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Spatio-Temporal Annual Changes of Mangrove Vegetation Coverages in Porong Estuary Based on Sentinel-2 Imagery

Herlambang Aulia Rachman[1*], Abd Rahman As-Syakur[2]
[1]Prodi Ilmu Kelautan Fakultas Pertanian Universitas Trunojoyo Madura
Jl. Raya Telang No 02 Kamal Bangkalan Madura 69162 Jawa Timur
[2]Prodi Ilmu Kelautan Fakultas Kelautan dan Perikanan Universitas Udayana
Kampus Bukit Jl. Raya Kampus Unud Jimbaran Kuta Selatan 80361 Bali
[*]herlambang.rachman@trunojoyo.ac.id
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Abstrak

Mangrove merupakan ekosistem khas pesisir dengan produktivitas tinggi dan memiliki sejumlah jasa ekosistem. Namun ekosistem ini rentan terutama di daerah perkotaan karena perubahan penggunaan lahan dan penebangan liar. Sidoarjo merupakan salah satu kawasan perkotaan yang paling berkembang di Provinsi Jawa Timur, dengan ekosistem mangrove yang tersebar di sepanjang muara Porong. Muara ini juga merupakan lokasi semburan lumpur dari bencana lumpur Lapindo yang terkenal sejak tahun 2006. Penelitian ini bertujuan untuk menganalisis perubahan tutupan mangrove di sekitar muara Porong dengan menggunakan data citra satelit. Fractional Vegetation Coverage (Fv) digunakan untuk mengkuantifikasi perubahan tutupan vegetasi mangrove di Hutan Mangrove dari tahun 2015 – 2021. Hasil penelitian menunjukkan bahwa terjadi perubahan tutupan mangrove di daerah penelitian. Tingginya perubahan dari lo vegetasi coverage (LVC) menjadi Full Vegetation Covarege (FCV) seperti yang ditemukan di muara Sungai Porong. Kondisi ini kemungkinan disebabkan oleh proses sedimentasi akibat semburan lumpur dari bencana gunung api.

Kata Kunci *: Fractional Vegetation Cover (FVC); mangrove, muara porong, Sentinel-2*

Abstract

Mangrove is a typical coastal ecosystem with high productivity and has a number of ecosystem services. However this ecosystem is vulnerable particularly in urban areas due to land use change and illegal logging. Sidoarjo is one of the most developed urban area in the East Java Province, with mangrove ecpsystem scattered along the Porong estuary. This estuary is also the location of mudflow from the famous Lapindo mud disaster since 2006. This study aims to analyze the changes of mangrove coverages around the Porong estuary using satellite imagery data. Fractional Vegetation Coverage (Fv) was used to quantify the changes of mangrove vegetation coverage of Mangrove Forest from 2015 – 2021. The results show that there is a change in mangrove coverages in the area of study. The high change from lo vegetation coverage (LVC) to Full Vegetation Covarege (FCV) as found in the mouth of Porong River. This condition maybe caused by sedimentation process due to mudflow from volcanic disasters.

Keywords ***:*** *Fractional Vegetation Cover (FVC); mangroves, porong estuary, Sentinel-2*

INTRODUCTION

Mangrove ecosystem is one of the largest forest ecosystems in the tropical and sub-tropical region. This ecosystem mostly grows in the intertidal zone and adjacent also frequently distributed along estuarine or riverside near the coastal areas. Mangroves are known to have high ecosystem services such as feeding and nursery ground for many marine organisms, carbon sequestration, protecting coastline from erosion or big ocean waves, and filtering the sediment before enter the sea (Analuddin et al., 2020; da Silva et al., 2018; Pennings et al., 2021; Yuanita et al., 2021). The land conversion due to human activities or natural disaster are the most significant threats for the mangrove forest ecosystems and have severe impact in changes of mangrove coverages (Hamilton, 2013; Mondal et al., 2021). The information about changes in spatio-temporal distribution of mangrove coverage is the critical component to estimate how much the changes value.

Satellite imagery is an one of the most advance technology to monitor the change of vegetation cover due to their temporal resolution and timely

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updated. In recent decades, numerous studies have been conducted using the the application of remote sensing combining with GIS to analyze the changes of vegetation coverage in spatio-temporal scales. The mapping of the mangrove vegetation coverage is very challenging because mostly location in remote areas and facing the high cloud cover in tropical areas. Currently, the free access satellite imagery with moderate resolution (10 – 30 m) namely Landsat and Sentinel have been widely used in various studies to quantify the change of mangrove coverages (Baloloy et al., 2020; Pimple et al., 2018; Quyet et al., 2021). In recent years, the used of cloud computing for remote sensing analyse has been increase such as Google Earth Engine (GEE). This tools allow open access platform with high performance to analyse the spatial data for earth observation both of regional or global studies (Pimple et al., 2018).

This study located in Porong Estuary, known as the largest river-estuarine area in East Java Province. The study area is also located close to the famous mud-volcanic disaster in Indonesia namely "Lumpur Sidoarjo" (LUSI). Some studies have analysed the sediment load from the LUSI has generated high sedimentation rate on the Porong estuary and the adjacent areas (Beselly et al., 2021; Sidik et al., 2016). Hasil penelitian sebelumnya menunjukkan bahwa terjadinya akresi (penambahan sedimen) pada bagian muara sungai menyebabkan pertambahan dari pertumbuhan mangrove pada wilayah pesisir (Sidik et al., 2016). In previous studies, the data used was mostly based on field data collection. So in this study, an analysis will be conducted using remote sensing data to see the rate of change in mangrove area based on the FVC value. It is expected that the results of this study can show comprehensively which locations have experienced changes in mangrove area, especially around the Porong River Estuary.

METHODS

Study Area

This study was conducted in Porong Estuary, administratively located at Sidoarjo Regency, East Java (Figure 1). Mangrove ecosystems grow along the river to estuaries and towards the sea. Furthermore, there are many aquaculture ponds in this area for various commodities such as shrimp, milkfish, etc (Noor & Wulandari, 2018). This river is the largest river in Sidoarjo Regency and is the main outlet of the Lapindo Sidoarjo Mudflow (LUSI) disaster that has occurred since 2006. The high sediment load flow at this location is thought to cause high sedimentation at the mouth of the river. Which is the growth of Mangrove Forest was influenced by the dominant substrat by sediment from the river flow. Where mangrove growth is significantly influenced by substrate conditions which are dominated by sediments from river flow.

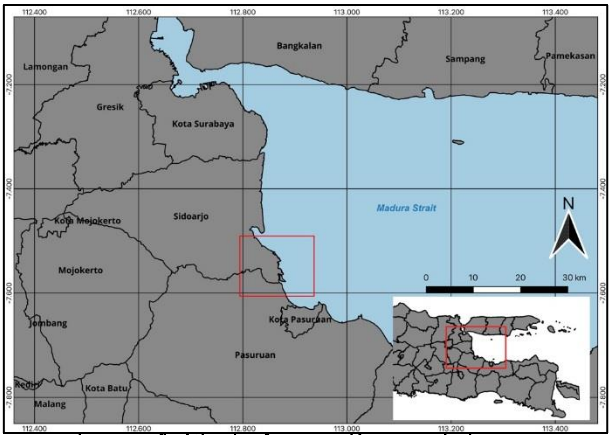

Figure 1. Study Area in Porong Estuary

Data

In this research, we used the Sentinel-2 imagery, developed by European Space Agency (ESA). This satellite has a multispectral imager instrument (MSI) with 13 spectral bands spectral in visible and infrared channel with various spatial resolution (10 m, 20 m, 60 m). This study mainly using Sentinel-2 Imagery level 1C Top of Atmosphere (TOA) reflectance products from 2015 – 2020. To obtain annual changes of mangrove vegetation cover, we created annual composites of all images using median reflectance values after cleaned from cloudy or no-data pixels. We analysed and obtained the dataset using Google Earth Engine (GEE) image collections. This tool has high performance to image processing for land use/land cover classification with large and long temporal scales. Detail of this imagery were listed in Table 1.

Table 1. Sentinel-2 band list

Band	Central Wavelength (nm)	Spatial Resolution (m)
B2 (Blue)	490	10
B3 (Green)	560	10
B4 (Red)	665	10
B5 (Red Edge 1)	705	20
B6 (Red Edge 2)	740	20
B7 (Red Edge 3)	783	20

Band	Central Wavelength (nm)	Spatial Resolution (m)
B8 (NIR)	842	10
B8A (Red Edge 4)	865	20
B11 (SWIR1)	1610	20
B12 (SWIR 2)	2190	20

Image Analysis

This study applied the Normalized Difference Vegetation Index (NDVI) to determine the level of vegetation cover. NDVI is the most widely adopted vegetation index and have high sensitivity in particular to vegetation coverage (Peng et al., 2012). Detailed calculation of the NDVI expressed as the normalize difference between the spectral reflectance of Near-Infrared (NIR) band and red band. In the case of Sentinel-2 imagery, the equation of NDVI defined as :

$$NDVI = \frac{B_8 - B_4}{B_8 + B_4}$$

Where B8 is the NIR Band channel of Sentinel 2 imagery, and B4 defined as Red Band. Furthermore, in this study, we analysed changes in coverages of mangrove using Fractional Vegetation Index (Fv). The method assumes that the pixel consist two component, soil and vegetation. The Fv was expressed as:

$$Fv = \frac{NDVI - NDVI_s}{NDVI_v - NDVI_s}$$

Where NDVIs define as the NDVI value of pure non vegetation pixel and NDVIv is pure of vegetation pixel. The value of NDVIv is the maximum value of NDVI and define as the high vegetation cover. Otherwise, the minimum value of the NDVIs is defined as the non-vegetation cover, it could be that the value represents soil, water, or buildings that are not vegetation. The result of Fv will devided into 5 classes based on their value, Full Vegetation Coverage (FVC, 0.9 to 1), High Vegetation Coverage (HVC, 0.5 to 0.9), Medium Vegetation Coverage (MVC, 0.26 to 0.5), Low Vegetation Coverage (LVC, -1 to 0.6) and No Coverage (NC) (Peng et al., 2012). For the analysis of changes, an overlay is performed based on the class findings, which are then determined to be 1 - 4 stages of decline (i.e., 2016 is FVC and 2021 is LWC, so the result is 3 step decrease).

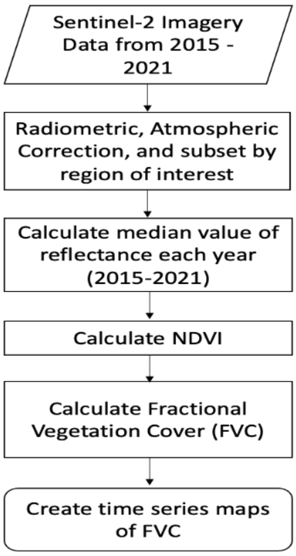

Figure 2. The Flowchart of calculate Fractional Vegetation Cover (FVC) by Sentinel-2 Imagery

RESULTS AND DISCUSSION

In this FVC analysis, the vegetation index data used was based on calculations from NDVI. The results show that Sentinel-2 satellite imagery can well observe changes in mangrove vegetation cover in the Porong River. In general, there are several locations, especially those right at the mouth of the river and the beach, that experience a significant increase in FVC area. Figure 3 show the results of the Fv calculation based on Sentinel 2 imagery from 2015 to 2021. The results of this calculation are divided into five categories, ranging from No Coverage (NC) to Full Vegetation Coverage (FVC). The result show that mangrove forest with FVC in Porong Estuary mainly distributed over two adjacent areas, in the northern and southern parts of Porong River. The annual composite have increased slightly during 2015 to 2021, especially in the part closest to the coast. The spatial analysis of the changes the mangrove forest more detail in the following paragraph (Fig 4 and Fig 5).

In 2015, mangrove coverage with FVC classes are mainly found along the shore, with a total area withof FVC reach 712.74 ha. The spatial distribution of FVC class mostly in the near of the sea and slightly in the riverbank. In this period, the estuary of the Porong River was classified as NC (No Coverage) and LVC (Low Vegetation Cover). On the inside, behind the mangrove area along the coast, the most dominant class is LVC with the majority

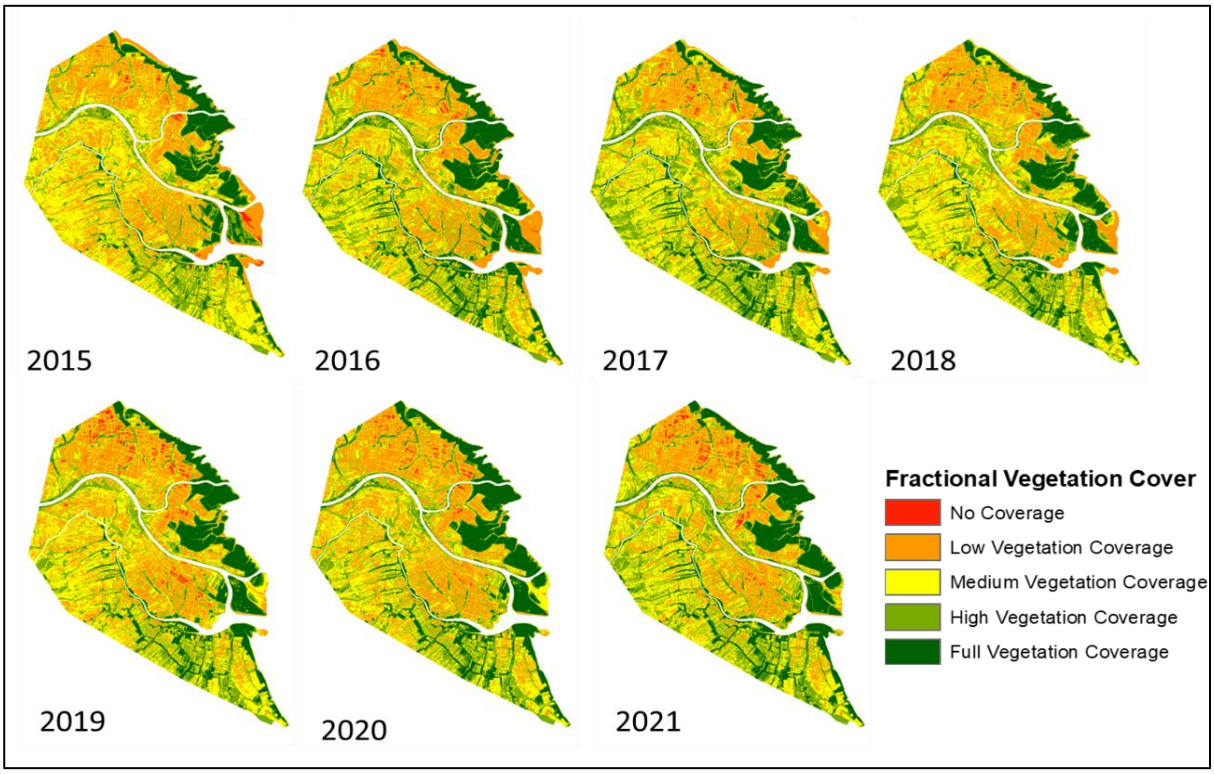

Figure 3. The annual variaton of Fractional Vegetation Cover (Fv) of Mangrove Vegetation in Porong Estuary

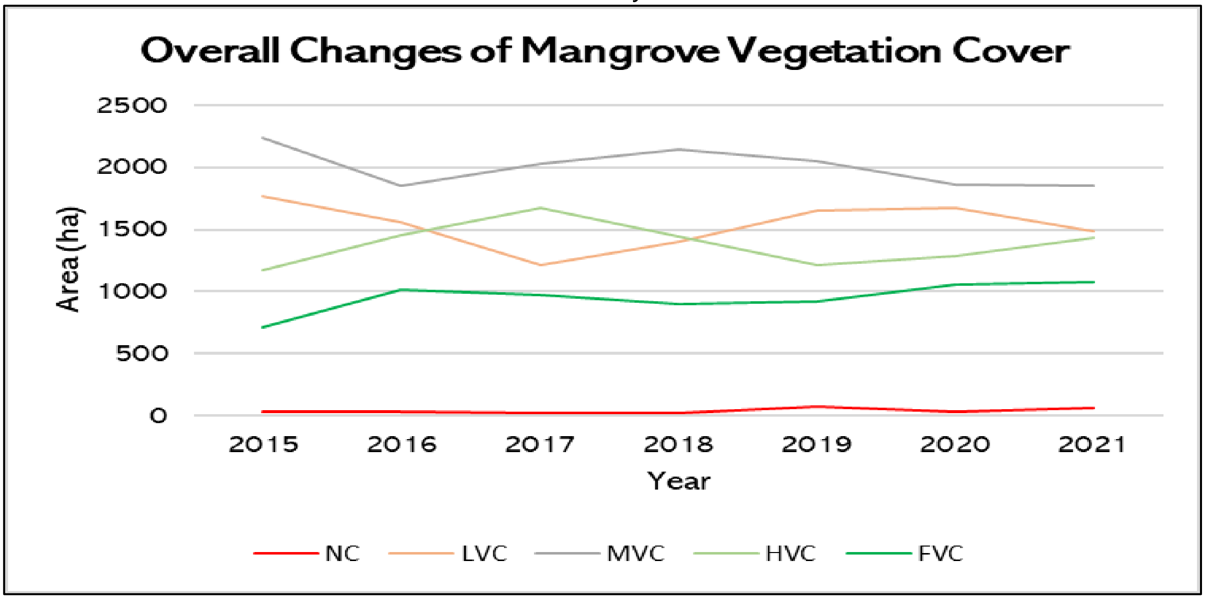

Figure 4. Overall changes of Fv in Mangrove Forest during 2015-2021

being fish ponds. For the HVC class, the dominant distribution is along the river the south side of the Porong River. While in northern part, the dominant categories are LVC and NC, where the landuse of this area mostly are fishponds. For several locations that have MVC categories, most of them dominant on the south side closed to the highway and this area mostly as settlement. During the 2016 to 2017, the changes of the mangrove coverage was found mostly in front of the river estuary. In this period, the areas with classified in NC and LVC has changed to MVC and HVC. This demonstrates that mangroves began to grow from propagules to saplings during this time period. Moreover in 2018-2019, mangrove coverage in the north side of Porong Estuary has increased significantly.

According to Figure 3, each class has changed in total area on average from 2015 to 2021, except for the FVC class, which grows every year. Meanwhile, no significant increase in vegetation cover was seen in the NC category over the research period. The LVC class revealead a decreasing area approximately 550.7 ha from 2015 to 2017, then an increase of 463.01 ha in 2020. The 2017 decline was due to conversion into higher-level classes (MVC, HVC, and FVC), which increased compare to the total area. The opposite condition occurred in 2019 where the HVC class experienced an increase while other classes experienced a decreased. Throughout the research year, the FVC class tends to increase every year (except 2018), where the total change reaches 367 ha.

Figure 4 shows the changes of Fv classes of mangrove vegetation during periods of 2015 – 2021. Based on analysis using Fractional Vegetation Coverages (Fv) show that the Mangroves vegetation slightly increase during the periods. Significant changes were found in areas near the coast either in the north or near river mouths. On the north side, mangrove cover changes increased by three steps from LVC to FVC. Similar conditions exist in nearby river mouth and Delta, which are undergoing a transition from LVC to FVC (3 step increase). Total the areas that convert from LVC to FVC was about 109.86 ha. In the south side, the 3 step increase of Fv class dominant occurred along the coast. For locations further from the coast, particularly in the north side, most of them experienced the Fv class decreased with an average of 1 to 3 decrease steps. Based on visual interpretation using true color images (RGB), the ponds are major interior feature, indicating a reduction in vegetation cover from LWC in 2015 to NC in 2021.

Table 2. Coverages change detection (ha) matrix (2015 – 2021)

Fv Class		2021					
		NC	LVC	MVC	HVC	FVC	Total
2015	NC	**5.12**	18.08	4.96	3.40	2.34	33.93
	LVC	58.23	**1030.58**	469.28	91.90	109.86	1759.86
	MVC	1.14	367.36	**1136.26**	668.30	59.89	2232.97
	HVC	0.22	43.71	188.05	**596.09**	339.04	1167.13
	FVC	0.02	23.56	46.47	73.81	**568.71**	712.58
	Total	64.75	1483.32	1845.03	1433.52	1079.86	**5906.50**

To identify the converted class and its quantity, a changes matrix in Table 2 was generated from the images in Figure 3. The diagonal section was described as unchanged of Fv classes. The value above the diagonal define as the increasing steps and above as the decreasing steps. This matrix demonstrates that MCV is the category of the largest Fv with no change in area (1136.26 ha). Based on visual interpretation, the dominant landcover of MVC was the settlement and agriculture areas. The maximum (increase) change was found in MVC to HVC (1 steps) with 668.30 ha and LVC to MVC (2 Steps) with 469.28 ha. Meanwhile, the changes reached three steps of progression (LVC to FVC and NC to HVC), approximately about 112 ha. The dominant changes that reach 3 and 4 steps occur in coastal areas (Fig 3). The most extensive decline category occurred in the transition from LVC to MVC (1 step) with 367.36 ha and MVC to HVC (1 step) with 188.05 ha. Meanwhile, the reduction that reached three stages (FVC to LVC and HVC to NC) was only 24 ha. Changes in mangroves converted into fishpond areas as majority of the decreasing steps.

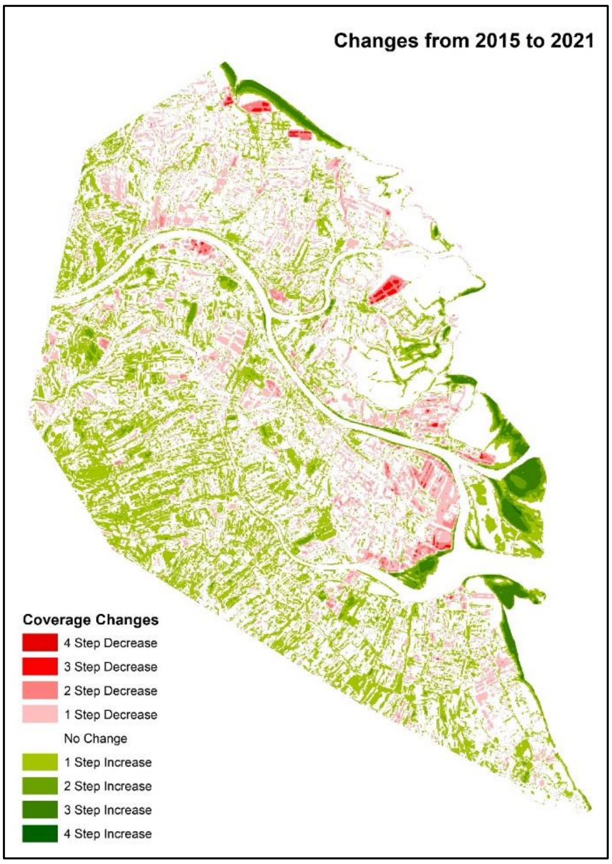

Figure 5. The changes of Fv during 2015-2021

In general, the distribution of mangrove coverage based on visual interpretation in Porong Estuary are distributed over the Delta in estuary and along the river. This research was detecting the changes in mangrove coverages based on Fractional Vegetation Coverages (Fv) from 2015-2021 using Sentinel-2 imagery and analysed by GEE cloud computing. Based on this method, it was found that several location experienced changes in the extent of mangrove coverage, especially in the Delta and North side. The increase in area may due to the sediment discharge from the Porong River (Beselly et al., 2021; Sidik et al., 2016, Hidayah et al., 2023). The sedimentation in coastal areas causes the growth area of mangrove have additional locations. The sediment supply from river flows promotes mangrove growth by providing substrates and nutrients necessary for the development of mangrove forests. (Lovelock et al., 2017). Based on previous research, the presence of high sedimentation at this location increased the growth rate of Avicennia sp (Sidik et al., 2016). This species know that one of the mangroves with a high tolerance for salinity. Besides the increase, some location points such as near settlements and ponds experienced a decrease in mangrove cover. The conversion of land into ponds and the expansion of residential areas are the causes of this condition. In most cases, human activities such as cultivation, agriculture, and settlement exacerbate the transition from coastal to inland (Mondal et al., 2021). As is well known, Sidoarjo Regency is a sub-urban area that serves as a buffer city for Surabaya, the major city in East Java.

CONCLUSIONS

Sentinel-2 images can analyze changes in mangrove cover in the Porong River Estuary between 2015 and 2021. According to the findings of the analysis, the primary class cover change in the area near the coast was from rare vegetation (NC - MVC) to dense vegetation (HVC and FVC). There is also a decrease in the class of vegetation coverages where mangroves are converted to ponds in some locations. As a future research recommendation, the computation of Fv not only uses NDVI but also other vegetation index variables to reach the findings. The necessity for field verification of mangrove species developing in new sites may also necessitate additional identification.

DAFTAR PUSTAKA

Analuddin, K., Kadidae, L. A. O. D. E., Ode, L. A., Yasir, M., Septiana, A., Sahidin, I., Syahrir, L. A., Rahim, S., Ode, L. A., Fajar, A., & Nadaoka, K. (2020). Aboveground biomass , productivity and carbon sequestration in Rhizophora stylosa mangrove forest of Southeast Sulawesi , Indonesia. *Biodiversitas*, *21*(3), 1316–1325. https://doi.org/10.13057/biodiv/d210407

Baloloy, A. B., Blanco, A. C., Rhommel, R., Ana, C. S., & Nadaoka, K. (2020). Development and application of a new Mangrove Vegetation Index (MVI) for rapid and accurate mangrove mapping. *ISPRS Journal of Photogrammetry and Remote Sensing*, *166*, 95–117.

Beselly, S. M., Wegen, M. van der, Grueters, U., Reyns, J., Dijkstra, J., & Roelvink, D. (2021). Eleven Years of Mangrove – Mudflat Dynamics on the Mud Volcano-Induced Prograding Delta in East Java , Indonesia: Integrating UAV and Satellite Imagery. *Remote Sensing*, *13*, 2–28. https://doi.org/https://doi.org/10.3390/rs13061084

Da Silva, V. E. L., Teixeira, E. C., Batista, V. S., & Fabre, N. N. (2018). Spatial distribution of juvenile fish species in nursery grounds of a tropical coastal area of the south-western Atlantic. *Acta Ichthyologica Et Piscatoria*, *48*(3), 9–18. https://doi.org/10.3750/AIEP/02299

Hamilton, S. (2013). Assessing the role of commercial aquaculture in displacing mangrove forest. *Bulletin of Marine Science*, *89*(2), 585–601.

Hidayah, Z., Rachman, A.R & As-Syakur, A.R. (2023). Pemetaan kondisi hutan mangrove di kawasan pesisir Selat Madura dengan pendekatan Mangrove Health Index memanfaatkan citra satelit Sentinel-2. *Majalah Geografi Indonesia*, 37(1), 84-91.

Lovelock, C. E., Sorrell, B. K., Hancock, N., Hua, Q., Lovelock, C. E., Sorrell, B. K., Hancock, N., Hu, Q., & Swales, A. (2017). Mangrove For Development on Shore in New Zealand. *Ecosystems*, *13*(3), 437–451. https://doi.org/10.1007/S10021-010-9329

Mondal, B., Kumar, A., & Roy, A. (2021). Spatio-temporal pattern of change in mangrove populations along the coastal West Bengal , India. *Environmental Challenges*, *5*(September), 100306. https://doi.org/10.1016/j.envc.2021.100306

Noor, M. T., & Wulandari, U. (2018). The density and diversity of mangrove species relation to the sustainability of fisheries resources in Sidoarjo Regency. *International Journal of Fisheries and Aquatic Research*, *3*(2), 8–12.

Peng, J., Liu, Y., Shen, H., & Han, Y. (2012). Vegetation coverage change and associated driving forces in mountain areas of Northwestern Yunnan , China using RS and GIS. *Environmental Monitoring and Assessment*, *184*, 4787–4798. https://doi.org/10.1007/s10661-011-2302-5

Pennings, S. C., Glazner, R. M., Hughes, Z. J., Kominoski, J. S., & Armitage, A. R. (2021). Effects of mangrove cover on coastal erosion during a hurricane in Texas, USA. *Ecology*, *102*(4), 1–8. https://doi.org/10.1002/ecy.3309

Pimple, U., Simonetti, D., Sitthi, A., Pungkul, S., Leadprathom, K., Skupek, H., Som-ard, J., Gond, V., & Towprayoon, S. (2018). Google Earth Engine Based Three Decadal Landsat Imagery Analysis for Mapping of Mangrove Forests and Its Surroundings in the Trat Province of Thailand. *Journal of Computer and Communications*, *6*, 247–264. https://doi.org/10.4236/jcc.2018.61025

Quyet, N., Hoa, N. H., Nguyen, V. D., & Quang, P. D. (2021). Detecting Changes in Mangrove Forest in Mangrove Forests From Multi-Temporal Sentinel-2 Data in Tien Yen District Quang Ninh Province. *Management of Forest Resources and Environment*, *11*, 1–13.

Sidik, F., Neil, D., & Lovelock, C. E. (2016). Effect of high sedimentation rates on surface sediment dynamics and mangrove growth in the Porong River , Indonesia. *Marine Pollution Bulletin*, *107*(1), 355–363. https://doi.org/10.1016/j.marpolbul.2016.02.048

Yuanita, N., Kurniawan, A., Muhamad, I., & Maureza, F. (2021). A physical model simulation of combination of a geo-bag dike and mangrove vegetation as a natural coastal protection system for the Indonesian shoreline. *Applied Ocean Research*, *108*(January), 102516. https://doi.org/10.1016/j.apor.2020.102516