Spatial analysis of mangrove cover change and land suitability for its rehabilitation in Tanjungpinang City, Riau Islands Province, Indonesia

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Abstract. This study aims to quantify the changes in mangrove cover in Tanjungpinang City from 2007 to 2023 and assess the land suitability for rehabilitation. A spatial approach was employed by overlaying land cover classifications derived from Landsat 7 ETM+ imagery in 2007, Landsat 8 OLI in 2015, and Sentinel 2A MSI in 2023. The analysis of land suitability for mangrove rehabilitation involved examining the physical condition of vegetation, environmental parameters (such as substrate, pH, salinity, and temperature), and current and tidal velocities. The outcomes revealed a decrease in mangrove area by 323.41 ha from 2007 to 2023, with an annual rate of change of 20.21 ha. Between 2007 and 2015, the rate of mangrove cover loss was 65.92 ha per year, whereas from 2015 to 2023, the mangrove area increased by 25.49 ha per year. The study identified 16 species of mangroves in Tanjungpinang City. Of the 22 locations observed, 21 were deemed highly suitable, and one was suitable for mangrove rehabilitation. Nevertheless, successful rehabilitation requires tailored strategies that consider the specific characteristics of each location.

Key Words: aquatic, coastal, google earth engine, land use change, remote sensing.

Introduction. Mangrove forests are very important to coastal regions and small islands, offering numerous ecosystem services and benefits to the environment and local communities. They contribute to shoreline stabilization, mitigate coastal erosion, and protect against storm surges (Hongwiset et al 2022; Karimi et al 2022; Rihulay & Papilaya 2022). Coastal regions are more dynamic than other areas on the Earth's surface, influenced by both natural processes and human activities along the shoreline (Suhana et al 2016). Therefore, mangrove forests serve as a natural barrier, enhancing resilience against climate change and human activities. This makes them an important element in sustainable coastal management strategies (Das et al 2022). However, mangrove forests in Indonesia have experienced significant changes, with notable declines in recent years due to factors such as residential development, aquaculture, pollution, deforestation, and conflicting interests (Hamzah et al 2023; Miller & Tonoto 2023; Rahmawaty et al 2023). These changes have resulted in a reduction in mangrove cover, impairing the ecosystem's capacity to perform crucial functions such as carbon sequestration, coastal protection, and providing habitat for various marine species (Amel & Lestari 2023). According to Rahadian et al (2019), based on 2005 data, there were 9361957 ha of mangrove land throughout Indonesia, and in 2009 there was a decrease in mangrove land area to 3244018 ha. Changes in mangrove forests that occur in coastal areas are not only caused by natural phenomena, but also by human activities in the vicinity that make them vulnerable to land use change (Mappanganro et al 2018). This situation indicates that mangrove degradation is driven by human population pressure, increasing economic demands, exploitation of wood products, and land conversion for other uses. Therefore, it is essential to analyze and evaluate the dynamics of mangrove forest cover changes. Remote sensing technology, particularly satellite imagery, is an effective method for monitoring mangrove ecosystems. Satellite imagery provides consistent, large-scale, and high-resolution data, making it a powerful tool for tracking changes in mangrove forests over time. However, conventional interpretation of satellite imagery is time-consuming and requires expensive hardware and software. The Google Earth Engine platform addresses these limitations by enabling access to large datasets and facilitating analysis and presentation without the need for high-specification computers, resulting in faster data processing (Fariz et al 2021). Analysis of mangrove cover change using Google Earth Engine involves the utilization of remote sensing technology, and machine learning algorithms can be applied to measure mangrove area efficiently and accurately. Research has shown that the Google Earth Engine platform, combined with Landsat and Sentinel satellite imagery, enables high-precision classification of mangrove cover, such as through the use of Random Forest classifiers (Kamisnuddin et al 2023; Munandar et al 2023; Rajendiren et al 2023). The existence of the Google Earth Engine platform enables efficient ongoing monitoring of mangrove ecosystems, aiding their conservation and management by providing important data on the spatial and temporal dynamics of mangrove cover.

The dynamics of mangrove forest change also occur in Tanjungpinang City, Riau Islands Province. The increasing population will be followed by the need for land for infrastructure development, industry, settlements, and other activities, triggering land use conversion including mangrove forest conversion, which in turn can encourage damage to coastal and marine resources. The condition of mangrove ecosystems in Tanjungpinang has been stressed by human activities, such as in Sei Carang and Tanjung Siambang, significantly impacting mangrove ecosystems (Maylani et al 2022; Daulay et al 2023). In addition, studies in Senggarang Besar show that mangrove ecosystems have been degraded, with varying degrees of density and canopy cover, suggesting the need for conservation and rehabilitation measures (Salam et al 2023). Activities such as land filling, bauxite mining, and logging have led to the degradation and destruction of mangrove forests in the area (Nengsih et al 2023). Meanwhile, Zulkarnaen et al (2022), mapping aberration-prone areas in Kampung Bugis and Senggarang villages as part of the coastal area in Tanjungpinang City, noted that both villages have the potential for coastal aberration disasters due to the loss of mangrove vegetation that has been converted into settlements. Winaz et al (2023) analyzed changes in the distribution of mangrove forest cover and density using Landsat 8 satellite imagery at several locations in Bukit Bestari District, Tanjungpinang City, which resulted in a magnitude of changes in mangrove land cover in Bukit District between 2014-2022. Efforts to conserve and rehabilitate mangrove ecosystems have been made, including socialization and counseling to increase community awareness and capacity regarding the benefits and conservation of mangrove forests (Zakia et al 2022). This study aims to determine the magnitude of changes in mangrove cover in Tanjungpinang City, spatially, from 2007 to 2023, and analyze the suitability of land for mangrove rehabilitation.

Material and Method

Description of the study sites. The study took place between February and June 2024 in Tanjungpinang City, located in the Riau Islands Province. Tanjungpinang City is situated on Bintan Island, positioned between 0°51' to 0°59' North latitude and 104°23' to 104°34' East longitude. The specific research site is depicted in Figure 1.

Materials. The study employed various tools including GPS devices, pH meters, measuring tapes, phi-band tools, plastic ropes, stakes, stationery supplies, thermometers, paint, work maps, and containers for collecting seawater and substrate samples. For data processing, computers equipped with ArcGIS 10.8 and Terrset software were utilized. The primary data sources used for analyzing mangrove cover change included Landsat 7 ETM+ images from 2007, Landsat 8 OLI images from 2015, and Sentinel 2A images from 2023. Furthermore, secondary data were gathered through literature reviews, administrative maps of Tanjungpinang City, land use maps, and additional supporting sources. Additionally, current speed data were obtained from publications by the Climatology, Meteorology, and Geophysics Agency.

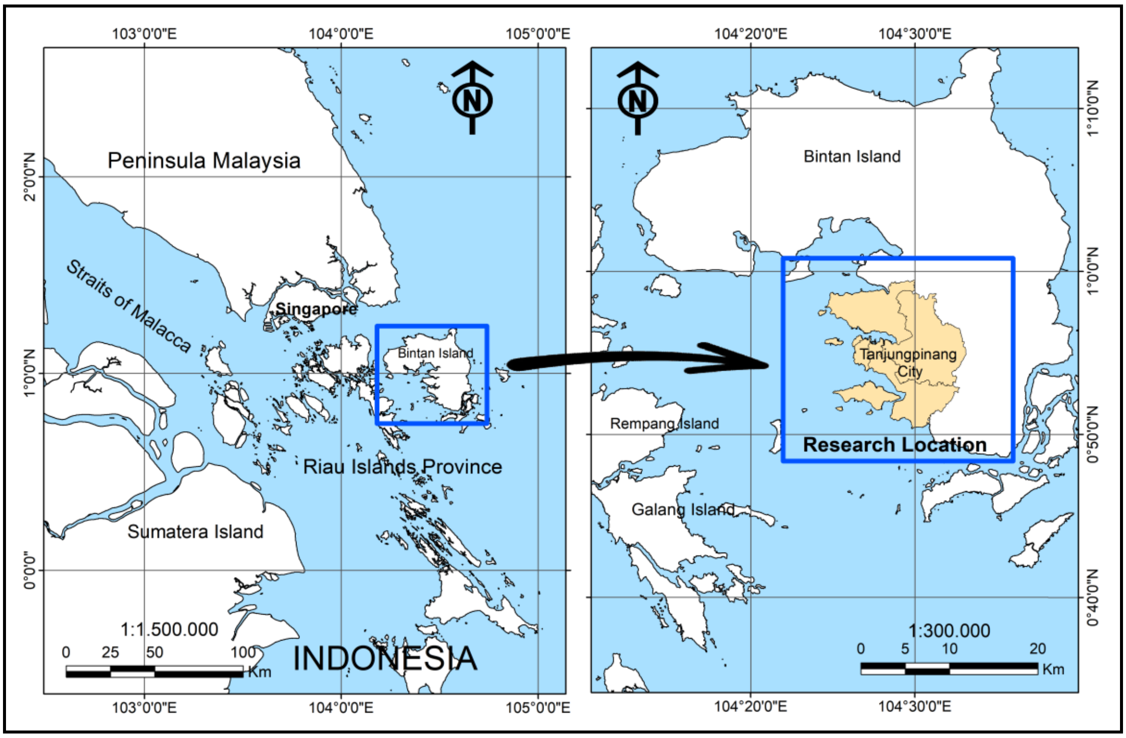

Figure 1. The location of Tanjungpinang City, Riau Island Province, Indonesia.

Methods. Data collection techniques for analyzing mangrove cover changes from Landsat 7 ETM+, Landsat 8 OLI, and Sentinel 2A images were obtained directly from Google Earth Engine (GEE). Data collection techniques for analyzing environmental conditions and mangrove vegetation were obtained from direct observations in the field (Zakia et al 2022; Malik et al 2023). In the research area, field observations were made in 23 locations spread across Tanjungpinang City. Observations were made to identify vegetation and environmental conditions including: mangrove species, substrate type, pH, salinity, and temperature. The collection of physical substrate data involved sampling substrates, pH measurements conducted using a pH meter, and temperature measurements with a thermometer. Salinity levels were determined through laboratory testing. The environmental parameter, measurements were conducted at the beginning of the study. In three specific locations - Senggarang Besar, Tugu Kepri on Dompak Island, and Kampung Bulang - line transects measuring 10x10 m were established. At each location there was one line transect, which consisted of 3 plots. Each plot consisted of 2x2 m subplots for seedling growth, 5x5 m subplots for sapling growth, and 10x10 m for tree growth. The data collection used for vegetation analysis with line transects is presented in Figure 2.

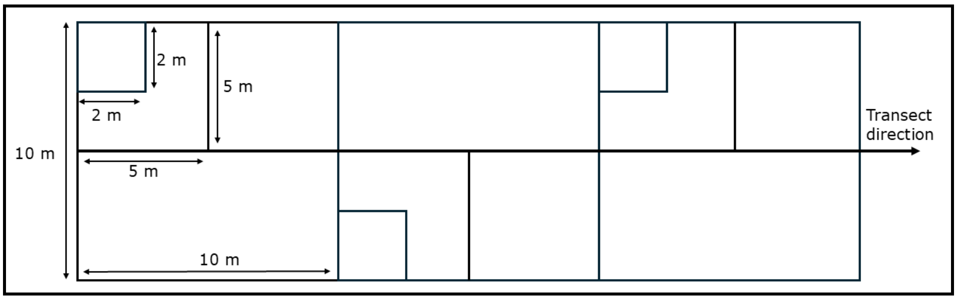

Figure 2. Measurement plot in the line transect.

Mangrove change analysis. Data analysis of mangrove cover change was conducted by processing Landsat 7 ETM+ images in 2007, Lansat 8 OLI in 2015, and Sentinel 2A MSI in 2023. The analysis was conducted in two stages. The first stage is the process of downloading satellite images, cropping, geometry correction, identification of land cover objects and groundcheck, and supervised classification (Raynaldo et al 2020). The image processing and interpretation stage was carried out using Google Earth Engine. The second stage is the identification of mangrove cover change data by overlaying several satellite images between land cover classes from 2007, 2015 and 2023. Furthermore, the change information is presented in the form of maps and tables. To calculate the rate of change in mangrove vegetation cover, the formula from Sodikin et al (2017) was used:

$$\Delta t = \frac{Lt_2 - Lt_1}{\Delta t}$$

Where: ΔL - the rate of change in mangrove cover area, calculated as ha per year; Lt_1 - the area in the initial observation year; Lt_2 - the area in the subsequent observation year; t - the time difference between these observations in years.

Analysis of land suitability for mangrove rehabilitation ind Tanjungpinang City. The analysis of land suitability for mangrove rehabilitation was based on field observations including parameters such as mangrove species, pH levels, salinity, temperature, and substrate conditions. Additionally, mangrove cover density classes were derived from NDVI calculations and line transect measurements conducted at three specific locations: Senggarang Besar River, Dompak Island (Tugu Kepri), and Kampung Bulang. The collected data were systematically tabulated and qualitatively analyzed. Land suitability for mangrove rehabilitation was assessed by assigning weights to each parameter using a scoring formula adapted from Utojo & Suyono (2004), as outlined in Table 1.

$$Wj = \left\lfloor \frac{(n - rj + 1)}{\sum (n - rp + 1)} \right\rfloor$$

Where: Wj - the parameter weight; n - the number of parameters; rj - the ranking order; rp - the nth parameter (p=1,2,3...n).

Table 1

Mangrove land suitability criteria for rehabilitation

Parameter	*Weight*	*S1*	*S2*	*S3*	*N*
Mangrove (species)	0.25	>5	3-5	1-2	0
Substrate type	0.21	Sandy mud	Muddy sand	Gravel sand	Rocky
Tidal type	0.18	Semi diurnal tide	Diurnal tide	Semi diurnal tide mix	Mixed diurnal tide
pH	0.14	6-7	5-6 and >7-8	4 -<5 and >8-9	<4 and >9
Sea current (m s^{-1})	0.11	<0.3	0.3 - 0.4	0.41 - 0.5	>0.5
Salinity (‰)	0.07	25-<29 or >33-37	29-33	0-1	0
Temperature (°C)	0.04	26-28	21-26	18-20	<18 or >28

Source: Barkey (1990); Kusmana et al (2003); Dahuri (2003); Kepmen LH 201/2004.

Analysis of land suitability for mangrove rehabilitation was carried out using the scoring method by dividing each parameter into 4 classes, namely: very suitable (S1), suitable (S2), moderately suitable (S3), and not suitable (N), with the value of each class being S1=4, S2=3, S2=2, and N=1. Furthermore, the land suitability value for mangrove rehabilitation planning is determined according to the score of each parameter using the following equation:

Suitability Score = Total score/The highest score x 100

Meanwhile, the land suitability class interval is obtained using the following formula:

Interval suitability = (Max value - Min value)/k

Where k is the desired number of suitability classes. Land suitability categories for rehabilitation were determined based on the percentage of suitability interval values (Table 2).

Table 2

Land suitability criteria for mangrove rehabilitation

Suitability interval	*Category*
76-100%	S1 (Very suitable)
51-76%	S2 (Appropriate)
26-51%	S3 (Moderately suitable)
≤26%	N (Not suitable)

Mangrove rehabilitation planning needs to consider the level of land suitability for the growth of certain mangrove species based on the physical and environmental conditions of the location.

Results

Land use cover change. The results of the analysis of remote sensing image interpretation with Google Earth Engine obtained 6 land use classifications, namely: built-up land, open land, mixed vegetation, shrubs, mangroves*,* and water bodies. The land cover area in Tanjungpinang in 2007, 2015 and 2023 is presented in Table 3.

Table 3

Land use in Tanjungpinang City in 2007, 2015, and 2023

Land use	*Land cover area (Ha)*					
	2007	*%*	*2015*	*%*	*2023*	*%*
Built-up land	1688.15	11.79	2770.35	18.93	3735.00	25.72
Open land	1868.90	13.06	2402,48	16.42	2115.05	15,89
Mixed vegetation	2589.47	18.09	1132.35	7.80	1557.98	10.73
Shrubs	5983.43	41.80	6610.56	45.17	4977.85	34.28
Mangrove forest	1762.32	12.31	1234.98	8.50	1438.92	9,91
Water body	421.44	2.57	372.11	2.56	503.43	3.47
Total	14313.71	100	14522.83	100	14520.45	100

According to Table 3, shrubland dominates the land cover, comprising 41.8% in 2007, 45.17% in 2015, and 34.28% in 2023. Figure 3 illustrates the trend of land cover changes from 2007 to 2023.

From 2007 to 2015, there was a rise in developed land, accompanied by expansions in open land and shrub cover. However, during the same period, there was a decrease in areas with mixed vegetation cover, mangrove forests and water bodies. One of the causes of the high change in built-up land cover during this period is the high development of urban facilities and infrastructure in Tanjungpinang City, such as the construction of the Riau Islands Provincial Government Center on Dompak Island and the development of the Tanjungpinang City government center in Senggarang. In addition, the establishment of Senggarang and Dompak as a Free Trade Zone (FTZ), which became the center of trade and industry in 2007, had an impact on increasing land needs for development activities. Meanwhile, between 2015 and 2023, the area of built-up land increased along with the addition of mixed vegetation, mangrove forests and water bodies. During the same period, there was a decrease in the area of open land cover and shrubs. The increase in the area of built-up land from 2007 to 2023 reached 121.25%, open land 23.46%, and water bodies 19.45%. However, during the same period, there was a decrease in the area of mixed vegetation land cover of 39.83%, shrubs 16.81%, and mangrove forests 18.35%. The extent of land use change in the period 2007-2023 is presented in Table 4.

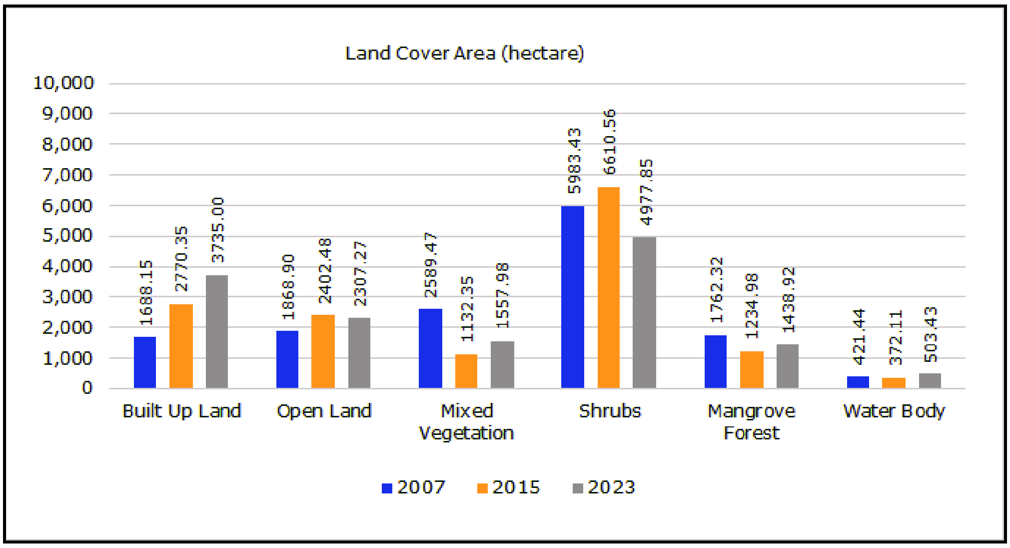

Figure 3. Changes in land use area in Tanjungpinang City (2007, 2015, and 2023).

Table 4

Extent of land use cover change in Tanjunpinang City

Land cover	*Land use change (Ha)*					
	2007-2015	*(%)*	*2015-2023*	*(%)*	*2007-2023*	*(%)*
Built-up land	1082.20	64.11	964.65	34.82	2046.85	121.25
Open land	533.58	28.55	-95.21	-3.96	438.37	23.46
Mixed vegetation	-1457.12	-56.27	425.63	36.11	-1031.49	-39.83
Shrubs	627.13	10.48	-1632.71	-24.70	-1005.57	-16.81
Mangrove forest	-527.34	-29.92	203.94	16.51	-323.41	-18.35
Water body	-49.33	-11.70	131.31	35.29	81.99	19.45

Mangrove land cover change. Mangrove vegetation in Tanjungpinang City is situated in coastal zones and along river estuaries. Data analysis reveals that mangrove vegetation underwent changes from 2007 to 2023. Table 5 presents the area and proportion of mangrove cover in Tanjungpinang City for 2007, 2015, and 2023. Based on Table 5, in 2007-2015, mangrove forests in Tanjungpinang City decreased by 527.34 ha or 29.9% since 2007. However, in the span of 2015-2023, mangrove forests increased by 203.94 ha or 16.5% from 2015. Thus, in the span of 16 years, in Tanjungpinang City, there was a decrease in mangrove cover area of 323.41 ha or 18.4% since 2007. The rate of change of mangrove cover between 2007 and 2015 was a decrease of 65.92 ha per year, while between 2015 and 2023 the rate of change increased by 25.49 ha per year. However, overall, in the period 2007-2023, the area of mangrove cover decreased with a rate of change of 20.21 ha per year. Maps of mangrove vegetation cover change for the years 2007-2015, 2015-2023, and 2007-2023 can be seen in Figures 4 to 6.

Table 5

Area and percentage of mangrove cover in Tanjungpinang City for 2007, 2015, and 2023

Land use	*Land cover area (Ha)*					
	Year 2007	*%*	*Year 2015*	*%*	*Year 2023*	*%*
Mangrove forest	1762.32	12.31	1234.98	9,20	1438.92	9.91
Non-mangrove	12551.39	87.69	13287.85	91.58	13081.53	90.13
Total	14313.71	100	14633.65	100	14520.45	100

One of the factors that increased mangrove cover in the 2015-2023 period is mangrove rehabilitation programs, such as mangrove planting, which have been run by the government and local governments, NGOs, and educational institutions. Based on data from the Riau Islands Provincial Environment and Forestry Service, there are about 181 ha of mangroves originating from government programs through mangrove planting in 2020 and 2021. Mangrove cover is distributed across four sub-districts in Tanjungpinang City. Table 6 displays the distribution of mangrove cover and its changes from 2007 to 2023 in each sub-district.

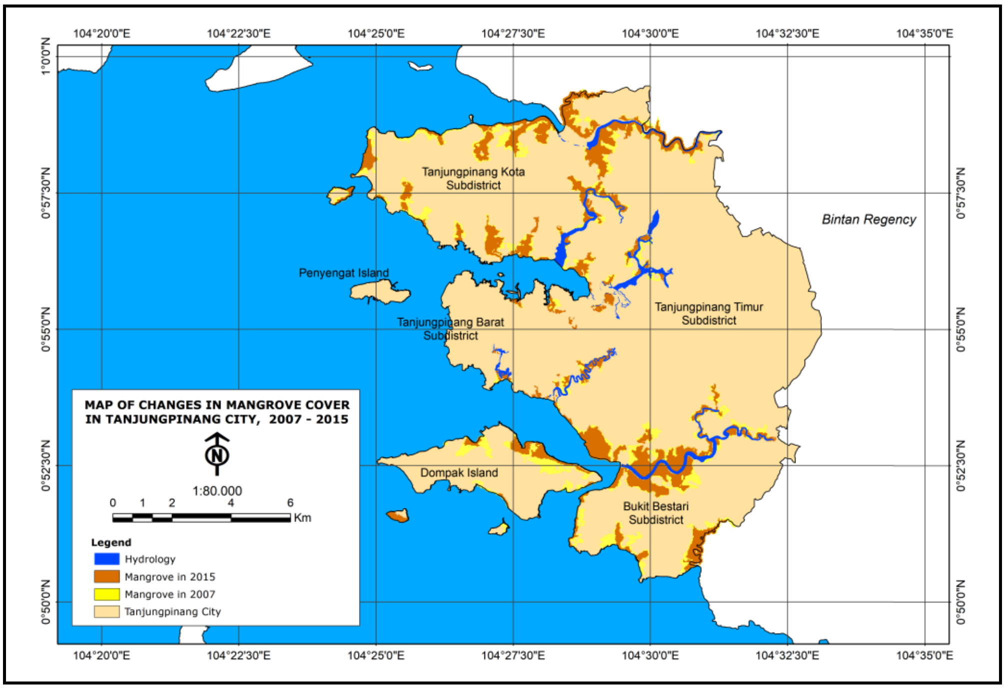

Figure 4. Changes in mangrove cover in Tanjungpinang, from 2007 to 2015.

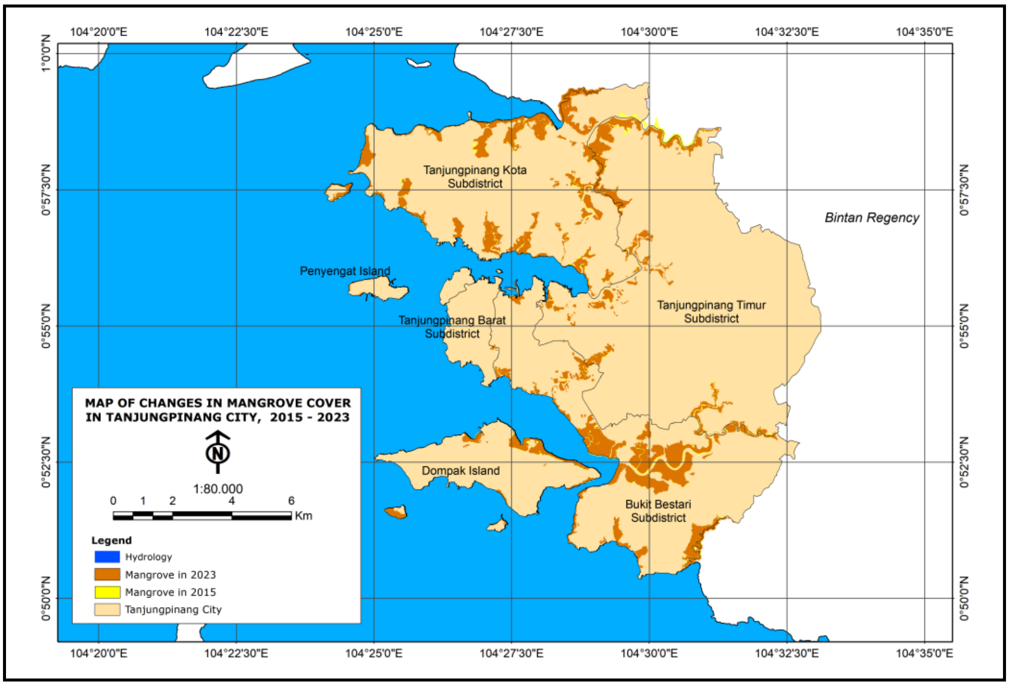

Figure 5. Changes in mangrove cover in Tanjungpinang, from 2015 to 2023.

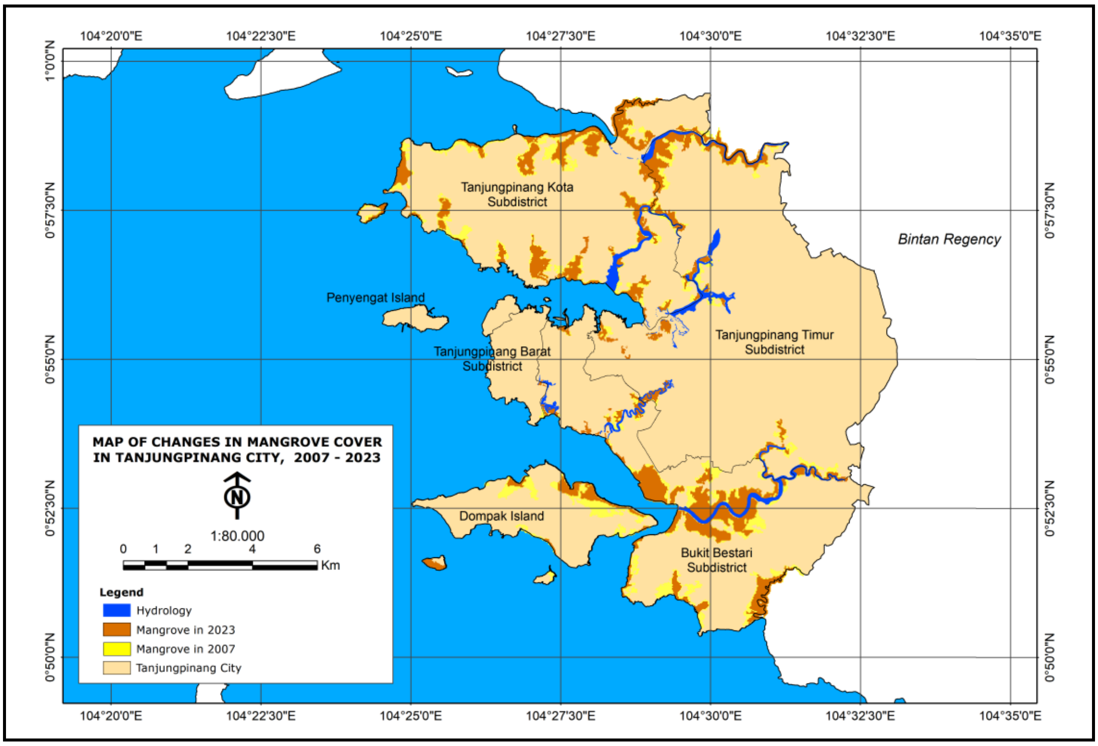

Figure 6. Changes in mangrove cover in Tanjungpinang, from 2007 to 2023.

Table 6

Mangrove cover area by subdistrict in 2007, 2015 and 2023

District	*Mangrove cover area (Ha)*			*Area of mangrove cover change (Ha)*		
	2007	*2015*	*2023*	*2007-2015*	*2015-2023*	*2007-2023*
Bukit Bestari	859.56	572.24	655.75	-287.32	83.51	-203.81
Tanjungpinang Timur	321.21	259.64	304.73	-61.57	45.09	-16.48
Tanjungpinang Kota	577.56	399.04	473.83	-178.52	74.79	-103.73
Tanjungpinang Barat	3.95	4.06	4.62	0.11	0.56	0.67
Total	1762.32	1234.98	1438.92	-527.30	203.95	-323.41

According to Table 6, Bukit Bestari sub-district has the largest mangrove distribution area compared to other sub-districts within Tanjungpinang City. Conversely, West Tanjungpinang sub-district has the smallest distribution. From 2007 to 2015, Tanjungpinang City experienced a reduction in mangrove cover totaling 527.3 ha. The most significant declines occurred in Bukit Bestari District and Tanjungpinang Kota District, decreasing by 287.32 ha and 178.52 ha, respectively. In contrast, from 2015 to 2023, there was an increase in mangrove cover area by 203.95 ha across all sub-districts. The largest increase was observed in Bukit Bestari sub-district, while the smallest increase occurred in Tanjungpinang Barat sub-district. Figure 7 shows the trend of mangrove land cover change in Tanjungpinang City in 2007, 2015 and 2023, in each sub-district. In Figure 7, it can be seen that from 2007 to 2015, there is a tendency to decrease the area of mangrove cover in all sub-districts, except in Tanjungpinang Barat sub-district. However, from 2015 to 2023, it increased in all sub-districts.

The high change in mangrove cover area in Bukit Bestari sub-district is due to the presence of strategic areas, such as the Dompak Free Trade Zone area and the Riau Islands Provincial Government Center on Dompak Island. In addition, Bukit Bestari sub-district also has bauxite mining sites that had been active until 2014. Meanwhile, the high change in mangrove cover area in Tanjungpinang Kota sub-district was triggered by the presence of the Tanjungpinang City Government Center and the Senggarang Free Trade Zone. Thus, in both sub-districts there is potential for land conversion, including mangrove forests, into other land uses such as settlements, industry, trade and services.

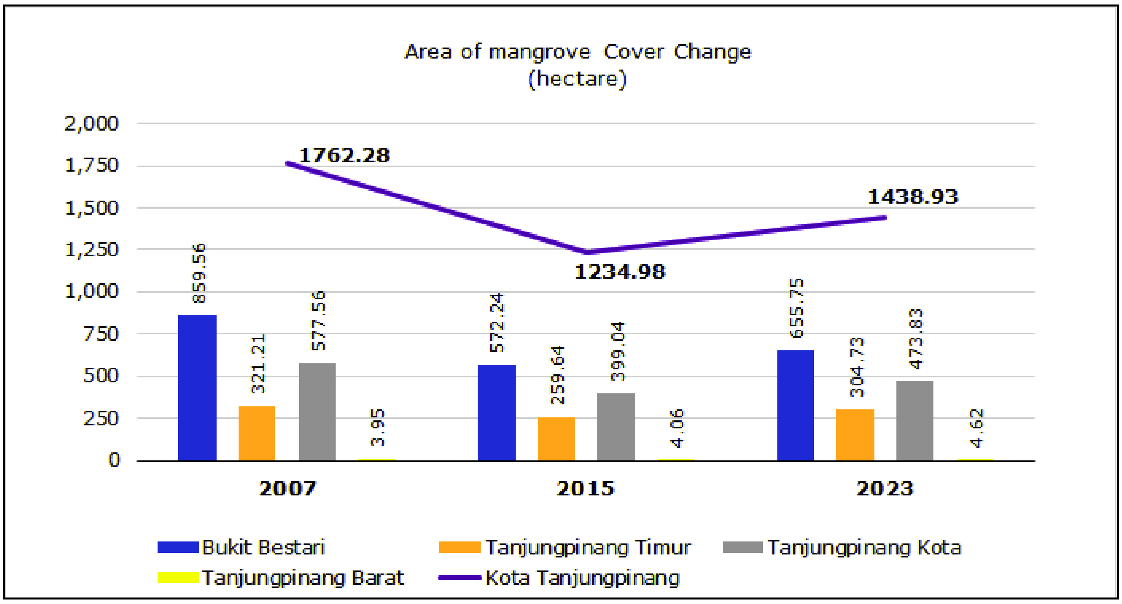

Figure 7. Graph of changes in mangrove land area in 2007, 2015, and 2023.

Mangrove species composition. The map of mangrove distribution in Tanjungpinang and the location of vegetation data collection and environmental parameters are presented in Figure 8. The results of observations of mangrove species identification are presented in Table 7.

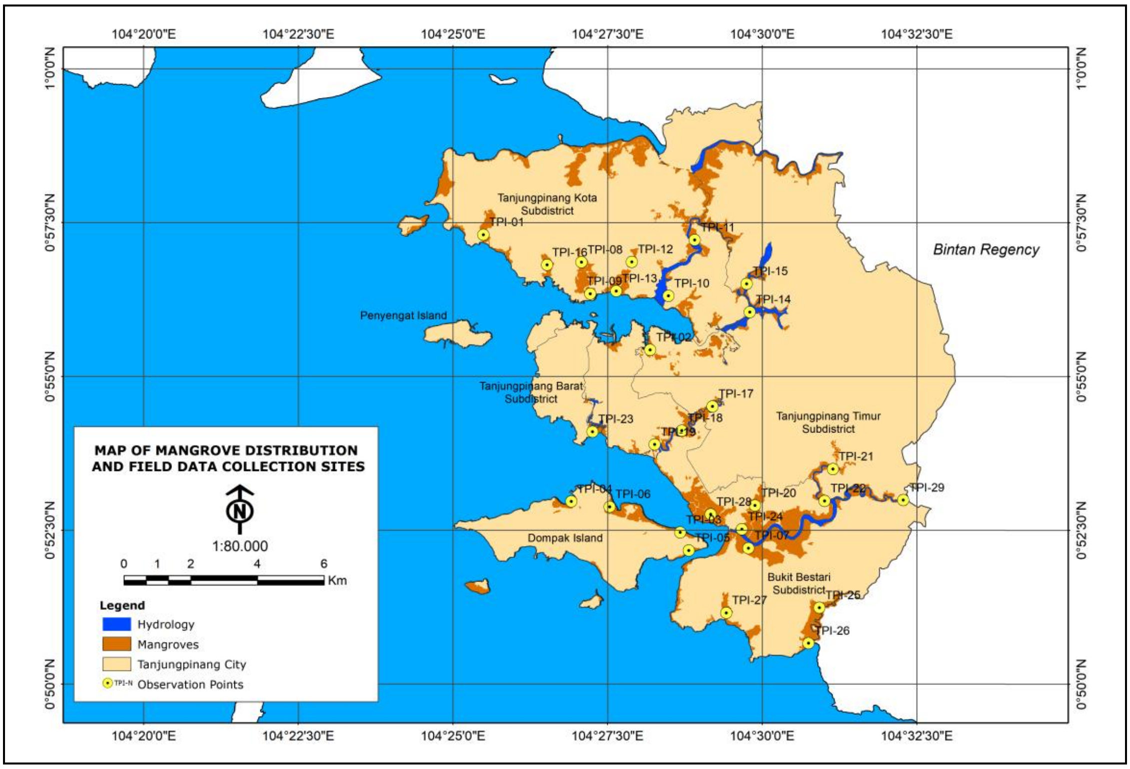

Figure 8. Map of mangrove distribution and field data collection sites.

Table 7

Mangrove species in Tanjunpinang City

Mangrove species	*Location*
Acanthus ilicifolius	Senggarang Besar
Avicennia alba	Senggarang Besar; Pulau Dompak (UMRAH); Muara Sungai Dompak; Hulu Sungai Ular; Hilir Sungai Ular; Hulu Sei Timun; Hilir Sei Timun; Hilir Sei Ladi; Kampung Bugis; Jembatan Sei Jang; Hilir Sei Jang; Jembatan Blongkeng; Jembatan 1 Dompak; Jembatan 3 Dompak; Kelam Pagi.
Avicennia rumphiana	Senggarang Besar; Kampung Bulang; Pulau Dompak (Jembatan 2); Pulau Dompak (Pelabuhan Lama); Hulu Sungai Ular; Hilir Sungai Ular; Hulu Sei Timun; Hulu Sei Ladi; Hilir Sei Ladi; Jembatan Sei Jang; Jembatan 1 Dompak; Jembatan 3 Dompak; Kelam Pagi.
Bruguiera cylindrica	Senggarang Besar; Kampung Bulang; Pulau Dompak (Tugu Kepri); Hulu Sungai Ular; Hulu Sei Ladi; Jembatan Sei Jang; Hilir Sei Jang; Jembatan Blongkeng; Jembatan 1 Dompak; Jembatan 3 Dompak; Kelam Pagi; Sei Jari.
Bruguiera gymnorrhiza	Senggarang Besar; Pulau Dompak (Pelabuhan Lama); Muara Sungai Dompak; Hilir Sungai Ular; Hulu Sei Timun; Hilir Sei Timun; Hulu Sei Ladi; Hilir Sei Ladi; Hulu Sei Carang; Hilir Sei Carang; Hulu Sei Jang; Jembatan Sei Jang; Hilir Sei Jang; Jembatan Blongkeng; Hulu Sungai Simpang Kiri; Jembatan Sungai Simpang Kiri; Jembatan 1 Dompak; Jembatan 3 Dompak; Hulu Sei Bladeng; Hilir Sei Bladeng; Sei Jari; Hulu Sungai Simpang Kanan
Ceriops decandra	Jembatan 1 Dompak; Sei Jari.
Ceriops tagal	Pulau Dompak (Tugu Kepri); Hulu Sungai Ular; Jembatan Blongkeng; Jembatan Sungai Simpang Kiri; Jembatan 1 Dompak; Hilir Sei Bladeng; Sei Jari.
Excoecaria agallocha L.	Senggarang Besar; Pulau Dompak (Jembatan 2); Hilir Sungai Ular; Hulu Sei Timun; Hulu Sei Carang; Hilir Sei Jang; Hulu Sungai Simpang Kiri; Jembatan Sungai Simpang Kiri; Hilir Sei Bladeng; Kelam Pagi; Hulu Sungai Simpang Kanan
Lumnitzera littorea	Senggarang Besar; Kampung Bulang; Pulau Dompak (Pelabuhan Lama); Muara Sungai Dompak; Hulu Sei Ladi; Hulu Sei Jang; Jembatan Sei Jang; Hilir Sei Jang; Jembatan Blongkeng; Hulu Sungai Simpang Kiri; Jembatan Sungai Simpang Kiri; Jembatan 3 Dompak; Kelam Pagi; Hulu Sungai Simpang Kanan
Lumnitzera racemose	Senggarang Besar; Jembatan 1 Dompak.
Nypa fruticans	Senggarang Besar; Pulau Dompak (Jembatan 2); Hulu Sungai Ular; Hilir Sei Ladi; Kelam Pagi.
Rhizophora apiculata	Senggarang Besar; Kampung Bulang; Pulau Dompak (Jembatan 2); Pulau Dompak (Pelabuhan Lama); Pulau Dompak (UMRAH); Pulau Dompak (Tugu Kepri); Muara Sungai Dompak; Hulu Sungai Ular; Hilir Sungai Ular; Hulu Sei Timun; Hilir Sei Timun; Hulu Sei Ladi; Hilir Sei Ladi; Hulu Sei Carang; Hilir Sei Carang; Kampung Bugis; Hulu Sei Jang; Jembatan Sei Jang; Hilir Sei Jang; Jembatan Blongkeng; Hulu Sungai Simpang Kiri; Jembatan Sungai Simpang Kiri; Jembatan 1 Dompak; Jembatan 3 Dompak; Hulu Sei Bladeng; Hilir Sei Bladeng; Kelam Pagi; Sei Jari; Hulu Sungai Simpang Kanan
Rhizophora mucronata	Senggarang Besar; Pulau Dompak (Jembatan 2); Pulau Dompak (UMRAH); Muara Sungai Dompak; Hulu Sei Timun; Hilir Sei Timun; Hilir Sei Ladi; Hulu Sei Carang; Hilir Sei Carang; Kampung Bugis; Jembatan Sei Jang; Jembatan Blongkeng; Hulu Sungai Simpang Kiri; Jembatan Sungai Simpang Kiri; Jembatan 3 Dompak; Hulu Sei Bladeng; Hilir Sei Bladeng; Kelam PagiHulu Sungai Simpang Kanan
Scyphiphora hydrophyllacea	Senggarang Besar; Kampung Bulang; Pulau Dompak (Pelabuhan Lama); Hulu Sungai Ular; Hulu Sei Timun; Hilir Sei Timun; Hulu Sei Ladi; Jembatan Sei Jang; Hilir Sei Jang; Jembatan Blongkeng; Jembatan Sungai Simpang Kiri; Jembatan 1 Dompak; Jembatan 3 Dompak; Hulu Sei Bladeng; Hilir Sei Bladeng; Kelam Pagi; Sei Jari.
Sonneratia alba	Senggarang Besar; Kampung Bulang; Pulau Dompak (Jembatan 2); Pulau Dompak (UMRAH); Muara Sungai Dompak; Hulu Sungai Ular; Hilir Sungai Ular; Hulu Sei Timun; Hilir Sei Timun; Hulu Sei Ladi; Hilir Sei Ladi; Hulu Sei Carang; Hilir Sei Carang; Kampung Bugis; Hilir Sei Jang; Jembatan 1 Dompak; Jembatan 3 Dompak; Kelam Pagi.
Xylocarpus granatum	Senggarang Besar; Kampung Bulang; Pulau Dompak (Tugu Kepri); Muara Sungai Dompak; Hulu Sungai Ular; Hilir Sungai Ular; Hulu Sei Timun; Hulu Sei Ladi; Hulu Sei Carang; Hilir Sei Carang; Hulu Sei Jang; Jembatan Sei Jang; Hilir Sei Jang; Jembatan Blongkeng; Hulu Sungai Simpang Kiri; Jembatan Sungai Simpang Kiri; Jembatan 1 Dompak; Jembatan 3 Dompak; Hulu Sei Bladeng; Hilir Sei Bladeng; Kelam Pagi; Sei Jari; Hulu Sungai Simpang Kanan

16 authentic mangrove species were identified in the study area (Table 7). The distribution of mangrove species in Tanjungpinang City is dominated by *Rhizophora apiculata*, spread in each observation location. The largest variety of mangrove species is in Senggarang Besar, with 14 species. The density level in Senggarang Besar, Tugu Kepri (Dompak Island), and Kampung Bulang can be categorized as ‘very dense’, between 1600-2900 trees ha^{-1}. The density of tree-level vegetation in Senggarang was 1600 trees

ha^{-1}, the density in Kampung Bulang was 2367 trees ha^{-1}, and in Dompak Island (Tugu Kepri) the density of mangrove vegetation reached 2900 trees ha^{-1}.

Environmental conditions of the mangrove ecosystem in Tanjungpinang. Environmental elements such as air and water temperatures, salinity levels, pH levels, substrate types, dissolved oxygen (DO) levels, and sediment thickness are factors influencing the type and growth of mangrove vegetation in specific locations (Badu et al 2022). Understanding and monitoring these environmental parameters is essential for the conservation and sustainable management of mangrove habitats, ensuring their continued growth and ecological functions. Table 8 presents the environmental parameters of mangroves in the study site based on direct field observations.

Table 8

Mangrove environmental condition based on observation location

Code	*Location*	*Mangroves (number of species)*	*Substrate*	*pH*	*Temperature (°C)*	*Salinity (‰)*	*Dissolved oxygen (mg L^{-1})*
TPI.01	Senggarang Besar	14	Silty sand	7.37	28.6	32	3.934
TPI.02	Bulang Village	7	Mud	7.94	31.9	32	2.951
TPI.03	Dompak Island (Bridge 2)	4	Mud	8.03	31	24	10.820
TPI.04	Dompak Island (Old Port)	5	Mud	-	-	-	-
TPI.05	Dompak Island (UMRAH)	6	Mud	-	-	-	-
TPI.06	Dompak Island (Tugu Kepri)	4	Mud	7.52	32.2	30	7.869
TPI.07	Dompak River Estuary	7	Mud	-	-	-	-
TPI.08	Hulu Sungai Ular	8	Silty sand	7.61	29.1	21	7.869
TPI.09	Downstream of Ular River	7	Mud	-	-	-	-
TPI.10	Hulu Sei Timun	9	Gravelly mud	7.52	30.3	31	-
TPI.11	Downstream Sei Timun	6	Mud	8.12	29.2	30	8.852
TPI.12	Hulu Sei Ladi	9	Mud	7.42	29.0	28	-
TPI.13	Downstream Sei Ladi	7	Mud	7.46	28.2	23	10.820
TPI.14	Hulu Sei Carang	6	Mud	7.82	30.5	27	-
TPI.15	Downstream Sei Carang	5	Sandy mud	7.72	31.8	30	6.885
TPI.16	Bugis Village	4	Mud	8.10	29.1	32	9.836
TPI.17	Hulu Sei Jang	4	Mud	8.15	31	10	-
TPI.18	Sei Jang Bridge	9	Mud	7.94	31	25	5.902
TPI.19	Downstream Sei Jang	9	Mud	-	-	-	-
TPI.20	Blongkeng Bridge	9	Sandy mud	7.93	30.4	8	6.885
TPI.21	Hulu Sungai Simpang Kiri	6	Mud	7.83	31.5	8	-
TPI.22	Simpang Kiri River Bridge	8	Mud	6.74	31.5	18	5.902
TPI.23	Bridge 1 Dompak	11	Silty sand	-	-	-	-
TPI.24	Bridge 3 Dompak	10	Gravelly mud	7.14	31.4	20	1.967
TPI.25	Hulu Sei Bladeng	5	Mud	-	-	-	-
TPI.26	Downstream Sei Bladeng	7	Mud	7.90	30.5	9	7.869
TPI.27	Kelam Pagi	11	Sandy mud	7.87	31.3	24	10.820
TPI.28	Sei Jari	7	Mud	7.39	31.1	25	9.836
TPI.29	Hulu Sungao Simpang Kanan	6	Sandy mud	7.93	30	2	-

Mangrove growth is influenced by various substrates such as mud (silt), fine sand, and medium sand, which play an important role in supporting various mangrove tree species (Lewerissa et al 2018; Tuhumury & Louhenapessy 2023). Substrate characteristics, including color and particle size, can affect the growth and survival of mangrove seedlings, with yellow latosols identified as effective substrates for seedling production (Costa et al 2016). Substrate characteristics in the study area vary, generally consisting of mud, silty sand, sandy mud, gravelly sand. Most of the substrate present in the study area is muddy in 20 sites. Silty sand is in 3 sites, sandy mud is in 3 sites, gravelly mud is in 2 sites. However, in general, the characteristics of the substrate in Tanjungpinang City are suitable for mangrove growth. According to Bengen et al (2023), *Rhizophora* spp. can grow well on muddy substrates, and can tolerate sandy mud substrates

The pH in the aquatic environment is an important factor associated with the composition of various mangrove species. Analysis of the pH data obtained from the study sites showed a pH range between 6.7 and 8.2. The outcomes indicate that the water conditions at the study site are within the range suitable for the growth of mangrove vegetation and other aquatic organisms. The appropriate pH content for mangrove growth usually ranges from 6.5-8.5 (Azizah et al 2021).

Salinity is dynamic, can vary and can change depending on influencing factors, such as evaporation rates, rainfall, freshwater mixing rates, ocean currents, mineral content, and tides. Salinity in the waters of Bintan Island, including Tanjungpinang, ranges from 30 to 34‰, while around the estuary has a relatively lower value, from 24 to 28‰ (Azizah 2017). Likewise, based on BMKG data, the waters of Tanjungpinang City have a salinity range of 31-32‰. The average water temperature is 31°C. Based on the data obtained at the observation locations, the salinity of seawater in the study area varies. Salinities with a value between 20-30‰ can be found in Sei Ular, Sei Ladi, Sei Timun (downstream), Sei Carang, Sei Jang, Sei Jari, Dompak Island, Bridge 1 Dompak, Bridge 3 Dompak, and Kelam Pagi. Salinities with values between 30-37‰ are located in Senggarang Besar, Sei Timur (upstream), Kampung Bugis, and Kampung Bulang. Salinities with a value of less than 9‰ can be found in in Simpang Kiri (upstream), Sei Bladeng, Blongkeng Bridge, and Simpang Kanan River.

The speed of ocean currents in the waters of Tanjungpinang City varies depending on tidal conditions and on the specific location. Research in the coastal waters of Tanjungpinang City shows that current speeds range from 0.02 to 0.26 m s^{-1}, with directions from east to southwest and west, although some currents move northwest and north (Lestari 2020). Current speed can affect mangrove growth, especially when mangroves are still in seedling form during the rehabilitation process, inhibiting the growth of young mangroves. Therefore, during mangrove rehabilitation, it is necessary to have planting techniques according to the current conditions. Based on BMKG data obtained in May 2024, the current speed in Tanjungpinang waters ranged from 0 to 10 cm s^{-1} or <0.1 m s^{-1}. This indicates that the current speed is low, being tolerable by mangrove growth in Tanjungpinang waters. The tidal pattern in Tanjungpinang shows variations throughout the year, influenced by factors such as the rainy season and the El Niño Southern Oscillation (ENSO) phenomenon (Ramadani et al 2022). In Tanjungpinang City, the type of tides observed are mixed tides, prevailing semi-diurnal, with two high and two low tides daily (Suhana et al 2023). Figure 9 shows the tides in Tanjungpinang waters that occur for 12 hours a day. On June 15, 2024, the highest tide was at 18:00 pm with a sea level of 1.74 m and the lowest ebb occurred at 10:39 pm with a sea level of 0.66 m.

Land suitability for mangrove growth. The success of mangrove planting in rehabilitation efforts is determined by an understanding of the characteristics of mangrove growth and distribution, as well as the support of physical conditions. Guidelines for mangrove planting in an area can describe whether the location used is suitable for mangrove rehabilitation or not. Based on the results of field observations, the level of land suitability for rehabilitation in the research location is included in the category of 'very suitable' and 'suitable'. Figure 10 presents a map of land suitability for mangrove rehabilitation based on the level of saturation obtained from observations in the field. Table 9 shows the results of the analysis of land suitability for mangrove rehabilitation at the observation site.

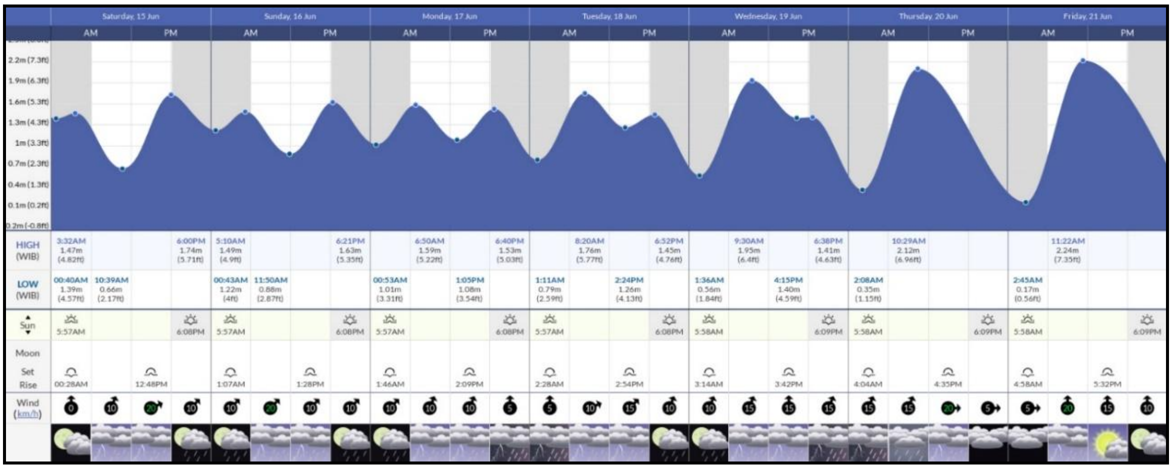

Figure 9. Semidiurnal tidal type in Tanjungpinang City (source: https://www.tide-forecast.com/system/charts-png/Tanjungpinang/tides.png).

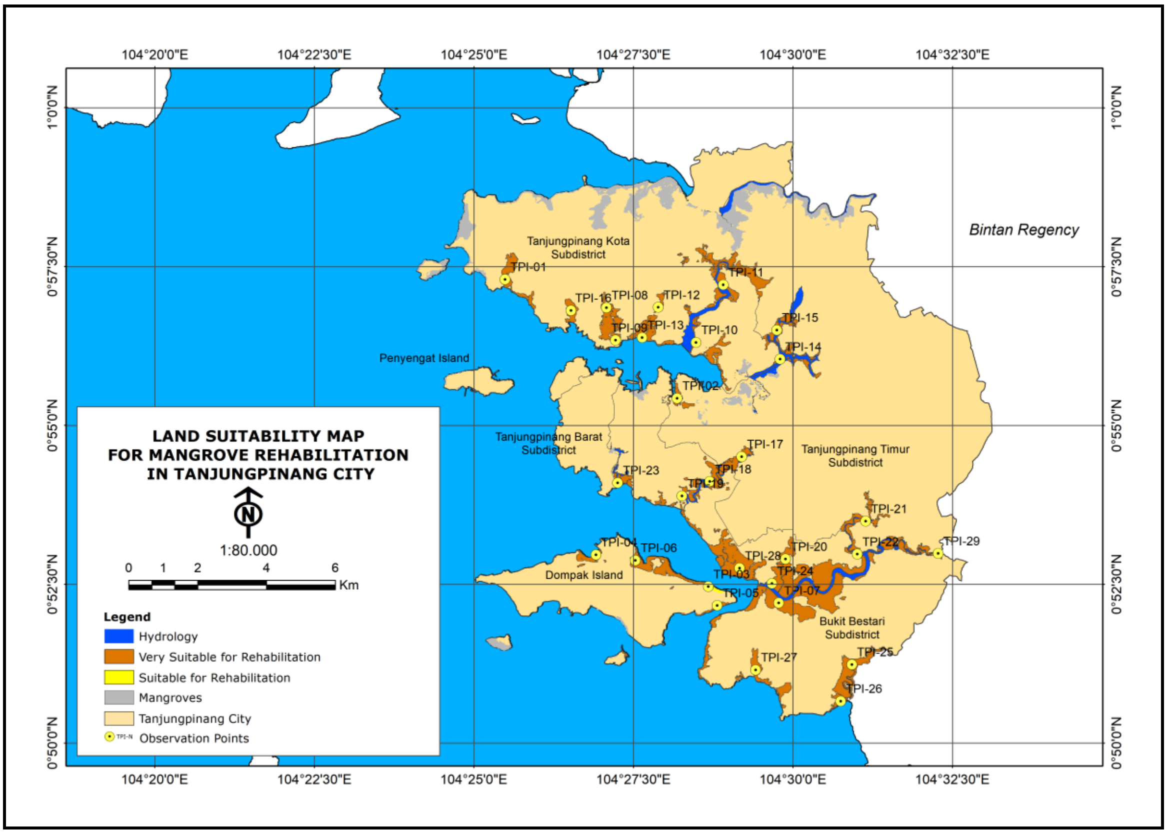

Figure 10. Land suitability map for mangrove rehabilitation.

Table 9

Land suitability for mangrove rehabilitation in Tanjungpinang

Location code	*Mangroves (number of species)*	*Substrate*	*Tidal type*	*pH*	*Sea current ($m\ s^{-1}$)*	*Salinity (‰)*	*Temp (°C)*	*Value (%)*	*Category*
TPI.01	14	PL	SD	7.37	<0.3	32	28.6	83.2	Very suitable
TPI.02	7	L	SD	7.94	<0.3	32	31.9	88.5	Very suitable
TPI.03	4	L	SD	8.03	<0.3	24	31	75.5	As per
TPI.04	5	L	SD	-	-	-	-	-	-
TPI.05	6	L	SD	-	-	-	-	-	-
TPI.06	4	L	SD	7.52	<0.3	30	32.2	84.2	Very suitable
TPI.07	7	L	SD	-	-	-	-	-	-
TPI.08	8	PL	SD	7.61	<0.3	21	29.1	85.2	Very suitable
TPI.09	7	L	SD	-	-	-	-	-	-
TPI.10	9	LK	SD	7.52	<0.3	31	30.3	78.0	Very suitable
TPI.11	6	L	SD	8.12	<0.3	30	29.2	87.0	Very suitable
TPI.12	9	L	SD	7.42	<0.3	28	29.0	90.5	Very suitable
TPI.13	7	L	SD	7.46	<0.3	23	28.2	90.5	Very suitable
TPI.14	6	L	SD	7.82	<0.3	27	30.5	90.5	Very suitable
TPI.15	5	LP	SD	7.72	<0.3	30	31.8	84.2	Very suitable
TPI.16	4	L	SD	8.10	<0.3	32	29.1	78.2	Very suitable
TPI.17	4	L	SD	8.15	<0.3	10	31.0	82.2	Very suitable
TPI.18	9	L	SD	7.94	<0.3	25	31.0	90.5	Very suitable
TPI.19	9	L	SD	-	-	-	-	-	-
TPI.20	9	LP	SD	7.93	<0.3	8	30.4	87.5	Very suitable
TPI.21	6	L	SD	7.83	<0.3	8	31.5	87.5	Very suitable
TPI.22	8	L	SD	6.74	<0.3	18	31.5	89.5	Very suitable
TPI.23	11	PL	SD	-	-	-	-	-	-
TPI.24	10	LK	SD	7.14	<0.3	20	31.4	79.0	Very suitable
TPI.25	5	L	SD	-	-	-	-	-	-
TPI.26	7	L	SD	7.90	<0.3	9	30.5	87.5	Very suitable
TPI.27	11	LP	SD	7.87	<0.3	24	31.3	90.5	Very suitable
TPI.28	7	L	SD	7.39	<0.3	25	31.1	90.5	Very suitable
TPI.29	6	LP	SD	7.93	<0.3	2	30.0	87.5	Very suitable

Note: L – mud; LP – sandy mud; PL – silty sand; LK – gravelly mud; SD – semi diurnal tide; TPI.n – observation point number.

Conclusions. There have been fluctuations in mangrove land cover in Tanjungpinang City from 2007 to 2023. From 2007 to 2015, the rate of mangrove loss decreased, at 65.92 ha $year^{-1}$, while from 2015 to 2023, there was an increase in mangrove cover at a rate of 25.49 ha $year^{-1}$. However, overall, there was a decrease in mangrove cover area over the entire period from 2007 to 2023, with a rate of change amounting to 20.21 ha $year^{-1}$. Based on the analysis of mangrove vegetation in Tanjungpinang, a diverse array of mangrove species was identified, totaling 16 true mangrove types across the study area. The assessment of land suitability for mangrove rehabilitation indicates that the majority of the area is highly suitable for mangrove planting. The level of land suitability for mangrove rehabilitation at the observation location has a very suitable (S1) and suitable (S2) category. The location that has a suitable category is in one location, namely at Dompak Island (Bridge 2), with a suitability value of 75.5%. Other locations have a very suitable category with a suitability interval value between 78.2-90.5%. Nevertheless, successful mangrove rehabilitation requires tailored strategies that consider the appropriate species and local characteristics of each rehabilitation site to ensure sustainable mangrove growth.

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