MANGROVE LEAF AREA INDEX (LAI) MAPPING USING WORLDVIEW-2 IMAGERY IN PERANCAK ESTUARY, BALI, INDONESIA

Aldo Restu Agi Prananda (1), Muhammad Kamal (1), Denny Wijaya Kusuma (2)

[1] Department of Geographic Information Science, Faculty of Geography, Universitas Gadjah Mada, Yogyakarta, Indonesia 55281
[2] Institute for Marine Research and Observation, The Ministry of Maritime Affairs and Fisheries, Jembrana, Bali, Indonesia
Email: aldo.restu.a@mail.ugm.ac.id; m.kamal@ugm.ac.id; dennykoesoema@kkp.go.id

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ABSTRACT: Mangrove forests are unique ecosystem that have many functions in the environment. Mangroves provide food and energy for tropical coastal ecosystem, habitat for coastal flora and fauna, and protection from coastal abrasion. The health status of mangrove could be represented using a biophysical tree parameter called Leaf Area Index (LAI). LAI can be defined as one half the total of green area per unit horizontal ground surface area. This study aims to (1) map the distribution of mangrove LAI in Perancak Estuary, Bali, Indonesia, using a high-spatial resolution WorldView-2 image data (2 m pixel size) and Normalized Difference Vegetation Index (NDVI), and (2) assess the accuracy of the LAI mapping. The selected mangrove site is under authority of Institute of Marine Research and Observation (IMRO) where continuous monitoring of mangrove health is conducted periodically, especially in the restored mangrove areas. Part of this study was designed to develop a baseline for mangrove LAI monitoring at some permanent sample sites. Mangrove objects were first visually discriminated from non-mangrove objects and the non-mangrove objects were masked out to focus on the mangrove objects. The LAI map was created based on the semi-empirical relationships between NDVI and field LAI values measured from hemispherical photograph. The corresponding values of both parameters were correlated to find the regression function for modelling the LAI map. The LAI map shows the distribution of high LAI values correspond to the mature planted mangroves, and the natural mangrove and young planted mangroves representing moderate and low LAI values, respectively. The accuracy of mangrove LAI map was high at 91 % and 1:1 plot shows the model was underestimated.

1. INTRODUCTION

Mangrove forests are unique ecosystems and have multiple functions in the environment. Mangroves grow in intertidal zones where terrestrial and marine ecosystems are involved. The mangrove area has a role as a provider of food and germplasm sources and habitat for several seas such as shrimp, fish and crabs (Naylor et al., 2000). Some terrestrial fauna such as birds, mammals, reptiles, algae, and fungi also form a big community with mangroves. Mangroves are considered as natural barriers along the coastline in the face of ocean dynamics (Kuenzer et al., 2011). Mangrove ecosystems play a role in controlling water quality, separating sediment and nutrients in polluted coastal areas (Walter et al., 2008). Mangrove communities have a role in providing benefits to human life (Alongi, 2008). The benefits provided by mangrove ecosystems on the environment is the reason why mangroves need to be protected. One of the actions is through the process of monitoring mangrove health conditions. Remote sensing provides an opportunity to map mangrove health conditions through biophysical parameters, namely leaf area index (LAI). Remote sensing data has been widely used to understand the spatial aspects of mangrove biophysical parameters such as LAI (Lucas et al., 2017).

LAI can be defined as one half the total of green area per unit horizontal ground surface area (Chen and Black, 1991). LAI is a function of the canopy system. The dynamics of canopy growth that related to the loss of canopy cover indicates that vegetation is in a stress condition. Because of that, LAI can be used as an indicator of mangrove health level (Heumann, 2011). Through this understanding, LAI have a function as a regulator of micro-canopy conditions such as water absorption in the canopy and radiation barriers. The spatial distribution of LAI needs to be mapped to produce information related to mangrove health conditions. Remote sensing has advantages in assessing and mapping the spatial aspects of LAI and has a monitoring function compared to direct measurement of LAI (Gholz, 1982).

Mangrove LAI mapping through remote sensing is done with a semi-empirical approach, namely analyzing the relationship between two variables. The two variables are image pixel values and LAI values measured in the field. Image pixel values are represented by vegetation indices (VIs). Vegetation index has been widely used in research related to LAI mapping. Kamal et al., (2016) mentioned that vegetation index is a proxy that can be used to estimate mangrove LAI. Normalized Difference Vegetation Index (NDVI) is a vegetation index that is relatively often used in estimating LAI as a study conducted by Green et al., (1997) which uses NDVI as a proxy. NDVI can measure the level of health and the level of greenness of vegetation. Field LAI values can be obtained through hemispherical photography techniques using tools with fish-eye lensed cameras (Zhang et al., 2005). Hemispherical photography captures the pattern of light penetration in the canopy structure, so that the leaf area units can be quantified.

LAI mangrove mapping by utilizing vegetation index and hemispherical photography is considered as one of the efficient methods compared to other methods and the method is non-destructive (Jonckheere et al., 2004). The image of high spatial resolution in mangrove mapping can improve accuracy and is more effective than aerial photo interpretation (Kamal and Phinn, 2011). Some images such as WorldView-2 have sensitivity in capturing the reflection of mangrove vegetation (Wicaksono and Farda, 2016).

This study aims to (1) map the distribution of mangrove LAI in Perancak Estuary, Bali, Indonesia, using a high-spatial resolution WorldView-2 image data (2 m pixel size) and NDVI as a proxy, and (2) assess the accuracy of the LAI mapping.

2. MATERIAL AND METHOD

2.1 Study sites

Perancak Estuary is centered at $117^{0}30'30''$ E and $8^{0}23'30''$ S and part of the administrative area of Jembrana Regency, Bali Province, Indonesia. Perancak Estuary is dominated by land use in the form of ponds and mangrove vegetation. This estuary contributes to the diversity of various mangroves in which there are 9 types of mangrove species namely *Sonneratia alba, Rhizopora apiculata, Avicennia marina, Bruguiera gymnorrhiza, Rhizopora stylosa, Rhizopora mucronata, Ceriops decandra, Ceriops tagal, and Excoecaria agallocha*. The research site is represented in Figure 1.

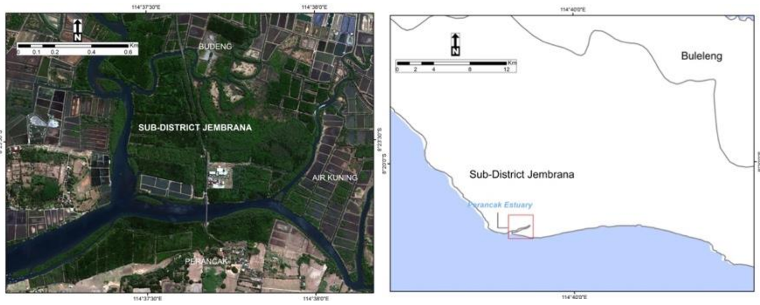

Figure 1. Map of study area of Perancak Estuary, Bali

2.2 Field LAI measurement

Field measurements were carried out on July 9-17, 2018 with a total sample of 50 samples. The sample technique used is a transect based on mangrove density variation. The spectral pattern in the image was used as a reference in sampling. A total of 50 samples were collected in this study. Thirty-four samples were used as sample model and 16 samples used as validation sample. Measurement of mangrove LAI data in the field was done by visiting each sample that has been planned. The sample plot size used was 4 x 4 m. In each sample plot, the coordinate recording process was carried out to plot the location points using a handheld Global Navigation Satellite System (GNSS) receiver (Figure 2b). In each sample plot, the mangrove canopy was photographed upward with nine photo-shoots using hemispherical camera. The nine canopy photos were taken randomly yet ensuring the extent of the canopy that matches the sample plot size was covered. Shooting was done in upward conditions with a consistent height (1,5 m). Hemisphere photo shooting techniques can be seen in Figure 2a. In addition, the height of mangrove stands was also measured using a laser rangefinder and mangrove species was identified. The mangrove species identified during the field work were dominated by *Rhizopora sp* (Figure 2c) and *Avicennia sp*.

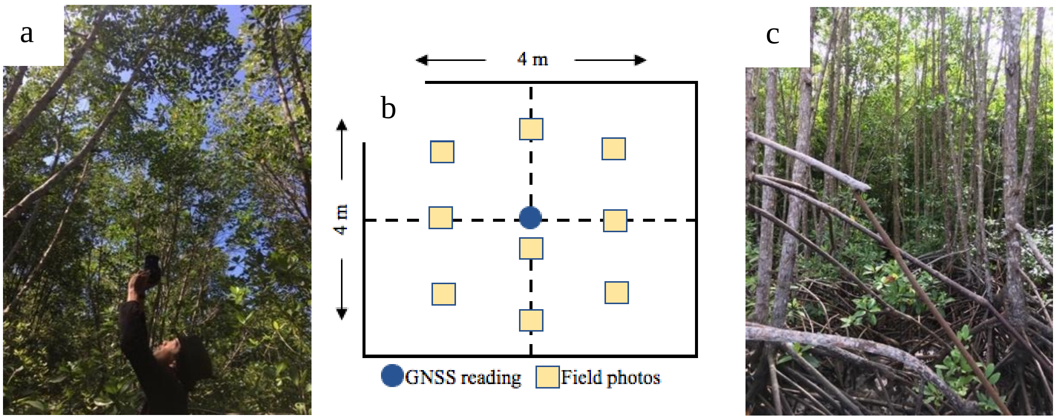

Figure 2. (a) Hemispherical photography technique, (b) field plot and measurement point, (c) picture of planted *Rhizopora sp*

2.3 LAI data processing

LAI data results from field measurements are processed using CAN-EYE software (https://www6.paca.inra.fr/can-eye). This software can quantify photos taken from hemispherical camera system. The nine photos that have been taken in the field were the main data in the quantification process called the Elementary Sampling Unit (ESU). Before starting the data processing, the camera calibration step was carried out to find the camera's focus point, which is the optical center stage and the calibration projection function (Figure 3a, b). Both calibrations were the initial stages that affect the results of the next quantification process. After the calibration process was completed, the process of defining parameters was the next pre-processing stage. This stage was the process of selecting parameters for LAI data processing. The parameters used were username, image size, optical center & projection function, Circle of interest (COI), Sub-sample factors, angular resolution, Cover, and FAPAR. Nine photos were inputted to perform data processing stages. At this stage photos were selected and can be discarded if there are objects such as bars and shadows taken along which will block the canopy picture and will affect quantification values. In the next stage, gamma correction was done to equalize the brightness of each photo (Figure 3c). There were two classes used namely green vegetation and sky as background. The assumption is that the objects in the photo will be explained as green vegetation and sky (Figure 3d). The level of greenness can be adjusted according to the density of the canopy depicted in the photo. The calculation results were LAI, F-cover, FAPAR, and other information in the form of graphs and excels.

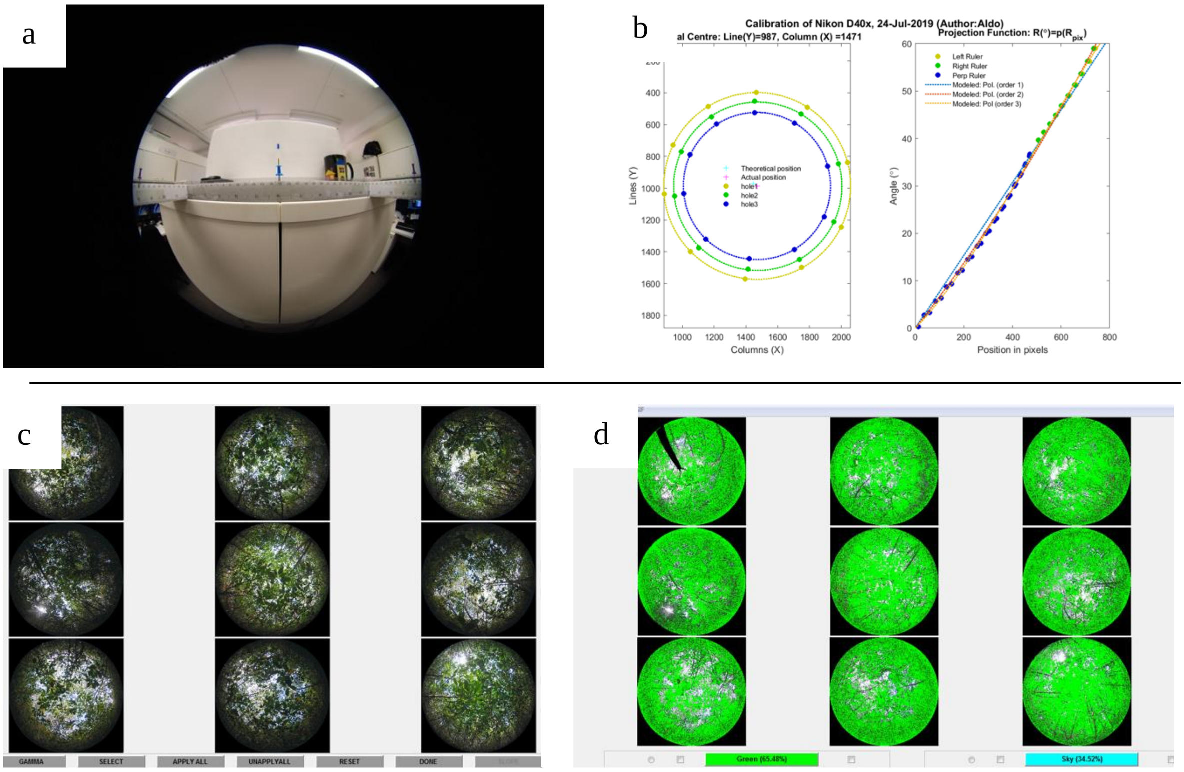

Figure 3. LAI data processing using CAN-EYE software: (a) optical center and projection function calibration, (b) the graph result of calibration, (c) selected photos with gamma correction, (d) classification process of LAI

2.4 NDVI Values for LAI calculation

In this study NDVI was used to estimate the LAI and then refined it to become a mangrove LAI map at Perancak Estuary, Bali. NDVI is a vegetation index resulting from the ratio between NIR and red channels with the following formulas.

$$NDVI = (NIR - Red)/(NIR + Red) \tag{1}$$

NDVI is related to the level of greenness and the level of vegetation health and correlates with the LAI value (Rouse et al., 1974). NDVI values were obtained through the contribution of several channels from WorldView-2 image recording date September 18, 2018 namely (blue: 450-510 nm), (green: 510-580 nm), (red: 630-690 nm), and (NIR: 770 -895 nm). WorldView-2 image has a high spatial resolution of 2 m that can improve the accuracy of mangrove LAI mapping. In the process of obtaining the NDVI values, a masking process is carried out between the mangrove object and non-mangrove object (Figure 4a-c). NDVI formulation is applied using the band math feature in the ENVI software to produce an image of the NDVI transformation result. The coordinates of each samples are used as a region of interest (ROI) feature to get LAI values based on NDVI. The last process is exporting the ROI to produces NDVI values in tabular form.

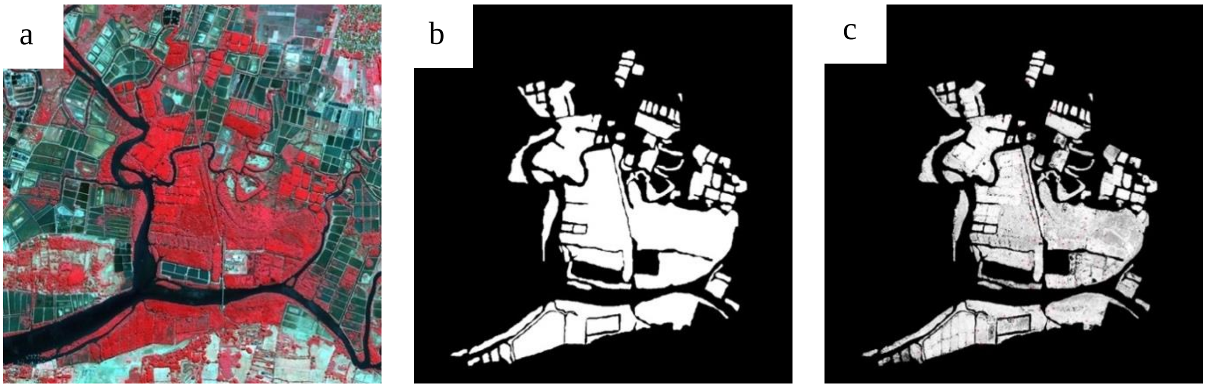

Figure 4. (a) WordView-2 image of several object using image composition 743, (b) mangrove object masking, (c) NDVI transformation image with ROI sample

2.5 Mapping LAI using correlation and regression analysis

The making process of mangrove LAI map in this study uses a semi-empirical approach, which is an approach by utilizing the relationship between two different variables. The two variables are the pixel value of the image represented by NDVI as the independent variable and the field LAI value as the dependent variable. These two variables are related by using correlation analysis and regression analysis. Correlation analysis illustrates the strength of the relationship between two variables in the form of positive or negative relationships. While regression analysis can be used to find out how strongly the independent influence affects the dependent variable so that an estimation can be made. The resulting LAI map was obtained through correlation analysis and analysis of simple regression analysis in the form of equations

$$y = ax + b \qquad (2)$$

The form of the regression analysis equation called the coefficient of determination was used to estimate the LAI and make a map of LAI. The equation y = ax + b was applied through the band math feature in the ENVI software where (y = is assumed to be the predicted LAI value, a = slope refers to the equation number, b = intercept refers to the equation constant, and x = NDVI image. The result of applying the equation was the image with predicted field LAI value, the last step was the process of density slice to divide the class of LAI value, the class used was as many as 4 classes adjusting to the minimum data and the maximum LAI data in the image statistics. Map layout process was done in ArcGIS software that produces a map of the LAI mangrove at Perancak Estuary, Bali.

2.6 Accuracy assessment of LAI map

The accuracy assessment of mangrove LAI mapping was performed using Standard Error Estimate (SEE). The accuracy assessment aim was to determine the effect of using different vegetation index on the accuracy of mangrove LAI mapping. SEE measurement shows how much error is the NDVI vegetation index value of the mangrove LAI measurement in the field. SEE is calculated using the formula:

$$\text{SE (Standard error)} = \sqrt{\frac{\sum (y-y')^2}{n-2}} \qquad (3)$$

where y = reference value, y '= estimation value, n = number of samples. The smaller the SE value, the more accurate the mangrove LAI map. A 1: 1 plot relationship graph is also used to determine the accuracy of the mangrove LAI map using X-axis (validation samples of field LAI values) and Y-axis (NDVI image). If the position of data distribution is above the 1: 1 line, it can be said that the estimation and LAI map is overestimated, while if the position of data distribution is below the 1: 1 line, then the mangrove LAI estimation and map can be said to be underestimated.

3. RESULT AND DISCUSSION

3.1 LAI and NDVI values

Table 1 shows the results of information value through NDVI transformation and LAI data processing using CAN-EYE software. The data generated in the form of data 34 sample models that are used to estimate the value of mangrove LAI to produce maps.

Table 1. Values of NDVI and LAI derived from NDVI transformation and hemispherical photography measurement.

Sample Number	LAI Values	NDVI
1	2,18	0,8186
2	1,27	0,7594
3	0,43	0,6979
4	1,34	0,7859
5	1,36	0,7863
6	0,96	0,7108
7	1,24	0,7572
8	1,68	0,805
9	1,2	0,755
10	1,7	0,8054
11	1,2	0,7551
12	1,98	0,8155
13	1,93	0,8144
14	1,32	0,7801
15	1,67	0,8002
16	1,16	0,7374
17	2,37	0,8273

Sample Number	LAI Values	NDVI
18	1,77	0,8104
19	1,29	0,7743
20	1,04	0,7163
21	0,68	0,7064
22	1,41	0,7894
23	1,23	0,7916
24	1,69	0,805
25	1,57	0,7961
26	2,23	0,8238
27	1,41	0,7892
28	2,3	0,8272
29	1,34	0,7833
30	1,45	0,795
31	2,2	0,8203
32	1,29	0,765
33	1,45	0,7959
34	1,08	0,7271

Data of field mangrove LAI value has a range of values between 0.43 to 2.37 where 0.43 is the minimum value of LAI and 2.37 as the maximum value of LAI. The calculated LAI value was the effective value of LAI. In general, through these results the mangrove LAI value in Perancak Estuary was influenced by the condition of the mangroves planting type. While the NDVI values recorded ranged from 0.69 to 0.82. This NDVI value can be said to be sensitive enough to capture spectral reflections from LAI mangroves. NDVI values and calculated field mangrove LAI values were then used to perform correlation and regression analyzes in which NDVI acts as an independent variable and field mangrove LAI values as dependent variables.

3.2 NDVI and Field LAI relationship for mangrove LAI mapping

The relationship between the two variables in this study resulted from modeling through the relationship between NDVI values and field LAI values. The relationship described is the result of statistical analysis through simple linear regression. Previously, all 34 model samples used for modeling and mapping were already in normally distributed conditions after the

Kolmogorov-Smirnoff normality test. The results of correlation analysis and regression between variable LAI field values and NDVI can be seen in Figure 5.

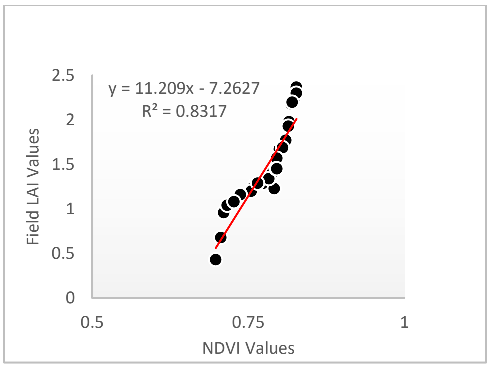

Figure 5. Regression function plot between NDVI and field LAI values

Based on Figure 5, NDVI has a strong relationship to the value of mangrove LAI and has the ability to describe the value of LAI mangrove LAI in the field. This is because basically NDVI is an index related to the level of greenness and health of a vegetation. The coefficient of determination of the relationship between NDVI and LAI is equal to R^2 = 0.83 which can be said to be a strong relationship. This value illustrates that NDVI has a significant influence in representing the value of mangrove LAI in the field. These results are then used for the next process in making mangrove LAI maps. The regression function of the NDVI model is where the LAI value = 11,209 NDVI - 7,2627 is used to make the LAI map.

3.3 LAI distribution map for monitoring mangrove condition at Perancak Estuary

Figure 6 shows a map of the LAI distribution in the Perancak Estuary, Bali. Maps were generated through estimations using the equation model (LAI value = 11,209 NDVI - 7,2627). The map illustrates the value of mangrove LAI quantitatively where the mangrove LAI value is a representation of the level of mangrove health. The estimated LAI value is divided into 4 classes, namely the first class with a range of LAI values 0 - 0.6 representing the low LAI class, the second class with a range of values 0.6 - 1.3 representing the low to moderate LAI class, the third class with a range 1.3 - 2 representing the LAI class being moderate, and the fourth class with a range of 2 - 2.6 representing the high LAI class. Overall mangrove LAI values in the Perancak range is from 0.6 to 2.6. Through this mangrove LAI map, the distribution value of high LAI is related to the condition of adult mangroves and planted results, while the value of low LAI is related to young mangroves and natural mangroves. The number of planted mangroves in Perancak Estuary are dominated by species of *Rhizopora sp.* and *Avicennia sp*. which have high stands with dense canopy conditions. This causes the LAI represented is high value. The value of LAI distribution in moderate class are influenced by variations in the types of mangroves, mainly related to the stand, species, and varying canopy density. The natural mangroves that have low LAI values are caused by mangrove conditions that are affected by ponds and other human activities. The other reason is natural mangroves having a low density of canopy. However, there are several natural mangrove conditions in a research location that are identified as *Bruguiera sp.* species having high LAI values. Field analysis shows that the *Bruguiera sp*. conditions, have almost the same characteristics as *Rhizopora sp*. with high standing conditions. In general, the condition of mangroves in the Perancak Estuary has limits on the condition of planted mangroves and natural mangroves. The process of restoration and rehabilitation can be done on the condition of natural mangroves that are affected by pond activities.

Figure 6. Mangrove LAI Distribution Map at Perancak Estuary, Bali

3.4 LAI map accuracy assessment

Accuracy assessment used in this study is the plot of goodness of fit 1: 1 and standard error estimation (SEE). The number of samples used is 16 validation samples of the LAI measurement field. The results can be seen in Figure 7 which shows the distribution of mangrove LAI estimation data distribution related to LAI data in the field. Plot 1: 1 shows the mangrove LAI map underestimated in the estimated range of values (0,7-1,3) and (2.1-2.4). Underestimated data that representing low LAI value is caused by the soil background factor which affects the LAI estimation. While underestimated data at high LAI values because there are some objects such as mangrove shrubs that are not recorded because the shooting process is done at an altitude of 1.5 m from the ground surface (Ruslisan et al., 2018). Overestimated in the range of LAI values (1,3-1,5) is influenced by variations in mangrove stands with canopy density that is not too dense so that objects such as trunks and ground backgrounds come to be recorded and have implications for the LAI estimation results. Sky background can affect the estimation results and there are some errors in processing LAI data using CAN-EYE. The SE of the mangrove LAI map is 0.19. Error caused by the effect of inaccurate GNSS recording. Through this SE value, it can be explained that the mangrove LAI map in the Perancak Estuary, Bali has a high accuracy with 91%.

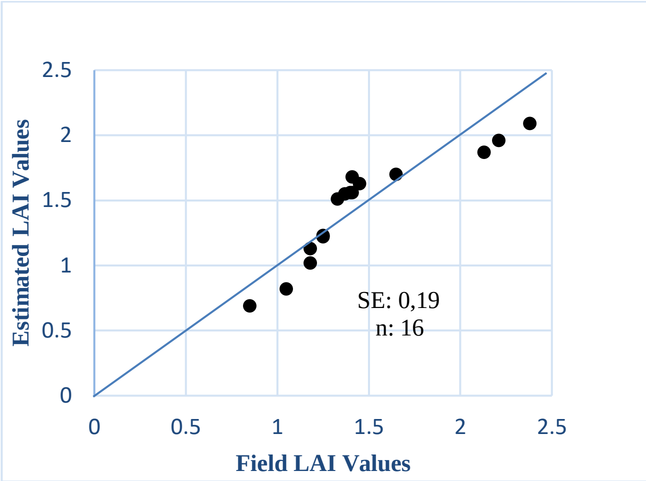

Figure 7. Plot Goodness of Fit of NDVI

4. CONCLUSION

NDVI has a strong relationship with the value of mangrove LAI in the field. This strong relationship can be interpreted that NDVI is able to produce a map of mangrove LAI through a prediction and estimation. The mangrove LAI map in the Perancak Estuary has a range of values between 0.6 - 2.6 which is divided into 3 classes, namely low, moderate, and high LAI classes. Low LAI values are distributed in areas of natural mangroves and young mangroves and are influenced by ponds. Moderate LAI values are distributed in mangrove areas with varying stands. High LAI values are distributed in planted mangrove areas with high density. This condition can be used as a baseline for the process of monitoring and rehabilitation of mangroves in the Perancak Estuary. Restoration needs to be carried out in natural mangrove areas that are affected by pond activities, while mangrove monitoring and maintenance in planted mangrove areas needs to be done periodically to maintain the functioning of the mangrove ecosystem in Perancak Estuary, Bali. The accuracy of Perancak's mangrove LAI map was high at 91% and can represent the mangrove health value.

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