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Mangrove land cover changes in North Singkawang, West Kalimantan, Indonesia analyzed using Landsat 8 images

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Abstract. *Widiastuti T, Astiani D, Roslinda E, Ekyastuti W, Ekamawanti HA. 2024. Mangrove land cover changes in North Singkawang, West Kalimantan, Indonesia analyzed using Landsat 8 images. Biodiversitas 25: 3160-3167.* North Singkawang Sub-district, located within Singkawang City in West Kalimantan Province, Indonesia is a coastal area with significant potential for mangrove forests. Recently, the district has experienced considerable land use changes, including the conversion of land for settlements, fish ponds, agricultural purposes, and coastal abrasion at various locations. To support the sustainability of mangrove forests, it is crucial to gather data on the area and distribution of these forests. This study aimed to investigate changes in the area and distribution of mangrove forests within this district. A survey method was employed for this investigation. Mangrove vegetation was assessed using visual interpretation of Landsat 8 OLI_TIRS images from 2016, 2019, and 2022. The Geographic Information System (GIS) application, specifically ArcGIS 10.8 software, was utilized to create maps and analyze land cover changes. The total area of mangrove forest was 514.95 hectares. Land cover in the North Singkawang mangrove forest area, in 2016, 2019, and 2022, consisted of mangrove forests, community crop areas, fish ponds, and open fields. Between 2016 and 2019, open fields (45.81 hectares) and community crop areas (9.84 hectares) were converted into mangrove forests through reforestation. During the same period, deforestation occurred as natural mangrove forests were converted into community crop areas (36.49 hectares), and open fields were transformed into community crop areas (0.03 hectares). From 2019 to 2022, community crop areas (6.93 hectares) were converted into mangrove forests, while deforestation resulted in the conversion of mangrove forests to open fields (15.37 hectares). From 2016 to 2022, mangrove forest cover increased by 10.72 hectares, community crop areas expanded by 19.74 hectares, the area of fish ponds remained unchanged, and open fields decreased by 30.46 hectares. The increase in mangrove forest cover was attributed to natural regrowth and reforestation activities, while the reduction in mangrove forests was primarily driven by anthropogenic activities, particularly the conversion of mangrove forests for crop production.

Keywords: Deforestation, image interpretation, land use change, reforestation, remote sensing

INTRODUCTION

Mangroves are ecosystems located in the intertidal zone where marine, brackish, riverine, and terrestrial waters strongly interact. These ecosystems thrive in tropical and subtropical regions, particularly between latitudes 25°N and 25°S. Naturally, mangrove forests exhibit specific zoning based on the species adapted to these environments, with the distribution of mangrove species being influenced by air temperature and salinity. Mangrove zoning typically begins at the sea with species such as *Avicennia marina* (Forssk.) Vierh., *Sonneratia alba* Sm., and *Rhizophora apiculata* Blume, followed by species that grow further inland, such as *Xylocarpus granatum* J.Koenig, *Ceriops decandra* (Griff.) Ding Hou, *Avicennia rumphiana* Hallier f., and *Rhizophora mucronata* Lam. (Katili et al. 2017). With over 4.25 million hectares, Indonesia hosts the largest mangrove forests globally, which are essential sources of ecosystem products and services, including carbon sequestration (Wiarta et al. 2019; Astiani et al. 2024), and serve as nurseries and spawning grounds for various marine biota. Additionally, these forests provide minerals, medicines, and help mitigate climate change effects (Friess and Webb 2014). The carbon uptake and storage capacity of mangroves are comparable to other tropical forest types (Astiani et al. 2017). Despite their significant roles, the destruction of mangrove forests occurs at an alarming rate (Hamilton and Friess 2018); in Indonesia alone, the mangrove forest area has decreased by an estimated 2.15 million hectares.

Mangroves grow along seashores near estuaries that carry water, mud, and sand deposits. They thrive in areas with sediment deposits from surrounding rivers, under protected and relatively calm coastal conditions. These ecosystems store large amounts of carbon, both in the trees that form the mangrove forests and in organic soil sediments (de Jong Cleyndert 2020). Mangroves consist of Dicotyledoneae or Monocotyledoneae plants that share taxonomic relationships up to the class level and have similar morphological and physiological adaptations to tidal habitats. However, population growth and increased human activities, such as land development, aquaculture, mining, and tourism, have led to a reduction in mangrove forests, thereby diminishing their ecological functions and disrupting the ecosystem (Khakhim et al. 2021). Continuous monitoring of the status and condition of mangrove forests is crucial to ensure their conservation and the sustainability of their resources (Mbata et al. 2022).

Remote sensing is a technology developed to obtain information about objects, areas, or phenomena on the earth's surface without direct contact. Remote sensing images accurately represent the appearance and location of objects on the earth's surface, covering large areas and providing periodic recordings, which facilitate time-series analysis. Geographic Information Systems (GIS) are developed to process and analyze spatial data based on satellite imagery, offering capabilities such as mapping, measuring, monitoring, and modeling. This technology is critical for processing and analyzing large datasets, supporting decision-making, and providing appropriate recommendations (Bhatti et al. 2019). GIS applications are especially valuable in spatial studies due to their accuracy, analytical capabilities, and reporting functions, allowing for the storage and retrieval of data as needed.

Satellite imagery, a widely used remote sensing tool, plays a critical role in studying mangrove ecosystems (Wang et al. 2019). Information on land cover in mangrove areas can be derived through satellite image interpretation, as the unique geographical location of mangroves at the land-ocean interface provides distinct recording characteristics compared to other terrestrial vegetation. The interpretation of remote sensing images for mangrove forest land cover is useful for various purposes, including estimating firewood biomass availability, assessing succession stages, and identifying forest damage. Landsat 8 imagery, for instance, has been utilized to monitor mangrove land cover at different observation times. Changes in mangrove forest land cover are among the phenomena that can be identified using GIS technology, with analysis typically conducted using ArcGIS software (Eddy et al. 2021).

North Singkawang Sub-district in Singkawang City, Indonesia, has significant potential for mangrove forests, although land clearing for settlements, fish ponds, agricultural land, and coastal abrasion has altered several locations. The rapid land use changes in this developing area require special attention. Studying these changes is crucial to understanding the social and economic development of the population and for better land management and sustainable development (Murty et al. 2022). It is assumed that in developing areas, rapid land use changes indicate the need for improved land management strategies. Reliable data and information are essential to support the sustainability of mangrove forests. Remote sensing technology has proven effective in identifying mangrove ecosystems and tracking changes over time.

This study aimed to assess changes in the area and distribution of mangrove forests in North Singkawang. The findings provide crucial information for mangrove inventory and monitoring activities, which form the basis for effective mangrove forest management. The primary contribution of this paper lies in the analysis of mangrove land cover in North Singkawang, utilizing Landsat 8 OLI_TIRS visual analysis for the years 2016, 2019, and 2022. This study applied GIS with the ArcGIS 10.8 software to analyze land cover changes, providing relevant information to aid decision-making in mangrove forest management in the North Singkawang Sub-district.

MATERIALS AND METHODS

Study area

The study area for this research comprised the entire mangrove forest region within the North Singkawang Sub-district, Singkawang City, West Kalimantan Province, Indonesia. The mangrove forest is located on the west side of North Singkawang Sub-district, between 108°58'03" E-108°59'10" E and 0°56'08" N-1°00'02" N. This area covers 514.95 hectares and extends along the coast, including the villages of Selakau, Semelagi Besar, Semelagi Kecil, Setapuk Besar, Setapuk Kecil, Sungai Rasau, Sungai Bulan, Naram, and Sungai Garam Hilir.

Procedures

This study employed a survey method, utilizing Landsat 8 OLI and TIRS images of the North Singkawang Sub-district, Path 122, and Row 59 for the years 2016, 2019, and 2022 as primary data sources. These images were obtained from the United States Geological Survey (USGS) website (http://earthexplorer.usgs.gov). Additional supporting data included the 2020 digital topography map of Indonesia at a 1:50,000 scale, accessed from the website (http://tanahair.indonesia.go.id). The tools used in this study included computer devices equipped with ArcGIS 10.8 software for data storage, processing, and analysis; a Global Positioning System (GPS) for determining position coordinates during field checks; and cameras for documentation purposes.

The initial stage involved pre-processing the satellite images to prepare them for analysis. This step aimed to enhance the clarity of geographic data in digital form, making the object display more distinct. A natural color composite using band 432 was employed to emphasize the mangrove cover in the images. During this stage, the Landsat 8 images were cropped to limit the study area according to the boundaries of the North Singkawang Sub-district, using the topography map of Indonesia. Digital enhancement techniques were applied to sharpen the overall appearance of the objects, facilitating the interpretation of mangroves and non-mangroves (Wiguna et al. 2022).

The primary data were obtained by visually interpreting mangrove forest cover from the Landsat 8 OLI_TIRS images, focusing on key elements of image interpretation. The interpretation of land cover in mangrove areas followed the classification of land cover for forestry purposes (Ministry of Environment and Forestry 2020). Based on the interpretation results, tentative maps of the North Singkawang Mangrove Forest Cover were created for the years 2016, 2019, and 2022. To determine changes in mangrove cover from 2016 to 2022, an overlay analysis was performed, comparing the 2016 mangrove cover tentative map with the 2019 map, and the 2019 map with the 2022 map. Field observations, or ground checks, were conducted to validate the interpretation results against actual field conditions. Sample locations for these observations were selected based on the tentative mangrove forest land cover change map, considering factors such as accessibility and the distribution of land cover types. A total of 31 sample locations were identified. At each observation point, the coordinates were recorded, and interviews and documentation were conducted to gather information and verify the accuracy of the visual analysis. Changes in mangrove forests were assessed through multi-temporal and spatial analysis (Nguyen et al. 2020).

Data analysis

The ground check results were used to validate the tentative mangrove cover map. The accuracy of the visual interpretation was assessed using an error matrix table (confusion matrix), which provided measures such as user's accuracy, producer's accuracy, overall accuracy, and kappa accuracy (Sari et al. 2021). If the accuracy level exceeded 85%, the interpretation results were deemed reliable for further analysis. If the accuracy was below 85%, the interpretation process was repeated until the required accuracy was achieved. Once the accuracy was confirmed, the land cover in the mangrove forest area of North Singkawang Sub-district was mapped for the years 2016, 2019, and 2022. Changes in mangrove forest cover were analyzed using ArcGIS 10.8 software, with a quantitative descriptive analysis based on the mangrove forest land cover maps from 2016, 2019, and 2022. The research implementation stages are summarized in a flowchart (Figure 1).

RESULTS AND DISCUSSION

Lillesand et al. (2015) noted that Landsat 8 OLI and TRIS imagery obtained from USGS includes IT-level products that are geometrically and radiometrically corrected. An interpretation of Landsat imagery from 2016, 2019, and 2022 for the mangrove area in the North Singkawang Sub-district revealed four distinct types of land cover: mangrove forests, community crop areas, fish ponds, and open fields.

An accuracy test was conducted to evaluate the visual interpretation by comparing the classified land cover with actual field conditions. The accuracy test results yielded a user's accuracy value of 100%, indicating that the land cover classification from the imagery was highly accurate and suitable for further analysis.

Between 2016 and 2022, the types of land cover-mangrove forests, community crop areas, fish ponds, and open fields-remained consistent. However, there were changes in the area occupied by each land cover type over the six years. The largest land cover category was mangrove forests, while open fields occupied the smallest area. The specific areas of each land cover type for 2016, 2019, and 2022 are presented in Table 1.

Mangrove forests

Mangrove forests near the coastal area show signs of logging, evident from furrows and visible puddles of water or logging traces (Figure 2). The vegetation within these mangrove forests is diverse, comprising species such as *A. marina*, *Rhizophora* sp., *Avicennia lanata* Ridl., *Bruguiera cylindrica* (L.) Blume, *Hibiscus tiliaceus* L., *Terminalia catappa* L., *Excoecaria agallocha* L., and *Leucaena leucocephala* (Lam.) de Wit. According to Mbata et al. (2022), *R. mucronata* is a mangrove species particularly susceptible to logging due to the high quality of its wood, which is used for charcoal production, building materials, and other purposes.

The mangrove forest area in 2016 measured 350.30 hectares. Between 2016 and 2019, the area increased by 19.17 hectares. However, from 2019 to 2022, the mangrove forest area decreased by 8.45 hectares. These changes in mangrove cover occurred at various locations. Overall, over the six-year period, the total area of mangrove forests increased by 10.72 hectares.

Community-crops area

The community's crop areas generally consist of small-scale agricultural activities located close to residential areas. The precise locations of these croplands are often challenging to identify during Landsat image interpretation, necessitating field observations to confirm their locations. The crop areas are typically planted with species such as coconut and banana (Figure 3). Notably, there was no large-scale clearing of mangrove land for these crop areas.

Table 1. Area of mangrove land cover in North Singkawang Sub-district, Singkawang City, Indonesia in 2016, 2019 and 2022

Information	Land cover area (ha)					
	2016		2019		2022	
	Area	%	Area	%	Area	%
Mangrove forests	350.30	68.0	369.47	71.7	361.02	70.1
Community crops area	34.49	6.7	61.16	11.9	54.23	10.5
Fish-ponds	31.91	6.2	31.91	6.2	31.91	6.2
Open field	98.25	19.1	52.41	10.2	67.79	13.2
Total	514.95	100	514.95	100	514.95	100

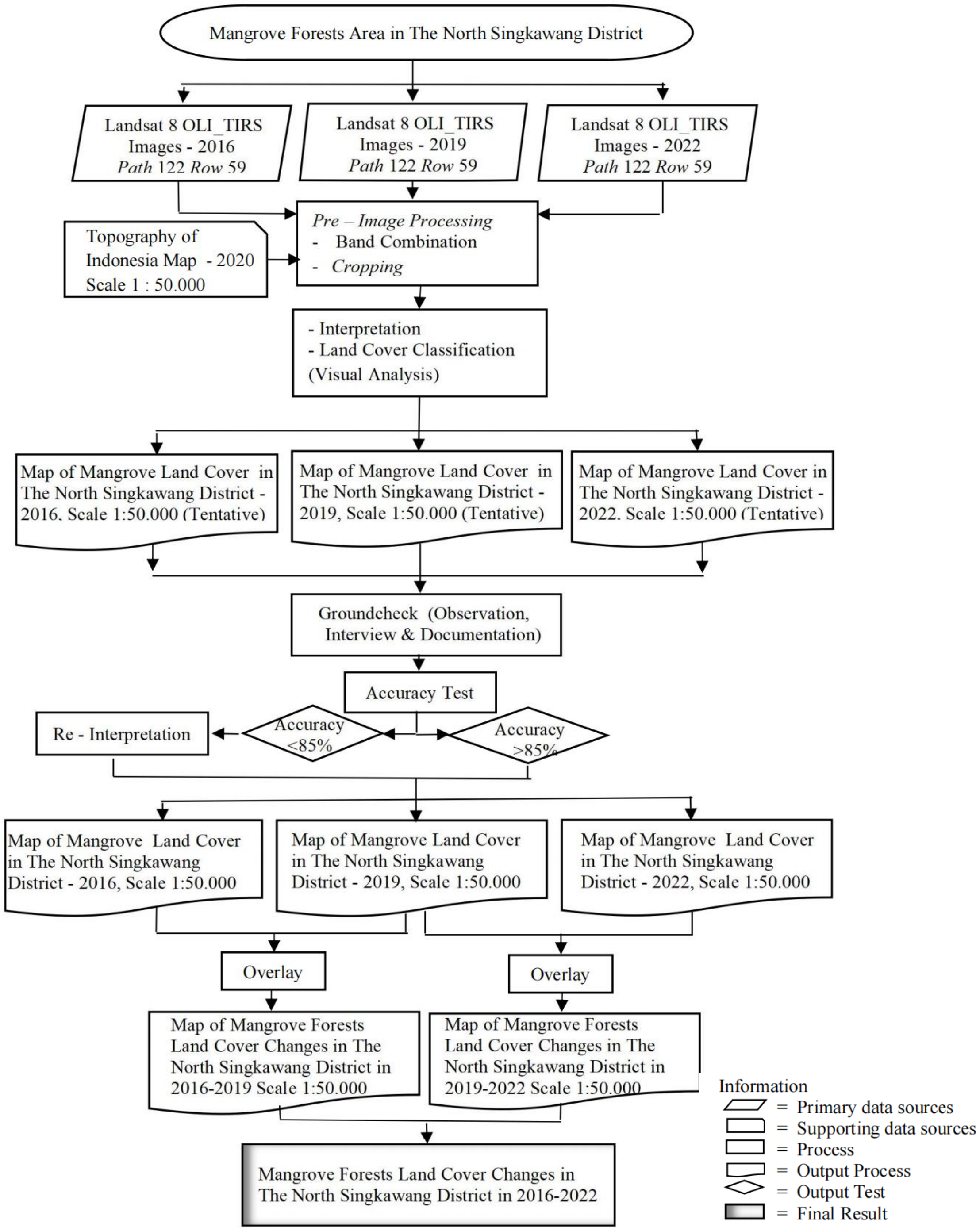


Figure 1. Research flowchart

In 2016, the community crop area within the North Singkawang mangrove region covered 34.49 hectares. This area increased by 26.67 hectares from 2016 to 2019, whereas it decreased by 6.93 hectares between 2019 and 2022. Overall, the community crop area expanded by 19.74 hectares from 2016 to 2022. There were fluctuations in the area size and shifts in the location of plantation land cover during this period. These changes have had socio-economic implications for the community, as the cultivation of crops with higher economic value has incentivized land conversion to community crop areas.

Fish-ponds

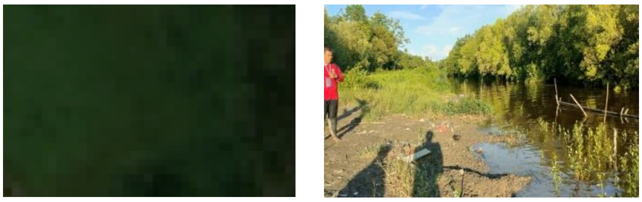
Fish ponds in this area were developed primarily for the cultivation of fish and shrimp and are mostly situated along the coastal regions (Figure 4). The fish pond system is designed to optimize the use of fishery resources. However, the bund patterns in the mangrove forest areas reveal the detrimental effects of onshore fishing activities. Mangrove trees not only support fish and shrimp farming but also contribute to the long-term sustainability of these ponds. When mangrove forests are damaged, the ecological carrying capacity can be compromised, potentially disrupting the sustainability of aquaculture operations. Fish ponds can be located in aquaculture zones behind tidal areas. Simple or traditional ponds within mangrove forest locations, when implemented with silvo-fishery practices, can actually support the preservation of mangrove forests. In the North Singkawang mangrove area, the fish pond area covered 31.91 hectares in 2016, and there were no changes in area or location in 2019 and 2022, indicating that both the size and site of the fish ponds remained consistent throughout this period.

Open field

Open fields refer to areas of land without vegetation, whether naturally occurring or resulting from human activities. In 2016, the open field area covered 98.25 hectares. By 2019, this area had decreased by 45.84 hectares, but it increased again by 15.38 hectares in 2022. The changes in the open field area involved an expansion in one location, offset by a reduction in other locations (Figure 5). Overall, from 2016 to 2022, there was a net reduction of 30.46 hectares in the open field area within the mangrove forest regions.

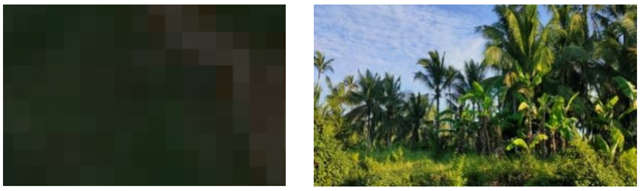
Land cover changes in the North Singkawang Mangrove Forests

The land cover classification for the mangrove forest area in the North Singkawang Subdistrict is presented through land cover maps for the years 2016, 2019, and 2022. A spatial analysis of these maps reveals that several areas experienced land cover changes due to land conversion. Each land cover class varied in area over time, reflecting the dynamic nature of land use in the region. The changes in land cover that occurred in the North Singkawang mangrove forest area over the 6-year period are described in two phases: from 2016 to 2019 and from 2019 to 2022. These changes are detailed in Table 2 and Table 3, with the distribution of changes illustrated in Figures 6 and 7. The results indicate that between 2016 and 2019, several significant changes in land cover occurred. Reforestation efforts were evident, as 45.81 hectares of open field and 9.84 hectares of crop land were converted into mangrove forests. However, there was also deforestation, with 36.49 hectares of mangrove forests being converted into crop land. Additionally, a small area of 0.03 hectares of open field was converted into crop land.



On images On site

Figure 2. Representation of mangrove forests on Landsat imagery and on site

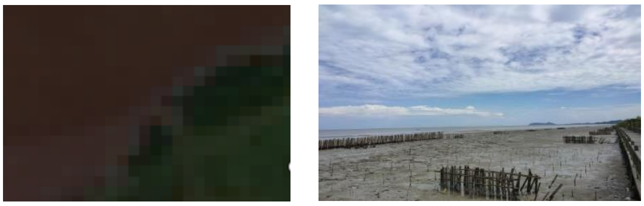


On images On site

Figure 3. Representation of the community's crops area on Landsat imagery and on site

On images On site

Figure 4. Representation of fish-ponds on Landsat imagery and on site



On images On site

Figure 5. Representation of open field in the form of a stretch of land resulting from sedimentation on Landsat imagery and on site

Table 2. Changes in mangrove land cover in North Singkawang Sub-district, Singkawang City, Indonesia from 2016 to 2019

Land cover 2016	Land cover 2019	Area (Ha)	Information
Open field	Mangrove forests	45.81	Reforestation
Open field	Community crops area	0.03	Non-forest
Open field	Open field	52.41	No change
Community crops area	Mangrove forests	9.84	Reforestation
Community crops area	Community crops area	24.64	No change
Fish - ponds	Fish - ponds	31.91	No change
Mangrove forests	Mangrove forests	313.82	No change
Mangrove forests	Community crops area	36.49	Deforestation
	Total	514.95	

Table 3. Changes in mangrove land cover in North Singkawang Sub-district, Singkawang City, Indonesia from 2019 to 2022

Land cover 2019	Land cover 2022	Area (Ha)	Information
Mangrove forests	Open field	15.37	Deforestation
Mangrove forests	Mangrove forests	354.10	No change
Fish-ponds	Fish-ponds	31.91	No change
Community crops area	Mangrove forests	6.93	Reforestation
Community crops area	Community crops area	54.23	No change
Open field	Open field	52.41	No change
	Total	514.95	

Between 2019 and 2022, land cover changes were identified, revealing a reforestation effort where croplands were converted into mangrove forests, covering an area of 6.93 hectares. Additionally, deforestation occurred as mangrove forests were transformed into open fields, totaling 15.37 hectares. Consistent with the conditions observed from 2016 to 2019, the area designated for fish ponds remained unchanged.

Reforestation in mangrove forest areas, which had previously been degraded or damaged, involved both natural and artificial vegetation regeneration. Mangrove forests have reclaimed abandoned croplands, where agricultural activities had ceased. Reforestation efforts, particularly in coastal areas, have successfully transformed open land into mangrove forests. Conversely, deforestation occurred due to anthropogenic activities, such as clearing mangrove forests for community crops or fish ponds. The crops cultivated in these areas generally included coconut, banana, and a variety of other species. Coconut, being a strategic commodity, plays a significant social, cultural, and economic role. Banana trees, suitable for dry and critical areas due to their adaptability to tropical climates, were planted for conservation. Mixed croplands were cultivated to meet basic community needs rather than for commercial purposes.

Deforestation was driven by increasing population pressures and socio-economic policies (Herrmann et al. 2020). Such pressures on coastal areas led to a reduction in mangrove forest coverage. Changes in mangrove forests impact biodiversity, alter the structure and population of the ecosystem, and increase abrasion and sedimentation (Kaskoyo et al. 2023). Coastal abrasion can lead to diminished mangrove forest cover and disrupt forest structure and function. Decreases in mangrove forests contribute to climate change and increase vulnerability to natural disasters (Aduana-Alcantara et al. 2023). Effective management and protection of mangrove habitats must consider mean annual temperature and rainfall, as these factors significantly influence mangrove distribution (Ghayoumia et al. 2022).

Land use practices that disregard soil and water conservation principles can exacerbate environmental issues such as erosion in river basin areas. Erosion results in the loss of fertile topsoil and reduces the soil's capacity to absorb and retain water (Murty et al. 2022).

Figure 6. Map of changes in mangrove land cover area of North Singkawang Sub-district, Singkawang City, Indonesia in 2016-2019

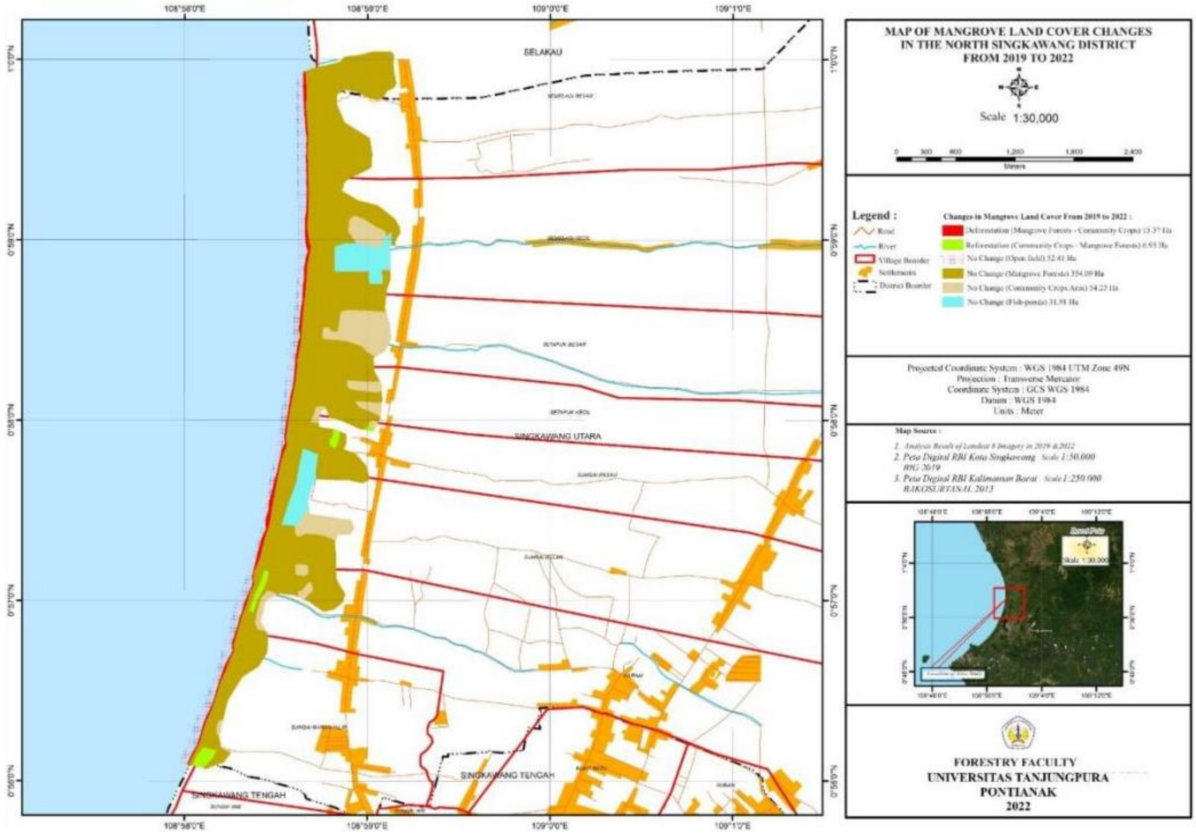


Figure 7. Map of changes in the area of mangrove land cover in North Singkawang Sub-district, Singkawang City, Indonesia in 2019-2022

Eroded soil particles are transported downstream, leading to sedimentation in coastal areas. Sediment, in the form of mud, supports mangrove vegetation growth. Mangroves help withstand waves, reduce abrasion, and mitigate flooding in coastal regions (Murty et al. 2022). However, high sedimentation can damage mangrove ecosystems. To maintain soil productivity, preventive measures and rehabilitation efforts must address erosion and sedimentation rates within watershed ecosystems. Mangrove forest conservation requires long-term support from integrated stakeholders, including government agencies, companies, and academics (Fitrianto et al. 2021).

Land cover changes in the North Singkawang Sub-district's mangrove areas were influenced by coastal abrasion due to wave activity. Residents' activities, such as creating fish ponds for fish and shrimp cultivation, also played a significant role in these changes. Expansion of agricultural land, along with pond and road construction in mangrove areas, contributed to mangrove forest degradation. Local communities cleared mangrove forests for crop cultivation, and landowners converted mangroves into agricultural land (Budi et al. 2022). The conversion of mangrove forests significantly affected their coverage (Murillo-Sandoval et al. 2022). Conservation efforts by the government, NGOs, academics, and local communities aimed to restore mangrove functions through activities such as planting on bare land, replanting dead mangroves, and cleaning up plastic waste (Anwar et al. 2021). Community awareness and concern for mangrove sustainability are crucial for providing benefits to both the forests and the local population (Manalo 2023).

One factor enhancing mangrove reforestation in North Singkawang is the success of reforestation programs on open fields created by mud sedimentation. Local community NGOs, such as Surya Perdana Mandiri (SPM) in Setapuk Besar Village, have played a vital role in implementing community-based strategies that consider socioeconomic and ecological aspects (Neupane et al. 2017). A significant relationship exists between people's attitudes toward mangrove forests and their awareness of conservation efforts. Forest management must address ecological, social, and economic factors (Garcia et al. 2020). Since 2009, SPM has led various mangrove plantation and conservation activities, planting approximately 350,000 mangroves over an area of 30 hectares, including 127 meters of new coastal land. These conservation successes have created business opportunities for the community, such as developing the area into a mangrove tourism destination with partial support from local government.

In conclusion, from 2016 to 2022, mangrove forest cover increased by 10.73 hectares (3.1%), community plantation areas expanded by 19.74 hectares (57.23%), the pond area remained unchanged, and open land decreased by 30.46 hectares (31%). The most significant change was the conversion of mangrove forests into community crop areas, driven by their higher economic value and contribution to basic needs and welfare. These land cover changes also led to ecological damage to mangrove forests. The research indicates a reduction in open land due to natural vegetation regrowth and successful community-led reforestation in sedimentation areas. Balancing the conversion of mangrove forests with the development of new mangrove areas is essential. Collaborative efforts from communities, relevant agencies, and stakeholders are necessary to improve the environmental, social, and economic quality of mangrove forest areas, ensuring they provide substantial benefits to society.

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