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Alterations in Land Cover over Five Years from 2014 to 2019 on Sembilan Island

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ABSTRACT

Reliable land-cover information is required for spatial planning on small coastal islands where plantations, mangroves, settlements, and aquaculture compete within a limited land area. This study analyzed land-cover categories and land-cover change on Sembilan Island, Pangkalan Susu Sub-district, Langkat Regency, North Sumatra, during the 2014-2019 period using satellite-image interpretation and Geographic Information System (GIS) analysis. The materials included the administrative boundary map of Sembilan Island, Landsat-8 imagery for 2014, Sentinel imagery for 2019, land-cover maps, field ground-check data, and supporting literature. Seven land-cover classes were identified: open land, mangrove, oil palm plantation, settlement, paddy field, shrubs, and pond. The island covered 1,509.57 ha. Oil palm plantation increased from 308.32 ha in 2014 to 654.26 ha in 2019, while mangrove increased from 348.19 ha to 448.30 ha. On the other hand, open land decreased from 356.79 ha to 28.30 ha, while shrubs fell from 125.03 ha to 7.48 ha. The transition matrix revealed that the most significant change was from open land to oil palm plantation, totalling 343.81 ha, followed by the conversion of shrubs to mangrove, which accounted for 109.71 hectares. The results reveal a simultaneous trend of plantation growth and mangrove restoration, highlighting the need for improved coastal spatial planning, field verification and regular GIS-based monitoring.

Keyword: Coastal Spatial Planning, Geographic Information System, Land Cover Change, Mangrove, Oil palm plantation, Sembilan Island

1. Introduction

Land cover describes the biophysical surface of the earth, whereas land use reflects the way humans utilize land for settlement, agriculture, plantation, aquaculture, infrastructure, conservation, and other activities. Land-cover change is therefore not only a mapping issue, but also an indicator of social, economic, and ecological pressure. In small coastal islands, the conversion of one land-cover type can immediately affect coastal protection, local livelihoods, biodiversity, and environmental stability because available land resources are limited.

Previous studies have shown that land-use and land-cover change is associated with population growth, commodity demand, accessibility, institutional policy, land tenure, and the economic value of specific land uses [1]-[7]. In coastal sceneries mangroves, ponds, settlements, agricultural fields and plantations often compete for space. Mangrove ecosystems provide coastal protection, habitat functions, sediment retention, carbon storage, and support for fisheries, while oil palm plantations remain economically important in many Indonesian and Southeast Asian landscapes [22], [26], [29]-[31]. This combination makes coastal land-cover change an important subject for integrated environmental and spatial-planning analysis.

Remote sensing and Geographic Information System (GIS) provide an effective approach for monitoring land-cover change because they enable repeated observation of land-cover patterns through time. Satellite imagery can identify land-cover classes, calculate area changes, and support transition-matrix analysis. A transition matrix is important because it identifies the direction of change, for example, whether an increase in plantation area results from open land, shrubs, or mangrove conversion [6], [9]-[11].

Sembilan Island is located in Pangkalan Susu Sub-district, Langkat Regency, North Sumatra Province. The island contains a mosaic of mangroves, oil palm plantations, settlements, paddy fields, shrubs, ponds, and open land. Current and spatially explicit information on land-cover change in this island is needed by local government and stakeholders to support sustainable land-resource management. The research gap addressed in this study is the limited availability of transition-based information that explains not only the magnitude of land-cover change, but also the specific land-cover pathways that occurred during the 2014-2019 period.

This study applied a driver-pressure-state-impact-response logic to interpret the land-cover changes. Drivers include population growth, accessibility, market demand and policy or rehabilitation programs. Such drivers induce pressures like land conversion, vegetation clearing, plantation establishment and mangrove rehabilitation. The pressures alter the state of land cover as measured by the maps of 2014 and 2019 and the transition matrix. Changes in state conditions cause ecological and social effects. Spatial zoning, mangrove protection, restoration techniques, land use planning and ongoing surveillance are some of the solutions (Figure 1).

Figure 1. The driver-pressure-state-impact-response framework for analyzing land-cover changes in Sembilan Island.

The objectives of this study were to classify the land-cover types on Sembilan Island, quantify the changes of land-cover from 2014 to 2019, identify the direction of land-cover changes and analyze the likely causes and implications of land-cover changes for coastal environmental governance and spatial planning.

2. Method

2.1. Study Area and Research Materials

This study was carried out on Sembilan Island, located in the Pangkalan Susu Sub-district of Langkat Regency, North Sumatra Province, between January and June 2020. Spatial data examination was conducted at the Forest Inventory Laboratory, Faculty of Forestry, Universitas Sumatera Utara, Medan. The resources utilised in this research were the administrative boundary map of Sembilan Island, land-cover maps from 2014 and 2019, Landsat-8 imagery from 2014, Sentinel satellite imagery from 2019, field verification data, and relevant literature. The apparatus comprised a computer, ArcGIS software, Global Positioning System (GPS), and digital cameras.

2.2. Data Collection

The research employed both primary and secondary data. Primary data were acquired directly from the research location via on-site verifications. GPS technology was used to obtain the coordinates of land-cover reference sites and the observed conditions in the field were recorded via digital cameras. Secondary data included satellite imagery, administrative maps, previous land-cover maps, statistical data and literature relevant to land-cover changes, mangrove ecosystems, remote sensing, GIS and spatial planning.

2.3. Imagery Evaluation and Land-Cover Classification

Image evaluation was performed utilising unsupervised classification. Spectrally similar pixels in the satellite imagery were grouped into clusters before field checking. The preliminary classification map was then used as a reference during ground checks. After field verification and visual interpretation, the spectral clusters were interpreted and merged into seven final land-cover classes: open land, mangrove, oil palm plantation, settlement, paddy field, shrubs, and pond. GIS was used to clip the imagery to the Sembilan Island boundary, to manage spatial data, calculate land-cover areas and to prepare land-cover maps.

The classification workflow consisted of preparing the 2014 Landsat-8 imagery and 2019 Sentinel imagery, harmonizing the image data with the Sembilan Island boundary, conducting unsupervised classification, interpreting the clusters into land-cover classes, validating the interpreted classes through field ground checks, calculating the area of each class, and producing land-cover maps for 2014 and 2019. Quantitative confusion-matrix values were not available in the source manuscript; therefore, this revision reports the field-verification procedure and land-cover transition analysis without presenting overall accuracy or kappa statistics.

2.4. Land-Cover Change and Transition Analysis

Land-cover area was calculated in hectares and as percentages of the total island area. Land-cover change was determined by subtracting the 2014 area from the 2019 area for each class. A transition matrix was subsequently created by superimposing the land-cover maps from 2014 and 2019. This matrix provides stable land-cover classes and specific transitions between classes, and enables the analysis of plantation growth, mangrove restoration and other land-cover dynamics.

3. Result and Discussion

3.1. Land-Cover Types and Area Distribution

GIS analysis showed that Sembilan Island covered 1,509.57 ha. Seven land-cover classes were identified, namely open land, mangrove, oil palm plantation, settlement, paddy field, shrubs, and pond (Figure 1 and Table 1). Open land means land without a lot of vegetation or buildings. Mangrove is a term used for vegetation communities in tidal zones along the coast. Oil palm plantation is a cultivated land to produce palm oils. Settlement consists of residential buildings, offices, schools and roads and public facilities. Paddy Field is a land for cultivation of rice. Shrubs include land covered by grasses, ferns, creeping plants and woody vegetation less than about two meters in height. Ponds refer to permanent or seasonal water bodies used or formed in the coastal landscape [21]-[25].

Table 1. Land-cover classes and area changes on Sembilan Island in 2014 and 2019

No	Land-cover class	2014 area (ha)	2014 area (%)	2019 area (ha)	2019 area (%)	Change (ha)
1.	Open land	356.79	23.64	28.30	1.87	-328.49
2.	Mangrove	348.19	23.07	448.30	29.70	+100.11
3.	Oil palm plantation	308.32	20.42	654.26	43.34	+345.94
4.	Settlement	32.25	2.14	32.25	2.14	0.00
5.	Paddy field	111.07	7.36	111.07	7.36	0.00
6.	Shrubs	125.03	8.28	7.48	0.50	-117.55
7.	Pond	227.91	15.10	227.91	15.10	0.00
	Total	**1,509.57**	**100.00**	**1,509.57**	**100.00**	

In 2014, the largest land-cover class was open land, covering 356.79 ha or 23.64% of Sembilan Island. Mangrove was the second largest class with 348.19 ha or 23.07% followed by oil palm plantation with 308.32 ha or 20.42% and pond with 227.91 ha or 15.10% (Table 1). By 2019, the land cover structure had undergone dramatic changes (Figure 2). The dominant class was oil palm plantation with area of 654.26 ha or 43.34% of the island. Mangrove also grew to 448.30 ha or 29.70%. In contrast, open ground decreased sharply to 28.30 hectares, which is 1.87%, and shrub coverage decreased to 7.48 hectares, which is 0.50%.

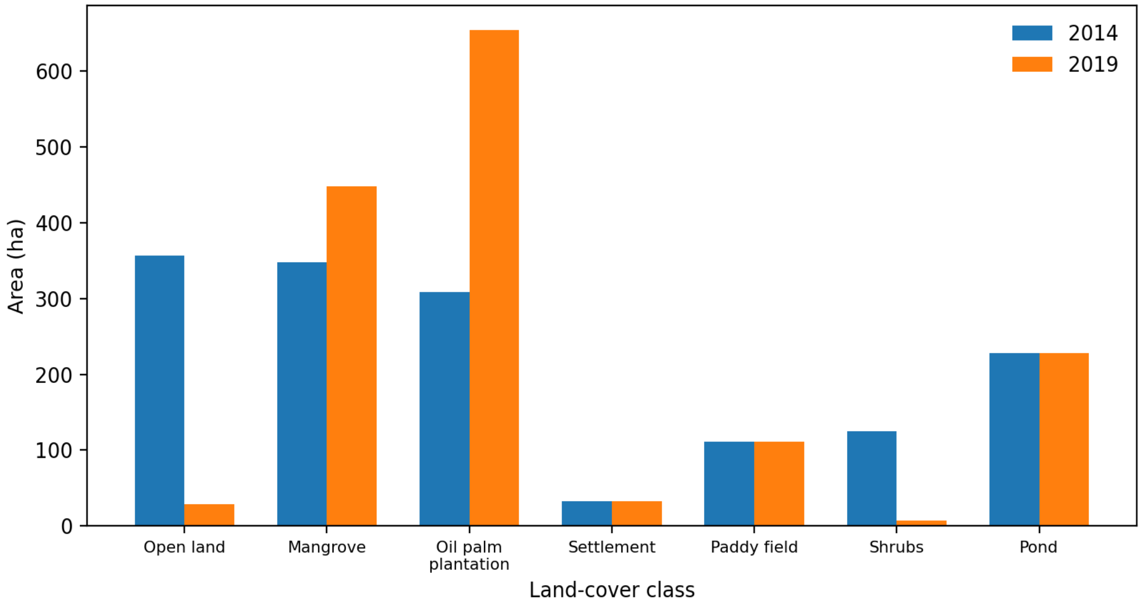

Figure 2. Analysis of land-use regions on Sembilan Island in 2014 and 2019.

3.2. Land Cover Change from 2014 to 2019

The transition matrix provides a full view of the dynamics in the land-cover changes. Residential areas, rice fields, water bodies and most of the established oil palm plantations were stable land cover types. The most significant change was the transformation of open land into oil palm plantations with an area of 343.81 hectares. This single transition covered about 22.78% of the island area, indicating that the expansion of plantations was the most dominant land-cover event in the study period (Table 2).

Table 2. Transition matrix of land-cover change for Sembilan Island in 2014–2019 (hectares)

No	2014 \ 2019	Open land	Mangrove	Oil palm plantation	Settlement	Paddy field	Shrubs	Pond	2014 total
1.	Open land	12.98		343.81					356.79
2.	Mangrove		338.59	2.12			7.48		348.19
3.	Oil palm plantation			308.32					308.32
4.	Settlement				32.25				32.25
5.	Paddy field					111.07			111.07
6.	Shrubs	15.32	109.71						125.03
7.	Pond							227.91	227.91
	2019 total	**28.30**	**448.30**	**654.26**	**32.25**	**111.07**	**7.48**	**227.91**	**1,509.57**

The second most significant shift was from shrubs to mangrove, encompassing 109.71 hectares. This trend indicates a restoration, rejuvenation or revival of the previously disturbed coastal flora in the mangrove ecosystems. A small but ecologically important change from mangroves to shrubs was observed covering 7.48 ha and could be an indicator of degradation or changes in the structure of vegetation in some coastal areas. Another restricted conversion was from mangrove to oil palm, which included 2.12 hectares. Despite its limited size, this region holds significant environmental importance due to the great ecological value of mangroves for coastal defence, fisheries habitat, sediment retention, and carbon sequestration (Figure 3 and Figure 4) [22], [26], [29].

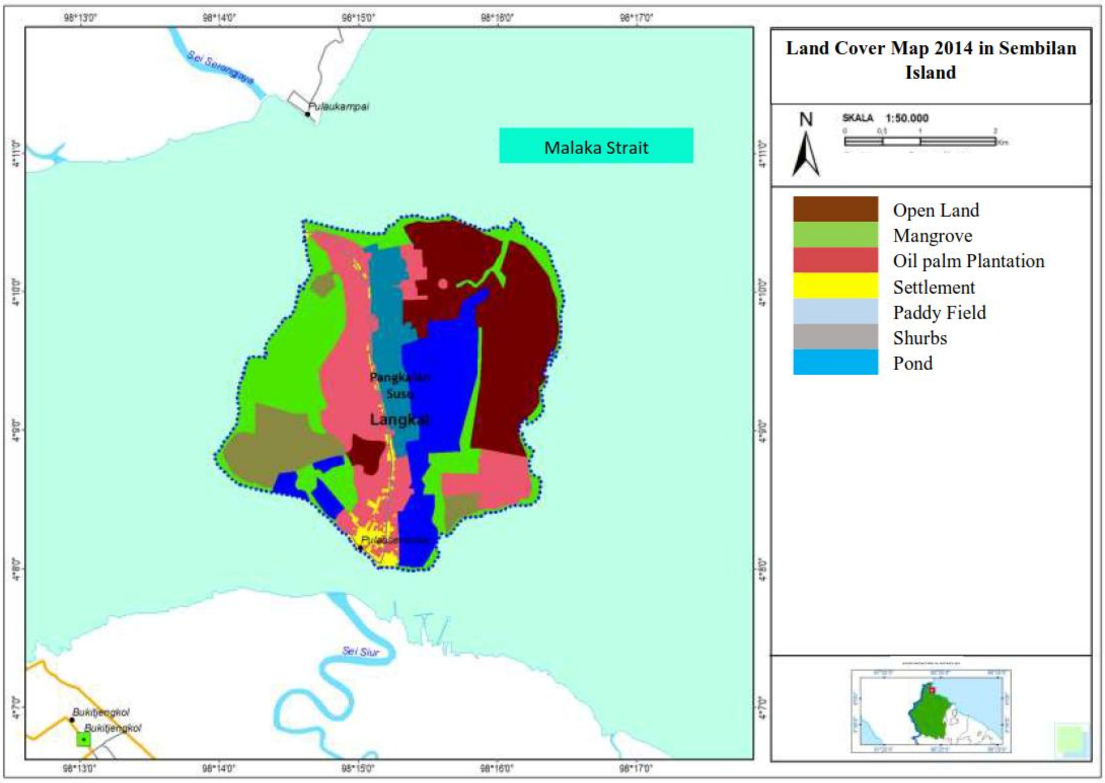

Figure 3. Land cover map 2014 in Sembilan Island.

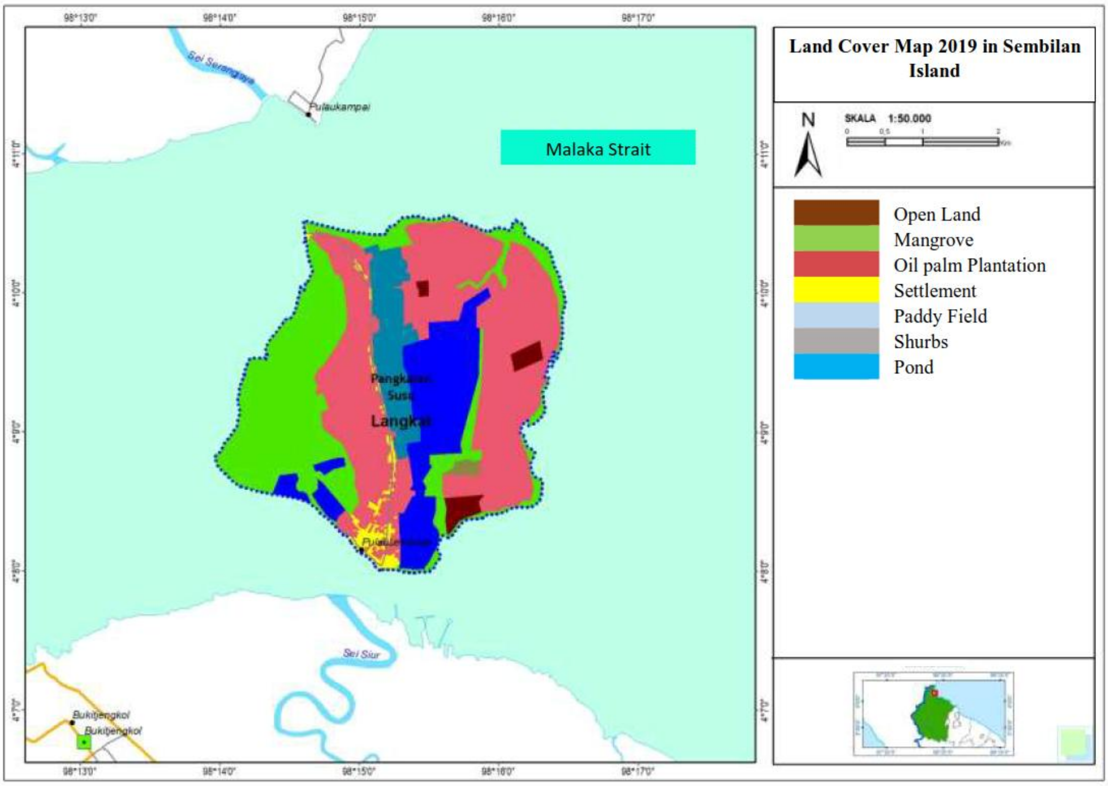

Figure 4. Land cover map 2019 in Sembilan Island.

3.3. Determinants of Alterations in Land-Cover

The transformation of open terrain into oil palm plantations was the primary land-cover change on Sembilan Island. This tendency suggests that open spaces were deliberately transformed into economically productive plantation areas. The expansion of oil palm cultivation (345.94 ha) has dramatically changed the land-cover structure of the island with plantation as the dominant land-cover category in 2019 (Figure 4). This process is consistent with a wider land-use pattern where agricultural and plantation activities are more prevalent in areas with available land and where access or market incentives facilitate cultivation [1]-[7], [30], [31].

For expanding the mangrove territory by 100.11 hectares a more complex analysis is required. The transition matrix indicates that the main contributor to mangrove expansion was from shrub to mangrove while a small amount of mangrove transitioned to other classes. This pattern indicates the potential for mangrove restoration, natural regrowth or the reclassification of impaired vegetation as mangrove coverage following field assessment. If the increase indicates actual restoration or natural regrowth of the mangrove ecosystems, this is a positive ecological indicator as mangroves increase resilience along the coast, enhance fisheries, and assist in combating climate change [22], [26], [29].

The loss of open land and shrubbery suggests that previously non-intensive or transitional land types have been converted to more stable or productive land-cover classes. Open land decreased by 328.49 hectares and shrub decreased by 117.55 hectares. The large decrease of open land is strongly related to the expansion of oil palm plantations, while the decrease of shrubbery is mostly related to the increase of mangroves. These results point to two conflicting dynamics that influence land cover change on Sembilan Island: economic transformation toward plantations and ecological restoration toward mangroves.

Between 2014 and 2019, settlements, rice paddies and ponds were stable. Such a consistency may imply slow growth of developed regions and aquaculture in the five years. But the consistency of area values does not imply that these land uses are without environmental impact. Ponds and communities are located in a coastal environment where drainage, tidal currents and land use boundaries may influence adjacent mangrove and agricultural areas.

3.4. Implications for Environmental and Land Cover Planning

The identified changes in land cover have direct implications for the management of coastal areas. Although the expansion of oil palm cultivation can bring economic benefits, it needs to be regulated by land use planning to prevent the invasion of mangroves and other sensitive ecosystems. As a small island, land-use decisions have limited biological buffering capacity; therefore, assessment of plantation growth should consider drainage, soil quality, coastal setbacks and conservation zoning.

The protection of mangroves needs to be a priority because they increase the durability of the coast, provide a habitat for fisheries, sequester carbon and stabilize sediments. Field validation and ongoing management are needed to ensure that the observed increase in mangrove area will create functioning mangrove ecosystems in the restored areas. Areas of shrub or oil palm plantations on former mangroves should be investigated as they may reflect stress from degradation or conversion.

The research also shows the need for frequent, confirmed satellite observation. Frequent land-cover mapping can support municipal authorities and stakeholders in rapidly detecting land transformation, in evaluating restoration effectiveness, and in spatially planning data-driven. In an effort to enhance the dependability of the land-cover change analysis, future oversight should include a recorded sample framework, validation-point matrix, confusion matrix, complete accuracy metrics, producer's accuracy, user's accuracy and concordance statistics [27], [28].

3.5. Study Limitations and Suggestions

The source document used in this research lacks a complete validation-point table and confusion matrix, which is a limitation. So initial field-reference data was needed for regeneration of quantitative accuracy measurements. Future studies should use consistent acquisition seasons, cloud-free images, well-documented training and validation datasets, and higher resolution images or ground-based assessments of vegetation when available. Such improvements are especially important to discriminate open terrain, bushes, young oil palm plantations and modified mangrove areas, which may exhibit similar spectral or structural characteristics in satellite images.

4. Conclusion

In 2014 and 2019, Sembilan Island comprised seven categories of land cover: open land, mangrove, oil palm plantation, habitation, paddy field, shrubs and pond. Over the span of five years, oil palm plantations expanded from 308.32 hectares to 654.26 hectares, establishing themselves as the predominant land-cover category in 2019. The area of mangrove cover expanded from 348.19 hectares to 448.30 hectares. Conversely, the open land area decreased from 356.79 hectares to 28.30 hectares and shrubbery from 125.03 hectares to 7.48 hectares. The rice paddies, the water bodies and the habitations were homogenous. The transition matrix indicated the highest conversion was from open land to oil palm plantation (343.81 ha), then from shrubs to mangrove (109.71 ha). These trends suggest that the land-cover changes on Sembilan Island were influenced by concurrent plantation growth and the restoration or rehabilitation of mangroves. The findings underscore the necessity for spatial planning that regulates plantation growth, safeguards mangrove regions, assesses mangrove rehabilitation, and formalises regular GIS-based land-cover surveillance for coastal governance.

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Conflict of Interest
The authors declare no conflict of interest.

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