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Recent update of mangrove carbon-stock estimation using vegetation index analysis at Youtefa Bay, Jayapura, Papua, Indonesia

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ABSTRACT

The vegetation indices are commonly applied in carbon stock estimation. Vegetation index transformation, which uses several satellite imagery bands, could highlight the vegetation's characteristics. In situ method in measuring mangrove carbon stock does have a high accuracy value. However, this method is ineffective considering the area and terrain are challenging that consumes time and cost. Remote sensing technology offers a solution to these conditions. This study aims to determine the best vegetation index used in mapping mangrove carbon stock at The Youtefa Bay, Papua, Indonesia. The method used was by applying a Remote sensing approach with several indexes used as well as Difference Vegetation Index (DVI), Enhanced Vegetation Index (EVI), Normalized Difference Vegetation Index (NDVI), and Soil Adjusted Vegetation Index (SAVI). The results showed that the best vegetation index for estimating the mangrove species' carbon stock *Bruguiera cylindrica* and *Rhizophora apiculata* was obtained from the NDVI index with R^2 value were 0.5838 and 0.7149, respectively. While the *Rhizophora mucronata* species was obtained by using the EVI index with an R^2 of 0.578. The total biomass of carbon stock in the *Bruguiera cylindrica* species based on image extraction was 613.51 tons for 37.92 ha, *Rhizophora apiculata* was 483.17 tons for the area of 98 ha, and *Rhizophora mucronata* was 377.03 tons for the total area of 77.31 ha.

Key words : *Mangroves, Carbon stock, Vegetation index*

Introduction

Mangrove forest is coastal ecosystems that have a significant role in absorbing and storing carbon (Xiong *et al.,* 2018) denoted by its it is ability to absorb and store large amounts of organic matter (Twilley *et al.,* 1992). Mangroves in the tropics area are estimated to be able to store carbon ±1023 mg C/ha (Donato *et al.,* 2011). They reduce CO_2 through the sequestration mechanism or absorption of CO_2 from the atmosphere, and then bound and stored as biomass (Kepel *et al.,* 2017; Asadi *et al.,* 2019). Thus, conservation of mangrove forest can be a good strategy to combat the global warming (Prasita *et al.,* 2019).

Indonesia has 22.6% of the world's total mangrove area, which is around 3,112,989 ha (Donato *et al.,* 2011). Mangrove forest ecosystems in Indonesia can absorb carbon in the atmosphere around 67.7% $MtCO_2$/year (Sedelie *et al.,* 2011). The largest distribution of mangroves in Indonesia is in Papua, with an area of 1,350,600 ha or nearly a third of the national mangrove area. (Noor *et al.,* 2006; Wahyudi *et al.,* 2018). One of the potential mangrove forests in Papua is located in Youtefa Bay at Jayapura.

To date deforestation of mangrove forests is a problem in this area. There was a significant decrease in the mangrove area of 159.33 ha within 23 years.Comparative data recorded in 1994 and 2017 shows a reduction in mangrove area from 392.45 ha to 233.12 ha (Hamuna *et al.*, 2017). Considering the importance of mangrove forest for carbon absorption, the reduction of mangrove area in the Youtefa Bay may directly influence the carbon stock in this area. Thus, it is very crucial to monitor the carbon stock update in the Youtefa Bay.

The use of the *in situ* method to measure mangrove stock carbon has high accuracy. However, this method was ineffective given the rugged terrain to reach and spent a lot of money and time (Hirata *et al.*, 2014). Remote sensing technology offers a solution to this problem. The vegetation index is a common and widely used method for assessing and mapping land cover and carbon stocks in vegetation (Wicaksono *et al.*, 2016; Prasetyo *et al.*, 2019; Munawar *et al.*, 2020; Yulianto *et al.*, 2020). Each vegetation index has different characteristics that determine the accuracy value in predicting land cover and carbon stocks (Mitra *et al.*, 2011; Prasetyo *et al.*, 2019; Rajaguguk *et al.*, 2018). Several studies have found the use of remote sensing approaches.

Huete *et al*. (1997) analyzed several indices (NIR/RED, EVI, SAVI, and NDVI) to determine biomass estimation accuracy using Landsat ETM+ and MODIS. This study found that the NDVI saturated in high biomass areas such as Amazon or tropic forests, while EVI was sensitive to canopy variations. Another study using remote sensing data to biomass estimate is based on canopy density was conducted by Frananda *et al.* (2015). The study compared vegetation indices (NDVI, SR, TVI, RVI, SAVI, and EVI) to assess carbon stock mangrove in the Segoro Anak, Alas Purwo Park, Banyuwangi, East Java. The result showed that the EVI has the highest accuracy for mapping mangrove carbon stock. Pandey *et al.* (2018) conducted estimates of biomass mangroves in Bhitarkanika India mangrove forest used NDVI and EVI index. The research provided biomass assessment found slightly better when using the EVI compared to NDVI derived biomass.

Concerning various remote sensing-based vegetation indexes for carbon stock estimation mentioned in the previous studies. this study applies several vegetation indices, including the Vegetation Difference Index (DVI), the Enhanced Vegetation Index (EVI), the Normalized Difference Vegetation Index (NDVI), and the Soil Adjusted Vegetation Index (SAVI), to produce the best vegetation index applied in mangrove carbon stock mapping in the Youtefa Bay.

Methodology

Study Area

Youtefa Bay is located in Abepura Regency, Jayapura, Papua, and has a Nature Tourism Area's status, with an estimated area of 1,650 ha.Youtefa Bay is at coordinates 02°34'32 "- 0238'25" South Latitude and 14041'11 "- 140°44'25" East Longitude, with the southern and eastern parts dominated by mountains and the central and northern regions, are lowland (BKSDA, 2007). The Youtefa Bay area consists of three villages, namely Tobati (South Jayapura Regency), Enggros (Abepura Regency), and Nafri (Abepura Regency). Besides, four rivers disembogue into Youtefa Bay, such as the Acai River, the Siborgoni River, the PTC Entrop River, and the Hanyaan River (Jayapura Regional Environmental Agency, 2008).

Methods

Preprocessing

This study used the Sentinel-2A level 1C satellite recorded on October 3, 2019. Level 1C shows that the image passed a geometric correction, while the radiometric correction was at the TOA (Top of Atmosphere) Reflectance level (ESA, 2015). Therefore, it is necessary to make a further correction, such as the BOA (Bottom of Atmosphere) reflectance.

BOA correction uses the DOS (Dark Object Subtraction) Method to eliminate atmospheric disturbances and cleanup digital interpretation interference (Pratama *et al.*, 2019). This method's choice was due to the correction parameters and the atmospheric effect model were unknown, both of which could assume atmospheric conditions during image acquisition. DOS uses the entire image reflectance value approach minus the darkest object's reflectance value (dark object).

It assumed that the darkest object is a body of water that has a value of 0 (zero), so if the minimum value in the image is not yet at a value greater than or less than 0 (zero), then the minimum value used as a deduction value (Zhang *et al.*, 2010)

$\rho_s = \rho_{TOA(\lambda)} - minimun\ value_{TOA}$

Where ρ_s is the surface reflection value at the atmospheric correction level, and $\rho_{(TOA\lambda)}$ is the reflection value at the TOA reflectance correction level.

Processing

A vegetation index is a form of spectral transformation applied to multichannel imagery to highlight aspects related to vegetation density, biomass content, Leaf Area Index (LAI), or chlorophyll concentration. This definition can practically conclude that the vegetation index is used to present or carry out analyzes related to vegetation phenomena (Danoedoro, 2012). The index used in this study were the Vegetation Difference Index (DVI), the Enhanced Vegetation Index (EVI), the Normalized Difference Vegetation Index (NDVI), and the Soil Adjusted Vegetation Index (SAVI).

1. Difference Vegetation Index

   DVI = NIR – RED (Tucker, 1979)

2. Enhance Vegetation Index

   $EVI = G \frac{(NIR - RED)}{L + NIR + (RED * C1) + (BLUE * C2)}$ (Huete, 2002)

G = Gain faktor (2.5); C1 and C2 = Coefficient correction for atmospheric aerosol scattering (6.0 and 7.5); L= Soil adjustment factor (1.0).

3. Normalized Difference Vegetation Index

   $NDVI = \frac{NIR - RED}{NIR + RED}$ (Rouse *et al.*, 1973)

4. Soil Adjusted Vegetation Index (SAVI)

   $SAVI = \frac{NIR - RED}{(NIR + RED + L)} (1 + L)$ (Huete, 1988)

L= first order (L= 0.5).

Ground-Based Data

Determination of the research station was conducted by purposive sampling method, i.e., the determination/sampling technique deliberately and based on certain considerations and objectives (Sugiono, 2010). Determination and consideration were made based on the vegetation's character (homogeneous) or based on species zoning by conducting visual observations and ground checks at the research location.

Plotting sample measuring 10 m x 10 m. Retrieval field data includes measuring the stem's diameter, carried out at chest height or DBH (Diameter at Breast High). According to Darusman (2006), in general, the DBH value is 1.3 m from the ground. For plank-rooted and breath root trees, the DBH was measured by adding 50 cm from the root boundary or upper support if the last supports' size exceeds 130 cm. Each stem was measured by wrapping a measuring tape around the tree trunk, with the video straightened in all directions.

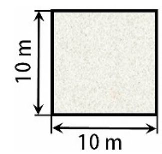

Fig. 1. The plot of field data collection

Analysis of the estimated carbon stock of mangroves is carried out using allometric models based on the species of mangrove. The allometric model is based on the regulation of the Forest Research and Development Agency P.01 / VIII-P3KR / 2012 and Krisnawati *et al.* (2012) (Table 1).

Afterward, the estimation equation for carbon stocks (National Standardization Agency, 2011) can describe as follows:

C = B x 0.47

C= Total carbon stock (kg); B= Biomass (kg); and 0.47=Coefficient factor.

Carbon Stock Modelling

Carbon stock biomass mapping was by performing regression analysis. The regression analysis used in this study was linear regression analysis. Linear regression analysis is a regression built based on a linear relationship between the independent and de-

Table 1. Allometric models of mangrove species

Species	Allometric
Bruguiera cylindrica	$B = 0.2064\ D^{2.34}$ (Komiyama *et al.*, 2005)
Rhizophora apiculata	$B= 0{,}043\ D^{2{,}63}$(Amira, 2008)
Rhizophora mucronata	$B= 0.1466\ D^{2.3136}$(Dharmawan, 2013)

B = Biomass (kg/m^2), D = tree diameter (cm)

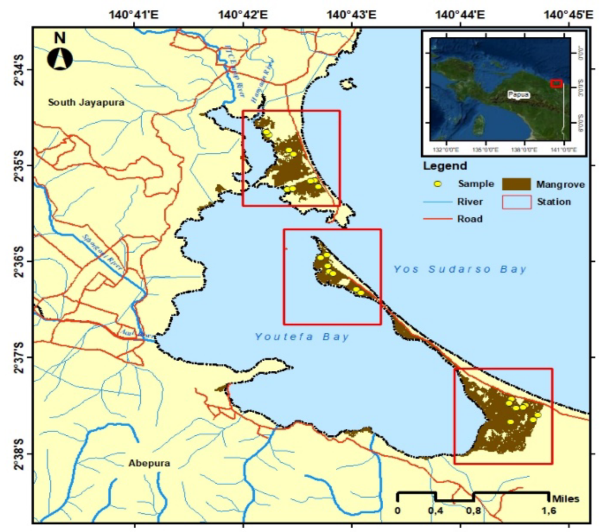

Fig. 2. Study area Identifying mangrove species was carried out directly when data collection referred to Noor *et al.* (2006). In this study, three stations were taken as observation points, i.e., Station 1 located at Enggros Village, Station 2 was at Kampung Tobati, and Station 3 was at Kampung Nafri. Each station consists of 8 observation points, with a total of 24 sampling points. The observation points are shown in Figure 2 and 3. The total number of points includes 8 points for each mangrove species studied, namely *Bruguiera cylindrica, Rhizophora apiculata, and Rhizophora mucronata.*

pendent variables. The independent variable is a variable that affects the outcome of the dependent variable. The independent variable was marked by x, and y symbol was the dependent variable (Stein, 2002).

The variable x shows the index value, and the y variable offers the biomass value of the field carbon stock. Regression analysis assessment is measured based on the results of the Coefficient of determination (R^2). The Coefficient of determination (R^2) is the value used to explain the variation between the independent and dependent variables' values. The Coefficient of determination is in the range of 0 to 1. The closer to 1 is the better and more appropriate relationship between the two variables. This case means that the dependent variable (y) is more relevant and can be explained by conditions in the independent variable (x).

The regression equation can be written as follows (Gujarati *et al.*, 2010):

$y = ax + b$

Results and Discussion

Vegetation Index Transformation

The DVI value in this study ranged from 0.4126 to 0.3376. Previous research conducted by Nguyen and Tran (2016) resulted in DVI values ranging from 0.05 to 0.30. Morz and Sovieraj (2004) produced DVI values of -1.13 to 0.46, while Mokkaram *et al.* (2015) yielded a DVI value of -0.08 to 0.12.

Richardson and Wiegland (1977) stated that the DVI value ranges from -1 to 1. The DVI value < 0 (zero) describes water bodies and clouds, while vegetation object's values range from 0.01 to 1. Referring to this theory, the range of the DVI values in this study was appropriate. All vegetation indices used in this study have been masked (cutting) from the image of non-vegetation objects. So, only vegetation objects are displayed.

The EVI value in this study ranged from 0.150596 to 0.368999. Cavanaugh *et al.* (2008) produced the EVI values from 0.1 to 0.5 to study the variability of mangrove climate. Kustandiyo *et al.* (2015), in a survey of mangrove density in Segara Anakan, Cilacap Regency, obtained EVI values ranging from -0.003 to 0.639. Pastor-Guzman *et al.* (2018) yielded an EVI of 0.25 to 0.4 in assessing changes in a mangrove forest area on the Yucatan Peninsula on the Caribbean coast. Regarding the value range of the EVI transformation, Sudiana and Diasmara (2008) explained that the index value > 0.1 indicates an increase in the degree of greenness indicated as a vegetation object. The EVI value transformation generated in this study has a lower limit value of 0.150596 or a value > 0.1, which means a vegetation object. Fensholt *et al.* (2006) stated that the index value > 0.1 indicates that the sensor maximally records vegetation objects' green value.

Huete (2002) states that the EVI value ranges from 0 to 1. This range only describes vegetation objects. If we cross-check Hatfield and Prueger's (2010) theory, which states that the EVI value ranges from -1 to 1, this value still contains non-vegetation objects such as water bodies and clouds, and soil.

In this study, the results of the NDVI index transformation ranged from 0.423671 to 0.819874. These values show the accurate description by describing the image object as vegetation (mangrove vegetation). This range of values has taken into account items other than mangrove vegetation, such as water bodies, clouds, and soil that have been removed.

NDVI's range of -1 to +1 values does not only reflect the density of vegetation. The Earth Observation System (2020) describes in more detail the scope of negative values that reflect the study object not only clouds, water bodies, and snow, but ranges close to 0 (zero) can also represent rock objects and expose the land; the range 0.1-0.3 reflects the constructed land area; and the range 0.4-1 represents vegetation objects. Mroz and Sobieraj (2004) compared the land cover index around the Vistula River, Northern Poland, using SPOT, which showed NDVI results ranging from -1 to 0.81. The same study was also conducted by Sugianthi *et al.* (2012) with Landsat TM and ETM + images, showing a range of NDVI values from 0.46 to 0.87. Forestriko (2015) conducted research related to estimating mangrove carbon stocks in the Segara Anakan Area, Cilacap, Central Java, using the NDVI index based on Landsat 8 OLI, which obtained NDVI values ranging from 0.25 to 0.6.

SAVI values are in the range of -1 to 1. The higher the value, the higher the vegetation density value. SAVI results from image processing in this study ranged from 0.297465 to 0.544993. Forestriko (2015), in an estimation survey of mangrove carbon stocks in the Segara Anakan mangrove area, Cilacap, Indonesia, with the SAVI index based on Landsat 8 OLI,

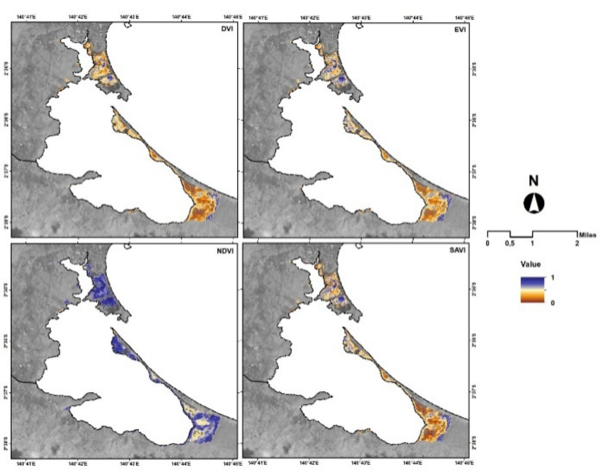

Fig. 3. Index transformation in this study, the regression analysis for the DVI index obtained the highest Coefficient of determination (R^2) for *Rhizophora mucronata* (R^2 = 0.5580), followed by *Bruguiera cylindrica* (R^2 = 0.4051) and *Rhizophora apiculata* with R2 = 0.361. The R^2 value of 0.558 for *Rhizophora mucronata* indicates that 55.80% of the carbon biomass stock in the field can be described or explained by DVI.

has a value range of 0.4 - 0.9. Ricke *et al.* (2019) produced SAVI index values ranging from 0.05 to 0.7 for carbon stock mapping studies in Kendari, Southeast Sulawesi.

Nguyen and Tran (2016) conducted a similar study using Landsat imagery in the Thai Thuy region, Thailand resulting in a SAVI index value from 0.049 to 0.21. Xia *et al.* (2020) used Landsat 8 OLI in detecting mangrove objects in the Shankou Mangrove Forest Area, Guanxi Zhuang, China, using several SAVI indexes with a value range of -0.2 to 0.7.

The regression analysis on EVI obtained the highest determination coefficient (R^2) for *Rhizophora mucronata* with (R^2 = 0.578), followed by *Rhizophora apiculata* with R^2 of 0.419, and *Bruguiera cylindrica* with R^2 of 0.4165. The R^2 value of 0.578 for *Rhizophora mucronata* means that 57.8% of the biomass carbon stock in the field can be described or explained by EVI. The regression analysis results on the NDVI index of the three types of mangroves produced the highest Coefficient of determination (R^2) for *Rhizophora apiculata* with an R^2 of 0.7149. This value means that 71.49% of *Rhizophora apiculata* biomass carbon stock in the field can be described or explained by NDVI. The R^2 value of *Bruguiera cylindrica* has an R^2 value of 0.5938 and *Rhizophora mucronata* with an R^2 of 0.3035.

The regression analysis of the SAVI relationship with each mangrove species resulted in the highest Coefficient of determination (R2) for *Rhizophora mucronata* with a value of 0.5125. These results indicate that 51.25% of the biomass carbon stock of *Rhizophora apiculata* in the field can be described or explained by SAVI. The R2 value for *Rhizophora apiculata* has an R2 value of 0.4482 and for *Bruguiera cylindrica* of 0.467.

Mapping of Carbon Stock Distribution Based on Best Index

The mapping of the distribution of carbon stock biomass in each type of mangrove was performed based on the highest Coefficient of determination (R^2) as the regression analysis results generated for each index. Based on Table 2, the highest R^2 values for mangroves *Bruguiera cylindrica* and *Rhizophora apiculata* were generated from the NDVI index with R2 values of 0.5838 and 0.7149, respectively. In contrast, *Rhizophora mucronata* was obtained from the EVI index with an R^2 of 0.578.

Bruguiera cylindrica

The biomass distribution map of carbon stock for *Bruguiera cylindrica* was generated from the regression equation, which was resulted from the relationship between NDVI and field data of *Bruguiera cylindrica*. The regression equation used was y = -4346.3x + 3513.1 with R^2 of 0.5938. The R^2 value of 0.5938 means that 59.38% of the *Bruguiera cylindrica* carbon stock in the field can be described or explained by NDVI.

Hartoko *et al.* (2014) conducted a mapping of the *Bruguiera cylindrica* using Geo Eye images resulting in an R-value of 0.729 while using Quickbird imagery resulted in an R-value of 0.813. Both values were more significant or higher than those produced in this study. Still, this result is reasonable considering the higher spatial resolution of GeoEye (0.46 m) and Quickbird (0.6 m) (Digital Globe, 2019). Sentinel-2A image with a spatial resolution of 10 m. Pratama *et al.* (2019) produced an R^2 value of 0.6677 to see the mangrove density using Sentinel-2A. This value was higher than that produced in this study. And the results of Sugianthi *et al.*'s (2012) research, which had an R^2 value of 0.6321 using Landsat TM.

In theory, Landsat processing results should be lower than that of Sentinel, considering that the spatial resolution of Landsat is 30 m lower than Sentinel's 10 m. The difference in the accuracy values due to various factors, such as technical field factors in the form of less representative sample data for the *Bruguiera cylindrica* mangrove species, can also result from atmospheric disturbances in the form of small aerosols causing disruptions in the value of image reflection (Candra *et al.*, 2016).

Figure 5 shows the modeling result's distribution showing that the mangrove species *Bruguiera cylindrica* carbon stock biomass values ranged from 12.19 to 180.855 kg. Based on the resulting map, the mangrove *Bruguiera cylindrica* has a high carbon value symbolized by red, low carbon biomass values with a green symbol. The number of distributions is tiny. The total biomass of carbon stock in the *Bruguiera cylindrica* based on image extraction was 613.51 tons, which covered 37.92 hectares.

Rhizopora apiculata

The distribution map of carbon stock biomass for *Rhizophora apiculata* species was generated from the NDVI index's regression equation. The regression analysis results between the NDVI value and the carbon stock field data yielded an equation y = -7065.1x + 5474.9. Hartoko *et al.* (2014) conducted a mapping of the *Rhizophora apiculata* using Quickbird imagery, resulting in an R-value of 0.655. These results were smaller or lower than those produced in this study, which the R^2 of 0.7149. These results may indicate that the NDVI index is more suitable for mapping *Rhizophora apiculata* than *Bruguiera cylindrica* species. It is due to the higher Quickbird's spatial resolution than the Sentinel-2A. The R^2 value of 0.7149 means that 71.49% of the *Rhizophora apiculata* carbon stock in the field can be described or explained by NDVI. By comparing with the research conducted by Pratama *et al.* (2019), this study's results are higher, considering that both used the same Sentinel-2A.

Figure 5 shows the results of carbon stock biomass modeling for the species *Rhizophora apiculata*. By

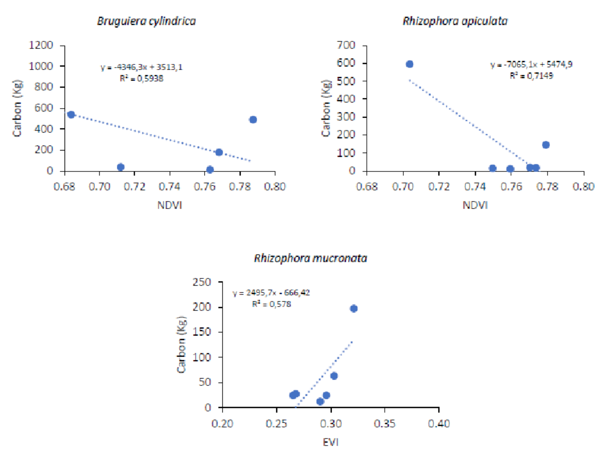

Fig. 4. The index relationship regression with each species of mangrove

Table 2. The Coefficient of determination (R^2) based on regression statistical analysis of each vegetation index and mangrove species

Mangrove Species	Coefficient Determination (R^2)			
	NDVI	DVI	EVI	SAVI
Bruguiera cylindrica	0.5938	0.4051	0.4165	0.4673
Rhizophora apiculata	0.7149	0.3610	0.4190	0.4482
Rhizophora mucronata	0.3035	0.5580	0.5780	0.5125

considering the map, the produced carbon stock biomass of *Rhizophora apiculata* was in the range of 40.845 - 41.619 kg. It indicates the value of carbon stock biomass in *Rhizophora apiculata* species was lower than *Bruguiera cylindrica*. A presume arose that the population density of *Rhizophora apiculata* was less dense than that of *Bruguierra cylindrica*. The total biomass of carbon stock in *Rhizophora apiculata* species based on image extraction is 483.17 tons with a total area of 98 hectares.

Rhizophora mucronata

The carbon stock distribution map of *Rhizophora mucronata* demonstrates a regression equation with y = 2495.7x-666.42 with an R^2 of 0.5780. The R^2 value of 0.5780 means that EVI can explain 57.80% of the *Rhizophora mucronata* carbon stock in the ecosystem. Hartoko *et al.* (2014) created a *Rhizophora mucronata* map using Quickbird with an R-value of 0.866, while Geo Eye produced an R of 0.8093. Those values were higher than those made in this study due to reasons given the higher spatial resolution of Quickbird and Geo Eye than Sentinel-2A imagery. Pratama *et al.* (2019) used Sentinel-2A and produced a higher R^2 value of 0.739 on the EVI index than this study's results.

Figure 5 shows the carbon stock distribution value produced by *Rhizophora mucronata* using EVI. The range of biomass values for the resulting carbon stock ranged from 9.104 to 67.373 kg. Station 3 had high carbon stock biomass values, which is labeled red color. The yellow to orange color symbolized the medium value found in Station 1, while Station 2 had the low value marked with green color. The total biomass of carbon stock in the *Rhizophora mucronata* based on image extraction was 377.03 tons, which covered 77.31 ha.

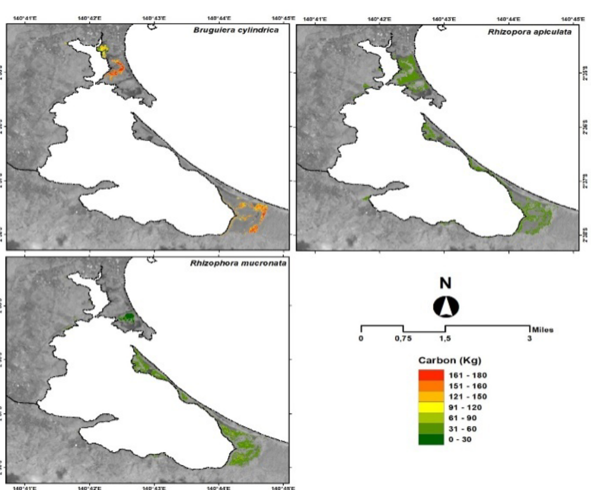

Fig. 5. Map of Mangrove Carbon Stock Distribution in each mangrove species

Conclusion

The best vegetation index for estimating carbon stock biomass for mangrove species *Bruguiera cylindrica* and *Rhizophora apiculata* was analyzed using the NDVI index with R^2 values of 0.5838 and 0.7149, respectively. In contrast, the *Rhizophora mucronata* had an R^2 of 0.578, performed using the EVI index.

The total biomass of carbon stock in the *Bruguiera cylindrica* species based on image extraction is 613.51 tons, which covered 37.92 ha, *Rhizophora apiculata* is 483.17 tons with a total area of 98 ha, and *Rhizophora mucronata* was 377.03 tons with a coverage area of 77.31 hectares.

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