International Journal on Advanced Science Engineering Information Technology

Vol.10 (2020) No. 6
ISSN: 2088-5334

Analysis of Carbon Stock Distribution of Mangrove Forests in The Coastal City of Benoa, Bali with Combination Vegetation Index, and Statistics Approach

A Siddiq[a], M Dimyati[a], A Damayanti[a,1]

[a]*Department of Geography, Faculty of Mathematics and Natural Science, Universitas Indonesia, Depok, 16424, Indonesia*
E-mail: [1]astrid.damayanti@sci.ui.ac.id

***Abstract*— Mangrove forests have an essential role in reducing the impact of global warming in the urban and surrounding areas; one of them is through carbon sequestration. Carbon sequestration is needed to reduce greenhouse gases in the atmosphere. The capacity of carbon sequestration or carbon stocks of mangrove forests can be seen from its biomass value. This study aims to produce a regression model between the vegetation index and the carbon stock of mangrove forests so that carbon stocks can be seen easily from satellite imagery and analyze their distribution in the Coastal City of Benoa, Bali. The distribution of carbon stocks was analyzed using a combination of vegetation index approach and statistical regression analysis. The vegetation index used is ARVI and EVI obtained from processing Sentinel 2-A satellite imagery in 2020. Mangrove forest biomass values are derived from allometric equations. After getting the amount of biomass, a regression model was built with a vegetation index. The model with the highest level of accuracy is used to process the image of the whole mangrove forest. This study's results indicate that the regression model formed by the ARVI has the highest level of accuracy compared to the EVI, with the best regression model for predicting carbon stock values is the exponential regression model with an ARVI vegetation index variable. High carbon stock values are distributed in almost all regions of Benoa Bay.**

***Keywords*— ARVI; Benoa Bay; carbon stock; EVI; sentinel-2.**

I. INTRODUCTION

The occurrence of climate change is increasingly a concern for human survival on earth. One of the causes of climate change is due to global warming that is happening right now. Global warming is a form of ecosystem imbalance on the earth due to increasing the average temperature of the atmosphere, sea, and land on earth [1]. Global warming occurs because of the greenhouse effect, which increases the concentration of carbon dioxide (CO2) and other gases in the atmosphere [2].

Various actions and efforts can be taken to anticipate the effects of global warming. One of them is through the carbon sequestration in the atmosphere by mangrove forests. Carbon sequestration can be seen from the carbon stock of vegetation. Apart from being a place to find food and shelter for living things, mangrove forests also function as carbon storage [3]. Available data shows that mangrove forests have a five times faster absorption rate of carbon in the air than forests on land [4], [5].

One of the problems faced by mangrove forests is its location on the coast [6]. Sloping land and usually a center of economic activity, it is possible for significant land changes to occur every year. Benoa Bay, located in Badung Regency and Denpasar City, Bali Province, is a location that is the center of economic activity in the Province of Bali as well as a mangrove conservation forest area. Changes in land use in the coastal city of Benoa Bay threaten the continuity of mangroves as well as the availability of biomass as a critical component in the biogeochemical cycle.

Mangrove forests in the Benoa Bay region are significant because they are viewed from the physical, ecological, and economic aspects [7], [8]. Benoa Bay mangrove forests have an essential role in the urban environmental urban system as the lungs of the city, given its strategic location in urban areas [9]. Its contribution to oxygen production and absorbing carbon emissions is instrumental in urban areas where there is limited green open space. Besides, the mangrove ecosystem also has a function from the biological aspect, namely maintaining the stability of the productivity and availability of natural resources in coastal areas and small islands.

In 2014 Benoa Bay became the site of a reclamation project; as a result, the stability of the mangrove ecosystem was disrupted. Disruption of the mangrove forest ecosystem positively influences the sustainability of mangrove forests.

The high sedimentation that enters the mangrove area so that it covers most of the breath roots is there cause the roots of the mangrove breath are challenging to take oxygen from the air for the process of metabolism. In reasonable condition, these roots should be seen on the surface of the soil. This incident largely destroyed the mangroves in the northern reclamation area of the Benoa Harbor project development.

In this study, we are trying to use remote sensing methods to estimate carbon stocks' value from mangrove forests. The remote sensing method is considered more productive even though its accuracy is not as good as the field's calculations. The aim of this research is: (1) Generate a regression model of vegetation index with carbon stocks of mangrove forests in Benoa Bay, Bali, which has high accuracy, and (2) Mapping the spatial distribution of carbon stocks of mangrove forests in Benoa Bay, Bali in 2020.

There are several studies that we use as references for carbon stock research of mangrove forests. Various vegetation species found in Benoa Bay [10]. Namely, *A. marina*, *C. tagal*, *R. apiculata*, *R. mucronata*, *R. stylosa*, *S. alba*, *S. caseolaris*, and *X. granatum*. The allometric equation of each species was found in a study conducted by Manafe et al. [3] and Wang et al. [11] and estimated the value of biomass in this study. Research on stock and carbon absorption estimates was conducted by Rahman et al. [12], in the mangrove forest on the Tallo River, Makassar. Hartoko et al. did the development of a biomass carbon algorithm for mangrove vegetation in Kemujan, Karimunjawa National Park, Parang Island, and Demak Coastal Region [13]. The comparison of Landsat 8 Oli and Sentinel 2-A imagery to estimate Astriani et al. carried out palm oil carbon stocks. in 2017 [14]. Manafe et al. researched the assessment of surface biomass and carbon stock in Avicennia marina and Rhizophora mucronata tree stands in the coastal waters of Oebelo, Kupang Regency [3].

Research related to the estimation of forest carbon stocks was also conducted by Widhi, utilizing Landsat 8 imagery in the Tesso Nilo national park, Riau [15]. Research conducted by Pambudhi estimated forest carbon stocks in Long Pahangai District, West Kutai Regency, using the ALOS AVNIR-2 image in 2012 [16]. A study by Wang et al. calculated biomass values using UAV-LiDAR and Sentinel 2A images in the Northeast of Hainan Island, China [11]. Yusandi and Jaya conducted an estimator model of mangrove forest biomass using Landsat 8 satellite imagery in the working area of a forest concession company in West Kalimantan [17]. Jin et al. have also studied biomass calculations using sentinel image 2A., but what is calculated is biomass from cornfields [18].

II. MATERIAL AND METHOD

A. Study Area and Data

The satellite imagery used in this study is Sentinel-2 satellite imagery in 2016 and 2020. Image Sentinel-2 has a Central Wavelength ranging from 443 nm to 2190 nm. The lowest central wavelength is band 1 with a wavelength of 443 nm, while the highest central wavelength is band 12 with a wavelength of 2190 nm. Citra sentinel-2 has 5 VNIR bands, namely band 5, band 6, band 7, band 8, and band 8a. Band 2, band 3, and band 4 are visible color bands, red in band 4, green in band 3, and blue in band 2. Further specifications can be seen in Table I.

TABLE I
SPECIFICATION SENTINEL-2 BANDS [19]

Band	Resolution	Wavelength	Description
Band 1	60 m	443 nm	Ultra-Blue (Coastal and Aerosol)
Band 2	10 m	490 nm	Blue
Band 3	10 m	560 nm	Green
Band 4	10 m	665 nm	Red
Band 5	20 m	705 nm	Visible and Near Infrared (VNIR)
Band 6	20 m	740 nm	Visible and Near Infrared (VNIR)
Band 7	20 m	783 nm	Visible and Near Infrared (VNIR)
Band 8	10 m	842 nm	Visible and Near Infrared (VNIR)
Band 8a	20 m	865 nm	Visible and Near Infrared (VNIR)
Band 9	60 m	940 nm	Short Wave Infrared (SWIR)
Band 10	60 m	1375 nm	Short Wave Infrared (SWIR)
Band 11	20m	1610 nm	Short Wave Infrared (SWIR)
Band 12	20 m	2190 nm	Short Wave Infrared (SWIR)

This research covers all mangrove forests in Benoa Bay, Bali. The mangrove forest studied is mangrove forest, which is included in the Ngurah Rai Forest Park in Benoa Bay's waters (figure 1). The territorial waters of the Benoa Bay are in the southeast part of Bali Island. The area is a semi-enclosed area with a reasonably narrow bay mouth that separates Serangan Island and Tanjung Benoa.

These waters are in the City of Denpasar and Badung Regency. Precisely southern Denpasar District, Kuta District, and South Kuta District. Also, the waters in the bay are surrounded by 12 villages, and there are six villages in Denpasar City and even six other villages in Badung Regency. Benoa Bay area is visited by many tourists, both local and foreign because this region is also one of Bali's island destinations [20]. At present, in the waters, there have also been several reclamations in the form of the reclamation of Serangan Island, Benoa Harbor, and the toll road that can significantly change the waters in the bay.

B. Variable and Data Collection

In determining the spatial distribution of mangrove forest carbon stocks, an estimation model of the value of biomass and carbon stocks of mangrove forests is needed. The model can be obtained using several variables. This study used three variables, namely the carbon stock value from the sample point and the pixel value from the vegetation index (ARVI, and EVI). We used as independent variables are pixel values from the vegetation index of ARVI, and EVI. In contrast, the estimation model of carbon stock value itself becomes the dependent variable in this study.

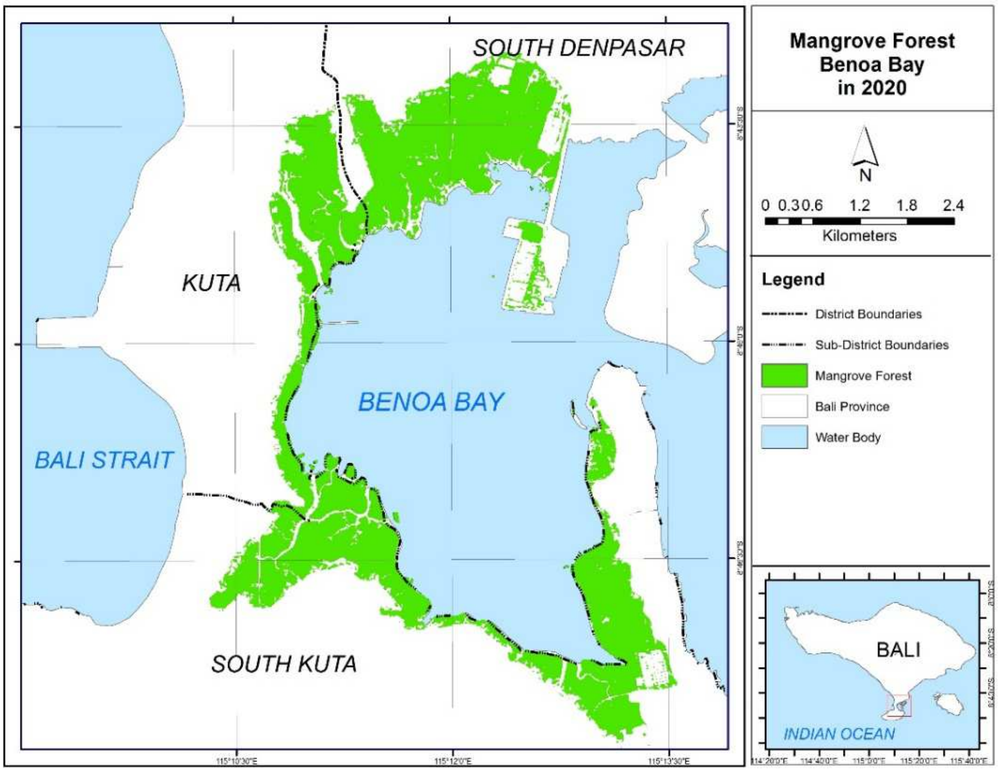

Fig. 1 Mangrove Forest Benoa Bay in 2020.

Researchers get the sample data on the measurement of carbon stocks of mangrove forests in Benoa Bay, Bali, with the method of literature study, so researchers get data on carbon stock measurement in 2016 [21]. We use measurement data from 30 sample points to create regression models and perform accuracy tests. The carbon stock value is adjusted first with the resolution and pixel value of the Sentinel-2 satellite imagery in 2016. We obtained the pixel value of the vegetation index of ARVI and EVI by processing Sentinel-2 satellite image data.

C. Mapping of Mangrove Land Cover

Land cover classification is processed using the supervised classification method. This technique is carried out by the procedure of sampling several pixels for each class/object. This sample or area of interest is used to obtain each object/class's pixel value characteristics. All pixels that are not sampled will be grouped about the pixel value of the sample characteristics taken by applying statistical calculations [22]. In this study, we differentiate land cover classifications from Mangrove and Non-Mangrove land cover. Transformation Vegetation Index

After obtaining the border of mangrove and non-mangrove forest land cover, then proceed with the calculation using the vegetation index algorithm. The vegetation index is one of the parameters used to analyze an area's vegetation state [23]. In this study, the vegetation index used is ARVI and EVI. The pixel value will be used as a unit of analysis in this study. Classification is processed by entering the ARVI algorithm and EVI algorithm in the math/raster calculator band in the QGIS software. The vegetation index will also be compared and tested for regression and correlation statistics to see the most accurate model to estimate biomass and carbon stock estimates.

The main advantage of the ARVI index is its capacity to reduce the influence of the atmosphere by using the blue band in making atmospheric corrections on the red band [24]. The ARVI formula is formulated as in equation 1. The index values range from -1 to 1, with higher pixel values corresponding to the vegetation's health and greenness.

$$ARVI = \frac{NIR - (RED - \gamma(BLUE - RED))}{NIR + (RED - \gamma(BLUE - RED))} \qquad (1)$$

γ: uses the value 1 for gamma
NIR: Reflectance value of a near-infrared channel
RED: The reflectance value of the red channel
BLUE: Reflectance value of the blue channel.

Enhanced Vegetation Index (EVI) is the development of methods for determining the vegetation index. This method to overcome the limitations of NDVI is to optimize the signal sensitivity better vegetation in areas with high biomass, increasing the level of the greenness of plants through the influence of background signal ground and canopy, and reduce the effects of atmospheric conditions on the vegetation index. EVI is more responsive to canopy structure variations, including Leaf Area Index (LAI), canopy type, plant physiology, and canopy architecture than NDVI, which generally only responds to the amount of chlorophyll [25]. EVI can be calculated using equation 2.

$$EVI = G \text{ x } \frac{(NIR - RED)}{(NIR + (C1 \text{ x } RED) - (C2 \text{ x } BLUE) + L)} \qquad (2)$$

L: calibration factor of the canopy and soil effect (0.5 value)
C1, C2: aerosol coefficients are 6.0 and 7.5, respectively
G: gain factor (worth 2.5)
NIR: Reflectance value of a near-infrared channel
RED: The reflectance value of the red channel
BLUE: Reflectance value of the blue channel.

D. Carbon Stock Modelling

The regression model formation was carried out using SPSS and Microsoft Excel applications by looking at the highest regression values between vegetation indexes, namely ARVI, and EVI with estimated biomass and carbon stock values [14]–[18]. In the SPSS application, a regression model is formed by entering the independent variables X1 (ARVI), and X2 (EVI), and entering the dependent variable Y (carbon stock sample value). Then use the "Analyze" menu on the SPSS toolbar, select "regression". The output will produce a regression model that will be tested for accuracy. In Microsoft Excel, the regression model is formed by looking at the equation with the highest regression value in the trendline scatter plot. The selected regression model was then used to map carbon stocks in the Benoa Bay region. In making carbon stock maps, we used a raster calculator tool and entered the selected regression equation with the vegetation index variable. This step was carried out on the Sentinel-2 image in 2020.

E. Accuracy Test

We use the regression model test's accuracy by comparing measurement data from field samples with predictive data or regression results. Then, we calculate the value of the deviation from the field data. RMSE (Root Mean Square Error) is calculated using equation (3).

$$RMSE = \sqrt{\frac{(y-y')^2}{n}} \tag{3}$$

y = field carbon stock
y' = carbon stock from the regression model
n = total of sample

III. RESULT AND DISCUSSION

A. Vegetation Indices Classification

The results of Sentinel-2A image processing with ARVI algorithm calculations produce pixel values ranging from 0 to 1. Then from the ARVI index, 4 classifications were formed, namely the range of values 0 – 0.3, 0.3 – 0.5, 0.5 – 0.7, and 0.7 – 1. Classification is formed to facilitate the visual interpretation of maps. In figure 2, Benoa Bay mangrove forests in 2016 were dominated by high ARVI values, i.e., dominated by values between 0.5 to 1. ARVI values that have the highest value, namely in the range of values 0.7 to 1, are in the northern and southwestern areas of Benoa Bay, precisely in the Districts of South Denpasar and South Kuta. The lowest ARVI value is in the range of 0 to 0.5 only on the edge of the Mangrove Forest but relatively scattered throughout the edge of the Benoa Bay Mangrove Forest.

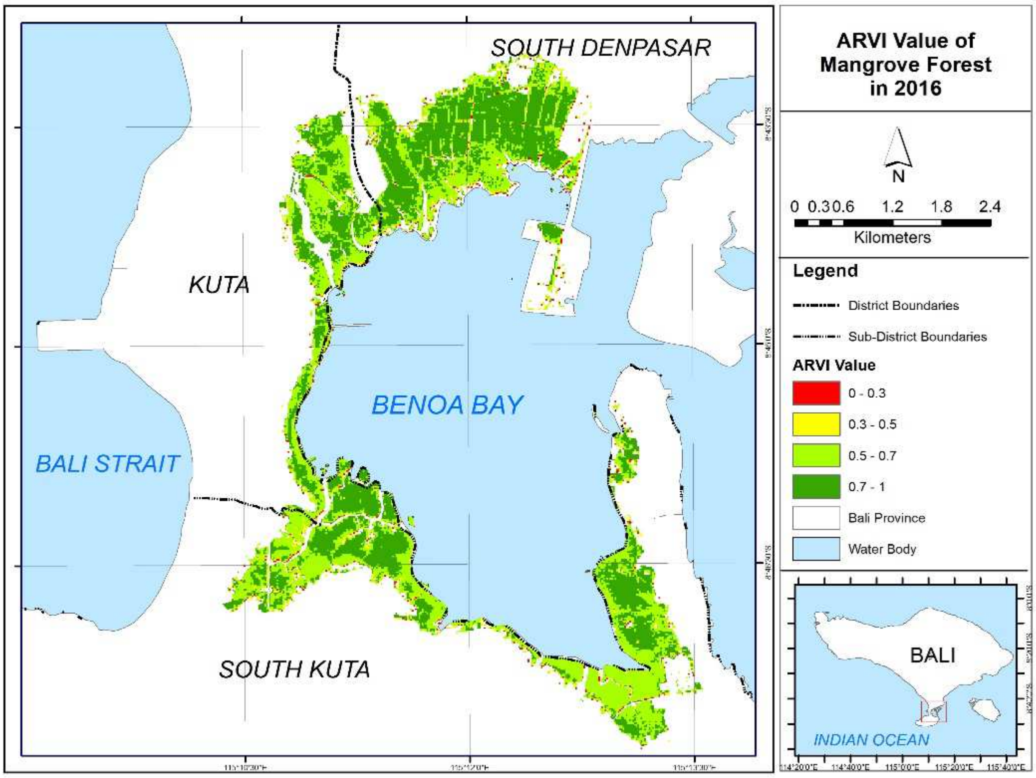

Fig. 2 ARVI Classification 2016

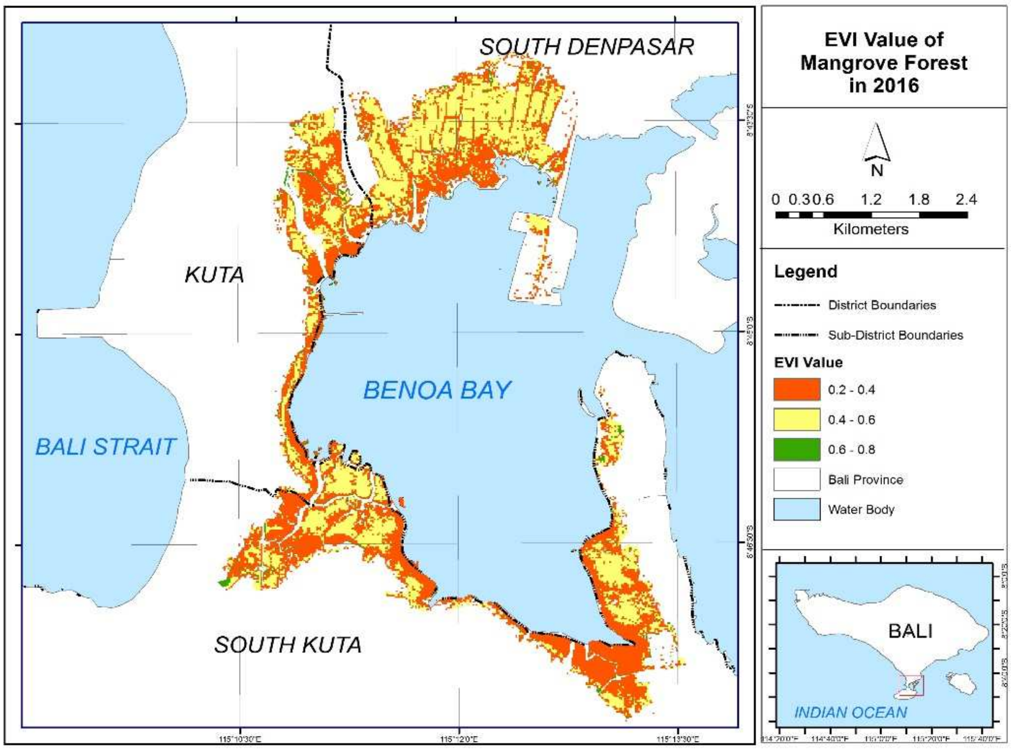

Fig. 3 EVI Classifivcation 2016

In the mangrove forest cover in 2016, the EVI vegetation index value obtained has a value ranging from 0.2 to 0.8. These values are grouped into 3 classes, namely classes with values ranging from 0.2 – 0.4, 0.4 – 0.6, and 0.6 – 0.8. Figure 3 shows that the Benoa Bay mangrove forest cover in 2016 is dominated by a low to moderate EVI index range value. EVI values with a range of 0.2 – 0.6 are spread evenly throughout the Benoa Bay, while the highest EVI values, namely the range of values from 0.6 – 0.8, are only found in the southwest of Benoa Bay, precisely in the southern Kuta District.

B. Carbon Stock Modelling by Vegetation Indices

Regression models are formed using pixel values from 2 vegetation indices. From 30 sample points, 24 samples will be used for making regression models, and six samples are samples that are not included in the formation of the model. Six of these samples will be used to test the model's accuracy, which will be chosen based on the magnitude of the predictive power (R2).

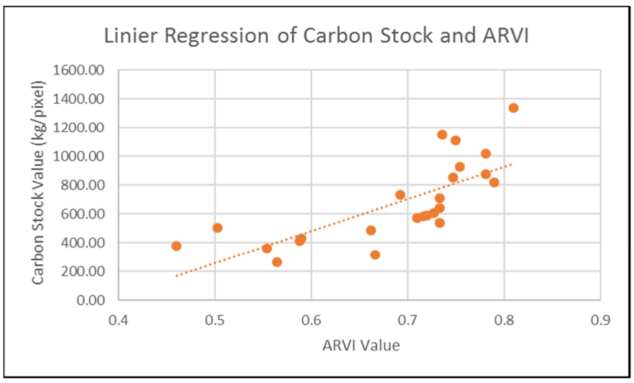

Fig. 4 Linear Regression with ARVI

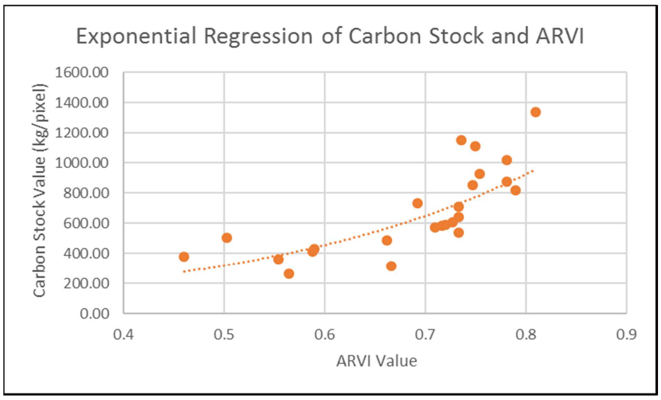

Fig. 5 Exponential Regression with ARVI

The models formed are as many as six models, including linear, exponential, and logarithmic regression models for each vegetation index of ARVI and EVI. Figure 4 shows a linear regression model with ARVI having a value of R2 0.51. Meanwhile, Figure 5 shows an exponential regression model with ARVI having an R2 value of 0.61. The logarithmic regression model with ARVI has an R2 value of 0.53 can be seen in Figure 6. Figures 7, 8, and 9 show the EVI regression model. The linear regression model with EVI has an R2 value of 0.21, and it can be seen in Figure 7. Meanwhile, Figure 8 shows an exponential regression model with an EVI having an R2 value of 0.19. Next, figure 9 shows the logarithmic regression model with EVI having an R2 value of 0.20.

The results of the model formed from the vegetation index can be seen in Table II. The model using the ARVI vegetation index has the highest R^2 in the exponential regression model. The model using the EVI vegetation index has the highest R^2 in the linear regression model, then from the best regression model of 6 models, it is used to estimate the carbon stock of the Benoa Bay mangrove forest in 2020.

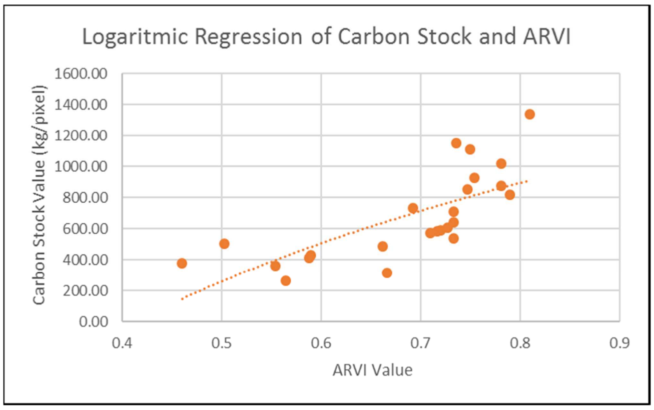

Fig. 6 Logarithmic Regression with ARVI

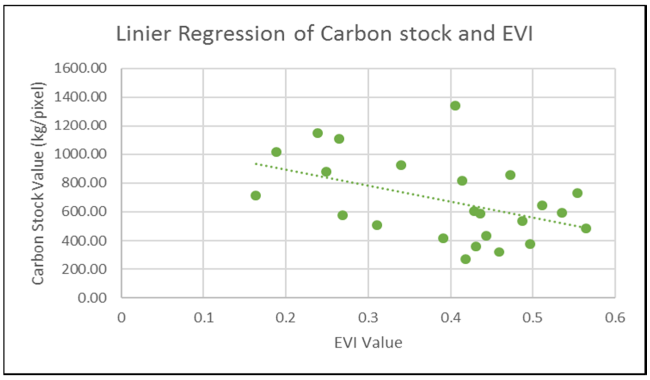

Fig. 7 Linear Regression with EVI

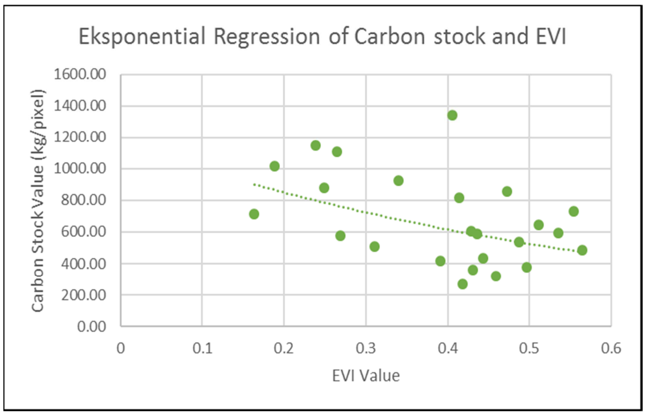

Fig. 8 Exponential Regression with EVI

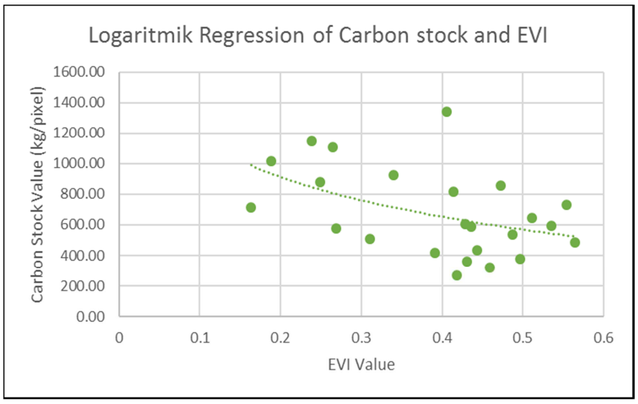

Fig. 9 Logarithmic Regression with EVI

TABLE II
CARBON STOCK REGRESSION MODEL BY VEGETATION INDEX

Vegetation Index	Regression Model	R^2
ARVI	y = 2398.752x – 969.68	0.51
	$y = 47.762e^{3.7398x}$	0.61
	y = 1460.2ln(x) + 1241.5	0.53
EVI	y = -1117.7x + 1118.2	0.21
	$y = 1172.6e^{-1.607x}$	0.19
	y = -375.1ln(x) + 309.35	0.20

C. Accuracy Test

The sample used for accuracy testing must have the same value variations as the sample data used to create the model. So, in the selection of samples for accuracy, testing must be done by looking at the lowest and highest values of measurement data in the field. After sorting the data from lowest to highest, the researcher makes a segment in the carbon stock value data. The lowest carbon stock data value is 265.72 kg/pixel, and the highest is 1339.89 kg/pixel. The median value is at 802.80 kg/pixel. Data needed for accuracy testing is 20% of the total data obtained or equal to 6 samples, so the researchers decided to take data for accuracy testing of 3 samples valued between 265.72 kg/pixel and 802.20 kg/pixel, and three samples valued between 802.20 kg/pixel up to 1339.89 kg/pixel.

We formed six models. Model 1st is chosen with the highest predictive power value. The model chosen was an exponential regression model using the ARVI variable, with an R^2 of 0.6189We tested its accuracy by calculating the RMSE using six samples for modeling. The aim is to get high accuracy first, before modeling for 2020. Table III shows the RMSE calculation so that the RMSE value is 158.34 kg, and the comparison can be seen in Figure 10.

TABLE III
RMSE CALCULATION

Field Carbon Stock	Carbon Stock Model	Deviation
398.24	428.28	30.04
530.54	596.42	65.87
600.59	706.74	106.14
761.30	733.68	27.61
975.64	810.96	164.67
1219.44	893.81	325.62
RMSE		158.34

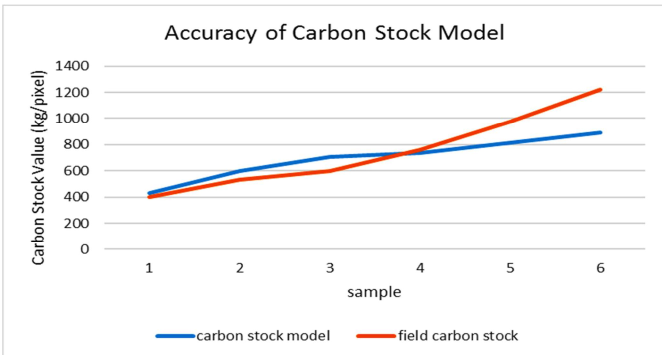

Fig. 10 Comparison of Field Data and Model

D. Carbon Stock Distribution of Mangrove Forests in 2020

Benoa Bay mangrove forests in 2020 were dominated by high carbon stock grades, which are more than 1000 kg/pixel. Figure 11 shows the Benoa Bay region dominated by dark green. Besides, the distribution of the lowest grade carbon stock value, which is the range of 0-200 kg/pixel values, is only spread on the edge of the Benoa Bay mangrove forest that is leaning towards the mainland. Carbon stock values with a range of carbon stock values of 200-1000 kg/pixel cluster in the southeast part of Benoa Bay, precisely in the District of South Kuta. The amount of the carbon stock can be seen from the presence of light green, yellow, bright orange, and dark orange in the southeastern part of Benoa Bay.

The total carbon stock of mangrove forests in Benoa Bay can be calculated using a simple calculation, and calculation defines by multiplying the number of pixels by the mean value of each class (for classes with amounts higher than 1000, the number of pixels is directly increased by 1000). A more detailed calculation can be seen in Table IV. The calculation shows the total carbon stock of Benoa Bay Bay mangrove forests in 2020 was 86.578.000 kg or equal to 95.434,30 Tons. Details of the entire carbon stock/class, including the range of values from 0 – 200 is 202.400 kg (223,10 Ton), the range of values from 200 – 400 is 882.000 kg (972,22 Ton), the range of values from 400 – 600 is 2.904.500 kg (3.201,60 Ton), the range of values from 600 – 800 is 6.951.000 kg (7.662,03 Ton), the range of values is 800 – 1000 is 15.209.100 kg (16.764,88 Tons), and the range of values of more than 1000 is 60.429.000 kg (66.610,44 tons).

TABLE IV
TOTAL CARBON STOCK

Range Value	Number of Pixels	Total Carbon Stock
0-200	2024	202.400 kg
200-400	2940	882.000 kg
400-600	5809	2.904.500 kg
600-800	9930	6.951.000 kg
800-1000	16899	15.209.100 kg
>1000	60429	60.429.000 kg
Grand Total of Carbon Stock in 2020		86.578.000 kg

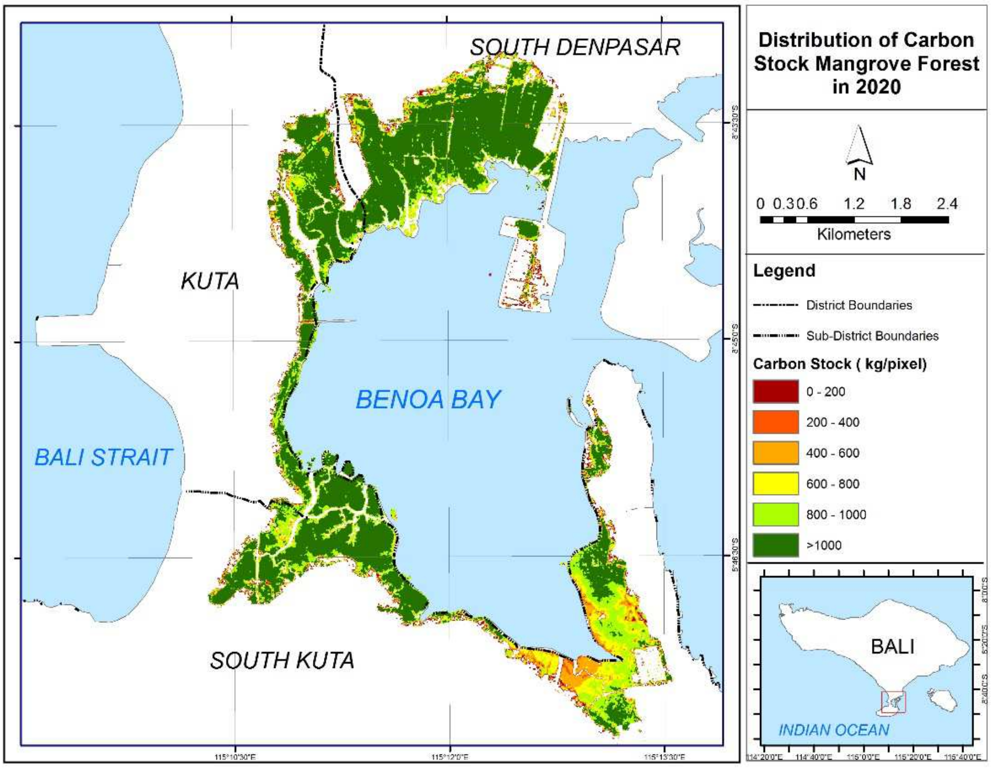

Fig. 11 Distribution of Carbon Stock Mangrove Forest 2020

IV. CONCLUSION

The carbon stock value with the ARVI vegetation index has a more reliable predictive power compared to the EVI vegetation index. The best regression model for predicting carbon stock values is the exponential regression model with an ARVI vegetation index variable. Regression models produce predictive power that is not too high. The regression model has not very high accuracy for estimating mangrove forest carbon stocks in Benoa Bay but is still feasible to use.

Overall, the Benoa Bay mangrove forest in 2020 has a high carbon stock value. High carbon stock values are distributed in almost all regions of Benoa Bay. The lowest carbon stock value is only found on the edge of the Benoa Bay mangrove forest that is leaning towards the mainland.

ACKNOWLEDGMENT

The author would like to thank the research activities of the Kemenristek/BRIN (contract number NKB-50/UN2. RST/HKP.05.00/2020, and addendum NKB-

2649/UN2.RST/HKP.05.00/2020), and the National Institute of Aviation and Space (LAPAN) for the Sentinel-2 satellite imagery that has been provided and is the most crucial requirement in this study. We also thank Erika Dwi Candra, a graduate of Gadjah Mada University, for giving previous research data on measuring carbon stocks. Without this data, this research cannot be processed smoothly.

REFERENCES

[1] Hasan, J. (2016). Minimalisasi Risiko Bencana Melalui Adaptasi Markisa (Masyarakat Miskin Sadar) Akan Dampak Pemanasan Global di Desa Lambusa. *Prosiding Seminar Nasional Geografi UMS*, 315–322.

[2] Martono. (2015). Fenomena Gas Rumah Kaca. *Forum Teknologi*, 05(2).

[3] Manafe, G., Kaho, M. R., Risamasu, F., Adisucipto, J., Kupang, P., Peternakan, F., … Penfui, A. (2016). Estimasi Biomassa Permukaan Dan Stok Karbon Pada Tegakan Pohon Avicennia Marina Dan Rhizophora Mucronata Di Perairan Pesisir Oebelo Kabupaten Kupang. *Jurnal Bumi Lestari*, *16*(2), 163–173.

[4] Heriyanto, N. M., Subiandono, E., Penelitian, P., Gunung, J., & No, B. (2016). Peran Biomasa Mangrove Dalam Menyimpan Karbon di Kubu Raya, Kalimantan Barat. *Jurnal Analisis Kebiajakan Kehutanan*, *13*(1), 1–12.

[5] Donato, D. C., Kauffman, J. B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninene, M. (2012). Mangrove Adalah Salah satu Hutan Terkaya Karbon di Kawasan Tropis. www.cifor.org

[6] Setyawan, A. D., & Winarno, K. (2006). Permasalahan Konservasi Ekosistem Mangrove di Pesisir. *BIODIVERSITAS*, *7*(April), 159–163. https://doi.org/10.13057/biodiv/d070214

[7] Lugina, M., Alviya, I., & Pribadi, M. A. (2017). Strategi Keberlanjutan Pengelolaan Hutan Mangrove di Tahura Ngurah Rai Bali. *Jurnal Analisis Kebiajakan Kehutanan*, *14*(1), 61–77.

[8] Pramudji. (2000). Dampak Perilaku Manusia Pada Ekosistem Hutan Mangrove di Indonesia. *Oseana*, *XXV* (2), 13–20.

[9] Suantika, W. (2015). Resistensi Masyarakat Lokal terhadap Kapitalisme Global: Studi Kasus Reklamasi Teluk Benoa Bali Tahun 2012-2013. *Jurnal Hubungan Internasional*, *VIII* (1), 47–62.

[10] Budi, D., & Faiqoh, E. (2015). Analisis Vegetasi dan Struktur Komunitas Mangrove di Teluk Benoa , Bali. *Journal of Marine and Aquatic Sciences 1*, *1*, 1–7.

[11] Wang, D., Wan, B., Liu, J., Su, Y., Guo, Q., Qiu, P., & Wu, X. (2019). Estimating Aboveground Biomass of The Mangrove Forests on Northeast Hainan Island in China Using an Upscaling Method from Field Plots, UAV- LiDAR Data and Sentinel-2 Imagery. *Int J Appl Earth Obs Geoinformation*, *85*(October 2019), 101986. https://doi.org/10.1016/j.jag.2019.101986

[12] Rahman, Effendi, H., & Rusmana, I. (2016). Estimasi Stok dan Serapan Karbon pada Mangrove di Sungai Tallo, Makassar. *Jurnal Ilmu Kehutanan*, *11*((2017)), 19–28.

[13] Hartoko, A., Chayaningrum, S., Ayu, D., Ariyanto, D., & Suryanti. (2015). Carbon Biomass Algorithms Development for Mangrove Vegetation in Kemujan, Parang Island Karimunjawa National Park, and Demak Coastal Area – Indonesia. *Procedia Environmental Sciences*, *23*(Ictcred 2014), 39–47. https://doi.org/10.1016/j.proenv.2015.01.007

[14] Astriani, H., Santoso, K. B., Arifatha, N., Prasetya, R., Utomo, S. D., Juniandari, V. C., & Kamal, M. (2017). Perbandingan Citra Landsat 8 Oli dan Sentinel 2-A Untuk Estimasi Stok Karbon Kelapa Sawit (Elais Guineensis Jacq) di Wilayah PT. Perkebunan Nusantara VII Unit Rejosari, Natar, Kabupaten Lampung Selatan. *Seminar Nasional Geomatika 2017: Inovasi Teknologi Penyediaan Informasi Geospasial Untuk Pembangunan Berkelanjutan*, (July), 20–28. https://doi.org/10.24895/SNG.2017.2-0.393

[15] Widhi, S. J. K., & Murti, S. H. (2014). Estimasi Stok Karbon Hutan Dengan Memanfaatkan Citra Landsat 8 Di Taman Nasional Tesso Nilo, Riau. *Jurnal Bumi Indonesia*, 3(2), 1–11.

[16] Pambudhi, A., Murti BS, S. H., & Zuharnen, Z. (2012). Estimasi Stok Karbon Hutan Dengan Menggunakan Citra Alos Avnir-2 Di Sebagian Kecamatan Long Pahangai, Kabupaten Kutai Barat. *Jurnal Bumi Indonesia*, *1*(1).

[17] Yusandi, S., & Jaya, I. N. S. (2016). Model Penduga Biomassa Hutan Mangrove Menggunakan Citra Satelit Resolusi Sedang di Areal Kerja Perusahaan Konsesi Hutan di Kalimantan Barat. *Bonorowo Wetlands*, 6(2), 69–81. https://doi.org/10.13057/bonorowo/w060201

[18] Jin, X., Li, Z., Feng, H., Ren, Z., & Li, S. (2019). Deep Neural Network Algorithm for Estimating Maize Biomass-Based On Simulated Sentinel 2a Vegetation Indices And Leaf Area Index. *The Crop Journal*. https://doi.org/10.1016/j.cj.2019.06.005

[19] ESA. (2015). *Sentinel-2 User Handbook*. ESA Standard Document, 64.

[20] Tanto, T. Al, Wisha, U. J., Kusumah, G., Pranowo, W. S., & Husrin, S. (2017). Karakteristik Arus Laut Perairan Teluk Benoa – Bali. *Jurnal Ilmiah Geomatika*, 23(1), 37–48. https://doi.org/http://dx.doi.org/10.24895/JIG.2017.23-1.631

[21] Candra, E. D., Mada, U. G., Harjo, H., Mada, U. G., Wicaksono, P., & Mada, U. G. (2016). Above Ground Carbon Stock Estimates of Mangrove Forest Using Worldview-2 Imagery in Teluk Benoa, Bali Above Ground Carbon Stock Estimates of Mangrove Forest Using Worldview-2 Imagery in Teluk Benoa, Bali. *IOP Conference Series Earth and Environmental Science* (November). https://doi.org/10.1088/1755-1315/47/1/012014

[22] Kiefer, and Lillesand. (1990). Penginderaan Jauh dan Interpretasi Citra (Translate by Dulbahri, Prapto Suharsono, Hartono, dan Suharyadi) Yogyakarta: *Gadjah Mada University Press.*

[23] Sudiana, D., & Diasmara, E. (2008). Analisis Indeks Vegetasi menggunakan Data Satelit. *Seminar on Intelligent Technology and Its Applications 2008*, (ISBN 978-979-8897-24-5), 423–428.

[24] Hanif, M. (2015). *Panduan ke 2 Bahan Pelatihan Penginderaan Jauh Tingkat Lanjut*. UNP.

[25] Huete, A. R. (1988). A Soil-Adjusted Vegetation Index (SAVI). *Remote Sensing of Environment* ·, (March 2014). https://doi.org/10.1016/0034-4257(88)90106-X