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Original Article

Spatial-Temporal Dynamics of Mangrove Cover Change in Tanjungpinang City, Riau Islands Province

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ABSTRACT
Tanjungpinang City is a coastal area surrounded by sea and characterized by a mangrove ecosystem. Coastal regions are more dynamic and vulnerable compared to other areas, both naturally and due to human activities. This study aims to determine the rate of mangrove cover change in Tanjungpinang City from 2007 to 2023, as well as to predict mangrove cover changes for the year 2035. The methodology employed involves spatial-temporal analysis of land cover change using Landsat 7 ETM+ imagery from 2007, Landsat 8 OLI imagery from 2015, and Sentinel-2A MSI imagery from 2023. Predictions for mangrove cover in 2035 were conducted using the Land Change Modeler. The results indicate that from 2007 to 2023, there was a decrease in mangrove area of 323.40 hectares, with a rate of 20.21 hectares per year. The predicted mangrove cover in Tanjungpinang City for 2035 is estimated to be 977.72 hectares, representing a decrease of 461.21 hectares (32.05%) from 2023.

KEYWORDS
Land Change Modeler, Google Earth Engine, mangrove cover prediction, Landsat, Sentinel-2A

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INTRODUCTION

The mangrove ecosystem is a coastal environment that plays a critical role in supporting the life of organisms in surrounding waters. According to Bengen et al. (2023), the functions of mangrove ecosystems can be categorized into three main areas: ecological functions, physical functions, and economic functions. Ecologically, mangrove forests serve as feeding grounds, spawning grounds, and nursery grounds for marine biota. Physically, mangroves act as wind and wave buffers, protect coastlines from erosion, trap sediments, prevent seawater intrusion, and process organic waste, including heavy metals. Economically, mangroves provide value and benefits that contribute to the welfare of coastal communities, and they can also serve as ecotourism sites with significant economic potential (Friess et al., 2019; Uddin et al., 2013).

However, the presence of mangrove forests in Indonesia has undergone significant changes. Land use changes are dynamic within a region, influenced by its development (Adawiyah et al., 2021). Rahadian et al. (2019) analyzed mangrove area changes in Indonesia from various sources between 1950 and 2017. According to their findings, based on BPDAS data from 2005, mangrove forests in Indonesia covered an area of 9,361,957 hectares. By 2017, data from the National Mangrove One Map indicated that this area had decreased to 3,361,216 hectares. The changes in mangrove forests along the coastline are not solely due to natural phenomena; they are significantly influenced by human activities in the surrounding areas, making coastal regions vulnerable to land use changes (Mappanganro et al., 2018). This dynamic change in mangrove forests is also observed in Tanjungpinang City. The continuous increase in population, coupled with the demand for land for infrastructure, industry, housing, and other activities, has led to land conversion, including the conversion of mangrove forests, ultimately resulting in the degradation of coastal and marine resources (Akram & Hasnidar, 2022).

Efforts to preserve mangrove ecosystems and curb deforestation rates require information regarding annual changes in mangrove area and potential future changes (Akdeniz et al., 2023; Verburg et al., 2004). Understanding land cover changes in the future is essential for supporting planning, protection, and rehabilitation of mangroves. Information on land use changes can be approached spatially through land cover change modeling. One effective method for monitoring mangrove ecosystems is using remote sensing technology with satellite imagery (Dimyati, 2022). Satellite imagery is a powerful tool for monitoring changes in mangrove forests over time due to its ability to provide consistent, large-scale, high-resolution data (Doodee et al., 2023; Giri, 2016; Rosalina et al., 2023; Zhang et al., 2023). Acquiring satellite imagery and processing it for mangrove mapping can be time-consuming when conducted through conventional interpretation methods and requires sophisticated hardware and relatively expensive software. Currently, the Google Earth Engine (GEE) platform can overcome these limitations in data processing. GEE provides satellite imagery with very low or cloud-free coverage (Papilaya, 2022). This platform enables access to very large datasets, allowing for analysis and presentation without needing high-specification computers, while also ensuring relatively rapid data processing (Fariz et al., 2021; Gorelick et al., 2017; Mutanga & Kumar, 2019; Prasetya & Wibowo, 2024). Utilizing Google Earth Engine allows for efficient, continuous monitoring of mangrove ecosystems, supporting conservation and management efforts by providing critical data on the spatial and temporal dynamics of mangrove cover.

Modeling future mangrove cover changes is also crucial for conservation efforts (Mohammad Malik et al., 2023). One method for modeling mangrove cover change is the Land Change Modeler (Afrita & Ramadhan, 2024; Darmawan et al., 2022). The Land Change Modeler predicts land use changes based on historical land conditions (Han et al., 2015). It predicts land cover changes using satellite imagery classified in the same order. Several studies have used the Land Change Modeler for land cover change predictions; however, its application for predicting mangrove cover changes remains limited. This study will predict changes in mangrove cover using the Land Change Modeler, utilizing Landsat 7 ETM+, Landsat 8 OLI, and Sentinel 2A satellite imagery.

Previous studies indicate that there has been limited research conducted in island regions with persistent cloud cover throughout the year, making it relatively difficult to obtain satellite imagery with minimal or no cloud cover. In this study, land cover classification maps will be generated using the GEE platform, which can provide cloud-free satellite imagery through cloud computing and machine learning technologies suitable for island regions. Furthermore, previous research has not comprehensively examined mangrove cover changes in Tanjungpinang City or predicted future changes in mangrove forests. Thus, this study aims to investigate the use of GEE to generate land cover classification maps combined with LCM as an alternative for predicting mangrove cover changes. The objective of this research is to determine the rate of mangrove cover change in Tanjungpinang City spatially over the period from 2007 to 2023, as well as to predict mangrove cover changes for the year 2035.

METHOD

Research Location

The research was conducted from February to June 2024 in Tanjungpinang City, Riau Islands Province.

Geographically, Tanjungpinang City is located on Bintan Island, at coordinates 0°51' to 0°59' North Latitude and 104°23' to 104°34' East Longitude. The research location is presented in Figure 1.

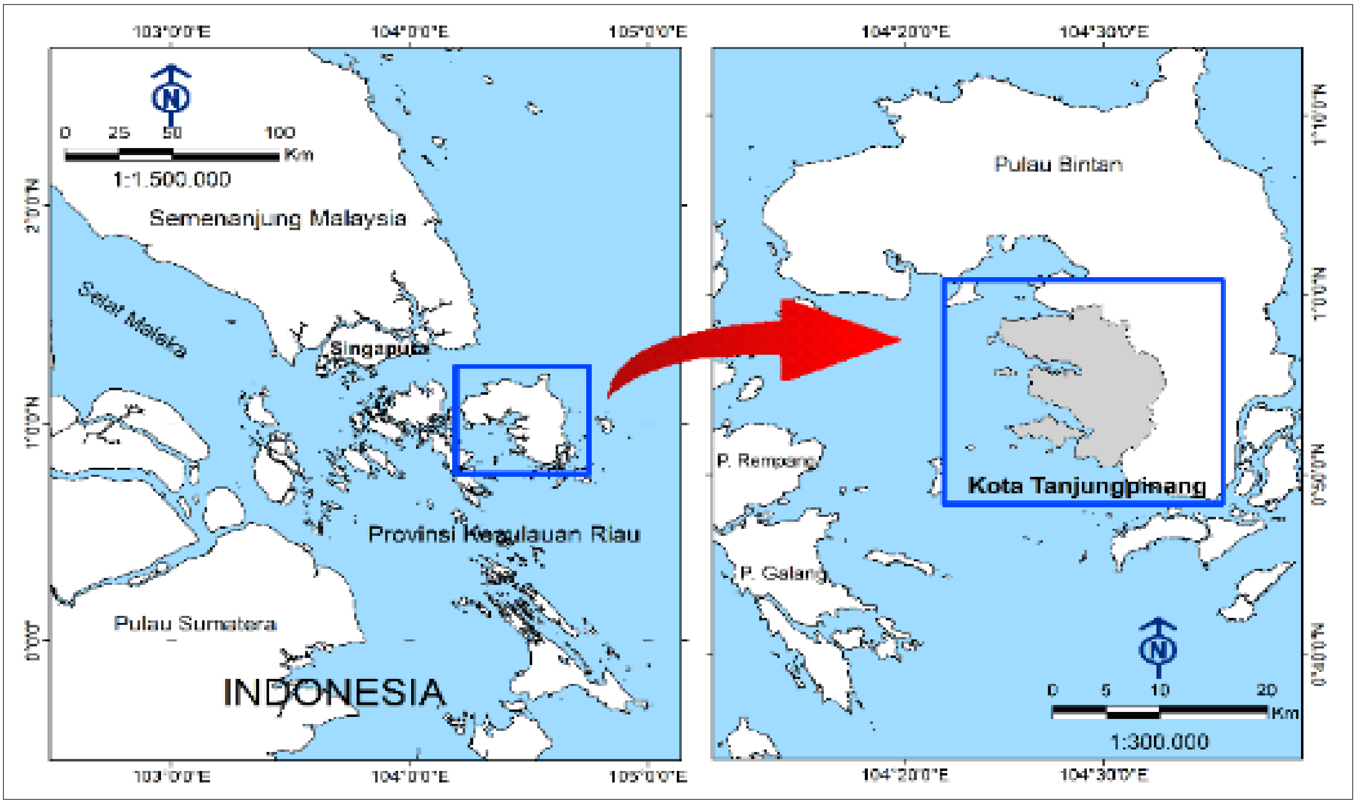

Figure 1. Research location Map

Tools and Materials

The tools used for data processing include hardware and the software ArcGIS and Terrset Idrisi. The primary data used in the analysis of mangrove cover change consists of Landsat 7, Landsat 8, and Sentinel 2A imagery. Additionally, secondary data were obtained from literature studies, administrative maps of Tanjungpinang City, land use maps, and other supporting data.

Data Collection Techniques

The research instrument employed in this study is a The data utilized for the analysis and prediction of mangrove cover changes were obtained from Landsat 7 ETM+ imagery from 2007, Landsat 8 OLI imagery from 2015, and Sentinel 2A MSI imagery from 2023, which were downloaded through the Google Earth Engine (GEE) platform at https://code.earthengine.com/. Furthermore, polygons delineating the administrative boundaries of Tanjungpinang City were required.

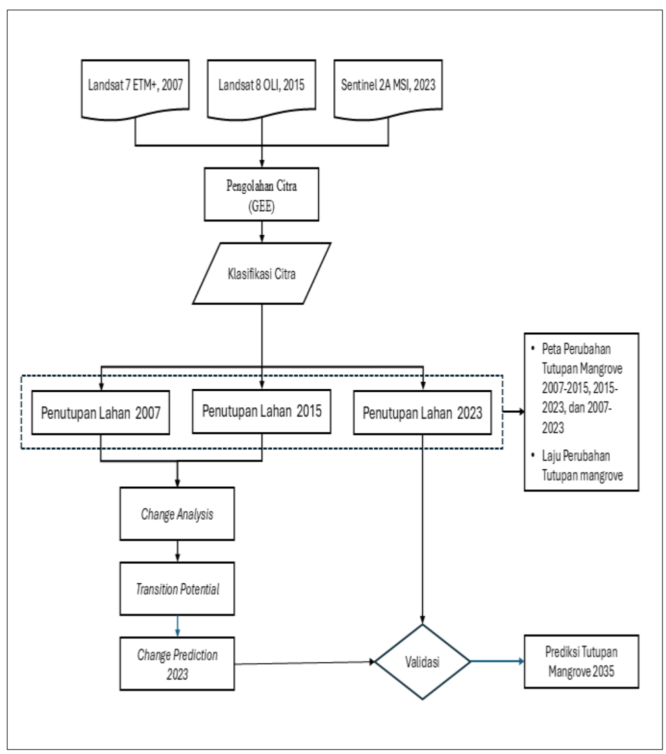

Figure 2. Procedure of Research

Data Analysis

The analysis of spatial-temporal dynamics of mangrove cover change was conducted in three stages. The first stage involved the downloading of satellite imagery data, data cropping, geometric correction, land cover object identification and ground truthing, as well as supervised classification (Raynaldo et al., 2020) to obtain mangrove cover maps for the years 2007, 2015, and 2023, using the Google Earth Engine platform.

The second stage involved identifying mangrove cover change data by overlaying several satellite images across the land cover classes resulting from the classifications for 2007, 2015, and 2023. Subsequently, the information on these changes was presented in the form of maps and tables. To calculate the rate of mangrove vegetation cover change, the formula from Sodikin et al. (2017) was used, as follows:

$$\Delta t = \frac{Lt_2 - Lt_1}{\Delta t} \quad \text{..} (1)$$

ΔL : represents the rate of mangrove cover change (ha/year)

Lt_1 : is the area at the initial observation year (hectares)

Lt_2 : is the area at the subsequent observation year (hectares)

Δt : is the time difference between the initial observation and the final observation (years).

The third stage involves predicting mangrove cover change for the year 2035. The prediction is carried out using the Land Change Modeler available in the Idrisi Terrset software. The data used for the analysis includes land cover maps for the years 2007, 2015, and 2023. The prediction process using the Land Change Modeler consists of three tabs: change analysis, transition potentials, and change prediction. Change analysis is the process of obtaining transition maps depicting changes between land cover classes from two land use maps for different years. The transition potential process generates maps indicating locations with potential land use changes, which serve as inputs for the land use change model. The change prediction process results in a matrix of probabilities for land use changes.

In this study, the prediction of mangrove cover change is conducted by analyzing land use changes from 2007 to 2015 to project land use changes for 2023. The projection results are validated using the land cover for 2023, which was previously created. Thus, the land cover for 2007 and 2015 is used to develop the projection model for land cover in 2023. The projection from 2023 to 2035 is based on the land cover conditions in 2023 through a probability value matrix generated by Markov Chain Analysis between the years 2007 and 2015. The Markov chain is a technique used in modeling to estimate potential future changes, represented by dynamic variables at specific times (Craig & Sendi, 2002).

Validation of the 2023 land cover prediction results is based on the validation test of the Kappa Index of Agreement value which provides the Kno, Klocation, Klocationstrata, and Kstandard indices. Kno is an indicator that measures overall agreement, Klocation is an indicator that measures the level of agreement between inputs and locations, Klocationstrata is the level of agreement by number, and Kstandard is a measure of the simulation's ability to obtain a perfect classification (Pontius, 2001). The Kappa value validation test refers to the values in Table 1.

Table 1. Kappa Value Validation Test

Kappa Value (%)	Strength of Agreement
<20	Poor
21-40	Fair
41-60	Moderate
61-80	Good
81-100	Very good

Source: Altman (1990)

RESULTS AND DISCUSSION

Land Cover Change in Tanjungpinang City for the Years 2007, 2015, and 2023

The analysis of remote sensing data using the Google Earth Engine platform yielded several land use classifications, including: forest, mangrove forest, open land, ponds, built-up land, mixed vegetation, shrubs, rivers, swamps, and other lands. To assess land cover changes over the period from 2007 to 2023, the area of each land cover type was compared. Land cover change is defined as the difference in area between various years in Tanjungpinang City. Table 2 presents the land use areas for the years 2007, 2015, and 2023 based on the processed remote sensing imagery data. According to Table 2, land use coverage in Tanjungpinang City in the years 2007, 2015, and 2023 is predominantly characterized by forest, mangrove forest, shrubs, open land, built-up areas, and additional shrubland.

Table 2. Land Use Areas in Tanjungpinang City for the Years 2007, 2015, and 2023

Land use	Land Cover Area (Ha)					
	2007	%	2015	%	2023	%
Forest	2511,86	17,30	921,20	6,34	1249,29	8,60
Mangrove Forest	1762.32	12,14	1234.98	8,51	1438.92	9,91
Open Land	1026,93	7,07	2119,82	14,60	1273,08	8,76
Pond	39,94	0,28	136,88	0,94	175,40	1,21
Built-up Land	1688.15	11,63	2770.35	19,08	3735.00	25.72
Mixed Vegetation	77,61	0,53	207,28	1,43	286,68	1,97
Shrubs	5983,43	41,21	6610,56	45,53	4977,85	34,28
River	381,49	2,62	235,24	1,62	328,03	2,26
Swamp	-	-	3,87	0,03	22,01	0,15
Other Land	1.048,71	7,22	280,27	1,93	1034,19	7,12
Total	14520,45	100	14520,45	100	14520,45	100

Source: Research Findings, 2024

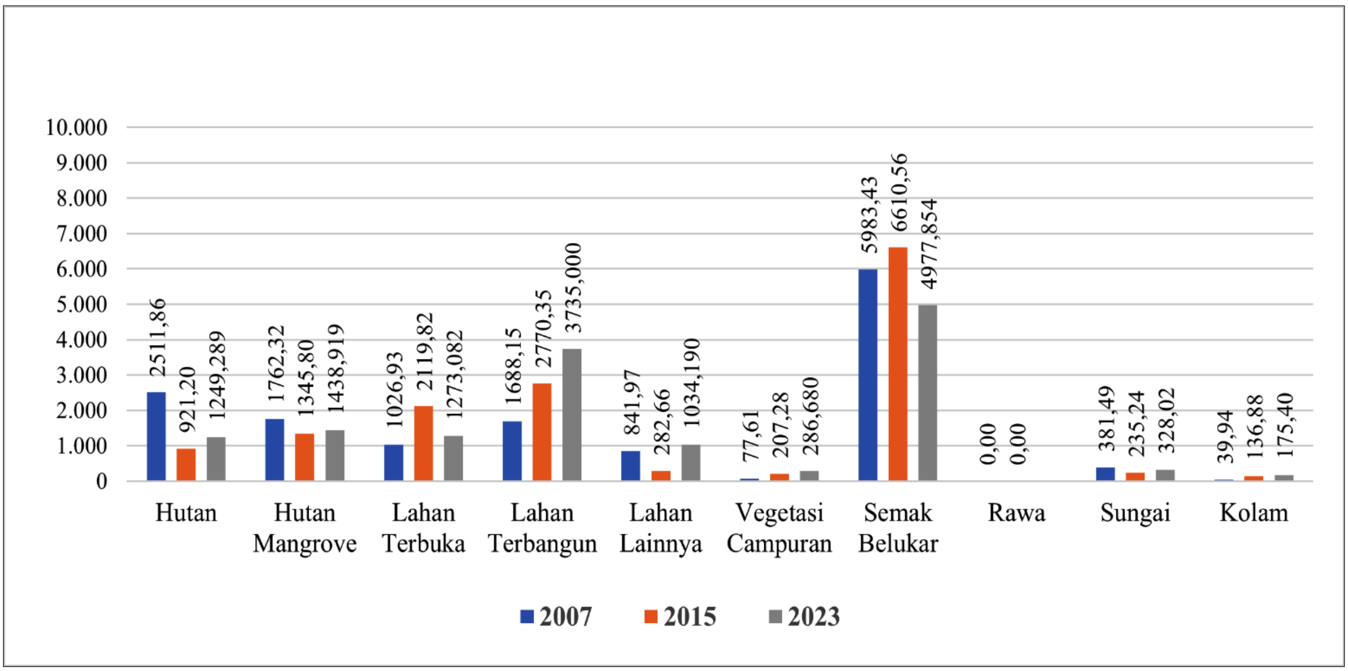

Figure 3. Graph of changes in land cover area in Tanjungpinang City (2007, 2015, and 2023)

The graph of land use cover change trends in 2007, 2015 and 2023 is illustrated in Figure 3. Meanwhile, the map of land use cover in Tanjungpinang City in 2007, 2015 and 2023 is shown in Figure 4.

Between the years 2007 and 2015, there was a degradation in the area of forest and mangrove cover, coinciding with an increase in the area of open land, built-up land, shrubs, swamps, and mixed vegetation. From 2015 to 2023, there was a decline in the area of open land and shrubs. Meanwhile, the areas of forest, mangrove forest, ponds, built-up land, mixed vegetation, rivers, swamps, and other lands increased compared to the land use areas in 2015. Overall, from 2007 to 2023, the areas of forest, mangrove forest, open land, shrubs, rivers, and other lands experienced degradation, while built-up land, mixed vegetation, ponds, and swamps saw an increase. Table 3 illustrates the changes in land use areas over the periods of 2007-2015 and 2015-2023.

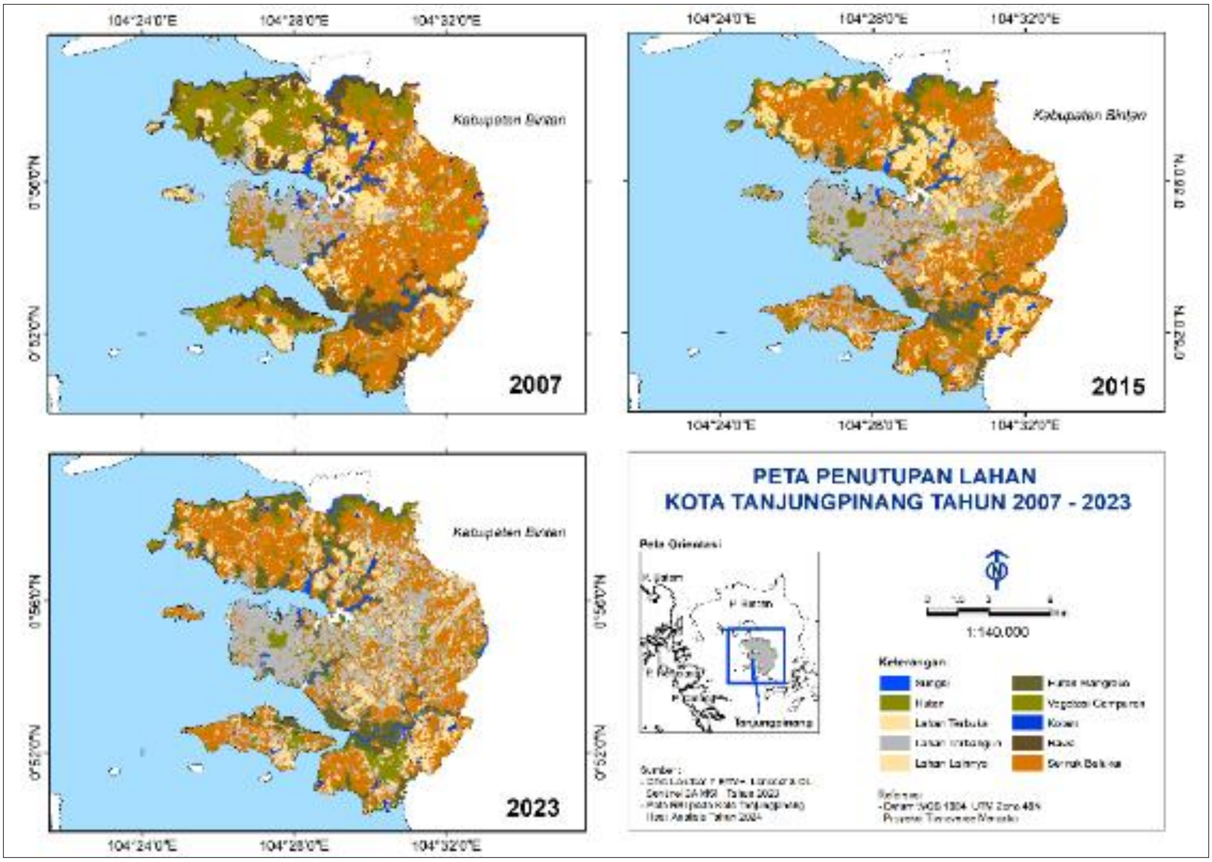

Figure 4. Land Cover Map of Tanjungpinang City in 2007, 2015, and 2023

Table 3. Extent of Land Use Cover Change in Tanjunpinang City

Land use	Land Use Change (Ha)					
	2007-2015	(%)	2015-2023	(%)	2007-2023	(%)
Forest	-1590,66	-63,3	328,09	35,6	-1262,57	-101,1
Mangrove Forest	-527,34	-29.9	203,94	16.5	-323,40	-22,5
Open Land	1.092,88	106,4	-846,74	-39,9	-246,14	-19,3
Pond	96,94	242,7	38,52	28,1	135,46	339,2
Built-up Land	1082.20	64.1	964.65	34.8	2046,85	54,8
Mixed Vegetation	129,67	167,1	79,40	38,3	209,07	72,9
Shrubs	627,13	10,5	-1632,71	-24.7	-1005,58	-20,2
River	-146,25	-38,3	92,78	39,4	-53,46	-14,0
Swamp	3,87	-	18,14	468,7	22,01	100,0
Other Land	-768,44	-73,3	753,92	269,0	-14,52	-1,4

Source: Analysis Results (2024)

Rate of Mangrove Cover Change in Tanjungpinang City from 2007 to 2023

Mangrove vegetation cover in Tanjungpinang City, located in coastal areas and along river mouths, has undergone continuous changes. Table 5 presents the area and percentage of mangrove cover in Tanjungpinang City for the years 2007, 2015, and 2023. In 2007, the composition of mangrove cover constituted 12.31% of the total land cover in Tanjungpinang City. By 2015, the percentage of mangrove cover decreased to 9.20%. Meanwhile, in 2023, the percentage of mangrove cover showed a slight increase compared to the conditions in 2015. Table 5 illustrates the area and changes in mangrove and non-mangrove cover in Tanjungpinang City for the years 2007, 2015, and 2023.

Based on Table 4, the rate of mangrove cover change in Tanjungpinang City can be calculated for each period. The rate of mangrove degradation from 2007 to 2015 was 65.92 hectares per year, while from 2015 to 2023, there was an increase in mangrove cover at a rate of 25.49 hectares per year. However, over the entire period from 2007 to 2023, the mangrove cover experienced degradation at an average rate of 20.21 hectares per year.

Table 4. Area and percentage of mangrove cover in Tanjungpinang City in 2007, 2015, and 2023

Land use	Land Cover Area (Ha)					
	Year 2007	%	Year 2015	%	Year 2023	%
Mangrove Forest	1762,32	12,14	1234,98	8,51	1438,92	9,91
Non-Mangrove	12758,13	87,86	13285,47	91,49	13081,53	90,09
Total	14520,45	100	14520,45	100	14520,45	100

Source: Analysis Results (2024)

Table 5. Mangrove Cover Area of Tanjungpinang City by Subdistrict in 2007, 2015 and 2023

District	Mangrove Cover Area (Ha)					
	2007	%	2015	%	2023	%
Bukit Bestari	861,69	48,90	564,93	45,75	649,99	45,17
Tanjungpinang Timur	321,21	18,23	269,40	21,82	313,58	21,79
Tanjungpinang Kota	577,56	32,77	399,19	32,32	473,88	32,93
Tanjungpinang Barat	1,81	0,10	1,40	0,11	1,48	0,10
Total	1762,27	100	1234.92	100	1438.93	100

Source: Analysis Results (2024)

Tabel 6. The Change og Mangrove Cover Area in Tanjungpinang City by District in 2007-2015

District	Year 2007	Year 2015 (Ha)			
		Decreased	Remain	Increase	Total Area
Bukit Bestari	861,69	322,30	522,61	42,32	564,93
Tanjungpinang Timur	321,21	114,12	224,00	45,40	269,40
Tanjungpinang Kota	577,56	218,47	358,96	40,24	399,19
Tanjungpinang Barat	1,81	1,81	0,00	1,40	1,40
Total	1762,27	656,70	1105,57	129,36	1234,92

Source: Analysis Results (2024)

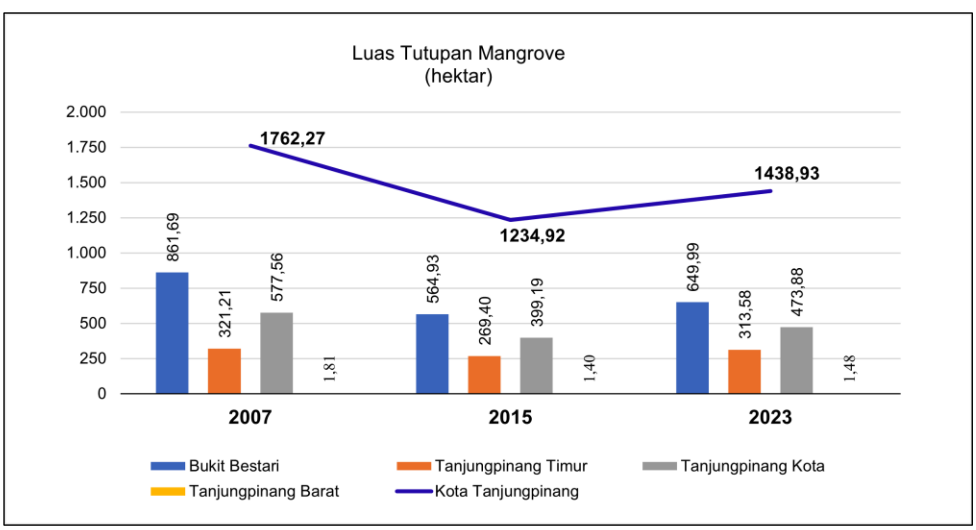

Figure 6. Graph of Changes in Mangrove Cover Area in 2007, 2015, and 2023.

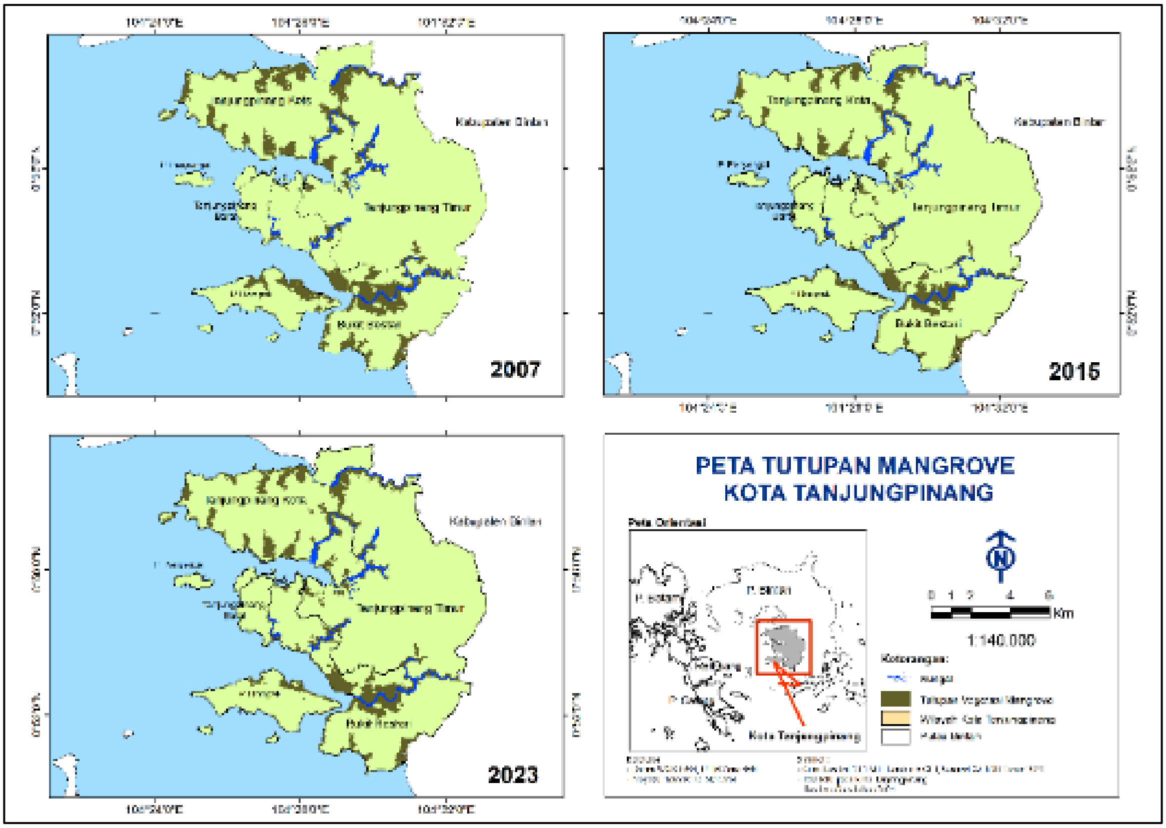

Figure 5. Mangrove Cover Map of Tanjungpinang City in 2007, 2015, and 2023

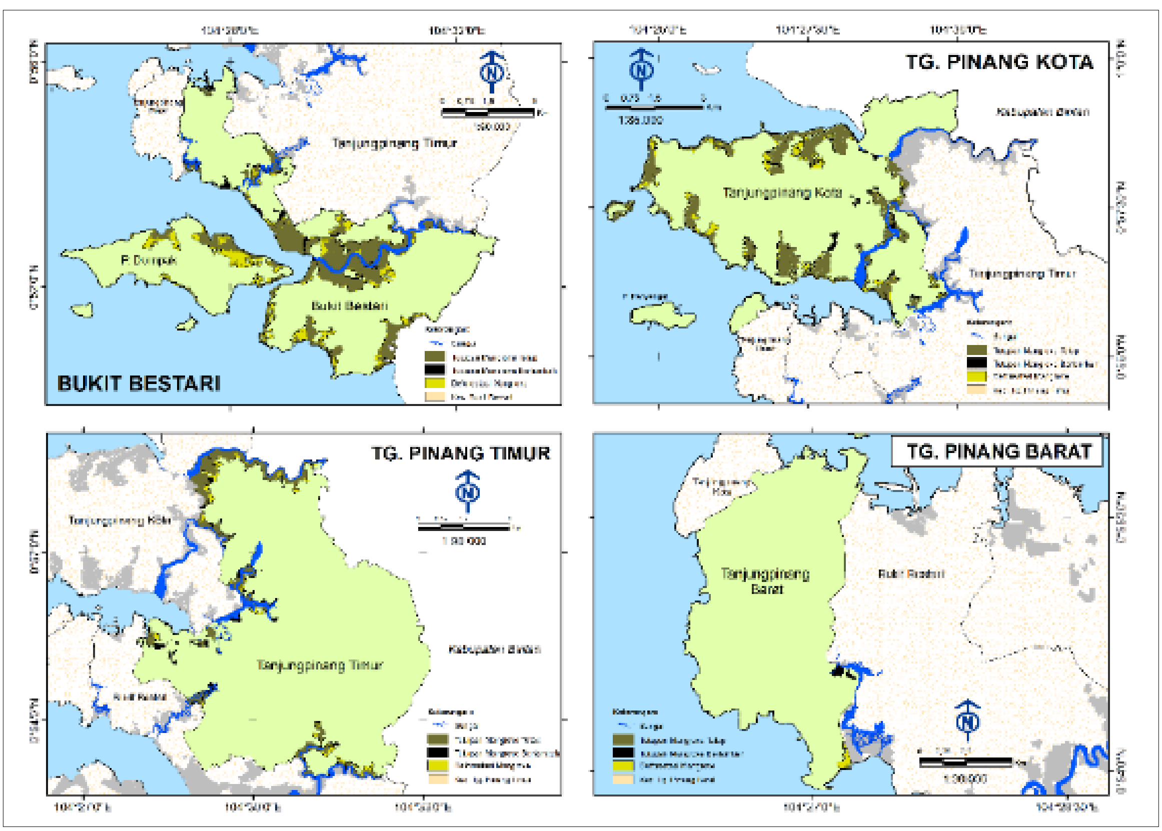

Figure 7. Map of Mangrove Cover Deforestation 2007 - 2015 Tanjungpinang City

Based on Figure 6, there is a decreasing trend in mangrove coverage across all districts from 2007 to 2015. Conversely, from 2015 to 2023, mangrove coverage in all districts showed an increase. In the Bukit Bestari District, the mangrove area in 2007 was 861.69 hectares, with deforestation of 322.30 hectares, 522.61 hectares remaining unchanged, and an increase of 42.32 hectares. Therefore, the total mangrove coverage in the Bukit Bestari District in 2015 was 564.93 hectares, reflecting a degradation of 29.7% compared to the mangrove coverage in 2007. The rate of change in mangrove coverage in the Bukit Bestari District from 2007 to 2015 was 37.10 hectares per year. Figure 7 presents a map of mangrove deforestation in Tanjungpinang City across each district during the period from 2007 to 2015.

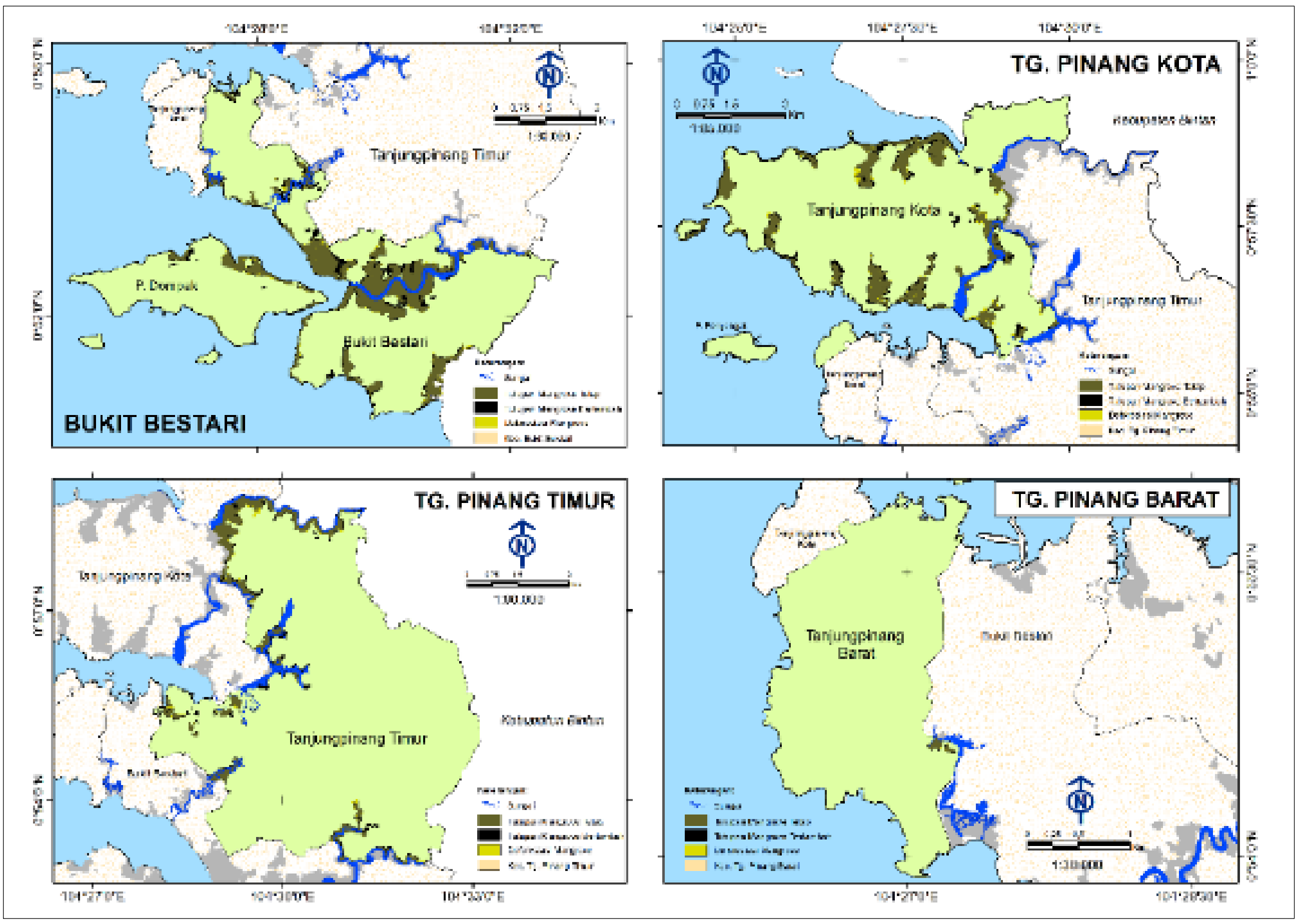

Figure 8. Map of Mangrove Cover Change 2015 - 2023 Tanjungpinang City

Table 7. Area of Mangrove Cover Change in Tanjungpinang City by Sub-district 2015-2023

District	Year 2015	Year 2023 (Ha)			
		Decreased	Remain	Increase	Total Area
Bukit Bestari	564,93	51,04	513,89	136,10	649,99
Tanjungpinang Timur	269,40	40,44	228,96	84,62	313,58
Tanjungpinang Kota	399,19	45,04	354,15	119,73	473,88
Tanjungpinang Barat	1,40	0,18	1,30	0,18	1,48
Total	1234,92	136,70	1098,30	340,63	1438,93

Source: Analysis Results (2024)

The significant changes in mangrove coverage in the Bukit Bestari District between 2007 and 2015 can be attributed to the presence of strategic areas, such as the Dompak Free Trade Zone and the Provincial Government Center of the Riau Islands on Dompak Island. Additionally, the Bukit Bestari District also includes active bauxite mining sites as of 2014.

In the Tanjungpinang Kota District, the mangrove coverage in 2007 was 577.56 hectares, with deforestation totaling 218.47 hectares, 358.96 hectares remaining unchanged, and an increase of 40.24 hectares. Thus, the total mangrove coverage in the Tanjungpinang Kota District in 2015 was 399.19 hectares, indicating a degradation of 30.8% compared to the mangrove coverage in 2007. The rate of change in mangrove coverage in this district from 2007 to 2015 was 22.29 hectares per year. The high rate of change in mangrove coverage in Tanjungpinang Kota is partially driven by the presence of the Tanjungpinang City Government Center and the Senggarang Free Trade Zone, leading to potential land conversion, including the transformation of mangrove forests into other land uses.

In the Tanjungpinang Timur District, the mangrove area in 2007 was 321.21 hectares, experiencing deforestation of 114.12 hectares, with 224.00 hectares remaining unchanged and an increase of 45.40 hectares. Consequently, the total mangrove coverage in the Tanjungpinang Timur District in 2015 was 269.40 hectares, reflecting a degradation of 16.1% from the mangrove coverage in 2007. The rate of change in mangrove coverage in Tanjungpinang Timur from 2007 to 2015 was 6.48 hectares per year.

In the Tanjungpinang Barat District, the mangrove area in 2007 was 1.81 hectares, with deforestation of 1.81 hectares and an increase of 1.40 hectares. Therefore, the total mangrove coverage in Tanjungpinang Barat in 2015 was 1.40 hectares, indicating a degradation of 22.6% from the mangrove coverage in 2007. The rate of change in mangrove coverage in this district from 2007 to 2015 was 0.1 hectares per year.

Changes in mangrove coverage in Tanjungpinang City across each district from 2015 to 2023 are presented in Table 7. The mangrove coverage in 2015 was 1,234.92 hectares, with deforestation totaling 136.70 hectares, 1,098.30 hectares remaining unchanged, and an increase of 340.63 hectares. Thus, the total mangrove coverage in 2023 is 1,438.93 hectares, representing a degradation of 16.5% compared to the mangrove coverage in 2015.

In the Bukit Bestari District, the mangrove coverage in 2015 was 564.93 hectares, experiencing deforestation of 51.04 hectares, with 513.89 hectares remaining unchanged and an increase of 136.10 hectares. Consequently, the total mangrove coverage in the Bukit Bestari District in 2023 is 649.99 hectares, reflecting a degradation of 15.1% compared to the mangrove coverage in 2015. The rate of change in mangrove coverage in Bukit Bestari from 2015 to 2023 is 10.63 hectares per year.

In the Tanjungpinang Kota District, the mangrove coverage in 2015 was 399.19 hectares, with deforestation totaling 45.04 hectares, 354.15 hectares remaining unchanged, and an increase of 119.73 hectares. Thus, the total mangrove coverage in the Tanjungpinang Kota District in 2023 is 473.88 hectares, indicating a degradation of 18.2% from the mangrove coverage in 2015. The rate of change in mangrove coverage in Tanjungpinang Kota from 2015 to 2023 is 9.34 hectares per year.

In the Tanjungpinang Timur District, the mangrove area in 2015 was 269.40 hectares, with deforestation of 40.44 hectares, 228.96 hectares remaining unchanged, and an increase of 84.62 hectares. Therefore, the total mangrove coverage in the Tanjungpinang Timur District in 2023 is 313.58 hectares, reflecting a degradation of 16.4% compared to the mangrove coverage in 2015. The rate of change in mangrove coverage in Tanjungpinang Timur from 2015 to 2023 is 5.52 hectares per year.

In the Tanjungpinang Barat District, the mangrove coverage in 2015 was 1.40 hectares, with deforestation of 0.18 hectares, 1.30 hectares remaining unchanged, and an increase of 0.18 hectares. Thus, the total mangrove coverage in the Tanjungpinang Barat District in 2023 is 1.48 hectares, indicating a degradation of 7.7% from the mangrove coverage in 2015. The rate of change in mangrove coverage in Tanjungpinang Barat from 2015 to 2023 is 0.01 hectares per year. Figure 8 illustrates the map of mangrove deforestation in Tanjungpinang City across each district for the period from 2015 to 2023.

Overall, between 2007 and 2023 the mangrove cover area in 2007 was 1762.27 hectares, experienced deforestation of 584.16 hectares, mangrove cover remained at 1178.10 hectares, and mangroves that experienced an increase of 260.83 hectares. So that the total area of mangrove cover in 2023 is 1438.93 hectares. Changes in mangrove cover in the period 2007-2023 in each sub-district can be seen in Table 8.

Table 8. Area of Mangrove Cover Change by Subdistrict 2007-2023

District	Year 2007	Year 2023 (Ha)			
		Decreased	Remain	Increase	Total Area
Bukit Bestari	861.69	288,50	556,37	93,62	649.99
Tanjungpinang Timur	321.21	105,80	232,18	81,40	313,58
Tanjungpinang Kota	577.56	188,05	389,55	84,33	473.88
Tanjungpinang Barat	1.81	1,81	0	1,48	1.48
Total	1762.27	584,16	1178,10	260,83	1438.93

Source: Result Analysis (2024)

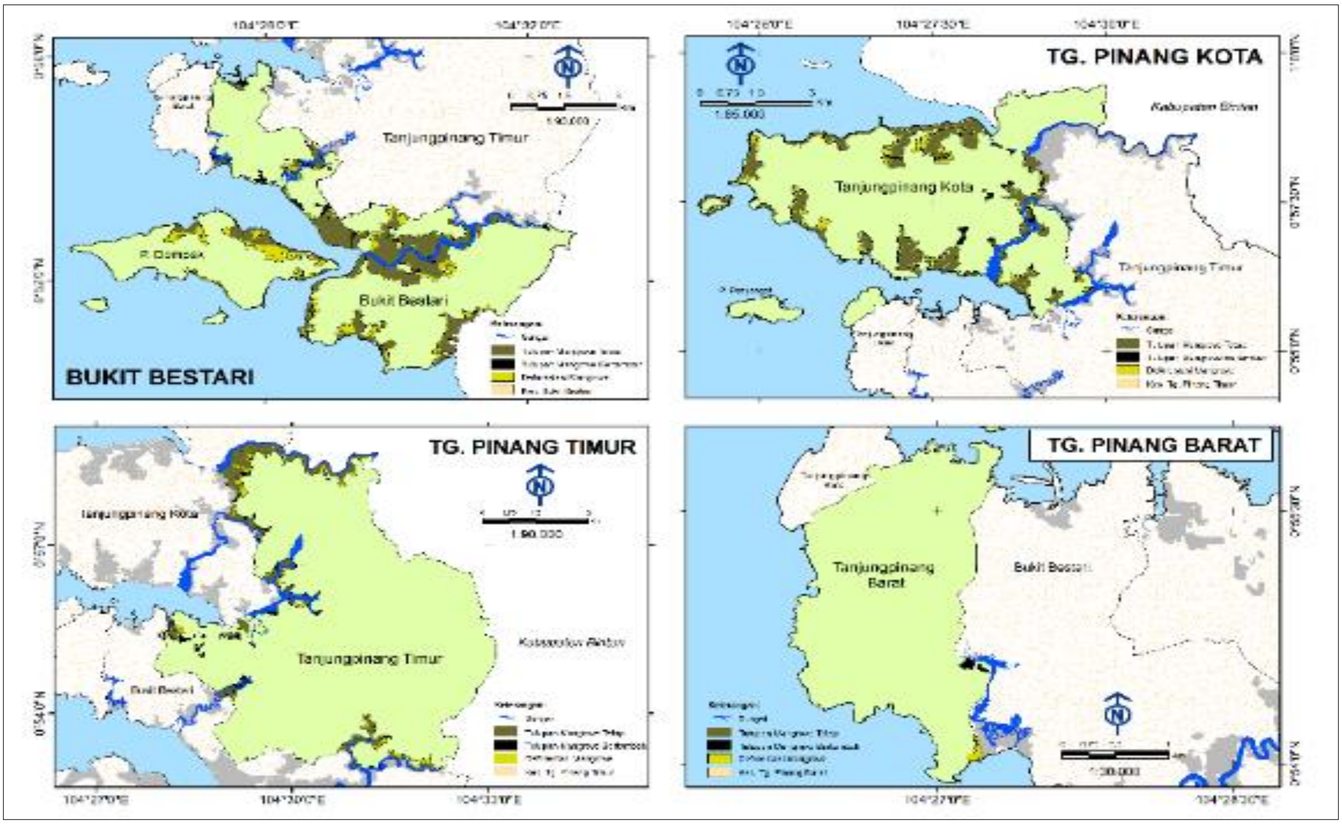

Figure 9. Map of Mangrove Cover Change 2007-2023 Tanjungpinang City

Between 2007 and 2023, the rate of change of mangrove cover in Bukit Bestari sub-district was 13.23 hectares per year, Tanjungpinang Kota sub-district was 6.48 hectares per year, Tanjungpinang Timur sub-district was 0.48 hectares per year, and Tanjungpinang Barat sub-district was 0.02 hectares per year. Figure 9 shows the Map of Mangrove Cover Deforestation in Tanjungpinang City in each sub-district between 2007-2023.

Prediction of Mangrove Cover Change in Tanjung pinang City for 2035

The prediction of mangrove cover change was conducted using the Land Change Modeler method within the Terrset Idrisi software. The Land Change Modeler (LCM) is employed to model future land cover changes by analyzing past trends (Awal et al., 2023; Darmawan et al., 2022; Nguyen et al., 2020). The prediction for mangrove cover in 2035 began with projecting land cover changes from 2007 to 2015 in order to forecast land cover for 2023. This projection aims to validate the predicted mangrove cover for 2023 against the actual mangrove cover data that has been previously established (Awal et al., 2023; Darmawan et al., 2022; Prabowo et al., 2017). Thus, land cover data from 2007 and 2015 were utilized to create the projection model for land cover in 2023. The projection from 2023 to 2035 is based on the land cover conditions in 2023 through a probability value matrix generated by Markov Chain Analysis between the years 2007 and 2015.

The transition matrix contains weights that guide land use movements based on driving factors that indicate the likelihood of each land cover class changing to other land cover categories (Awal et al., 2023). Land changes typically follow a pattern influenced by driving factors. In this study, three driving factors were used: road networks, residential areas, and government service centers. Figure 17 presents the actual land use map for 2023 alongside the projected land use map for 2023. The validation results of the Kappa Index of Agreement for the land use map of 2023 compared to the actual land use map for 2023 are shown in Table 9.

Table 9. Result Uji *Kappa of Agreement*

Kstandard	=	0,6165
Kno	=	0,7051
Klocation	=	0,7199
Klocationstrata	=	0,7199

Based on the Kappa Index of Agreement obtained, the overall agreement generally has Good criteria, where the Kno value is 0.7051, the Klocation value is 0.7199, the Klocationstrata value is 0,.7199, and the Kstandard value is 0.6165. Furthermore, the projection of land use change in 2035 was carried out by using change projection using Land Change Modeler.

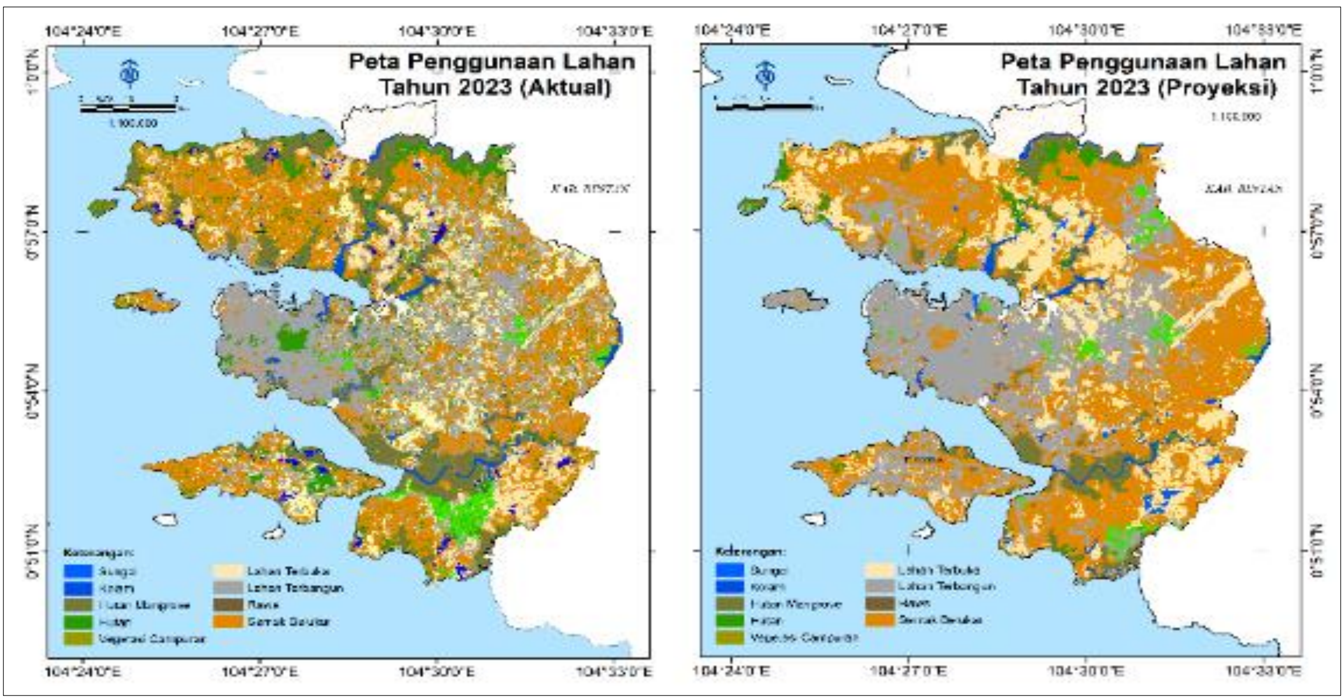

Figure 10. Validation of Projected 2023 Land Cover Map with Actual 2023 Land Cover Map Actual Year 2023 Land Cover

Table 10. Prediction of Mangrove Cover Changes in 2023 – 2035

Land Cover	2023		2035		Change Between 2023-2035	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Mangrove	1438.93	9.91	977,72	6,73	-461,21	-3,18
Non *Mangrove*	13081.52	90.01	13542,28	93,27	461,21	3,18
Total	14520,45	100	14520,45	100	0	0

Sumber : Hasil Analisis (2024)

The predicted changes in mangrove and non-mangrove coverage for the year 2035, based on Land Change Modeler analysis, are presented in Table 10. According to the baseline data from 2023, there is a projected decrease in mangrove coverage of 461.21 hectares, representing a reduction of 32.05%. The mangrove area in 2023, which is 1,438.92 hectares, is expected to decline to 977.72 hectares. This change occurs under the assumption that no policies or interventions are implemented to control or regulate regional development. Spatial temporal changes in mangrove cover in Tanjungpinang City in the range of 2007-2035 are presented in Figure 11. Meanwhile, the prediction of the area of mangrove cover change in each sub-district in 2023-2035 is presented in Table 11.

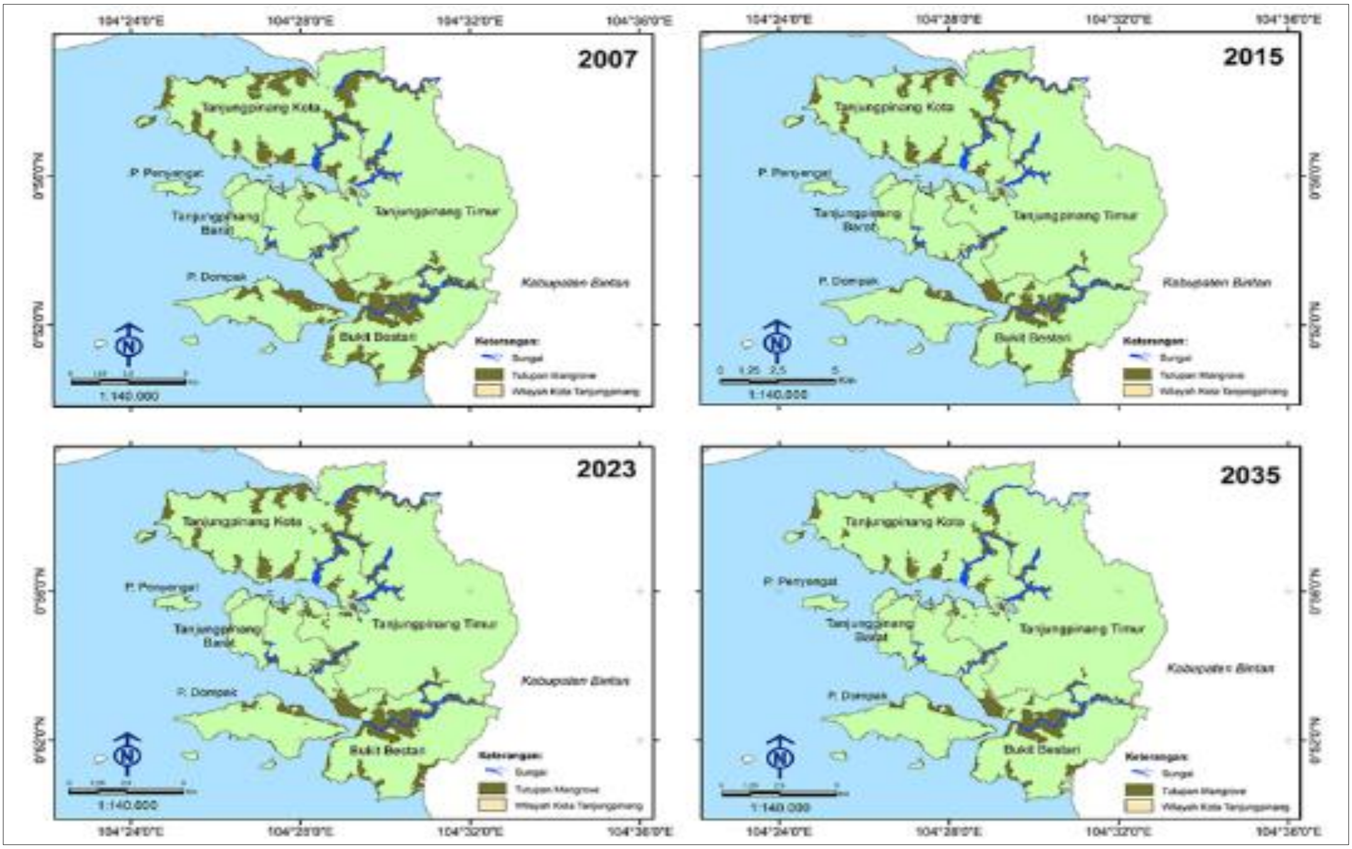

Figure 11. Map of Mangrove Cover Change in Tanjungpinang City 2007-2035

Table 11. Predicted Change in Mangrove Cover Area in 2023 - 2035 by Subdistrict in Tanjungpinang City

Disctrict	Mangrove Land Cover Area		Changes in Mangrove Land Cover Area	
	2023	2035	2023-2035	%
Bukit Bestari	649,99	495.84	-154,15	-23,72
Tanjungpinang Timur	313,58	156,26	-157,32	-50,17
Tanjungpinang Kota	473.88	323.63	-150,25	-31,71
Tanjungpinang Barat	1.48	1.99	0,51	34,50
Jumlah	1438.93	977,72	-461,21	-32,05

Source: Analysis Result (2024)

Based on the results of land cover projections in 2035, Tanjungpinang City experienced a decrease in mangrove cover area of 32.05 compared to mangrove cover in 2023. Based on the sub-district, mangrove cover in Bukit Bestari sub-district decreased by 23.72%, East Tanjungpinang sub-district decreased by 50.17%, Tanjunpinang Kota sub-district by 31.71%, and West Tanjungpinang by 34.50%. Changes in amngrove cover in Tanjungpinang City in each sub-district between 2007-2035 can be seen in Figures 12-15.

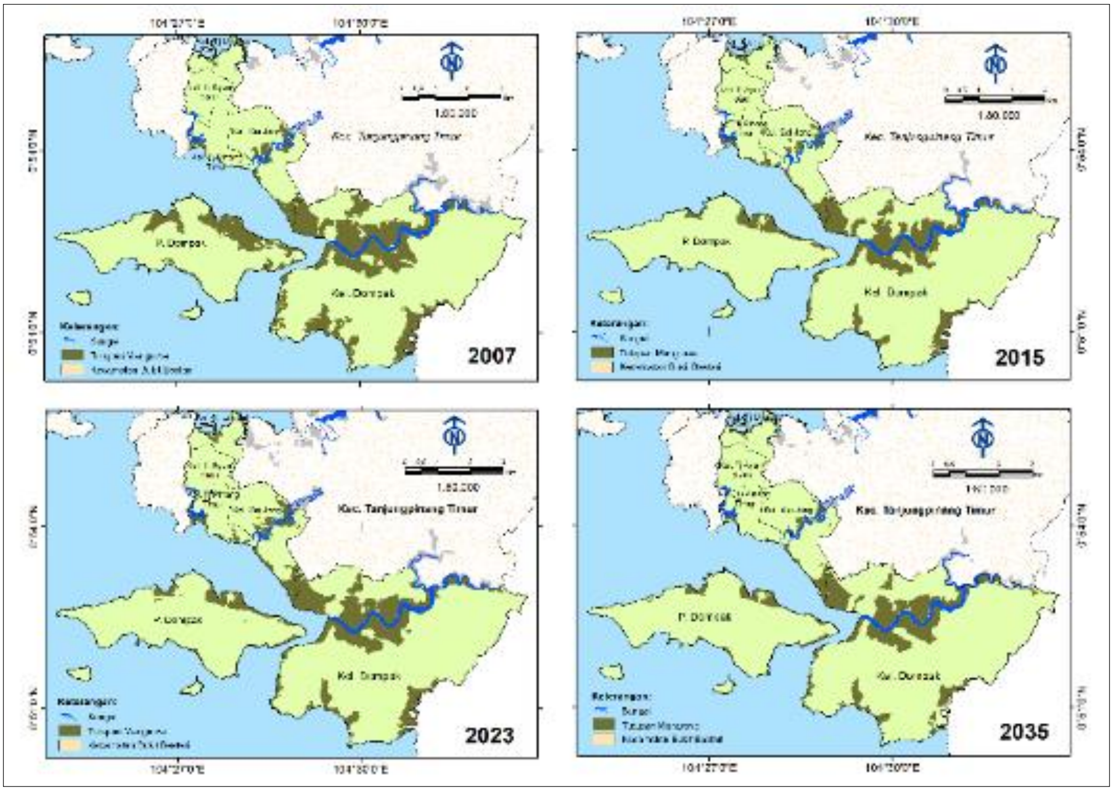

Figure 12. Map of Mangrove Cover Change in Bukit Bestari Sub-district 2007-2035

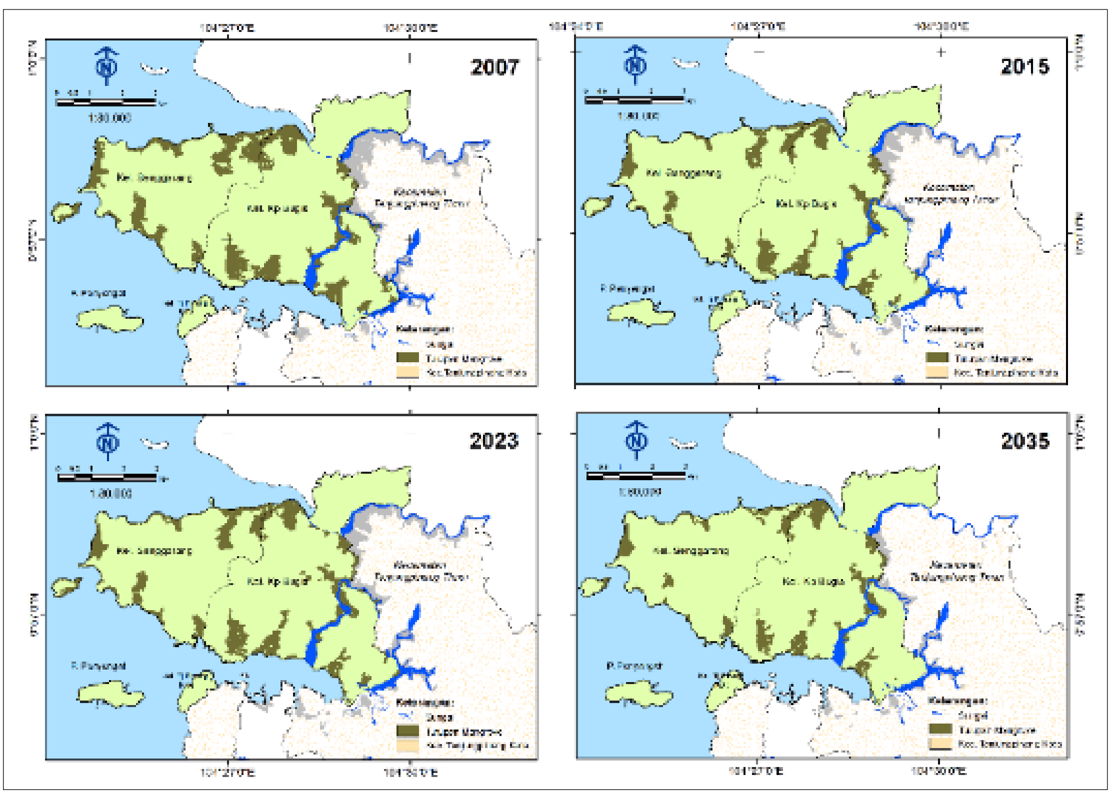

Figure 13. Map of Mangrove Cover Change in Tanjungpinang Kota Sub-district 2007-2035

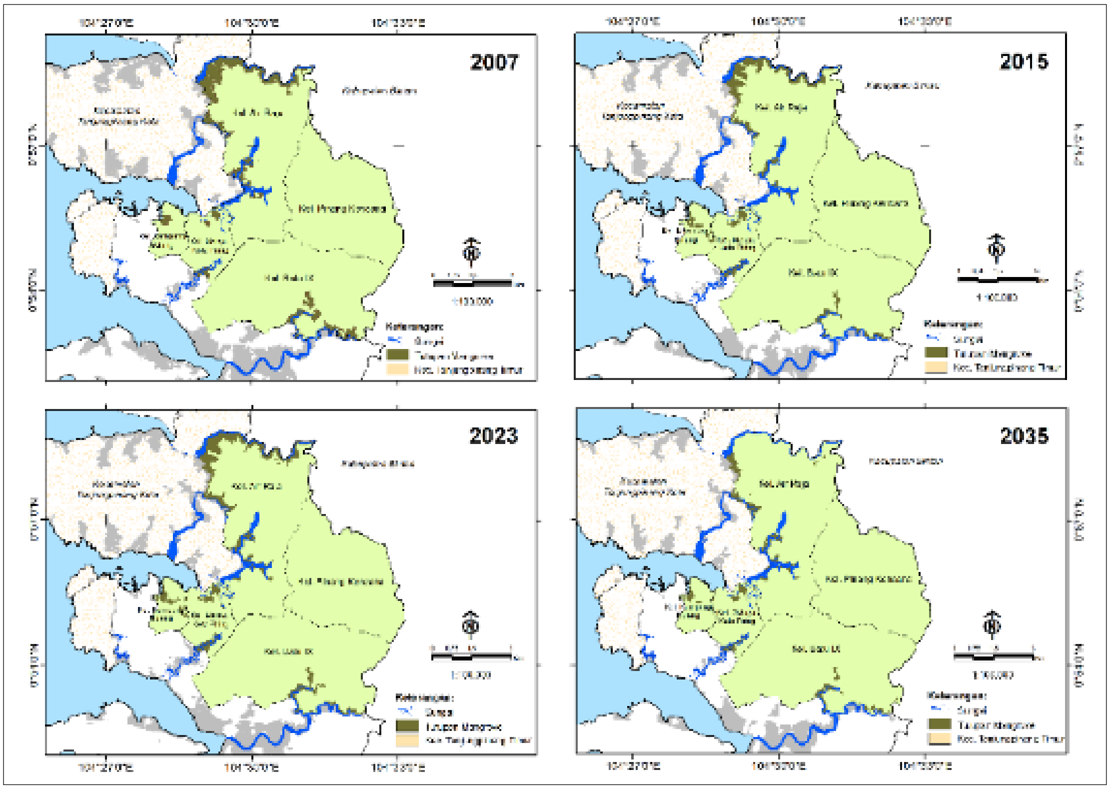

Figure 14. Map of Mangrove Cover Change in Tanjungpinang Timur Sub-district Year 2007-2035

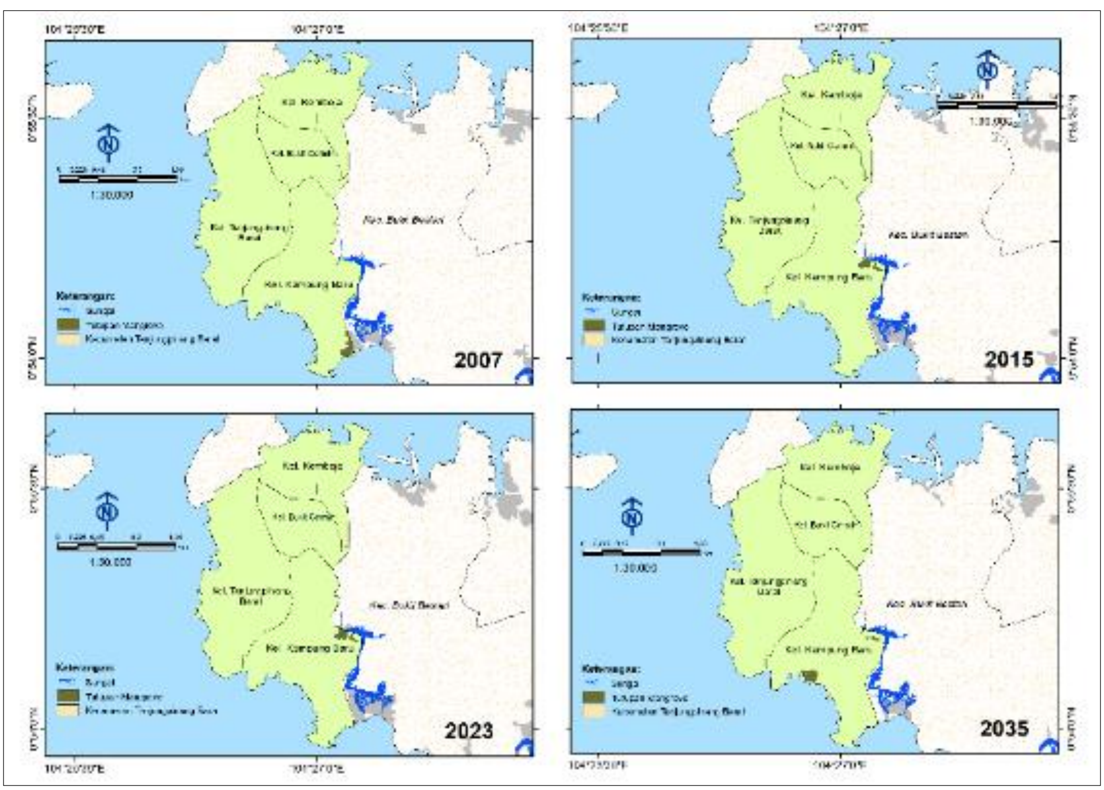

Figure 15. Map of Mangrove Cover Change in Tanjungpinang Barat Sub-district 2007-2035

Land use change is driven by the demand for housing, industry, agriculture, and other purposes, leading to substantial alterations in land use patterns, including changes in mangrove coverage. These changes are influenced by the complex interactions of anthropogenic and natural factors. These factors vary across different regions and time periods, impacting the extent and health of mangrove ecosystems.

Anthropogenic factors affecting mangrove change include population growth, coastal development, economic activities, and infrastructure development. Population growth is a significant driver of land cover change (Chiaka et al., 2024). Coastal development involving the conversion of coastal forests, salt marshes, and mangroves into cultivated areas and residential zones is also a major factor contributing to land use change, which can degrade habitat quality (Kumari & Pathak, 2023; Lopes et al., 2022). Field observations indicate that mangrove ecosystems in Tanjungpinang City are often in close proximity to residential areas, which may threaten their viability.

Economic activities frequently outweigh conservation efforts, resulting in significant habitat loss (Rahmawaty et al., 2023). The establishment of resorts, hotels, and industries in coastal zones has altered land use patterns, causing environmental degradation and shifts in local livelihoods (Kumar & Singh, 2022). For example, mangrove forests in the former bauxite mining sites in Senggarang Besar and Sei Carang in Tanjungpinang City remain open and unrehabilitated. Currently, these lands have not been reclaimed by the mining companies, nor have community replanting efforts been initiated (Lestari et al., 2023). Field observations have also identified other open lands from bauxite mining that have yet to be rehabilitated. Additionally, there is considerable tree clearing and mangrove land conversion by local communities for residential and commercial purposes, such as restaurants. If left unmanaged, these conditions will jeopardize the sustainability of the mangrove ecosystem in Tanjungpinang City in the future.

Infrastructure development also drives changes in mangrove coverage, increasing fragmentation, altering natural landscapes, and reducing the growth and recovery rates of mangroves (You et al., 2024). The conversion of mangrove forests for infrastructure development in Tanjungpinang City, such as the construction of the Riau Islands Provincial Government Center on Dompak Island, has significantly impacted mangrove coverage. According to Saputra et al. (2021), the area of mangroves on Dompak Island decreased by 34.19%, or 46 hectares, from 2007 to 2018. Field observations indicate that mangrove forests on Dompak Island have been converted into office buildings, roads, and residential areas, contributing to changes in mangrove coverage. Generally, existing mangrove forests still maintain good conditions and coverage. Therefore, policies for managing mangrove ecosystems are essential to preserve their existence and sustainability.

CONCLUSION

From the analysis conducted, it can be concluded that from 2007 to 2015, the rate of change in mangrove coverage was decreasing at a rate of 65.92 hectares per year. Conversely, from 2015 to 2023, the rate of change in mangrove coverage increased to 25.49 hectares per year. However, overall, from 2007 to 2023, there was a decline in mangrove coverage at an average rate of 20.21 hectares per year.

Based on predictions for mangrove coverage in Tanjungpinang City for the year 2035, it is estimated to be 977.72 hectares, representing a reduction of 32.05% from the mangrove coverage in 2023. The changes in mangrove coverage by district are as follows: Bukit Bestari District decreased by 23.72%, Tanjungpinang Kota District decreased by 50.17%, Tanjungpinang Timur District decreased by 31.71%, and Tanjungpinang Barat District increased by 34.50%.

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