PROS SEM NAS MASY BIODIV INDON
Volume 10, Nomor 1, Juni 2024 ISSN: 2407-8050
Halaman: 54-60 DOI: 10.13057/psnmbi/m100107

Mangrove cover change between 2003 and 2023 on the east coast of South Sumatera Province, Indonesia

Perubahan tutupan mangrove antara tahun 2003 dan 2023 di pesisir timur Provinsi Sumatera Selatan, Indonesia

NILAM SARIRAMADHANI KOESDARYANTO[1], MUTIARA WIJAYANTI[1], MARIO PINTOR DAVID SIMANJUNTAK[1], MUHAMMAD FAQIH MUHAIMIN FATHONI[1], MUHAMMAD FIRDAUS WIRAATMAJA[1], AHMAD DWI SETYAWAN[1,2,♥]

[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com

[2]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

Manuskrip diterima: 18 November 2023. Revisi disetujui: 5 April 2024.

Abstrak. *Koesdaryanto NS, Wijayanti M, Simanjuntak MPD, Fathoni MFM, Wiraatmaja MF, Setyawan AD. 2024. Perubahan tutupan mangrove antara tahun 2003 dan 2023 di pesisir timur Provinsi Sumatera Selatan, Indonesia. Pros Sem Nas Masy Biodiv Indon 10: 54-60.* Mangrove di pesisir timur Provinsi Sumatera Selatan menyediakan berbagai jasa lingkungan baik untuk umat manusia maupun hewan-hewan. Oleh karena itu, berbagai upaya diperlukan untuk memantau keberadaan mangrove untuk memastikan keberlanjutannya. Citra satelit, seperti Landsat, telah banyak digunakan untuk pemantauan keberadaan mangrove. Studi ini bertujuan untuk menentukan perubahan area mangrove pada area daratan secara temporal antara tahun 2003 hingga 2023. Perubahan yang terjadi pada mangrove dianalisis berdasarkan citra satelit Landsat 7, 8, dan 9. Citra satelit dilakukan klasifikasi menggunakan metode *maximum likelihood* menjadi tiga kelas, yaitu mangrove, tambak, dan badan air. Hasil analisis perubahan tutupan mangrove di pesisir timur Sumatera Selatan menyebutkan bahwa area mangrove pada tahun 2003, 2013, dan 2023 masing-masing adalah 115.072, 118.674, dan 97.332 ha. Area mangrove meningkat sebanyak 3,601.47 ha (+3.13%) pada periode 2003-2013 dan menurun sebanyak 21,342 ha (-17.98%) pada periode 2013-2023. Kebutuhan ekonomi masyarakat menjadi penyebab turunnya area mangrove karena diubah menjadi tambak. Konservasi dan rehabilitasi mangrove harus tetap dilakukan untuk menjaga manfaat-manfaat yang disediakannya.

Kata kunci: Deforestasi, Landsat, mangrove, *maximum likelihood*, Sumatera Selatan

Abstract. *Koesdaryanto NS, Wijayanti M, Simanjuntak MPD, Fathoni MFM, Wiraatmaja MF, Setyawan AD. 2024. Mangrove cover change between 2003 and 2023 on the east coast of South Sumatera Province, Indonesia. Pros Sem Nas Masy Biodiv Indon 10: 54-60.* Mangroves on South Sumatra, Indonesia's east coast, provide various environmental services for humans and animals. Therefore, efforts are needed to monitor the extent of mangroves to ensure their sustainability. Satellite imagery, such as Landsat, has been commonly used to monitor mangrove extent. This study aims to temporarily determine changes in mangrove land area between 2003 and 2023. Changes in mangrove land area were analyzed based on Landsat 7, 8, and 9 satellite image data. The satellite images were classified by supervised classification using the maximum likelihood method in three land classes mangroves, ponds, and water bodies. The results of mangrove cover analysis on the east coast of South Sumatra found that the area of mangroves in 2003, 2013, and 2023 reached 115,072, 118,674, and 97,332 ha. The mangrove area increased by 3,601.47 ha (+3.13%) in 2003-2013 and decreased by 21,342 ha (-17.98%) in 2013-2023. The community's economic needs cause a decrease in the mangrove areas, which are converted into ponds. Mangrove conservation and rehabilitation must continue to be carried out to maintain its environmental benefits.

Keywords: Deforestation, Landsat, mangrove, maximum likelihood, South Sumatra

INTRODUCTION

Mangroves are considered a high-priority crop within ecosystems in tropical and subtropical regions and extending into temperate zones (Friess et al. 2019). Mangrove ecosystems provide a diversity of high-value ecosystem services for the community, especially from food and biomass supply services, maintenance of biodiversity services, carbon dioxide capture and storage, coastal erosion prevention, and others (Villanueva et al. 2023). Mangrove ecosystems protection against storms and tsunamis (Sattayapanich et al. 2022). Mangrove forests provide food for aquatic biota, creating a climate that sustains and helps balance the water's biological cycle (Whitfield 2017). The root types of some mangrove species, such as *Avicennia* sp., *Rhizophora* sp., and *Sonneratia* sp., provide shelter for larval marine life (Yuliana et al. 2023).

Indonesia, a country dominated by the ocean, has abundant natural resources on its coasts. Natural resources on the coast of Indonesia such as seaweed, seagrass beds, coral reefs, and mangrove forests (Kawaroe et al. 2016;

Baderan et al. 2019; Risjani et al. 2021; Langford et al. 2022). Indonesia has mangrove forests with a total of 22.6% of the total mangrove forests in the world and is the country that has the largest mangrove forests, reaching around 3.2 million ha (Ilman et al. 2016). Mangrove forests in Indonesia are almost spread throughout the island's coast, one of which is on Sumatra Island (Firdaus et al. 2022). The island of Sumatra has a mangrove protection area, namely Sembilang National Park with a mangrove cover area of 88,555 ha (Febrianto et al. 2022). Langkat Regency, North Sumatra Province has 77.11 ha of mangrove cover, while in South Coast Regency, West Sumatra Province has 333 ha of mangrove cover (Meron and Triyatno 2022; Ginting et al. 2023). However, the area of mangrove forests continues to decrease rapidly due to the high level of human activity in coastal areas and the conversion of mangrove land for other purposes (Sobhani and Danehkar 2023). According to Hanggara et al. (2021), the distribution of mangrove forests in Sumatra gradually changes due to various activities that can reduce mangrove areas. As in South Sumatra, the total mangrove area in this province reaches 158,734 ha (Septinar et al. 2023). This area is spread in several areas, such as Banyuasin, Ogan Komering Ilir, and Musi Banyuasin District. Based on data from the South Sumatra Forestry Service, around 20 percent or 31,746 ha of mangrove forests are in critical condition, so the government must make many efforts and awareness from the local community (Come et al. 2023). The decrease in mangrove forest conditions was caused by encroachment for pond opening, wood harvesting, and oil palm plantation (Basyuni and Sulistiyono 2018).

Mangrove monitoring efforts are important to be carried out as a form of ecological approach in determining the condition of mangrove ecosystem health and to minimize the decline of mangrove ecosystem land that is converted into ponds and tourism to meet the economic needs of the area (Schmitt and Duke 2015). Efficient mangrove monitoring efforts can be done by remote sensing to provide data spatially and temporally accurately using satellite data (Paramasivam and Venkatramanan 2019). Satellite data used to monitor mangrove changes sourced from websites such as USGS (United States Geological Survey), MODIS (Moderate Resolution Imaging Spectroradiometer), AVHRR (Advanced Very High-Resolution Radiometer) (Cárdenas et al. 2017; Xiao et al. 2020). Remote sensing has been commonly used to monitor land conversion in various places, so that it can be relied upon for this study (Franch-Pardo et al. 2020). Therefore, the study aims to determine changes in mangrove cover on the east coast of South Sumatra based on remote sensing. The hope of this research is not only useful for researchers but also readers, so that later solutions can be found from the reduction of mangrove land due to human activities.

MATERIALS AND METHODS

Study area

This study area covers mangrove forests located on the east coast of South Sumatra, Indonesia, in 2003-2023, with special attention to mangrove dynamics in the area around Banyuasin, Musi Banyuasin, and Ogan Komering Ilir District (Figure 1). The coast of South Sumatra is a dense mangrove area, but more and more are being converted into ponds until now. But when monitored through satellite images, between 2003, 2013, and 2023, there have been significant changes in mangrove areas, so monitoring is important. Climate in South Sumatra Province is classified as wet (Q = 32%) according to Schmidt Fergusson’s classification (Wijayanti et al. 2020). According to Central Statistics Agency (BPS: Badan Pusat Statistik) of Sout Sumatra (2024), In 2023 the lowest temperature in South Sumatra is 22.40°C, and the highest temperature can reach 37.40°C, annual rainfall in this province is 2,218.9 mm/year, with a relative rainy period between October to November, indicating that most mangrove forests on the south coast of Sumatra are dominated by *Sonneratia alba*. This site selection was based on considering the density of mangrove forests in coastal areas of South Sumatra that have changed land use due to human activities.

Materials

The material used in this study was Landsat satellite imagery obtained from the USGS. Landsat satellite imagery has a fairly good spatial resolution of 30 × 30 m, suitable for land change analysis. Landsat is obtained from the website of an open-source satellite-imagery data provider, earthexplorer.usgs.gov. The data used are images in 2003 using Landsat 7, in 2013 using Landsat 8, and in 2023 using Landsat 9; QGIS, ArcMap 10.8, and Google Earth are used to process data from USGS. In making this map, QGIS can create and manage stacking layers and compile map data (Alcaras et al. 2021). ArcMap 10.8 is used to classify and analyze satellite imagery (Lü et al. 2019). Google Earth was used to test the accuracy of land use classification in the area studied (Liang et al. 2018).

Land cover classification procedures

Land cover classification is carried out by taking image data of South Sumatra Province on the USGS (United States Geological Survey) website. Selecting the coordinates in the South Sumatra region and then selecting the specified time range only to collect data in the South Sumatra area. Then, in the datasets menu, determine the land cover and Landsat that will be used; after that, several files appear that can be selected for download. Next, image preprocessing is performed with atmospheric correction to correct distortions by QGIS. Atmospheric correction is carried out to eliminate the atmosphere's influence on remote sensing data recorded by the sensor (Lin et al. 2015). Composite bands are then performed to combine the image bands and then calculate the reflectance using the calibration coefficient. Image classification is done using ArcGIS to separate objects in the image; determination of ROI (Region of Interest) by selecting areas representing each class. Then, training and classification are carried out using the specified ROI to train the classification model. The model is applied to the entire image to produce a classification map. The classification method uses maximum likelihood Classification, which quantitatively evaluates the variance and correlation of spectral response patterns when classifying unknown pixels (Saqui et al. 2016). Land classification is carried out by distinguishing land cover into mangrove, water bodies, and pond. Ponds are not included in the water body because it is to differentiate the classification results from the sea. After that, an accuracy test was carried out using the kappa coefficient (Figure 2).

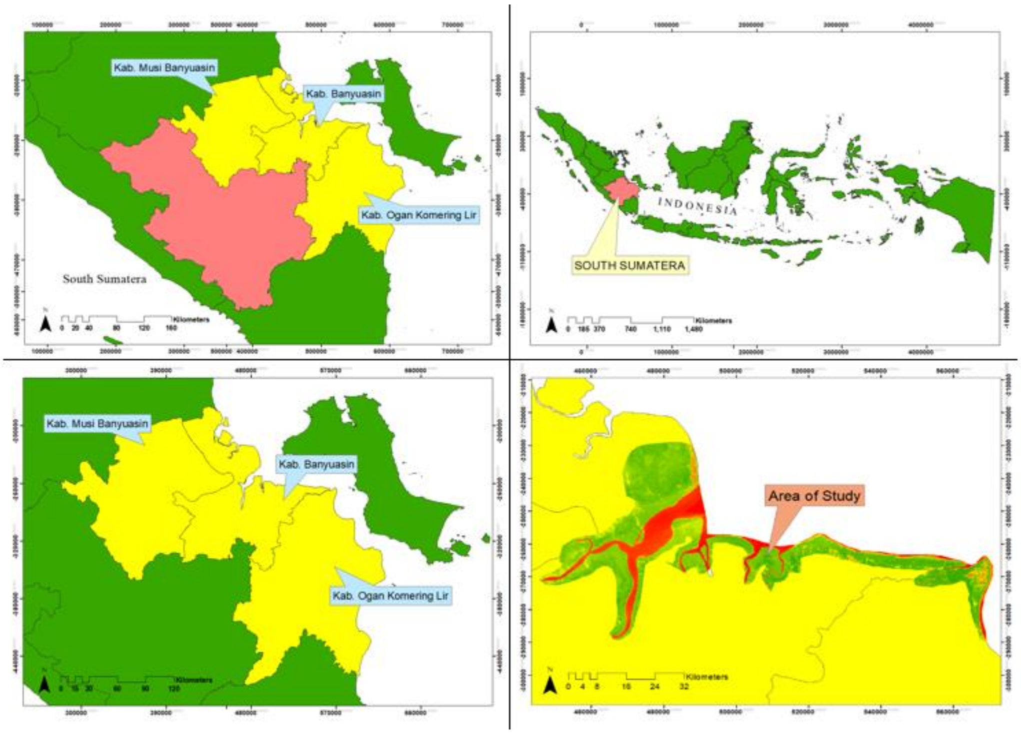

Figure 1. Map of the research location of mangrove area change on the east coast of South Sumatra Province, Indonesia

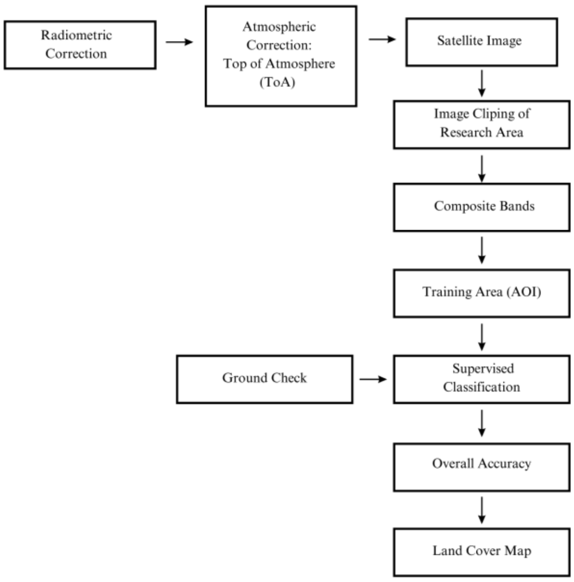

Figure 2. Land cover classification is to process flowchart

Table 1. Kappa interpretation (Parlika et al. 2022).

Kappa coefficient	Accuracy
< 0.20	Very Inaccurate
0.21 - 0.40	Inaccurate
0.41 - 0.60	Moderate
0.61 - 0.80	Accurate
0.81 - 1.00	Very Accurate

Land cover classification accuracy test

The Kappa accuracy test spots errors in classified areas (Conger 2017); this test determines the mapping accuracy. This test has interpretations classified in Table 1. If the kappa coefficient is below 0.20, it can be said to be very inaccurate; if it is 0.21-0.40, it can be said to be less accurate; if it is 0.41-0.60, it can be said to be moderate; if it is 0.61-0.80, it can be said to be accurate; and if it is at 0.81-1 then it can be said to be very accurate, this accuracy is done by creating a confusion matrix (Rwanga and Ndambuki 2017).

RESULTS AND DISCUSSION

Land cover accuracy test result

The results of testing the accuracy of image classification in 2003 using Landsat 7, having a coefficient value of 0.80, image classification testing in 2013 using Landsat 8, having a coefficient value of 0.79, and image classification testing in 2023 using Landsat 9, having a coefficient value of 0.82 (Table 2). It can be known that the satellite images used in mapping to meet the requirements because they have a good accuracy value so that they can be used for mapping activities and purposes (Thiagarajan et al. 2021).

Land cover change in South Sumatra

Table 3 shows that the total land use, including mangrove areas, water bodies, and ponds, in 2003 reached 170,457.75 ha, with land use for mangrove areas covering 115,072.29 ha, water bodies covering 33,715.71 ha, and ponds covering 21,669.75 ha. The total land use area in 2013 was 170,441.65 ha, including 118,673.76 ha of mangrove area, 35,304.94 ha of water body area, and 16,462.95 ha of pond area. In 2023, the total land use area reached 170,457.75 ha, with land use for the mangrove area of 97,332.03 ha, water body area of 39,720.69 ha, and pond area of 33,405.03 ha. Land use in 2003-2023 can be seen through the map presented in Figure 3.

In the period 2003-2013, there was an increase in the mangrove area of 3,601.47 ha (3.13%) and water body area of 1,589.23 ha (4.71%), while the pond area decreased by 5,206.8 ha (24.03%). In 2013-2023, the water body area increased by 4,415.75 ha (12.51%), followed by ponds which also increased by 16,942.08 ha (102.91%). In contrast, land use in mangrove areas decreased by 21,341.73 ha (17.98%) (Table 4).

Table 2. Kappa accuracy test results

Kappa coefficient		
2003	**2013**	**2023**
0.80	0.79	0.82

Table 3. The land cover area on the East Coast of South Sumatra between 2003-2023

Land uses classes	Area (ha)		
	2003	**2013**	**2023**
Mangrove	115,072.29	118,673.76	97,332.03
Water Body	33,715.71	35,304.94	39,720.69
Pond	21,669.75	16,462.95	33,405,03
Total	170,457.75	170,441.65	170,457.75

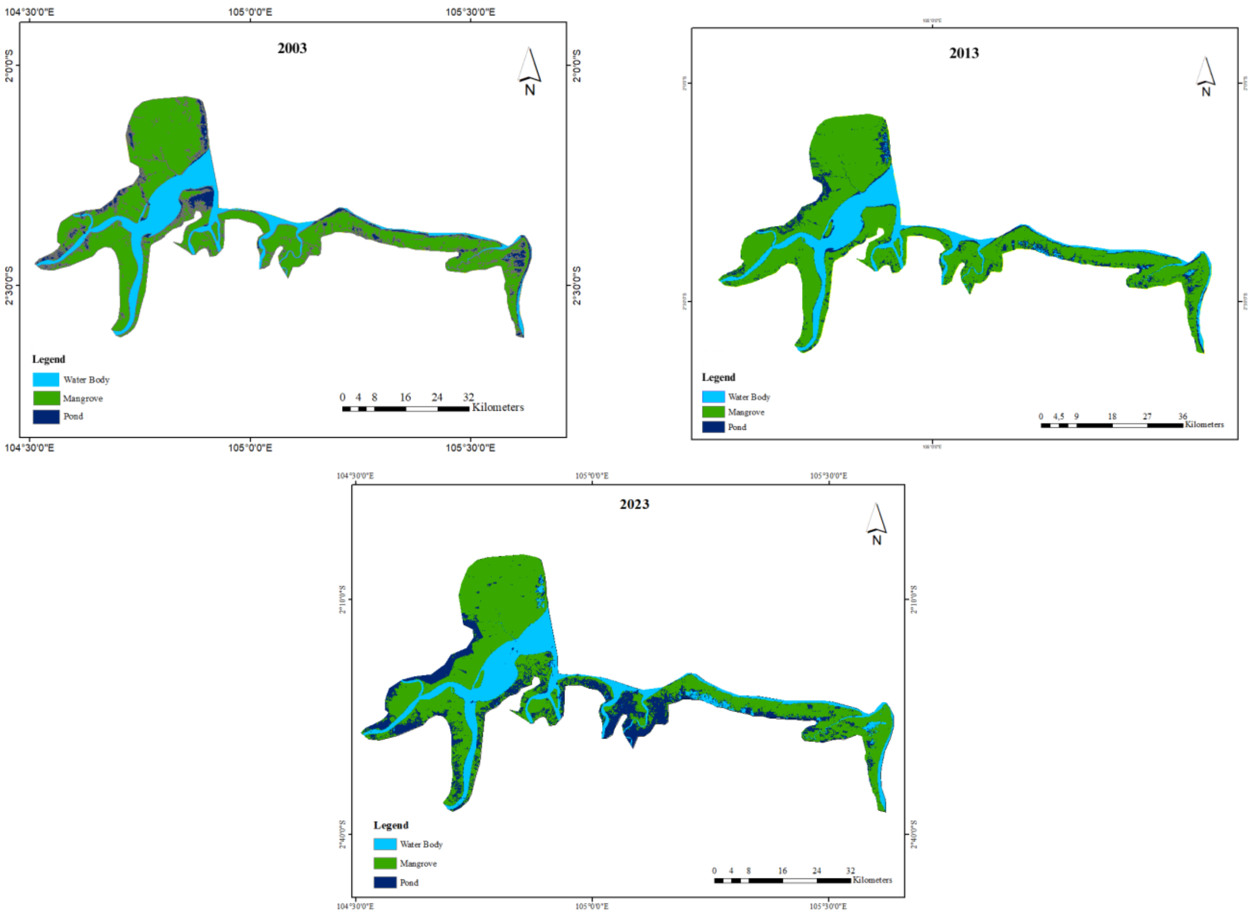

Figure 3. Land cover maps in 2003, 2013, and 2023 on the East Coast of South Sumatra

Table 4. Changes in land cover between 2003-2023

Land Use	Change (ha) (2003-2013)	Change (ha) (2013-2023)
Mangrove	3,601.47 (3.13%)	-21,341.73 (-17.98%)
Water Body	1,589.23 (4.71%)	4,415.75 (12.51%)
Pond	-5,206.8 (-24.03%)	16,942.08 (102.91%)

Note: (-) indicates a decrease in land use area change in South Sumatra between 2003 and 2023

Discussion

Changes in land use are caused by several factors, including population growth, which causes an increase in the need for certain types of land, and the change of professions due to shifts in economic structure and government policies so that the impact of land conversion occurs (Kirui et al. 2013). Changes in land use can result in increasing the area of land use from one or several categories accompanied by a decrease in the area of other categories in a certain period. This shows that changes in land use in an area can impact environmental balance (Sasmito et al. 2019).

Land use conditions in South Sumatra in 2003 was dominated by mangrove areas followed by water bodies, while the least land use was in pond areas. Similar to 2003, in 2013, land use is still dominated by mangrove areas then dominated by water bodies, for pond areas are also still little used when compared to both land use. For 2023, mangrove areas still dominate land use, while only a few pond areas occupy land in South Sumatra when compared to land use for mangrove areas and water bodies. This dominating mangrove condition occurs when the land cover on mangroves is higher than the ponds can be caused by a lack of attention from pond managers, so the pond area is smaller (Ahmed et al. 2023).

Land use changed in South Sumatra in 2003-2013, and visible land use changes were mangrove areas, which experienced an increase of 3.601,47 ha from the original area of 115,072.29 ha to 118,673.76 ha. Land use change in water body areas also showed an increase of 1,589.23 ha from the original in 2003 of 33,715.71 ha to 35,304.94 ha in 2013. Meanwhile, the pond area decreased by 5,206.8 ha from 21,669.75 ha to 16,462.95 ha. This follows research conducted by Valderrama et al. (2014) that there is an increase in land use in mangrove and water bodies, and land use is reduced in pond areas.

In 2013-2023, the water body area experienced an increase of 4,415.75 ha or 12.51% from the initial area of 35,304.94 ha in 2013, rising to 39,720.69 ha in 2023. Mangrove forests have been exploited for various forms of land use, including the construction of embankments (Ibharim et al. 2015). That embankment development is crucial because if the coastal embankment is damaged, seawater will enter the land to expand the water body (Dissanayaka et al. 2022). The water pond area also increase by 16,942.08 ha from the original area of 16,462.95 ha to 33,405.03. The pond areas have increased due to farmers opening aquaculture land on a large scale and converting the mangrove areas, which were supported by the increasing electrical power supply in the community and the presence of the fishery center (Tuholske et al. 2017). The conversion of mangrove land into ponds is based on the economic benefits opportunity, such as shrimp production and high income generated from another pond cultivated. The high demand for fish and shrimp has caused the expansion of pond areas to penetrate mangrove forests (Ahmed et al. 2023); therefore, land use in mangrove areas experienced an area reduction of 21,341.73 ha. Moreover, Gilani et al. (2021) revealed if pond activities cause an increase in land use, on the contrary mangrove conservation will experience a decrease in land use. The decrease in mangrove area due to land use as a pond area also reduces mangrove litter production as an ecological function that supports captured fisheries (Thomas et al. 2017).

The determining factor of mangrove's coverage change

The decrease in the mangrove area can be caused by natural factors such as coastal abrasion (Febrianto et al. 2022). The coastal abrasion is probably triggered by the reduction of mangrove forests in the areas; the reduction in mangrove forest area will later affect local communities on several factors, including ecological, social, economic, and cultural heritage (Mungai et al. 2019). Various factors can cause a decrease in mangrove density, one of which is human activities such as converting mangrove land into pond activities (Sunkur et al. 2023). The high activity of ponds for cultivation makes the pond area expand. The monitoring results on the image classification of land change in 2013 to 2023 show that mangrove ecosystems are reduced by -17.98% due to fisheries activities, as evidenced by the increase in pond land area reaching 102.91%. Water bodies that experienced an increase of 12.51% due to the number of brackish water ponds that increase yearly helped support the fisheries sector, especially fish farming of various types. So that not all additional water bodies are in mangrove land areas. Fish is the main commodity of various types, including snapper, milkfish, tiger shrimp, king shrimp, crab, and seaweed (De Alban et al. 2020). In addition to meeting local and regional market demand, fisheries production growth was triggered by export transactions, especially to the United States, Japan, and China.

Conservation efforts

Conservation efforts based on the determinants of mangrove area dynamics can be carried out by maintaining the condition of mangrove ecosystems and the diversity of flora and fauna. It can also be done by rehabilitating mangrove forests for conservation efforts involving the surrounding community, the government, and related non-government institutions (Sidik et al. 2018). Mangrove forest rehabilitation to restore or improve the quality of mangrove forests that have been damaged and maintain them (Romañach et al. 2018). The monitoring of mangrove land use changes from 2003, 2013, until 2023 on the east coast of South Sumatra, Indonesia, revealing land conservation efforts can be carried out by transferring land use changes to be more effective. There are many ways to use mangroves sustainably, including intercropping ponds, namely by combining ponds with mangrove planting on community forests, sustainable management with a logging cycle of 15-30 years, or depending on the purpose, and the cultural change on utilizing mangroves to obtain forest products other than wood (Thomas et al. 2018). Therefore, conservation is one of the efforts to protect the area on its flora and fauna, and everything to maintain the balance of nature.

Based on the results of research on the dynamics of mangrove changes in South Sumatra from 2003 to 2023, it can be concluded that there are changes in land cover and conversion of mangrove forests into pond areas. In Banyuasin, Ogan Komering Ilir, and Musi Banyuasin regencies, South Sumatra, there was an increase in mangrove forest land, reaching 3.13% in 2003-2013, but in 2013-2023, there was are reduction of -17.98%. This result is comparable to the pond area in 2003 - 2013, namely the reduction in pond land at -24.03, and in 2013-2023 found a very significant increase in pond land area, reaching 102.91%. With the increasing reduction of mangrove forest land on the coast of South Sumatra, efforts are needed to reduce the high rate of land reduction. Efforts can be made to rehabilitate mangrove forests as a form of conservation by involving the surrounding community, the government, and related non-government institutions.

ACKNOWLEDGEMENTS

Acknowledgments were given to the USGS as a satellite imagery provider as material for this study.

REFERENCES

Ahmed MU, Alam MI, Debnath S, Debrot AO, Rahman MM, Ahsan MN, Verdegem MCJ. 2023. The impact of mangroves in small-holder shrimp ponds in south-west Bangladesh on productivity and economic and environmental resilience. Aquaculture 571: 739464. DOI: 10.1016/j.aquaculture.2023.739464.

Alcaras E, Parente C, Vallario A. 2021. Automation of pan-sharpening methods for pléiades images using GIS basic functions. Remote Sens 13 (8): 1550. DOI: 10.3390/rs13081550.

Badan Pusat Statistik Sumatra Selatan. 2024. Curah Hujan (mm), 2023. Badan Pusat Statistik. https://sumsel.bps.go.id/id/statistics-table/2/MjIwIzI=/curah-hujan.html.

Badan Pusat Statistik Sumatra Selatan. 2024. Suhu Udara (Derajat Celcius), 2023. Badan Pusat Statistik. https://sumsel.bps.go.id/id/statistics-table/2/MjA0IzI=/suhu-udara--derajat-celcius-.html.

Baderan DWK, Hamidun MS, Utina R, Rahim S. 2019. The abundance and diversity of Mollusks in mangrove ecosystem at coastal area of North Sulawesi, Indonesia. Biodiversitas 20 (4): 987-993. DOI: 10.13057/biodiv/d200408.

Basyuni M, Sulistiyono N. 2018. Deforestation and reforestation analysis from land-use changes in North Sumatran Mangroves, 1990-2015. IOP Conf Ser: Mater Sci Eng 309 (1): 012018. DOI: 10.1088/1757-899X/309/1/012018.

Cárdenas NY, Joyce KE, Maier SW. 2017. Monitoring mangrove forests: Are we taking full advantage of technology. Intl J Appl Earth Observ Geoinf 63: 1-14. DOI : 10.1016/j.jag.2017.07.004.

Chang CW, Mori N. 2021. Green infrastructure for the reduction of coastal disasters: A review of the protective role of coastal forests against tsunami, storm surge, and wind waves. Coast Eng J 63 (3): 370-385. DOI: 10.1080/21664250.2021.1929742.

Come J, Peer N, Nhamussua JL, Miranda NAF, Macamo CCF, Cabral AS, Madivadua H, Zacarias D, Narciso J, Snow B. 2023. A socio-ecological survey in Inhambane Bay mangrove ecosystems: Biodiversity, livelihoods, and conservation. Ocean Coast Manag 244: 106813. DOI: 10.1016/j.ocecoaman.2023.106813.

Conger AJ. 2017. Kappa and rater accuracy: Paradigms and parameters. Educ Psychol Meas 77 (6): 1019-1047. DOI: 10.1177/0013164416663277.

De Alban JDT, Jamaludin J, Wong de Wen D, Than MM, Webb EL. 2020. Improved estimates of mangrove cover and change reveal catastrophic deforestation in Myanmar. Environ Res Lett 15 (3): 034034. DOI: 10.1088/1748-9326/ab666d.

Dissanayaka KD, Tanaka N, Hasan MK. 2022. Effect of Orientation and Vegetation Over the Embankment Crest for Energy Reduction at Downstream. Geosciences 12 (10): 1-23. DOI: 10.3390/geosciences12100354.

Febrianto S, Syafina HA, Latifah N, Muskananfola MR. 2022. Dinamika perubahan luasan dan kerapatan ekosistem mangrove di Kawasan Taman Nasional Sembilang menggunakan Citra Satelit Landsat 8. Jurnal Kelautan Tropis 25 (3): 369-377. DOI: 10.14710/jkt.v25i3.14909.

Firdaus K, Matin AMA, Nurisman N, Magdalena I. 2022. Numerical study for Sunda Strait Tsunami wave propagation and its mitigation by mangroves in Lampung, Indonesia. Results Eng 16: 100605. DOI: 10.1016/j.rineng.2022.100605.

Franch-Pardo I, Napoletano BM, Rosete-Verges F, Billa L. 2020. Spatial analysis and GIS in the study of COVID-19: A review. Sci Total Environ 739: 140033. DOI: 10.1016/j.scitotenv.2020.140033.

Friess DA, Rogers K, Lovelock CE, Krauss KW, Hamilton SE, Lee SY, Lucas R, Primavera J, Rajkaran A, Shi S. 2019. The State of the World's Mangrove Forests: Past, Present, and Future. Ann Rev Environ Resour 44 (1): 89-115. DOI: 10.1146/annurev-environ-101718-033302.

Gilani H, Naz HI, Arshad M, Nazim K, Akram U, Abrar A, Asif M. 2021. Evaluating mangrove conservation and sustainability through spatiotemporal (1990–2020) mangrove cover change analysis in Pakistan. Estuar Coast Shelf Sci 249: 107128. DOI: 10.1016/j.ecss.2020.107128.

Ginting SD, Rauf A, Rahmawaty. 2023. The Analysis of Land Use Change of Mangrove Ecosystem in Langkat, North Sumatera, Indonesia. J Environ Dev Stud 4 (2): 9-19. DOI: 10.32734/jeds.v4i2.12559.

Hanggara BB, Murdiyarso D, Ginting YR, Widha YL, Panjaitan GY, Lubis AA. 2021. Effects of diverse mangrove management practices on forest structure, carbon dynamics and sedimentation in North Sumatra, Indonesia. Estuar Coast Shelf Sci 259: 107467. DOI: 10.1016/j.ecss.2021.107467.

Ibharim NA, Mustapha MA, Lihan T, Mazlan AG. 2015. Mapping mangrove changes in the Matang Mangrove Forest using multi temporal satellite imageries. Ocean Coast Manag 114: 64-76. DOI: 10.1016/j.ocecoaman.2015.06.005.

Ilman M, Dargusch P, Dart P. 2016. A historical analysis of the drivers of loss and degradation of Indonesia's mangroves. Land Use Policy 54: 448-459. DOI: 10.1016/j.landusepol.2016.03.010.

Kawaroe M, Nugraha AH, Juraij J, Tasabaramo IA. 2016. Seagrass biodiversity at three marine ecoregions of Indonesia: Sunda Shelf, Sulawesi Sea, and Banda Sea. Biodiversitas 17 (2): 585-591. DOI: 10.13057/biodiv/d170228.

Kirui KB, Kairo JG, Bosire J, Viergever KM, Rudra S, Huxham M, Briers RA. 2013. Mapping of mangrove forest land cover change along the Kenya coastline using Landsat imagery. Ocean Coast Manag 83: 19-24. DOI: 10.1016/j.ocecoaman.2011.12.004.

Langford A, Zhang J, Waldron S, Julianto B, Siradjuddin I, Neish I, Nuryartono N. 2022. Price analysis of the Indonesian carrageenan seaweed industry. Aquaculture 550: 737828. DOI: 10.1016/j.aquaculture.2021.737828.

Liang J, Gong J, Li W. 2018. Applications and impacts of Google Earth: A decadal review (2006–2016). ISPRS J Photogrammetry Remote Sens 146: 91-107. DOI: 10.1016/j.isprsjprs.2018.08.019.

Lin C, Wu C C, Tsogt K, Ouyang Y C, Chang C I. 2015. Effects of atmospheric correction and pansharpening on LULC classification accuracy using WorldView-2 imagery. Inf Process Agric 2 (1): 25-36. DOI: 10.1016/j.inpa.2015.01.003.

Lü G, Batty M, Strobl J, Lin H, Zhu AX, Chen M. 2019. Reflections and speculations on the progress in Geographic Information Systems

(GIS): A geographic perspective. Intl J Geogr Inf Sci 33 (2): 346-367. DOI: 10.1080/13658816.2018.1533136.

Meron SQ, Triyatno. 2022. Utilization of Sentinel-2A Imagery for Mapping The Distribution of Mangrove Forests in The Mandeh Area, West Sumatera Province. Intl Remote Sens Appl J 3 (2): 49-54. DOI: 10.24036/irsaj.v3i2.35.

Mungai F, Kairo J, Mironga J, Kirui B, Mangora M, Koedam N. 2019. Mangrove cover and cover change analysis in the transboundary area of Kenya and Tanzania during 1986–2016. J Indian Ocean Reg 15 (2): 157-176. DOI: 10.1080/19480881.2019.1613868.

Paramasivam CR, Venkatramanan S. 2019. An introduction to various spatial analysis techniques. In: Venkatramanan S, Prasanna MV, Chung SY (eds.). GIS and Geostatistical Techniques for Groundwater Science. Elsevier, Amsterdam. DOI: 10.1016/B978-0-12-815413-7.00003-1.

Parlika R, Mahendra RR, Lutfi MRAR, Waritsin RK, Ramadhan HMT. 2022. Uji validitas website pendataan ekstrakurikuler menggunakan metode Correlation Pearson dan Kappa Cohen. Jurnal Ilmiah Ilmu Komputer Fakultas Ilmu Komputer Universitas Al Asyariah Mandar 8 (2): 63-70. DOI: 10.35329/jiik.v8i2.227.

Rwanga SS, Ndambuki JM. 2017. Accuracy assessment of land use/land cover classification using remote sensing and GIS. Intl J Geosci 8 (4): 611. DOI: 10.4236/ijg.2017.84033.

Risjani Y, Witkowski A, Kryk A, Górecka E, Krzywda M, Safitri I, Sapar A, Dąbek P, Arsad S, Gusev E, Rudiyansyah, Peszek L, Wrobel RJ. 2021. Indonesian coral reef habitats reveal exceptionally high species richness and biodiversity of diatom assemblages. Estuar Coast Shelf Sci 261: 107551. DOI: 10.1016/j.ecss.2021.107551.

Romañach SS, DeAngelis DL, Koh HL, Li Y, Teh SY, Barizan RSR, Zhai L. 2018. Conservation and restoration of mangroves: Global status, perspectives, and prognosis. Ocean Coast Manag 154: 72-82. DOI: 10.1016/j.ocecoaman.2018.01.009.

Saqui D, Saito JH, Jorge LADC, Ferreira EJ, Lima DC, Herrera JP. 2016. Methodology for band selection of hyperspectral images using genetic algorithms and gaussian maximum likelihood classifier. Intl Conf Comput Sci Comput Intelligence 2016: 733-738. DOI: 10.1109/CSCI.2016.0143.

Sasmito SD, Taillardat P, Clendenning JN, Cameron C, Friess DA, Murdiyarso D, Hutley LB. 2019. Effect of land-use and land-cover change on mangrove blue carbon: A systematic review. Global Change Biol 25 (12): 4291-4302. DOI: 10.1111/gcb.14774.

Sattayapanich T, Janmaimool P, Chontanawat J. 2022. Factors affecting community participation in environmental corporate social responsibility projects: Evidence from mangrove forest management project. J Open Innov: Technol Market Complex 8 (4): 209. DOI: 10.3390/joitmc8040209.

Schmitt K, Duke NC. 2015. Mangrove management, assessment and monitoring. In: Pancel L, Köhl M (eds.). Tropical Forestry Handbook. Springer Berlin, Heidelberg. DOI: 10.1007/978-3-642-41554-8_126-1.

Sembiring JP. 2016. Analisis perubahan luasan dan kerapatan mangrove di daerah pesisir Delta Upang Kabupaten Banyuasin Provinsi Sumatera Selatan dengan menggunakan citra Landsat. Universitas Sriwijaya, Palembang.

Septinar H, Putri YP, Midia KR, Bianto B. 2023. Upaya pelestarian hutan mangrove melalui pembibitan di Desa Sungsang IV Kabupaten Banyuasin. Environ Sci J 1 (2): 77-88. DOI: 10.31851/esjo.v1i2.11920.

Sidik F, Supriyanto B, Krisnawati H, Muttaqin MZ. 2018. Mangrove conservation for climate change mitigation in Indonesia. WIREs Clim Change 9 (5): e529. DOI: 10.1002/wcc.529.

Sobhani P, Danehkar A. 2023. Spatial-temporal changes in mangrove forests for analyzing habitat integrity: A case of Hara Biosphere Reserve, Iran. Environ Sustain Indic 20: 100293. DOI: 10.1016/j.indic.2023.100293.

Sunkur R, Kantamaneni K, Bokhoree C, Ravan S. 2023. Mangroves' role in supporting ecosystem-based techniques to reduce disaster risk and adapt to climate change: A review. J Sea Res 96: 102449. DOI: 10.1016/j.seares.2023.102449.

Thiagarajan K, Manapakkam Anandan M, Stateczny A, Bidare Divakarachari, P, Kivudujogappa Lingappa H. 2021. Satellite image classification using a hierarchical ensemble learning and correlation coefficient-based gravitational search algorithm. Remote Sens 13 (21): 4351. DOI: 10.3390/rs13214351.

Tuholske C, Tane Z, López-Carr D, Roberts D, Cassels, S. 2017. Thirty years of land use/cover change in the Caribbean: Assessing the relationship between urbanization and mangrove loss in Roatán, Honduras. Appl Geogr 88: 84-93. DOI: 10.1016/j.apgeog.2017.08.018.

Thomas N, Lucas, R, Bunting P, Hardy A, Rosenqvist A, Simard M. 2017. Distribution and drivers of global mangrove forest change, 1996–2010. PloS One 12 (6): e0179302. DOI: 10.1371/journal.pone.0179302.

Thomas N, Bunting P, Lucas R, Hardy A, Rosenqvist A, Fatoyinbo T. 2018. Mapping mangrove extent and change: A globally applicable approach. Remote Sens 10 (9): 1466. DOI: 10.3390/rs10091466.

Vebryanti A, Daud ID, Dungga NE. 2023. Damage Caused by *Spodoptera frugiperda* JE Smith on corn in climate zones in South Sulawesi, Indonesia. IOP Conf Ser: Earth Environ Sci 1255 (1): 012011. DOI: 10.1088/1755-1315/1255/1/012011.

Villanueva AJ, Vernaza-Quiñónez L, Granado-Díaz R. 2023. Disentangling the heterogeneity of mangrove managers' perception of ecosystem services. Ecol Econ 213: 107969. DOI: 10.1016/j.ecolecon.2023.107969.

Valderrama L, Troche C, Rodriguez MT, Marquez D, Vázquez B, Velázquez S, Vázquez A, Cruz MI, Ressl R. 2014. Evaluation of mangrove cover changes in Mexico during the 1970–2005 period. Wetlands 34 (4): 747-758. DOI: 10.1007/s13157-014-0539-9.

Whitfield AK. 2017. The Role of seagrass meadows, mangrove forests, salt marshes and reed beds as nursery areas and food sources for fishes in estuaries. Rev Fish Biol Fish 27: 75-110. DOI: 10.1007/s11160-016-9454-x.

Wijayanti R, Saleh E, Hanum H, Aprianti N. 2020. Climate Change Analysis (Monthly Rainfall) on Palembang Duku Production (*Lansium domesticum* Corr). Sriwijaya J Environ 5 (2): 120-126. DOI: 10.22135/sje.2020.5.2.120-126.

Xiao H, Su F, Fu D, Wang Q, Huang C. 2020. Coastal mangrove response to marine erosion: Evaluating the impacts of spatial distribution and vegetation growth in Bangkok Bay from 1987 to 2017. Remote Sens 12 (2): 220. DOI: 10.3390/rs12020220.

Yuliana E, Hewindari YT, Winata A, Djatmiko WA, Rahadiati A. 2019. Diversity and characteristics of mangrove vegetation in Pulau Rimau Protection Forest, Banyuasin District, South Sumatra, Indonesia. Biodiversitas 20 (4): 1215-1221. DOI: 10.13057/biodiv/d200438.