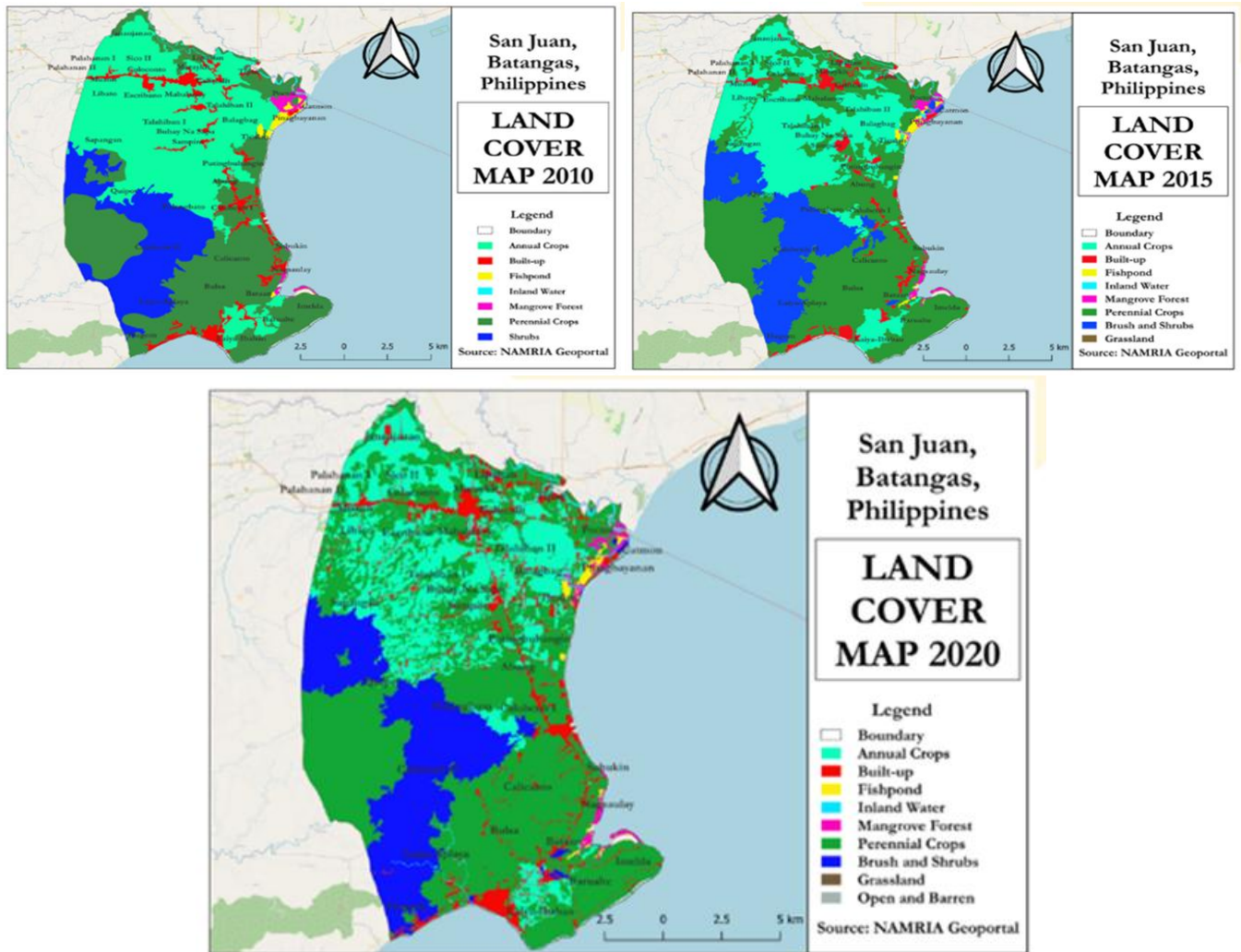


Figure 6. Land Cover Changes in San Juan, Batangas

Developing Holistic, Adaptive, and Evidence-Based Coastal Management Strategies

The evident fragmentation of various land cover types in San Juan, Batangas, poses significant challenges to the quality, connectivity, and long-term resilience of the remaining mangrove ecosystems. These fragmented landscapes not only impede natural regeneration and ecological function but also exacerbate the vulnerability of mangroves to climate and human-related risks. In response, mitigation measures must go beyond isolated and site-based interventions and must adopt holistic, adaptive coastal management strategies that address these issues at a landscape scale. Conservation measures must move beyond isolated, site-based interventions and shift toward holistic and adaptive coastal management strategies rooted in a landscape-scale perspective. This includes reducing anthropogenic pressures, particularly agricultural encroachment and urban sprawl, that significantly alter the structure and ecological function of otherwise healthy, interconnected mangrove systems. This paradigm shift

demands a systems-thinking approach that recognizes the interdependence between ecological and social components of coastal zones. It must be embedded in municipal land use planning to ensure that spatial development decisions do not compromise coastal resilience. Ultimately, protecting mangroves is not merely an environmental concern—it is a socio-economic imperative for communities whose livelihoods, food security, and survival depend on the ecosystem services these coastal forests provide.

IV. CONCLUSION AND RECOMMENDATION

The fragmentation analysis of San Juan, Batangas, from 2010-2020, reveals profound and noticeable shifts in landscape structure driven by urban expansion, agricultural intensification, and changing coastal land use. Significant variations across fragmentation metrics, such as the increasing number of patches and declining mean patch sizes, highlight the growing spatial disconnect between land cover types, particularly in agricultural and coastal zones. These changes are

not merely values but reflect broader and often unnoticed issues on ecological degradation, diminished habitat connectivity, and reduced landscape resilience, which continue to undermine the initiatives that aim to restore, protect, and manage the diminishing mangroves. The findings affirm that land cover changes and associated fragmentation do not occur in isolation. They interact with and influence adjacent ecosystems, compounding vulnerabilities across spatial scales. Therefore, addressing fragmentation demands more than reforestation—it requires a paradigm shift toward holistic, evidence-based, and landscape-scale planning. Despite the local government’s ongoing rehabilitation efforts, fragmented land use patterns persist, exacerbated by the absence of institutionalized funding mechanisms and the limited integration of scientific evidence into conservation planning. Once moderately cohesive, mangrove patches have either vanished from fragmentation records or been reclassified, signaling an alarming decline that calls for urgent, targeted protection and ecologically sound restoration strategies. Strengthening future analyses will require high-resolution satellite imagery and more granular change detection to accurately monitor land cover transitions and guide adaptive management. Municipal land use policies must adopt holistic and adaptive management strategies grounded in landscape ecology principles and integrate land cover change dynamics into zoning and development planning. By adhering to these scientific standards, San Juan, Batangas, can effectively address the growing vulnerability of its coastal communities to climate-related risks, safeguard its remaining mangrove ecosystems, and promote long-term socio-ecological resilience.

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