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Spatial Based Assessment of Land Use and Land Cover Change on the Different Landscape Patterns in the Wakatobi National Park, Indonesia

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ABSTRACT

The primary aim of this study was to assess multi-year land use and land cover (LULC) changes utilizing GIS techniques within different landscape patterns of the Wakatobi National Park, Indonesia. The study area, i.e., the Kapota Island is one of the important regions where its terrestrial ecosystem consists of protected and developed zones. A spatial pattern analysis technique was implemented to classify and assess changes in LULC from 1990 to 2020 using Landsat 5, 7, and 8 images. As many as 275 to 414 samples were used in the maximum likelihood procedure, and their accuracy was assessed following field investigations to understand the landscape response to LULC changes. A number of landscape metrics were calculated to understand the landscape patterns in the study region. The results of the analysis show that vegetated areas have changed from 1,111.6 ha in 1990, then to 1,410.9 and 1,227.5 ha in 2010, and 2020, respectively, and this is related to the climate, as during the peak dry season, planting patterns change, leading to a reduction in green cover compared to the rainy season. The results also reveal that landscape metric indices vary considerably according to the variation of nature conditions, especially in the extreme climate events and human intervention. This becomes the implication of the condition where the landscape pattern is realistically fragmented, and complex, with lower connectivity and greater diversity. This approach has proven effective in interpreting human interventions in land utilization, as well as assessing the influence of extreme climate events on ecosystem sustainability in small islands. The higher the spatial resolution of spatial images, the better the interpretation of ecological landscape structure, function, and changes. This study gives an important insight into spatial regulation, especially in the designation of spatial pattern delineation as well as land utilization and ecosystem management at small islands with a dominant protected function.

Keywords: LULC, GIS, landscape patterns, small island, ecosystem.

INTRODUCTION

Small islands are generally rich in natural resources that can be developed to support economic growth but are vulnerable to and experience degradation of biodiversity. The vulnerability of these ecosystems can be assessed through the aspects of ecological patterns, ecological functions, and ecological pressures in maintaining biodiversity (Hong *et al.*, 2024). The integration of GIS and landscape ecology provides important references for ecological protection from the impacts of economic development (Zeng *et al.*, 2022); spatial planning, and management, particularly land fragmentation in conservation areas (Zeng *et al*., 2022; Ma *et al*., 2022); sustainable regional planning (Shafie *et al*., 2023) be a procedure relative to its natural and non-disturbance process; and it could be hastened by the occurrence of disturbance regimes. The objective of this research is to survey the changes in a landscape structure, over a period of 30 years, to attain information, as to the current conditions of land use, utilizing landscape metrics in the watershed area of the Latian Dam, so as to analyze the results and the voids present, towards obtaining a specified sustainable regional planning for the abovementioned watershed. Land use was identified and reviewed by means of four Landsat satellite images for 1987, 1998, 2007, and 2017; and in this watershed, it was classified into four classes, (a; (Devi and Shimrah, 2022); fragmentation data on coastal ecosystems (Arasumani *et al*., 2024) they are currently threatened by invasive plant species. The Point Calimere Ramsar Site, located in India, contains coastal tropical dry evergreen forests, coastal grasslands, and mangroves that are now threatened by the invasion of Prosopis species. Consequently, several birds, mammals, and amphibians that depend on these habitats are also at risk. Therefore, tracking and monitoring invasive species is required for restoring wetland ecosystems and preventing further invasions. The present study investigated multi-season Sentinel-2 Spectral Temporal Metrics (STM). Several studies have shown that monitoring areas through this approach are effective in assessing conservation success (Parisi *et al*., 2023), disaster mitigation (Tang and Fujita, 2022), protection, and management of populations of rare species (Zhang *et al*., 2023), wildlife habitats in national parks (Russo-Petrick and Root, 2023).

Kapota Island is one of the inhabited islands within the Wakatobi archipelago and is part of the Wakatobi National Park. The area of the Wakatobi National Park is equivalent to the administrative area of Wakatobi Regency, encompassing both land and marine spaces. Currently, the Wakatobi National Park is designated as one of the 10 National Strategic Tourism Areas aimed at increasing tourist visits and revenue through the sustainable utilization of natural and environmental resources. As a national park, it plays a conservation role and can be utilized based on a zoning system for tourism and recreation purposes. The development of tourism and recreational areas must be supported by the availability of infrastructure. However, given that the land area of Wakatobi Regency is smaller compared to its marine area, careful planning is necessary for infrastructure development.

Basic infrastructure is needed to support the livelihoods of the community over time in line with population growth, which also requires adequate space. Land use and land cover (LULC) on the land area of the island undergo changes that impact the ecological landscape. Land cover data serves as a primary data source for measuring the complexity index of landscape structure (Barnoaiea, 2011). Landscape characteristics, including structure, function, and changes, are greatly influenced by human activities and time (Gkyer, 2013). Human activities are among the factors influencing landscape changes (Arora *et al*., 2021). Landscape matrices can be used for monitoring forests, ecosystem services, urban management, and biodiversity conservation (Yu *et al*., 2019). Landscape metrics can also be applied in ecosystem management for water, habitat, and land conversion (Boongaling, *et. al.*, 2018).

The integration of technology utilization between landscape ecology methods and spatial analysis facilitates the monitoring of landscape use and spatial structure patterns within a landscape. Higher spatial data accuracy allows for a more detailed interpretation of landscape pattern layers in land use and land cover (Sertel *et al*., 2018). Literature studies demonstrate that this methodological approach is used for observing fragmentation in watershed areas (Boongaling, Faustino-Eslava dan Lansigan, 2018; Talukdar *et al.*, 2021), urban areas in relation to air pollution (Ye *et al*., 2016), urban areas in relation to landscape fragmentation (Fan and Myint, 2014), and animal movement and isolation. Spatial-temporal land changes will affect habitat quality (Ge *et, al*., 2023).

This study was aimed at assessing multi-year LULC changes from 1990 to 2020 utilizing GIS techniques within different landscape patterns of a small island of the Wakatobi National Park, Indonesia. The Kapota Island was selected as study area, because it becomes one of the important regions where its terrestrial ecosystem consists of protected and developed zones. Integration of spatial-based assessment and landscape metrics is important in this context. In general, the utilization of landscape ecology and spatial analysis technology is still not widely adopted for small islands, particularly in the research concerning landscape composition and the value of spatial structure in area management and decision-making (Helmi *et al*., 2020). This method is also considered reliable for analyzing the dynamic processes of land conversion and providing insights into alternative land management.

MATERIAL AND METHODS

Study area

This research was conducted on Kapota Island, Wakatobi Regency, focusing solely on its terrestrial ecosystem (Figure 1). Administratively located in the Southeast Sulawesi Province, the island can be accessed via air transportation from the city of BauBau or Kendari, and by sea through Kendari, Baubau, Lasalimu, or Kamaru to Wangi-Wangi Island, then to Kapota Island. This area is part of the Wakatobi National Park, managed based on a zoning system with potential areas for nature tourism development. According to the Village Development Index data, the villages on Kapota Island fall into the most underdeveloped category, and the residents are categorized as poor, despite the tourism potential for development. Therefore, to increase local and regional income, this area has been designated as a National Strategic Tourism Area.

Spatial planning for land use on Kapota Island has been established to support the availability of tourism infrastructure and the local community livelihoods. Kapota Island consists of 5 villages (*i.e*., Kabita, Kabita Togo, Kapota, Kapota Utara, Wisata Kolo), with a population of 3.303 in 2010 and 4.674 in 2020. The average rainfall from 2012 to 2022 was a maximum of 321.055 mm/year and a minimum of 41.827 mm/year, with a maximum of 22 rainy days/year and a minimum of 5 rainy days/year. August, September, and October were the months with the lowest rainfall intensity. The soil structure is formed from coral rock weathering (limestone), with the dominant geological formations being limestone rocks and some Ambenua formations. This indicates that the plant growth on Kapota Island is highly constrained.

Data collection

Landsat images with a resolution of 30 meters from 1990, 2000, 2010, and 2020 were obtained from https://earthexplorer.usgs.gov/. The raster data were then analyzed to perform land cover and land use classification. Subsequently, vector data were converted into raster data for use in landscape ecology analysis.

Spatial pattern analysis

This analysis aimed to classify and assess the changes in LULC in the study area from 1990 to 2020. Satellite imagery data from Landsat 5, 7, and 8 were obtained from https://earthexplorer.usgs.gov/. The initial processing steps involved

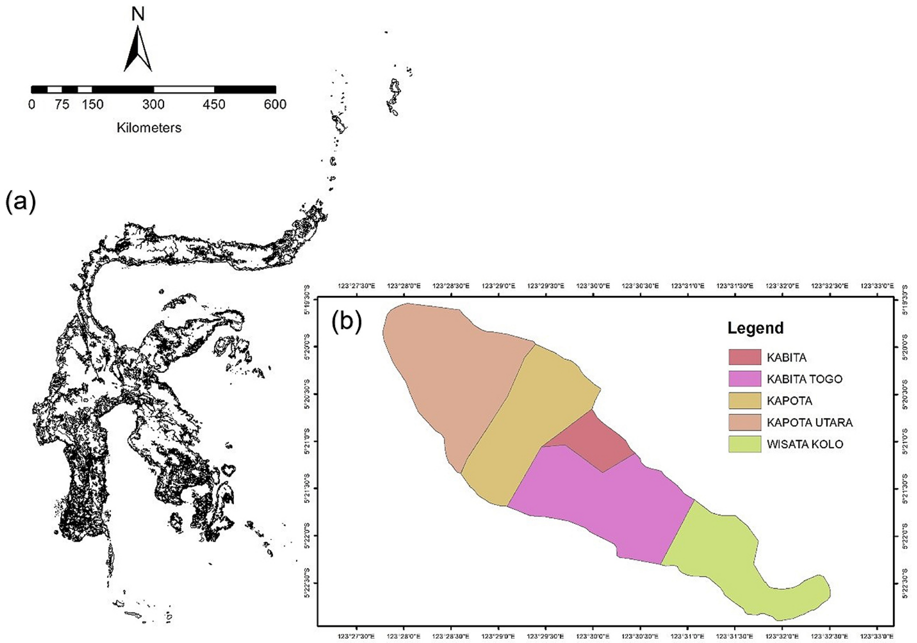

Figure 1. Study location (a) Sulawesi Island (b) Kapota Island, Wakatobi Regency, consisting of five villages

layer stacking in ENVI 5.2 before geometric and radiometric correction. The classification process was conducted in ArcGIS 10.8 using the maximum likelihood technique with a varying number of samples ranging from 275 to 414 for the time series of 1990–2020 with the assistance of Google Earth. The imagery was interpreted into 5 classes: vegetation, settlements, water bodies, coastline, and open fields. Classification accuracy was assessed by collecting ground control points using a Garmin 64s GPS device at research locations. Field investigations were conducted to understand the landscape response to land use changes.

Landscape ecology

The landscape metrics analysis requires LULC data of Kapota Island in raster/image format compatible with the data format used in Fragstats. This analysis includes five LULC categories: vegetation, settlements, open land, and water bodies. Landscape change analysis can effectively reflect spatial patterns that depict the shape, isolation, and configuration of habitat patterns based on land use/land cover and their ecological landscape impact through geometric features. Landscape patterns were analyzed using landscape metrics, which consisted of patch, class, and landscape metrics to measure various aspects of landscape patterns, such as fragmentation, heterogeneity, and connectivity (Figure 2). This analysis utilized the Fragstats 4.2 software obtained from https://fragstats.org/. Spatial, landscape, and land use patterns are interconnected (Yang *et al.,* 2020). The landscape pattern indices were calculated, and were used to understand the landscape pattern on Kapota Island (Table 1).

RESULT AND DISCUSSION

Land use and land cover of Kapota Island from 1990 to 2022

Satellite image data analysis of land use on Kapota Island categorized land use into 5 classes: beach, settlements, waterbody, openland, and vegetation. From 1990 to 2020, the highest land conversion occurred in settlement areas, with an area of only 14.22 hectares in 1990 expanded to 43.92 hectares in 2020. Openland, which covered 576.81 hectares in 1990, decreased to 428.49 hectares in 2020. Meanwhile, the beach area, which was 98.10 hectares in 1990, increased slightly to 101.70 hectares in 2020. Observations of the coastline are influenced by tidal conditions. During high tide when the satellite image was captured, the coastline appears wider, whereas during low tide, the area of inundation increases, making it appear as a sea area. This coastline data can be utilized as a tourism potential, offering beautiful stretches of white sand that enhance the natural beauty of Kapota Island. Additionally, coastal data or coastline data could be used to estimate coastal erosion (Table 2).

The land use trend data on Kapota Island also shows that the vegetated area varied, covering 1,111.59 hectares in 1990, then increased

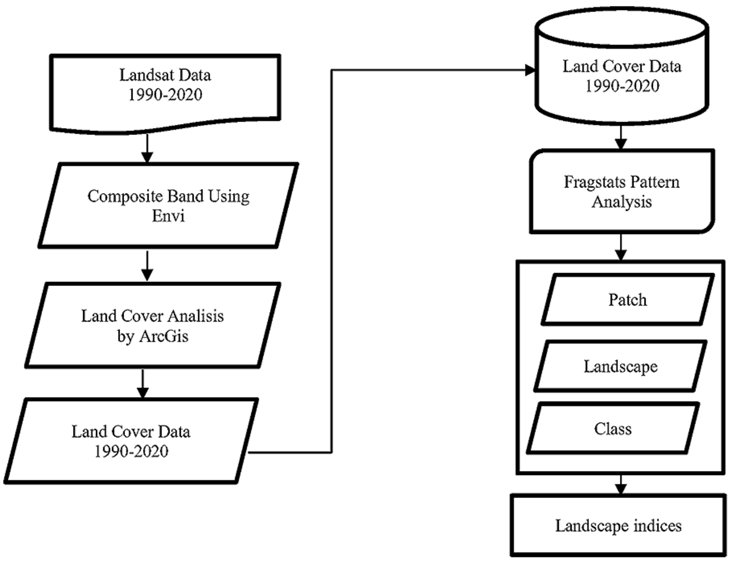

Figure 2. Flowchart of analysis procedure

Table 1. Landscape metric index (Hesselbarth, 2023; McGarigal and Marks, 1995

Category	Metric	Ecology
Metric class		
Area	CA (Class area) $CA = sum(AREA[patch_{ij}])$	Total area (hectares)
	LPI (Largest patch index) $LPI = \frac{max_{j=1}^{n}(a_{ij})}{A} \times 100$	Describes the percentage of large patches in the landscape and can indicate the superiority of a particular area. The larger the value, the clearer its superiority.
Aggregation	NP (Number of patches) $NP = n_i$	Number of patches, the simplest index to measure landscape fragmentation and separation. Indicates heterogeneity.
	PD (Patch density) $PD = \frac{n_i}{A} x\ 10000 \times 100$	Number of patches per unit area, which depicts the level of fragmentation in the landscape. The larger the PD value, the higher the landscape fragmentation and spatial heterogeneity.
	LSI (Landscape shape index) $LSI = \frac{e_i}{min\ e_i}$	Depicts the compactness of patches influenced by patch size. The higher the LSI, the more fragmented the patches.
	IJI (Interspersion and Juxtaposition index) $IJI = \frac{-\sum_{k=1}^{m}\left[\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right) ln\left(\frac{e_{ik}}{\sum_{k=1}^{m} e_{ik}}\right)\right]}{ln\ (m-1)} \times 100$	Depicts the uniformity of adjacency size for each class. Approaches 0 if a class only adjoins one other class and reaches 100 when a class is evenly adjacent to all other classes.
	AI (Aggregation index) $AI = \left[\frac{g_{ii}}{max - g_{ii}}\right](100)$	Depicts connectivity between patches and measures the potential connectivity between patches.
Metric landscape		
Aggregation	CONTAG (Contagion) $CONTAG = 1 + \frac{\sum_{q=1}^{n_a} P_q ln\ (P_q)}{2ln\ (t)}$	Describes trends of expansion or aggregation for various types of landscape patches. This indicator contains spatial information and values between 0 and 100.
Diversity	SHDI (Shannon's diversity index) $SHDI = \sum_{i=1}^{m}(P_i\ x\ ln\ P_i)$	Depicts the richness and complexity of land use types in the landscape, reflecting the number of patch types and changes in the proportion of each patch type in the overall landscape. The larger the value, the more uniform the proportion of each patch type.
	SIDI (Simpson's diversity index) $SIDI = 1 - \sum_{i=1}^{m} P_i^2$	Depicts a metric of evenness commonly used in biodiversity and ecology. Interpreted as the probability that two randomly selected cells come from the same class. Values range between 0 <= SIDI < 1, where SIDI = 0 when only one area is present and SIDI < 1 if the number of classes increases while the distribution proportion remains even.
	SHEI (Shannons's evenness index) $SHEI = \frac{-\sum_{i=1}^{m}(P_i \times ln\ P_i)}{ln\ m}$	Depicts a uniform distribution of landscape patches and is negatively related to the dominance index.
	SIEI (Simpson's evenness index) $SIEI = \frac{1 - \sum_{i=1}^{m} P_i^2}{1 - \frac{1}{m}}$	Depicts the ratio between the actual Simpson diversity index and the maximum theoretical Simpson diversity index. Values range from 0 < SIEI <= 1.

to 1,410.95 hectares in 2010, and decreased to 1,227.51 hectares in 2020. This variation is related to the climate, as during the peak dry season, planting patterns change, leading to a reduction in green cover compared to the rainy season. Changes in open land use coincide with changes in settlement land use, influenced by population growth in an area (Qi *et al.,* 2023). The land use change into settlements and openland reduces infiltration areas as well as habitat quality (Hu *et al.,* 2022). The distribution of land use on Kapota Island can be seen in Figure 3.

Observations of landscape patterns and changes in land use on small islands should consider several factors. First, natural factors, such as climate, are related to rainfall and growing substrates (geology, soil types, and slopes). Secondly, anthropogenic factors related to population growth, livelihoods, customs, and policy interventions (Cui *et al.*, 2022; Kurniawan *et al.*, 2019; Wu *et al.*, 2022).

Table 2. Land use and land cover trends on Kapota Island from 1990 to 2020

Landuse	Year			
	1990	2000	2010	2020
Vegetation	1,111.59	1,189.29	1,410.95	1,227.51
Beach	98.10	113.04	89.36	101.70
Openland	576.81	478.71	275.85	428.49
Waterbody	6.03	6.30	4.05	4.68
Settlement	14.22	19.08	26.54	43.92
Total	1,806.75	1,806.42	1,806.75	1,806.30

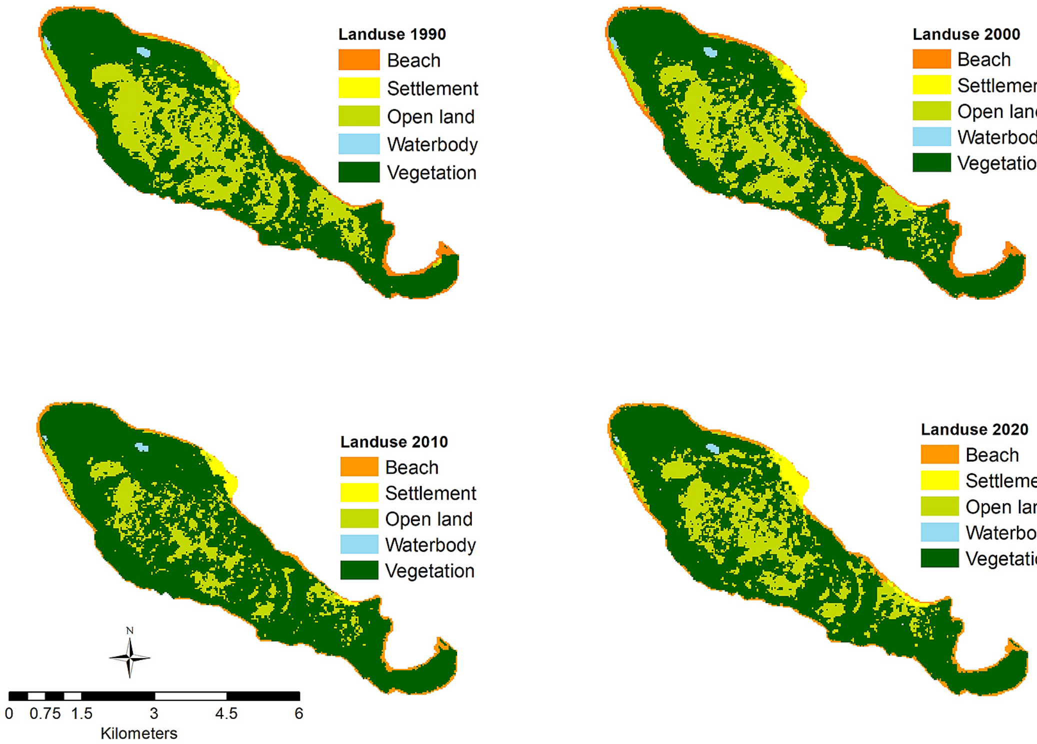

Figure 3. Land use maps of Kapota Island in 1990, 2000, 2010 and 2020

Landscape ecology and landscape patterns

The ecological landscape approach provides an overview of the complexity of interactions between humans and the environment in a region to support ecosystem sustainability and maintain a balance between human needs and nature conservation (Ma *et al.,* 2022; Wu *et al*., 2022). Landscape ecology can be used to monitor a landform through changes in landscape structure (Hu *et al.*, 2022; Zeng *et al.*, 2022), habitat fragmentation (Li *et al.*, 2022), habitat connectivity to facilitate animal movement and plant pollination (Cui *et al.*, 2022); environmental changes (Liang *et al.*, 2022), and conservation management (Zhang *et al.,* 2022). In larger terrestrial areas, land fragmentation indicates a decline in land function as habitat triggered by land use change (Bui and Mucsi, 2022). Meanwhile, the urgency of monitoring changes in landforms in conservation areas such as national parks, which are vulnerable to change due to tourism activities, is important as an effort to provide a database of degradation.

On Kapota Island, which is part of Wakatobi National Park, efforts are being made to provide tourism infrastructure, which of course requires temporary land while the available land is limited. In addition to tourism activities, agricultural activities also play a role in changing the landscape on Kapota Island. This is driven by population growth on the island. The appearance of the ecological landscape of Kapota Island from Landsat satellite imagery and interpretation results can be seen in Figure 4.

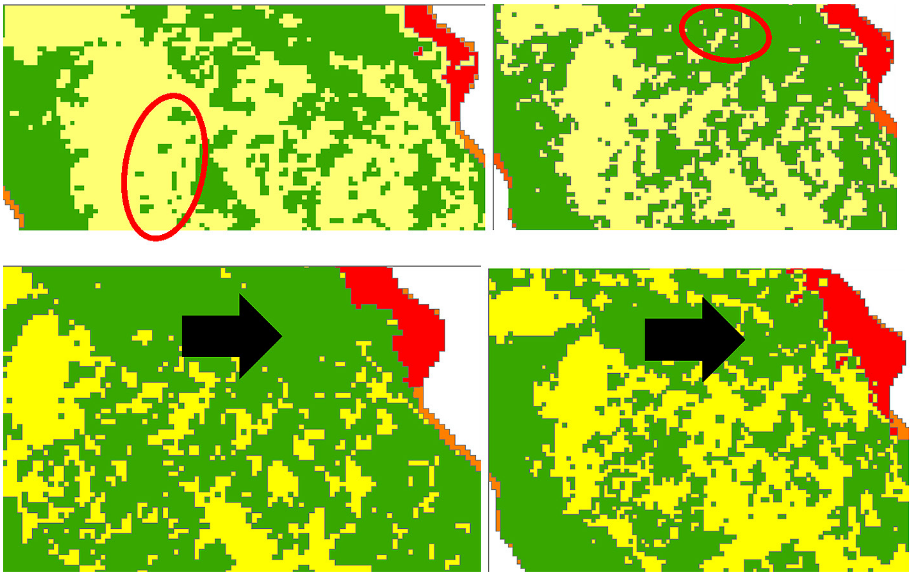

Figure 4. Types of habitat fragmentation on Kapota Island. Red circles indicate (a) Fragmentation in 1990, and (b) Perforation in 2000. Black arrows depict shrinkage between (c) 2010 and (d) 2020

With the expansion of tourism infrastructure development to support the role of Kapota Island as an Ecotourism Strategic Area, there has been development over the past two decades. This has resulted in a greater conversion of land into settlements. The most significant expansion has occurred in the northeast and southeast parts, where settlements developed faster than before the establishment of the Wakatobi National Park and government administrative regions. Along with this designation, the successful promotion of Wakatobi's natural beauty globally has led to an increase in tourist visits, thereby necessitating the development of tourism infrastructure and infrastructure to support government administrative activities. This has triggered population growth due to job opportunities and entrepreneurial opportunities. These conditions have driven the changes in landscape patterns and habitat quality, leading to a significant decline. Vegetation cover with medium to high density, dominated by vegetation structures such as trees, plays a crucial role in providing fresh water. Especially on inhabited small islands, water availability is essential to support life. Vegetation cover with medium density still exists on the north and south sides of Kapota Island but has been integrated with plantation activities, so in the future, it is hoped that this area will be maintained by limiting the expansion of agricultural activities. Direct land use for agricultural activities directly reduces habitat quality by creating habitat fragmentation for wildlife and the loss of native vegetation which plays an important ecological role.

Interpretation of metrics and landscape structure changes based on land use changes

Interpretation of landscape metrics based on class level

Changes in LULC present persistent and significant threats to eco-biodiversity stability (Anthony *et al.,* 2024). Spatial analysis and ecological landscape interpretation are effective tools for predicting, identifying, and monitoring environmental degradation to ensure environmental sustainability. Landscape metric interpretation, based on class levels of landscape change dynamics on Kapota Island from 1990 to 2020, is shown in Table 3.

On the basis of the results, the CA, LPI, AI, and IJI indices on vegetation land use experienced a continuous increase from 1990 and peaked in 2000, after which they gradually declined. Conversely, the NP, PD, and LSI indices declined from 1990 to 2000 before showing a gradual increase until 2020. Notably, despite these fluctuations, vegetation cover, the dominant land cover on Kapota Island, expanded steadily from 1990 to 2010 but experienced a decrease by 2020. This trend could be attributed to the expansion of settlements and the extreme climate of the island, characterized by consistently low rainfall.

The CA, LPI, and AI indices for openland declined until 2010 before gradually increasing until

Table 3. Interpretation of landscape level class metrics

Year	Landuse	CA	NP	PD	LPI	LSI	IJI	AI
1990	Beach	98.1	53	2.93	1.33	13.97	45.97	58.87
	Vegetation	1,111.59	88	4.87	57.41	12.02	34.60	89.96
	Waterbody	6.03	2	0.11	0.23	1.76	34.27	88.89
	Open land	576.81	90	4.98	24.67	14.53	19.17	82.79
	Settlement	14.22	6	0.33	0.67	3.04	59.62	81.72
2000	Beach	113.04	38	2.10	2.73	13.83	42.93	62.68
	Vegetation	1,189.62	53	2.93	64.63	11.22	36.07	91.03
	Waterbody	6.3	2	0.11	0.23	1.82	45.21	88.62
	Open land	478.71	156	8.63	17.42	15.21	19.07	80.22
	Settlement	19.08	3	0.17	0.89	2.60	50.05	87.82
2010	Beach	89.28	49	2.71	1.07	15.30	25.73	53.10
	Vegetation	1,411.02	39	2.16	77.56	9.69	44.76	92.99
	Waterbody	4.05	2	0.11	0.18	1.71	0.00	86.84
	Open land	275.85	169	9.35	2.81	17.20	9.65	70.13
	Settlement	26.55	2	0.11	1.25	2.74	72.36	89.01
2020	Beach	101.7	43	2.38	1.51	14.40	41.03	58.44
	Vegetation	1,227.51	55	3.04	65.85	11.37	39.21	91.03
	Waterbody	4.68	2	0.11	0.21	1.53	7.55	91.01
	Open land	428.49	155	8.58	13.19	16.70	21.86	76.92
	Settlement	43.92	7	0.39	1.76	4.07	62.61	85.18

2020. Conversely, the LSI, NP, and PD indices consistently increased since 1990, with a slight decline noted from 2010. Notably, the IJI index showed a gradual decline from 1990 to 2000, followed by a sharp decrease from 2000 to 2010, and then a gradual increase until 2020. Over the same period, the CA and LPI indices for settlements have steadily increased from 1990 to 2020, indicating continuous urbanization. Conversely, the NP and PD indices declined since 1990, but gradually increased from 2010 to 2020. The LSI index experienced a decline since 1990 but slowly rose from 2000 to 2020, reflecting some fluctuations in settlement patterns. The AI index increased from 1990 to 2010, before steadily decreasing until 2020. In contrast, the IJI index exhibited significant fluctuations, declining since 1990, gradually increasing in 2010, and then declining again.

For the beach class, the CA Index experienced a decline in 2000 but subsequently increased again in 2010. Similarly, the NP and PD indices fluctuated, decreased in 1990, increased in 2000, and then declined in 2010. Conversely, the LPI and AI indices increased in 1990, peaked in 2000, declined until 2010, and showed a slow increase by 2020. The LSI Index decreased in 1990, rose in 2000, peaked in 2010, and then slowly declined. Meanwhile, the IJI index showed a downward trend since 1990, peaked in 2010, and gradually increased until 2020. Over the same period, the indices CA and LPI about water bodies from 2000, experienced a decline, followed by a gradual increase from 2010. Meanwhile, the AI index declined until 2010, before experiencing a slow rebound. Interestingly, the NP and PD indices remained relatively unchanged. In contrast, the LSI index exhibited a steady increase since 1990 but declined from 2000 to 2020. Similarly, the IJI index depicted an overall increase since 1990, with a brief decline from 2000 to 2010 followed by an increase until 2020.

Overall, from 1990 to 2020, the study area experienced significant changes characterized by landscape fragmentation and dispersion, influenced by both natural factors and human activities. Fragmentation and dispersion can be accelerated by human interventions to meet socio-economic needs (Bui and Mucsi, 2022). The results of metric analysis indicate fluctuations in metric indices for each land use category except for waterbodies. The highest NP metric index is found in open land/agricultural fields. The NP metric measures the number of fragmented patches in a landscape. A landscape appears more fragmented if it has a high number of forest patches (NP) and a small class area (CA) compared to a landscape with low

NP and high CA values (Prasetyo, 2017). Vegetation cover experiences the highest fragmentation, as evidenced by the highest LPI values compared to other land covers. Additionally, open land/agricultural fields appear fragmented, indicated by high LPI values following vegetation cover. Agricultural activities such as coconut plantations, mixed gardens, and climatic factors contribute to fragmentation on Kapota Island. The process of metric change can indicate dynamics in land cover change. According to Sumasgutner *et al.* (2019), changes in landscape structure affect the availability of food, water, and changes in biodiversity that communities can obtain from available ecosystem services.

Interpretation of landscape metrics based on landscape level

Landscape metrics are used to interpret the conditions of fragmentation, dominance, and diversity of a land area. Dominance conditions can be indicated by LPI SHEI, while diversity is indicated by SHDI and fragmentation by IJI, NP, CONTAG, and LSI (Bui and Mucsi, 2022). The analysis results show that on Kapota Island, the NP, PD, and IJI indices from 1990 to 2020 continued to increase. When NP continues to increase, it means new fragments are formed, leading to continuous landscape fragmentation. However, if the fragments form and create a large unified fragment, NP will decrease. An increase in the IJI index indicates a more dispersed landscape, while the PD index depicts an increase in patches. The loss of patches in vegetated areas and open land, as well as conversion into built-up areas, will cause an increase in the PD index (Shafie *et al.*, 2023)be a procedure relative to its natural and non-disturbance process; and it could be hastened by the occurrence of disturbance regimes. The objective of this research is to survey the changes in a landscape structure, over a period of 30 years, to attain information, as to the current conditions of land use, utilizing landscape metrics in the watershed area of the Latian Dam, so as to analyze the results and the voids present, towards obtaining a specified sustainable regional planning for the abovementioned watershed. Land use was identified and reviewed by means of four Landsat satellite images for 1987, 1998, 2007, and 2017; and in this watershed, it was classified into four classes, (a. The increased in the CONTAG index in 2010 indicates a decrease in habitat fragmentation on Kapota Island, followed by fragmentation again in 2020. This could be influenced by the climate of Kapota Island at the time of satellite image acquisition. LSI decreased in 2010 and then increased in 2020. An increase in LSI indicates a more organized and complex landscape, while a decrease in LSI indicates that the fragment structure becomes more irregular and less complex (Bui and Mucsi, 2022).

The LPI index increased from 1990 to 2010 and then decreased in 2020, while the SHDI and SHEI indices fluctuated, showing a decrease in 2010 and an increase again in 2020. It is observed that the vegetation area increased and open land decreased, while the proportion of patches became more uneven. High SHDI/SIDI indices will be more heterogeneous compared to those with low SHDI/SIDI indices (Prasetyo, 2017). Referring to Table 4, it is evident that the landscape on Kapota Island was heterogeneous. This data can be used as an initial indicator of species abundance and biodiversity on Kapota Island.

On the basis of Figure 5, habitat fragmentation on Kapota Island is evident throughout the island. Fragmentation represents the heterogeneity of landscape structure, consisting of various types, sizes, and shapes that can lead to changes in landscape function (Prasetyo, 2017). Field visits revealed that in the areas with dense vegetation and little human disturbance, various bird species are often encountered. Meanwhile, in the areas where land clearing activities have occurred, and secondary vegetation dominated by *Macaranga sp*. a variety of perching birds were often found. Birds were frequently encountered around the road to Gowa Dewata and the southern part of Kapota Island towards Awolio Beach.

Table 4. Interpretation of landscape level metric

Year	NP	PD	LPI	LSI	AI	CONTAG	IJI	SHDI	SIDI	SHEI	SIEI
1990	239	13.23	57.41	11.63	85.92	58.55	31.6	0.88	0.52	0.55	0.65
2000	252	13.95	64.63	11.33	86.35	59.29	32.37	0.87	0.49	0.54	0.62
2010	261	14.45	77.56	10.50	87.45	65.89	32.55	0.70	0.36	0.44	0.46
2020	262	14.50	65.85	11.80	85.70	58.72	35.89	0.87	0.48	0.54	0.60

Figure 5. Landscape changes on Kapota Island: (a) open land and (b) open area in coconut plantation (documentation year 2019), (c) and (d) open land in mixed garden area (documentation year 2023)

Figure 6 shows the variation in 6 landscape indices from 1990 to 2020. Overall, 3 indices experienced an increase: SHDI, SIEI, and IJI, while the CONTAG, AI, and LPI indices decreased. It is also evident that the IJI index increased consistently, while the CONTAG and AI indices peaked and then decreased in 2020. A decrease in CONTAG means a reduction in the level of aggregation of different area types, while AI indicates the representation of relationships between patches of different landscape types. The increase in IJI indicates that the nodes of area types and other areas gradually balance out, with alternating shifts between various area types. Meanwhile, the diversity indices SIEI and SHDI, as well as the LPI index, show variations. Increases in SHDI and SIEI indicate that the proportion of the areas with different land uses in the landscape gradually becomes more uniform, and landscape diversity increases. A decrease in LPI means that large areas are gradually fragmented by other different areas. In general, the landscape pattern on Kapota Island is fragmented, and complex, with lower connectivity and greater diversity.

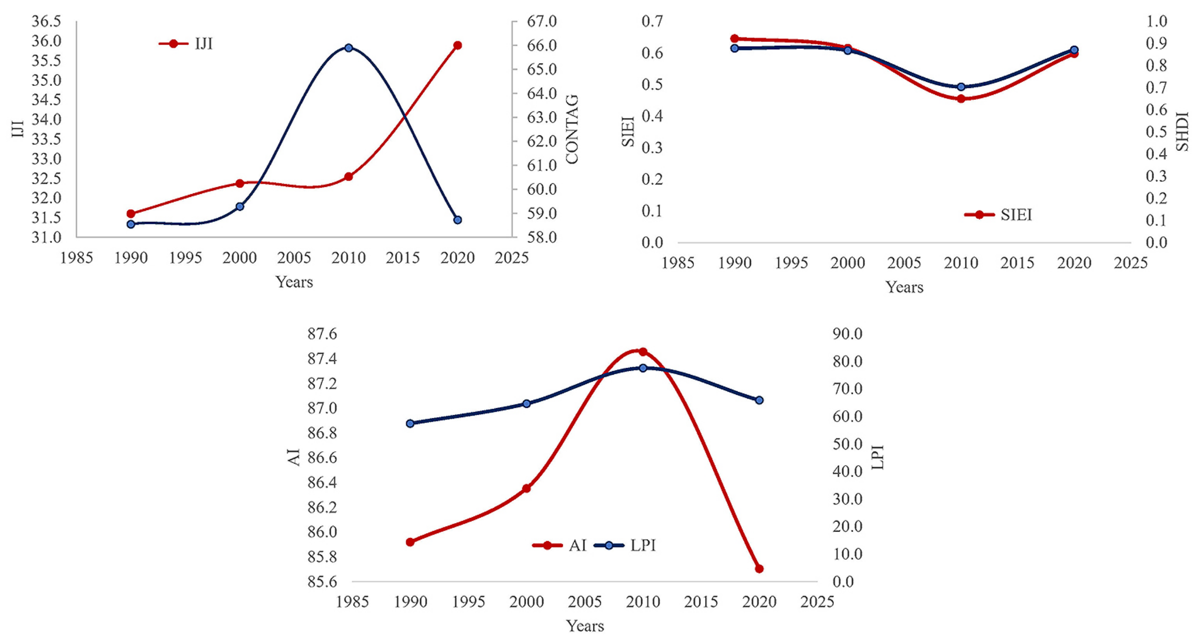

Figure 6. Landscape index changes on Kapota Island from 1990 to 2020, modified by Jiao *et al.* (2019)

Factors that influenced landscape change on Kapota Island

Climate aspects

The Climate Change Information Center of the Climatology Deputy of the Meteorology Climatology and Geophysics Agency released the average rainfall in Wakatobi Regency for the period from 1991 to 2020 (Figure 7). The months of July to October were typically dry, with August and September being the peak dry months, experiencing an average of only 4 rainy days. Wakatobi Regency is highly vulnerable to climate change (Munawaroh *et al.*, 2018). According to interviews with the local community, during the dry months, land fires often occur, triggered by cigarette butts or friction between dry plants. Dry climate conditions are associated with land fires (Cansler and Mckenzie, 2014). The lack of rainfall can cause damage to the agricultural and forestry sectors (Kis *et al.*, 2023). Extreme climate conditions also affect groundwater availability and soil moisture, thereby influencing plant growth. According to the information obtained from the local community, climate influences planting patterns and the livelihoods of people on Kapota Island.

Biophysical aspects of Kapota Island

From a biophysical perspective, the geological formation of Kapota Island is dominated by limestone, which is a phosphate rock composed of calcium carbonate. The morphology of Kapota Island is characterized by rugged and steep hills, caves, and underground rivers. The land system consists of a necklace land system and Rotan Island. The soil type on Kapota Island is coral rock, influenced by the rock formations that make up the island. The type of rock and soil, predominantly limestone, significantly affects the vegetation and the types of agricultural commodities grown. The biophysical factors of Kapota Island impose high constraints on various commodities, particularly concerning agricultural land suitability (Djaenudin *et al.,* 2011).

Socio-economic aspects

Historically, the population of Wakatobi Regency has fluctuated over the years. In 1954, the population was recorded at 56.920 people, which increased to 72.291 people in 1991, and further to 86.367 people in 1999. This fluctuation was attributed to the tendency of people to migrate, bringing their entire families, in search of livelihoods due to limited and infertile agricultural land. A significant increase in the population of Wakatobi occurred from 1999 to 2000 due to the conflict in Ambon, prompting Wakatobi migrants to return. Meanwhile, in Kapota Island, statistical data shows that in 2008, the population was 4.230, sharply increased to 5.199 in 2016, and then decreased to 4.674 in 2020. The population of Kapota Island has long been known for migrating to seek better opportunities elsewhere or for educational purposes. Those who remain engaged in farming, fishing, and working as ferry operators between Wangi-Wangi and Kapota Islands. Ferry operators take turns, allowing for alternate periods of rest and other activities such as farming or fishing. According to Village Profile data, the main livelihoods on Kapota Island include farming, fishing, trading, carpentry, and civil

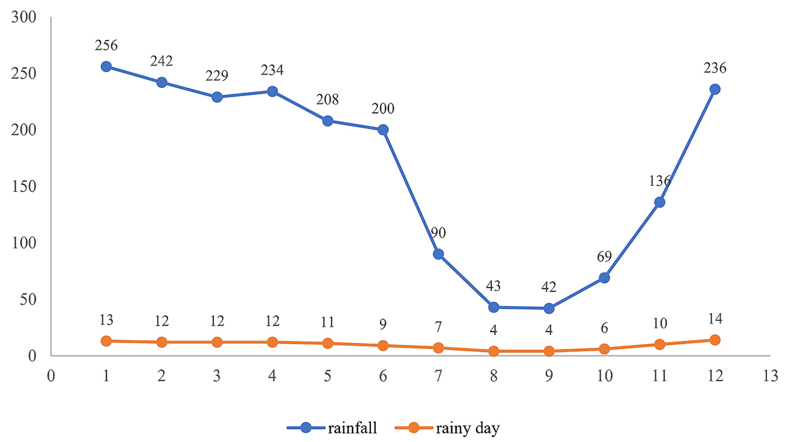

Figure 7. Average monthly rainfall and rainy days in Wakatobi Regency from 1991 to 2020 (Source: BMKG, 2021; book of rainfall and rainy days maps for the period 1991–2020 in Indonesia)

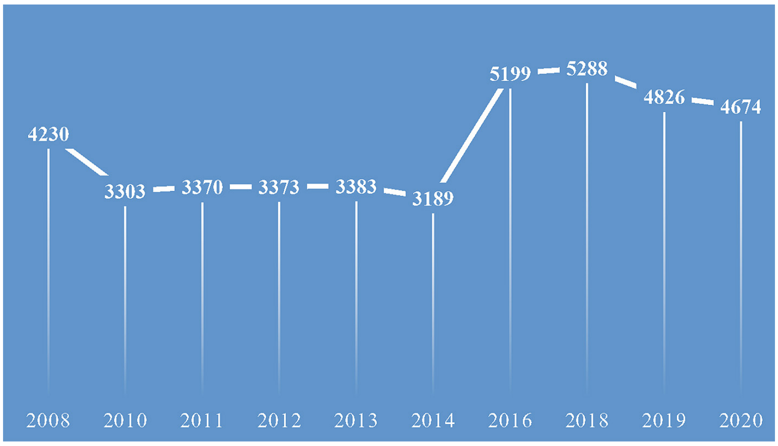

Figure 8. Population growth chart in Kapota Island from 2008 to 2020 (the data for the years 2009, 2015, and 2017 are not available)

service. Farming, particularly, is the predominant occupation, with many individuals engaging in multiple professions. Agricultural land in North Kapota Village covers an area of 254.56 hectares. Common crops grown on Kapota Island include coconut, cassava, bananas, pineapples, jackfruit, and cashew nuts. Farming practices on Kapota Island often involve intercropping to make the most of limited land. Apart from agricultural needs, land is also required for residential development due to population fluctuations on the island. The population growth on Kapota Island can be seen in Figure 8. The socioeconomic conditions of a region also influence changes in landscape patterns (Anthony *et al*., 2024).

Relationship between spatial and landscape ecology patterns

Spatial pattern analysis is crucial in landscape ecology, as it provides insights into ecological processes, biodiversity conservation, land management, and decision-making. The integration of both methods helps in understanding and managing the dynamic interactions between organisms and their environment on a broader scale (Cardille and Turner, 2017). GIS analysis and Fragstats play a role in evaluating landscapes for land use planning and zoning purposes (Hong *et al.*, 2024). The accuracy of landscape ecological interpretation is influenced by spatial data sources; the higher the spatial resolution, the better the resulting ecological interpretation. Particularly in island regions, during analysis, attention needs to be paid to the timing of image acquisition, tidal conditions, and climate (rainfall and rainy days).

The integration of spatial analysis and landscape ecology is crucial in monitoring environmental changes, especially in conservation areas. Ecological changes and their impacts on the environment can be depicted through landscape indices (Hong *et al.*, 2024). Several studies also suggest that this research can aid in decision-making regarding future landscape patterns and the development of ecological conservation policies, such as in national parks, watersheds, karst regions, and urban areas (Liu *et al.*, 2022; Parisi *et al.*, 2023; Tang *et al.*, 2022; Zeng *et al*., 2022; Zhang *et al*., 2022).

The role of monitoring in the management of natural resources on small islands

Marine, coastal, and small island areas possess unique ecosystems with diverse and productive habitats. The management of natural resources in marine, coastal, and small island areas must be carried out by applying sustainable principles to ensure the continued sustainability of these resources. Particularly on small islands designated as National Parks, the management of natural resources must be integrated across ecological, economic, socio-cultural, institutional legal, technological, and vulnerability aspects that influence their management.

In the case of Kapota Island, part of the Wakatobi National Park, sustainability strategies are implemented from an environmental perspective through zone-based management. This strategy involves allocating 30% of the total island area as green areas, consisting of densely populated trees. These green areas play a crucial role in water management and act as a buffer against the land fires caused by prolonged drought.

CONCLUSIONS

On the basis of the spatial-based assessment of LULC change within various landscape conditions, this study concludes that the multi-year (1990 to 2020) image analysis shows a clear LULC change both for developed (mainly open land and settlement) and vegetated areas. Developed area has increased significantly to the previous open land and within a limited extent of vegetated zones that have changed from 1,111.6 ha in 1990, then to 1,410.9 and 1,227.5 ha in 2010, and 2020, respectively. Change in vegetated area is presumably related to the climate, as during the peak dry season, planting patterns change, leading to a reduction in green cover compared to the rainy season. The study also concludes from the analysis of landscape metrics that landscape pattern in Kapota Island is fragmented, and considerable complex, and exhibits lower and more diverse connectivity. The LULC changes with different landscape patterns in Kapota Island were influenced by both natural and anthropogenic factors. Natural driving factors consist of climate and the biophysical conditions of the island, such as soil types and rock formations. In turn, anthropogenic factors are population growth, encouraged land clearing for urban expansion and agricultural development to meet livelihood needs.

From an intensive integrated spatial based LULC change assessment and landscape pattern analysis, it also can be concluded that the use of GIS techniques, employing multi-year images with moderate spatial resolution, is reasonably effective in identifying fragmentation patterns and spatial positions over specific periods of time within an area with a considerable complex pattern of LULC change. It can be ensured that the higher the spatial resolution of spatial images, the better the interpretation of ecological landscape structure, function, and changes. Overall, an integrated approach performed in this paper can serve as initial research to forecast ecosystem vulnerability in the past and for the future. This study also gives an important insight into spatial regulation, especially in the designation of spatial pattern delineation as well as land utilization and ecosystem management at small islands with a dominant protected function. Further studies on these issues are necessary to delve deeper into understanding and addressing these challenges.

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