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Land Cover Changes and Impacts of Massive Siltation on the Mangrove Segara Anakan Lagoon System, Cilacap Indonesia

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ABSTRACT

Changing coastal zones in Indonesia, such as coral reefs, seagrass, and mangroves, have an impact on tropical eco-systems. Excessive exploitation and sedimentation, in particular, have threatened the mangrove at Segara Anakan Cilacap. In order to evaluate temporal land cover changes and the impact of high siltation on the Segara Anakan lagoon system in Cilacap, Indonesia, a research was conducted. The land cover data from SPOT 4 was available in 2008, and the Sentinel-2A data was available in 2019. The Normalized Difference Vegetation Index (NDVI) was used to enhance the Macro Class with supervised classification utilizing Maximum Likelihood techniques. Mangroves and water bodies declined between 2009 and 2019, whereas settlements and farmland areas increased, according to this study. In the western part of Segara Anakan, extensive siltation altered the biomass, structure, and composition of mangrove vegetation. At high sedimented habitats, *Acanthus* and *Derris* dominate, followed by *Nypa*. The changes in land cover and land use had an impact on socioeconomic factors. Decreases in water bodies and mangrove areas, as well as an increase in farmland, were significantly linked to a shift in society's livelihoods from fishermen to farmers. The destruction of mangrove habitats in the Segara Anakan has been accelerated by anthropogenic activity and population pressure. Because this sensitive environment is constantly threatened by anthropogenic activity and climate change, effective management of the Segara Anakan Lagoon mangrove eco-system is important for its long-term viability.

Keywords: sedimentation, livelihoods change, coastal, Sentinel, land use.

INTRODUCTION

The Indonesian coastline stretching up to 79,464 km (Badan Pusat Statistik Indonesia, 2018) is covered by mangroves, coral reefs, sea-grass beds. Its coastal seas are characterized by high biodiversity and endemicity (Sukristijono, 2002). They protect ecosystems from natural hazards and provide livelihood for a large coastal human population (Alongi, 2002). However, this large population also threatens these protective and livelihood functions of coastal ecosystems. In 2018, approximately 65% of the total Indonesian population of 267 million people lived along the coast (Badan Pusat Statistik Indonesia, 2018), and it continues to increase. Furthermore, local mismanagement and misappropriation affecting coastal regions (Wever et al., 2012), resources over-exploitation (Siry, 2006; Dahuri & Dutton, 2000), and frequent natural disaster (Song et al., 2018) exacerbate the problems of coast.

In this paper the impact of improper management of upland agriculture as well as the resulting degradation of estuarine and coastal ecosystems from massive siltation were addressed (Hapsari et al., 2020; Lukas and Flitner, 2019) based on the observations in the Segara Anakan area in Central (Holtermann et al., 2009; Ardli et al., 2015).

The estuarine system of Segara Anakan lagoon with an area of 7,037.16 ha (Purwanto & Ardli, 2020) holds the most extensive mangrove ecosystem with more than 20 mangrove species (Setyawan et al., 2002; Hinrichs et al., 2009; Nordhaus et al., 2019; Koswara et al., 2017) along the southern coast of Java. The lagoon is the nursery ground of various fish species, such as *Stelophorus indicus*, *S. commersoni* and *Cromileptes altivelis* (Nuryanto et al., 2017). Between 1980 and 2000, its fishery resource decreased dramatically (Ardli & Wolff, 2009). Overfishing, illegal fishing methods, and the destruction of mangroves are all significant threats to the viability of coastal ecosystems (Siry, 2006). The Segara Anakan ecosystem is no longer able to maintain the resources of fisheries, as evidenced by the reduction of the eel population *Anguilla bicolor* (Setyaningrum et al., 2020; Piranti et al., 2019) and mud crab *S. serrata* (Setyaningrum et al., 2020; Sih Piranti et al., 2019; Widianingsih et al., 2019).

Land cover changes, such as conversion of mangrove forests for agriculture, aquaculture, as well as rural and industrial development has been a major issue in many coastal areas (Karki et al., 2018). In Segara Anakan, such changes are exacerbated by massive siltation of the lagoon due to processes occurring in the hinterland (Ardli and Wolff, 2009; Hapsari et al., 2020). Over four decades, the lagoon area declined by 58.8% from 17,090.1 ha in 1978 (Ardli and Wolff, 2008) to 7,037 ha in 2019 (Purwanto and Ardli, 2020). High sedimentation has also caused the mangrove substrate to harden, and as a consequence changes the vegetation structure.

Moreover, agricultural areas are present in some parts of the mangrove area.

There have been numerous studies on the Segara Anakan lagoon focusing on sedimentation, land cover change, illegal cutting, and destructive fishing methods (Ismail et al., 2018; Hapsari et al., 2020; Lukas & Flitner, 2019; Jennerjahn & Yuwono, 2009; Yuwono et al., 2007; Nurmalahayati et al., 2020; Pikowitzky et al., 2011). The most recent report on land use change was published in 2006, covering the SPOT 5 data set (Ardli & Wolff, 2009). For the last decades, no indication of the mangrove ecosystem change continues to occur, but there is no valid and up to date data available. Therefore, a study on land cover changes, especially in the mangrove areas affected by high sedimentation, is necessary.

MATERIALS AND METHODS

Study area

The Segara Anakan Lagoon (SAL) system is located in the humid tropical region in the southern coast of Central Java Island, west of the city of Cilacap (Figure 1).

The mean annual temperature is 27.2°C with little variation throughout the year. The mean annual precipitation reached 3,400 mm, with a dry season from July to September and a wet season from October to May. Peak rainfall occurs in November (Hapsari et al., 2020). The El Niño Southern Oscillation (ENSO) influences the interannual rainfall variability (Qian et al., 2010). The SAL is
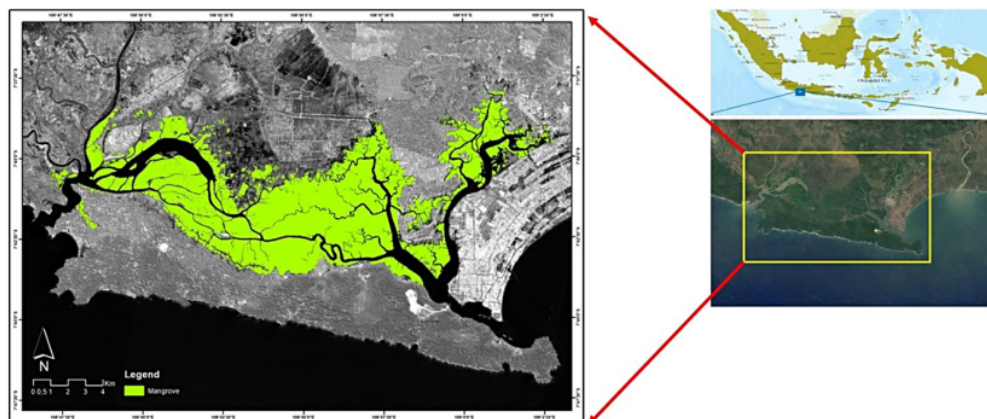

Figure 1. Map of research location

influence by semidiurnal tides with amplitudes varying from 0 to 2.57 m (Awaludin et al., 2017).

The lagoon is surrounded by a mangrove forest dominated by mangrove shrubs, *Acanthus* and *Derris* at the western part (Ardli & Yani, 2020) and *Rhizophora apiculata*, *Aigeceras corniculatum*, *Ceriops tagal* and *Nypa fruticans* at the eastern part of Segara Anakan (Nordhaus et al., 2019). The SAL catchment covers an area of approximately 450,000 ha (Lukas, 2015) and is drained by the Cintanduy River with a discharge range of 78–300 m^3/s (average 140 m^3/s) (Holtermann et al., 2009).

Data source and image analysis

The satellite imageries used in this investigation were the SPOT 4 image acquisitions from April 24, 2008, and the Sentinel 2A image acquisitions from May 22, 2019 (Table 1). The SPOT 4 image was obtained from the Remote Sensing Technology and Data Center of Indonesia's National Institute of Aeronautics and Space (LA-PAN) catalog website (inderaja-catalog.lapan.go.id). The Sentinel 2A image was made available on the Copernicus Open Access Hub website (https://scihub.copernicus.eu) by the European Space Agency (ESA). The spatial resolution of the multispectral SPOT 4 image is 20 meters, while the spatial resolution of the Sentinel 2A image is also 20 meters (resampled).

Radiometric correction is a starting point in image processing. Radiometric calibration and atmospheric adjustment were part of the procedure. The top of atmospheric reflection value was calculated using radiometric calibration (Kristianingsih et al., 2016). The Semi-Automatic Classification Plugin (SCP) function in the Quantum GIS application version 3.6 is used for radiometric calibration (Sutanto & Tjahjaningsih, 2016). The dark of subtraction (DOS) approach was used to rectify the atmospheric conditions, and multiple training areas in relatively deep water objects devoid of clouds were required. The intent of the atmospheric correction method was to make a custom image which was almost freely available of atmospheric

disturbances and had the lowest value of atmosphere reflection (Siregar et al., 2018). On the basis of the MODTRAN4 radiation transfer code, the method reduced water vapor, oxygen, carbon dioxide, methane, ozone, molecular, and aerosol scattering (Danoedoro, 2012).

The image of the object was enhanced, and noise was decreased, according to image sharpening (Silitonga et al., 2018). Mangrove identification through satellite images necessitated the use of color composites. Band combinations utilized to identify mangrove vegetation in SPOT 4 combine band 1+band 4+band 3 (Suwargana, 2008), whereas band 8a+band 11+band 4 was applied in the Sentinel 2A images, which displayed mangrove vegetation objects more optimally (Purwanto & Asriningrum, 2019). The presence of mangroves along the coast can assist in the identification of these objects. Mangrove leaves have a significant chlorophyll content, which absorbs red light and reflects it strongly in the infrared spectrum (Zhang, et al., 2012).

Mangroves and other land covers were classified using the supervised classification technique of Quantum GIS "The Open Source Software's" Semi-Automatic Classification (SCP) tool. Maximum Likelihood techniques were used to classify the data using Macro Class. It classifies the pixel values in the pixel sample based on the pixel value likelihood against a specific class. The pixel is not categorized, if the probability value is less than the specified threshold value (LAPAN, 2015). The layer with the field-checked sites is superimposed on the corrected satellite images to enhance the sample size for classification accuracy testing. Homogeneous polygons with identical spectral reflectance are drawn around such areas when seen in many band combinations. This generated a layer of polygons that were subsequently used to check the accuracy of the classified map (Ardli & Wolff, 2009).

A vegetation index approach was used to determine the presence of shrubs in the study area. The shrubs object has a very high density, which is one of its characteristics. To determine the distribution of shrubs at the research site, the

Table 1. Satellite images used in this study

Sensor	Platform	Spectral coverage	Number of channels	Spatial resolution (m)	Scene	Acquisition date
HRVIR (Visible & Infrared High-Resolution)	SPOT 4	60 km	4	20	Ki/Kj: 289/365	2008/04/24
Multispectral Instrument (MSI)	Sentinel-2A	290 km	13	20	Tile: 49MBM	2019/05/22

Normalized Difference Vegetation Index (NDVI) approach was utilized. The NDVI is a standard measure to determine the greenness of vegetation in satellite imagery (Nguyen et al., 2019). Because it uses a band ratio between the Near Infrared (NIR) and Red bands, this vegetation index method is particularly effective. The following is the NDVI equation.

$$NDVI = (NIR - Red) / (NIR + Red) \qquad (1)$$

NDVI calculations on SPOT 4 images used Band 3 (NIR) and Band 2 (Red), while on Sentinel 2A used Band 8a (NIR) and Band 4 (Red).

The geometry calculation menu in the arc map 10.4 software was used to calculate mangrove and non-mangrove area in hectares. The vertice coordinates in the map data are multiplied sequentially from the first vertex to the original vertex in order to calculate the area in a polygon area.

Polygon area was calculated by means of the following formula:

$$Area = \frac{\begin{matrix}(x1 * y2 - y1 * x2) + \\ +(x2 * y3 - y2 * x3) + \\ + \cdots + (xn * y1 - yn * x1)\end{matrix}}{2} \qquad (2)$$

where: x1 is the x coordinate of the 1st vertex and y2 is the y coordinate of the 2nd vertex onwards until the n coordinate is the last vertex. (https://www.mathopenref.com/coordpolygonarea.html, n.d.).

Differences between the classified imageries of each category of land cover were used to detect the changes in land cover (Conchedda et al., 2011; Munthali et al., 2020). Figure 2 presents the flow diagram for image processing.

RESULT

Table 2, Figures 3 and 4 depict the land cover and land-use changes in Segara Anakan 2008 to 2019. In 2008, the mangrove covered 28% of the study area, while the areas of forest, farm, water bodies, and the settlements covered 25, 22, 17 and 7%, respectively. In 2019, the mangrove area decreased to 27%, and the area of water bodies reduced to 12%. In contrast, farm area, forest, and settlement areas increased to 26%, 25%, and 9%, respectively. The most significant land cover change was in the area of water bodies with an annual reduction of 2.44% due to high siltation in the lagoon (Figure 3).
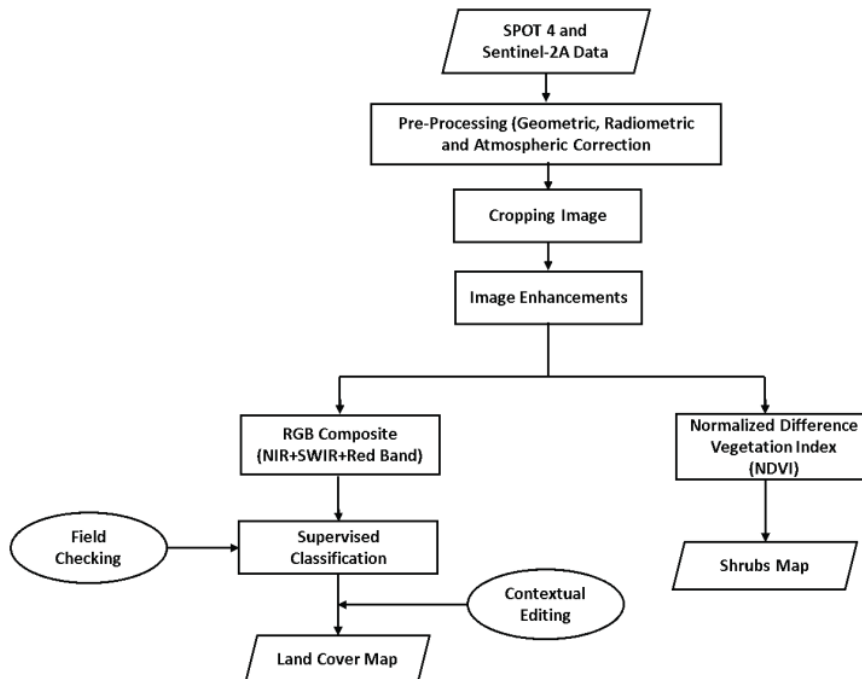

Figure 2. Image processing flow diagram

Table 2. Estimated area and land-changes for each land cover type

NO	Land cover	2008 (ha)		Total	2019 (ha)		Total	Area change (ha)	Annual change %
		West	East		West	East			
1	Mangrove	3,645	5,544	9,189(28%)	3,365	5,463	8,828(27%)	-361	-0.36
2	Forest	4,398	3,361	7,758(24%)	3,994	4,296	8,290(25%)	532	0.62
3	Waters	3,507	2,037	5,544(17%)	2,140	1,917	4,057(12%)	-1,488	-2.44
4	Farm area	2,388	4,893	7,280(22%)	4,403	3,964	8,367(26%)	1,087	1.36
5	Settlement	225	2,534	2,759(8%)	262	2,728	2,990(9%)	230	0.76
	TOTAL	14,164	18,368	32,532	14,164	18,368	32,532		
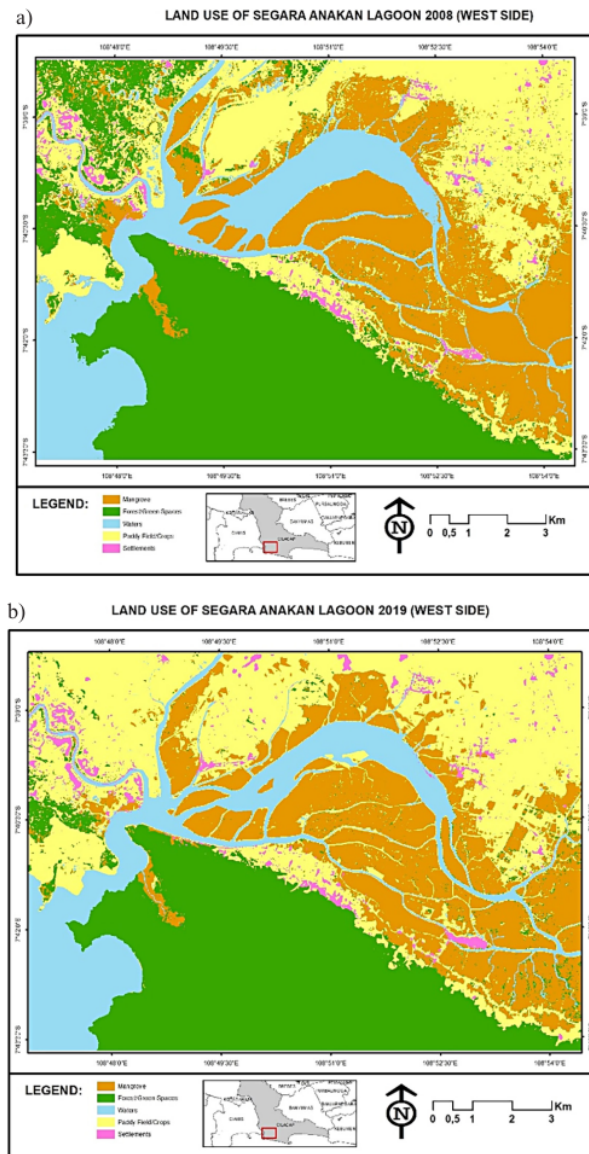
Figure 3. Land cover changes of the western part of Segara Anakan a) 2008, b) 2019
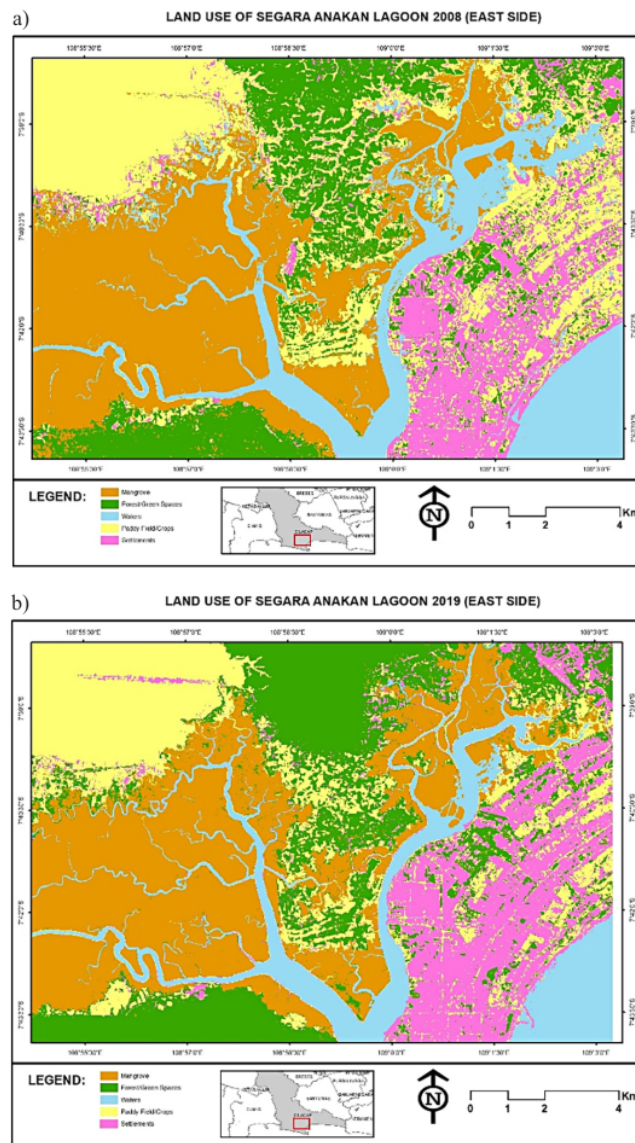
Figure 4. Land cover changes of the eastern part of Segara Anakan a) 2008, b) 2019

Between 2008 and 2019, the farm area had expanded more than any other land cover type at an annual rate of 1.36% or by about 98.8 ha per year. It was followed by increasing settlement (0.76% per year) and forest cover (0.62% per year). In the western part of the study area, the mangrove and other forests converted to farm areas, mostly to paddy fields (Figure 3). In contrast, those in the eastern part, they were mostly converted to settlement, though partially farm areas were covered

by vegetation. The extent of the water bodies has also decreased rapidly due to sedimentation, and subsequently overgrown by mangroves.

The observed changes in land cover and land use have an impact on the community livelihoods in the Segara Anakan area, administratively, the area includes two sub-districts, Kampung Laut in the west, and Cilacap Tengah in the eastern part. Kampung Laut consists of four villages, i.e., Panikel, Ujungalang, Ujunggagak, and Klaces. The
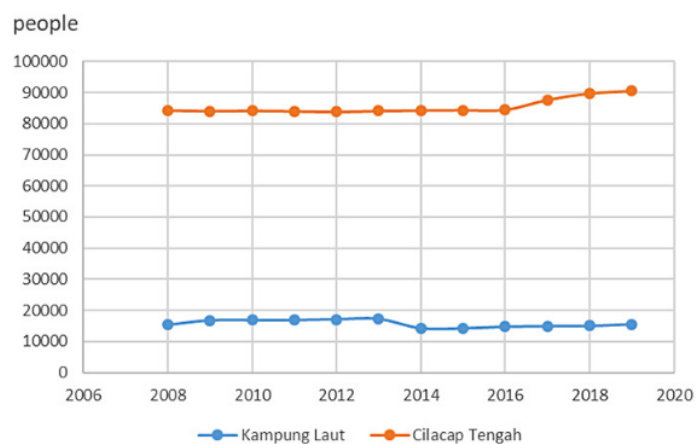
people

Figure 5. Human population changes during 2008–2019

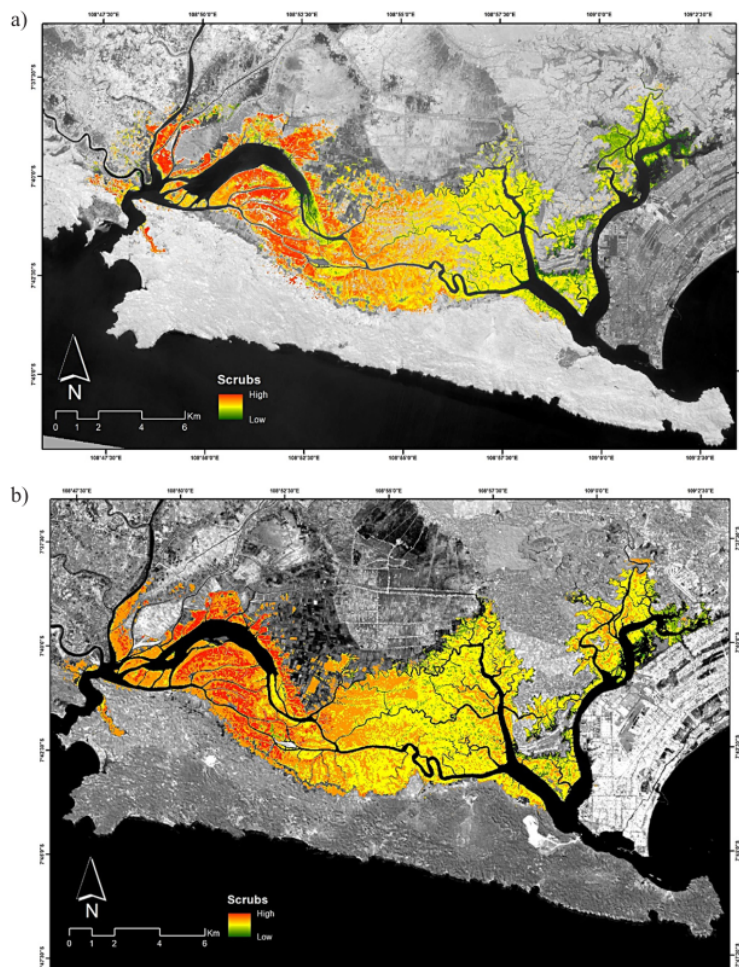**Figure 6.** Mangrove scrubs distribution at Segara Anakan a) 2008, b) 2019

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Table 3. Changes in livelihoods in Segara Anakan between 2009 and 2019 [Badan Pusat Statistik, 2009, 2020]

Livelihoods	District Kampung Laut				District Cilacap Tengah			
	2009	%	2019	%	2009	%	2019	%
Fisherman	2,803	56	2,051	44	1,828	18	1,133	11
Farmer	1,927	39	2,200	47	2,255	22	1,350	13
Labor	269	5	458	10	5,986	59	7,855	76
Total	4,999	-	4,709	-	10,069	-	10,338	-

human population of this sub-district was 15,349 in 2008 and 15,566 in 2019. Cilacap Tengah had a much larger population, about 84,268 in 2008, which then increased to 90,490 in 2019. This sub-district covers five villages, namely Kutawaru, Lomanis, Donan, Gunungsimping, and Sidanegara. Except for Kutawaru, the other villages are in the city of Cilacap (Figure 5).

In 2009, the population of Kampung Laut comprised 56, 39, and 5% represented by fishers, farmers, and factory labor, respectively. This has changed in 2019, when farmers represented 47% and fishers 44%. In Central Cilacap, in 2009, labor force represented 59% followed by farmers (22%), and fishers (18%). Within ten years, with the decline in mangroves, water bodies, and farmlands, in the eastern part of the study area, the share of farmers and fishers decreased by 13% and 11%, respectively. Meanwhile, labor force increased significantly to 76% (Table 3).

Siltation has an impact on the vegetation on the research site, in addition to affecting livelihoods. For example, the shrub density and dominance of *Acanthus* and *Derris* have changed. Due to the rapid pace of sedimentation in this area, shrubs covered most of the western sections in 2008 (Figure 6).

They grew in the center and western areas of Segara Anakan in 2019. They were also seen in numerous parts of the Segara Anakan's eastern region. It was determined that shrub expands to the east of the research area from 2008 to 2019.

A total of 53 mangrove species were observed in Segara Anakan, consisting of 17 major, and 11 minor species as well as 25 associate mangrove species. Previous studies had variously reported the number of mangrove species from same area as 27 (Setyawan et al., 2002); 26 (Hinrichs et al., 2009); 30 (Sanjatmiko et al., 2019); and 43 (Table 4).

Table 4. Mangrove species composition in the Segara Anakan lagoon system

No	Species	2002[a]	2009[b]	2019[c]	2020[d]		
					West	Central	East
	Major species						
1	*Avicennia alba*	✓	✓	✓	✓	✓	✓
2	*Avicennia marina*	✓	✓		✓	✓	✓
3	*Avicennia officinalis*	✓	✓	✓	✓	✓	✓
4	*Bruguiera cylindrica*	✓		✓		✓	✓
5	*Bruguiera gymnorrhiza*	✓	✓	✓	✓	✓	✓
6	*Bruguiera parviflora*		✓	✓	✓	✓	✓
7	*Bruguiera sexangula*	✓		✓		✓	✓
8	*Ceriops decandra*	✓	✓	✓	✓	✓	✓
9	*Ceriops tagal*	✓	✓	✓	✓	✓	✓
10	*Ceriops zippeliana*					✓	✓
11	*Lumnitzera littorea*		✓			✓	✓
12	*Lumnitzera racemosa*					✓	✓
13	*Nypa fruticans*	✓	✓		✓	✓	✓
14	*Rhizophora apiculata*	✓	✓		✓	✓	✓
15	*Rhizophora mucronata*	✓	✓	✓	✓	✓	✓
16	*Sonneratia alba*	✓	✓	✓	✓	✓	✓

Table 4. Cont. Mangrove species composition in the Segara Anakan lagoon system

No	Species	2002[a]	2009[b]	2019[c]	2020[d] West	2020[d] Central	2020[d] East
17	*Sonneratia caseolaris*	✓	✓	✓	✓	✓	✓
	Minor species						
18	*Acrostichum aureum*	✓	✓	✓	✓	✓	✓
19	*Acrostichum speciosum*			✓	✓	✓	✓
20	*Aegiceras corniculatum*	✓	✓	✓	✓	✓	✓
21	*Aegiceras floridum*			✓		✓	✓
22	*Excoecaria agallocha*	✓		✓	✓	✓	✓
23	*Heritiera littoralis*	✓		✓	✓	✓	✓
24	*Scyphiphora hydrophyllacea*	✓				✓	✓
25	*Sarcolobus globosus*			✓			
26	*Scaevola taccada*		✓				✓
27	*Xylocarpus granatum*	✓	✓	✓	✓	✓	✓
28	*Xylocarpus moluccensis*	✓	✓	✓	✓	✓	✓
	Associate species						
29	*Acanthus ilicifolius*	✓	✓	✓	✓	✓	✓
30	*Acanthus ebracteatus*		✓	✓	✓	✓	✓
31	*Barringtonia asiatica*			✓	✓	✓	✓
32	*Borassus flabellifer*				✓	✓	✓
33	*Calophyllum inophyllum*			✓		✓	✓
34	*Calotropis gigantea*	✓					
35	*Cerbera manghas*	✓			✓	✓	✓
36	*Cynometra iripa*					✓	✓
37	*Clerodendrum inerme*	✓					
38	*Derris trifoliata*		✓		✓	✓	✓
39	*Eucalyptus* sp. (planted)					✓	
40	*Ficus* sp.		✓				
41	*Finlaysonia maritima*			✓	✓	✓	✓
42	*Finlaysonia obovata*		✓				
43	*Hibiscus tiliaceus*		✓		✓	✓	✓
44	*Ipomoea pescaprae*			✓	✓	✓	✓
45	*Merope angulata*					✓	
46	*Pandanus tectorius*	✓			✓	✓	✓
47	*Pandanus odoratisima*			✓			
48	*Passiflora foetida*			✓	✓	✓	✓
49	*Terminalia catappa*			✓	✓	✓	✓
50	*Scirpus littoralis*	✓			✓	✓	✓
51	*Stachytarpheta jamaicensis*			✓			
52	*Cyperus alternifolius/welingi*	✓	✓		✓	✓	✓
53	*Wedelia biflora*		✓				
	Total	27	26	30	33	43	43

Note: a – Setyawan et al., 2002; b – Hinrichs et al., 2009; c – Sanjatmiko et al., 2019; d – this study.

DISCUSSION

The land-cover change in SAL continued since human settlers arrived in the adjacent area and converted native vegetation to agricultural land (Jennerjahn, et al., 2022). Altering the mangrove ecosystem to agriculture, aquaculture, settlement, tourism, and the industrial development affects its sustainability. At least partly due to land-cover change, diminishing

mangrove areas affects their carrying capacity to support various organisms that inhabit the habitat, thus decreasing their biodiversity.

Mangrove diversity has declined from moderate (Shannon index 2.33) in 2009 to a low diversity level (Shannon index 1.85) in 2015 (Koswara et al., 2017). This biodiversity decrease is also indicated by the dominance of two mangrove shrubs, *D. trifoliata* and *A. ilicifolius* (Ismail et al., 2018; Ardli & Yani, 2020). This is due to the fact that several mangrove species died once the area was silted up. They are unable to respond to the fast changes in substrate caused by siltation. Scrubs grew quickly after siltation, because there was suitable substrate and the canopy was open due to the loss of mangroves. Such decline affects the mangrove fauna, as seen in the decline of mud crab production during 2010–2017. The crab decline rate was 7.94 tons per year, during which the mangrove rate of decline reached 120.6 ha per year.

Extremely high sedimentation, particularly in the western area of Segara Anakan, has resulted in a change in salinity regime, which is now low. Though mangrove species, such as *Avicennia*, *Rhizophora*, and *Bruguiera*, have a reasonably wide tolerance for salinity limits (Kodikara et al., 2018), because of the increasing and hardening substrate their optimal growth is affected. This is in contrast to the woody vine *Derris trifoliata* and woody groundcover species *Acanthus ebracteatus* and *Acanthus ilicifolius*, which easily grow in the low salinity range, sunny area (Ball, 2016). This occurs especially in the western part of Segara Anakan, where the three understorey species were dominant (Ardli & Yani, 2020; Nordhaus et al., 2019; Koswara et al., 2017). The changes in salinity regime and hardness substrate promote plant mortality, resulting in a favorable habitat for understorey species such as *Derris* and *Acanthus* to grow.

In addition, the changes in land cover and use will have an impact on socioeconomic factors. The changes in livelihood from fisherman to farmer are highly correlated with decreasing water bodies and mangrove areas as well as growing farmland. Fishing, for example, was the primary source of income for 56 percent of inhabitants in the western region in 2009, but it dropped to 44 percent in 2019. It implies a 12% shift in farmer and labor costs. The changes in livelihoods are a strategy in activities for income generation (Malik et al., 2017; Munthali et al., 2020; Ligate et al., 2018; Khatiwada et al., 2017; Gils et al., 2019).

CONCLUSIONS

This research emphasized the critical connections between land cover change, siltation impacts in mangrove ecosystems, and socioeconomic factors. Mangroves and water bodies declined between 2009 and 2019, resulting in changes to farmland and human settlements. As a result, human livelihoods that were formerly based on fishing have shifted to farming. Massive siltation has altered the biomass, structure, and composition of mangrove vegetation, particularly in the western area of Segara Anakan, where the shrubs Acanthus and Derris are dominant. The Segara Anakan lagoon system mangrove conditions have continued to worsen, exacerbated by heavy siltation and a poorly managed mangrove program.

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