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Monitoring agroforestry for REDD+ implementation using remote sensing data and geographic information system: A case study of Repong Damar, Pesisir Barat Lampung

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Abstract. Repong Damar is a unique practice of agroforestry found in Lampung that has a canopy structure nearly similar to that of natural forest. Apart from its uniqueness and important roles, effort to map and timely monitor the condition over Repong Damar is very limited. This research aims to analyze the most appropriate and accurate method for detecting Repong Damar using satellite images and to understand the historical change of Repong Damar cover. We tried to relate this effort to REDD+ potential implementation through agroforestry by estimating the forest reference level (FRL) of Repong Damar. Three methods of detection were used i.e. Object Oriented Classification (OOC), Maximum Likelihood Classification (MLC) and Vegetation Indices Classification (VIC). The most accurate method for detecting Repong Damar was the OOC. By using this method, time-series change of Repong Damar from 1990 to 2018 was determined. FRL was established by multiplying carbon stock of Repong Damar and the time-series average coverage area of Repong Damar from 1990 to 2015, i.e. 33,187,752 tC/yr. The emission performance of Repong Damar in 2018 was calculated from the total carbon stock of Repong Damar in 2018 against FRL. Repong Damar has emitted 1,485,378 tons of carbon in 2018.

Keywords: GIS, REDD+, remote sensing, Repong Damar detection method

1. Introduction

The agroforestry systems in Southwest Sumatra range from sun and simple shaded coffee gardens to complex systems such as the damar-based agroforest [1]. Repong Damar has an ecosystem similar to natural forests with high species richness and high ecological complexity and closed nutrient cycles [2]. As a landscape that resembles natural forests, Repong Damar has a dynamic of change, including deforestation and forest degradation [3]. According to [4], damar trees - the main tree of Repong Damar- can live for up to 150 years, while in the Krui area, damar trees on average were aged more than 100 years old. Having an average tree age exceeding 100 years, Repong Damar contains a very significant carbon stock. Therefore, any deforestation and degradation in Repong Damar will emit the carbon that has been stored for hundreds of years into the atmosphere.

Indonesia's forests with more than 130 million ha or 70 percent of its land area has a great opportunity to implement REDD+. REDD+ is an economic incentive mechanism that is given to developing countries to encourage sustainable forest management in the context of reducing carbon emissions [5].

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Repong Damar which is physically similar to the natural forest has a potential to apply an REDD+ scheme. However, there are debates on implementing REDD plus on agroforestry land. As according to [6], agroforestry systems have not received sufficient attention in the UNFCCC (United Nation Framework Convention on Climate Change) climate change mitigation mechanism, including REDD+.

This study aims to determine the most appropriate detection/mapping technique for distinguishing Repong Damar from surrounding natural forests and to explore the potential of agroforestry for REDD+. Changes in land cover that occurred in Repong Damar of Pesisir Barat Lampung between 1990–2018 will be identified and the emissions produced by that activity will be calculated.

2. Study area

The study area was Pesisir Barat District of Lampung Province, which encompass 2,964 km^2 in the Southwest of Sumatra (figure 1). Geographically, Pesisir Barat Regency is located from 4°40′0″ to 6º0′0″ South and from 103°30′0″ to 104°50′0″ East. Repong Damar was grew mostly on the near coast area of this district, which is dominated by *damar* (*Shorea javanica)* with other companion plants such as *langsat*, *durian*, *petai* (stinky bean), *jengkol* (bitter bean) and mangosteen.

3. Materials

The materials used in this study include the following:

- Landsat Satellite Imagery of West Coast District Lampung Province (path 124 row 64 and path 124 row 63) in 1990, 1993, 2000, 2006, 2009, 2015, 2016 and 2018.
- The field survey point was used for evaluation of the results of image analysis.
- Base map or boundary map of the Pesisir Barat Lampung Regency.
- Inventory data of Repong Damar stands in Pekon Pahmungan and Pekon Gunung Kemala.

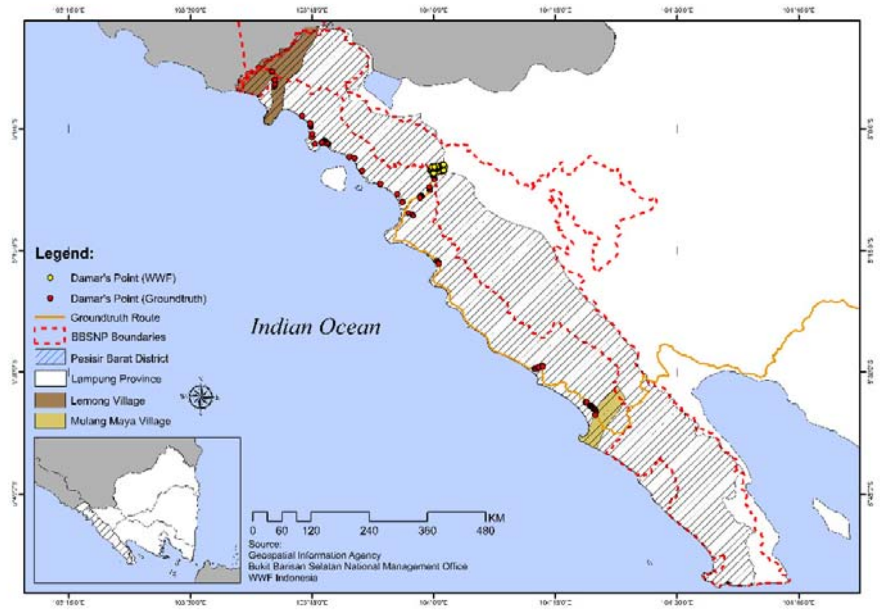


Figure 1. Study area

4. Methodology

Pre-processing of satellite image was conducted including downloading Landsat images from USGS Earth Explorer, image composite, subset, and image enhancement. For detection of Repong Damar, three detection techniques were used i.e. Maximum Likelihood Classification (MLC), Object Oriented Classification (OOC) and Vegetation Indices Classification (VIC). The best method was used to analyze the distribution of Repong Damar from 1990 to 2018.

MLC was conducted by selecting training areas of eight land-cover classes i.e. water body, natural forest, Repong Damar, mixed garden, land use, cloud, and cloud shadow. Training areas were assisted with ground truth. Ground truth points were also used for accuracy assessment using error matrix.

OOC was carried out by classifying objects that was processed from satellite image segmentation. In this study, a multiresolution segmentation algorithm was used. Objects classification was producing eight land-cover classes, i.e. water body, natural forest, Repong Damar, mixed garden, shrubs, built up and barrens, cloud, and cloud shadow. The nearest neighbor algorithm was used for classification. Accuracy assessment was also made using error matrix.

Three vegetation indices were evaluated for VIC i.e. NDVI (Normalized Difference Vegetation Index), EVI (Enhanced Vegetation Index) and NDWI (Normalized Difference Water Index). Around 300 point samples were taken from natural forests, Repong Damar and mixed garden, each. From this points, the pixel value of NDVI, EVI and NDWI were taken and descriptively analyzed to get the best algorithm that can differentiate Repong Damar. Thresholds were placed into the best algorithm using minimum, maximum, mean, standard deviation, upper and lower limit values to map Repong Damar. The best threshold to separate natural forests, Repong Damar and mixed gardens were evaluated using error matrix.

Carbon stock of Repong Damar was measured from 23 sample plots in Pahmungan Village and Gunung Kemala Village using a plot size of 400 m^2 refer to [7]. Trees (above 5 cm in diameter) in the plot were measured in height and diameter, and calculated to biomass using the tropical moist forest allometric equation [8] as expressed below:

$$\mathrm{AGB} = \mathrm{Exp}(-1.499 + 2.1481 \times \ln(\mathrm{DBH}) + 0.207 \times \ln(\mathrm{DBH})^2 - 0.0281 \times \ln(\mathrm{DBH}))^3) \times \mathrm{WD}$$

AGB is aboveground biomass (in kg); DBH is diameter at breast height (in cm); WD is wood density (in kg/m3). Biomass was transformed to carbon by multiplying AGB with 0.47 [7].

5. Results and discussion

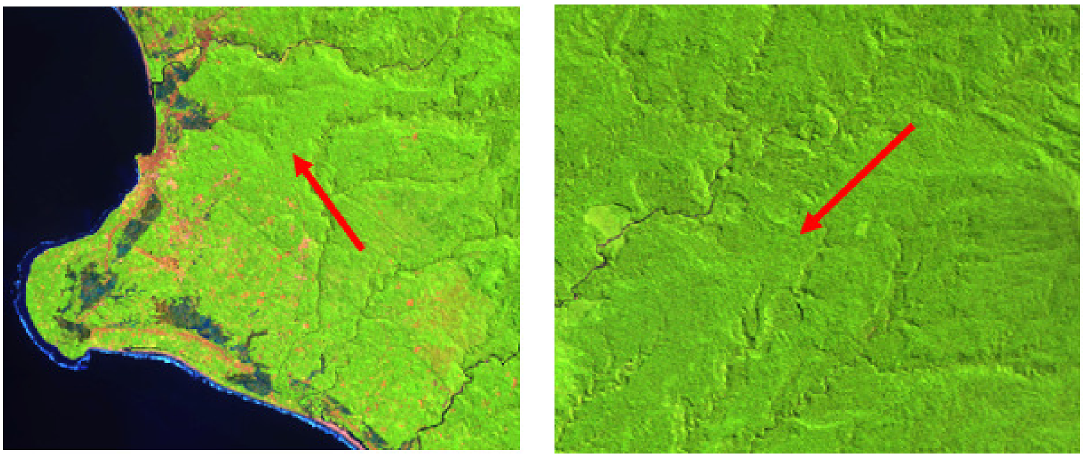
5.1. Repong Damar detection method

Visual differences between Repong Damar and natural forest are shown in figure 2. Repong Damar has a brighter green color compared to natural forest which has a darker green color.

5.1.1. Maximum likelihood classification (MLC). The results of the detection of Repong Damar cover using the MLC algorithm (supervised classification) shown in figure 3. This method showed that Repong Damar spread along in Pesisir Barat district. As seen in the picture, the distribution of Repong Damar in 2016 is more visible than in 2018.

5.1.2. Object oriented classification (OOC). Detection using this OOC method uses 3 homogeneity criteria based on three parameters, namely scale, shape and compactness. The three parameters used in this study are shown in figure 4.

5.1.3. Vegetation Indices Classification. The results of the vegetation indices are shown in figure 5. Figure 5 shows that the EVI algorithm was better able to separate Repong Damar from other classes.

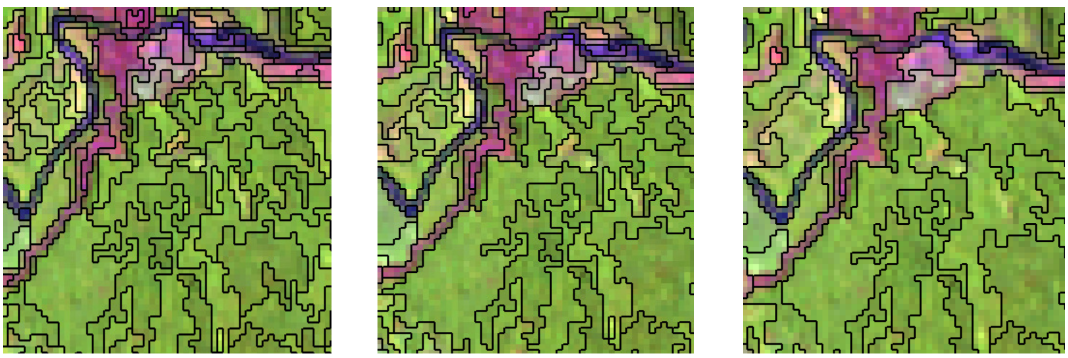


(a) (b)

Figure 2. Visualization of Landsat satellite images; (a) Repong Damar, (b) Natural forest.

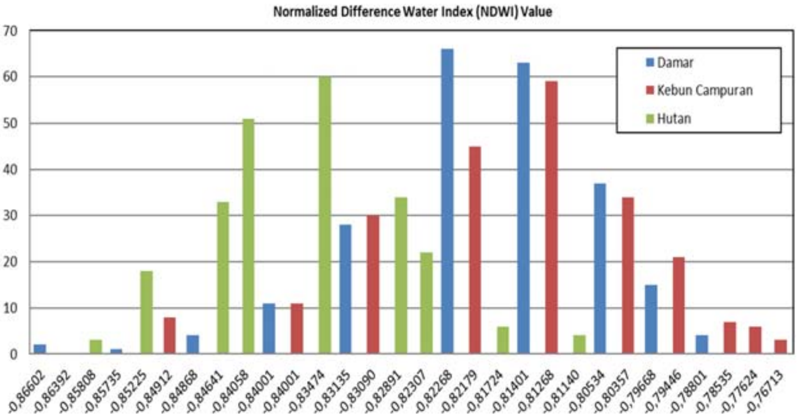
(a) (b)

Figure 3. The results of the detection MLC method, (a) 2016 and (b) 2018.

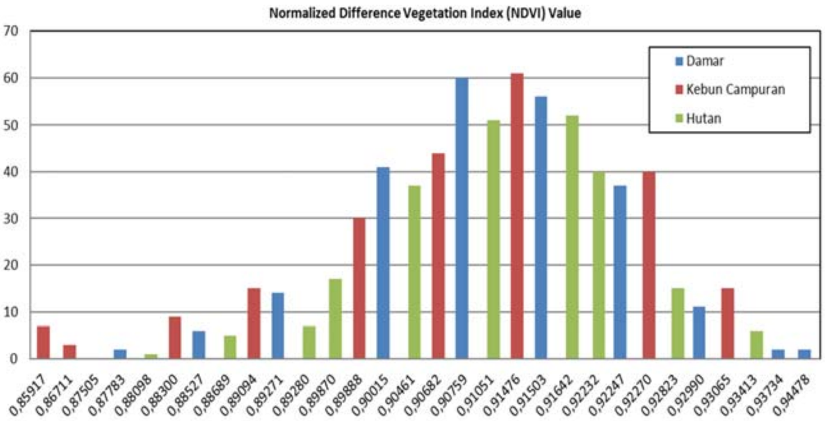


(a) (b) (c)

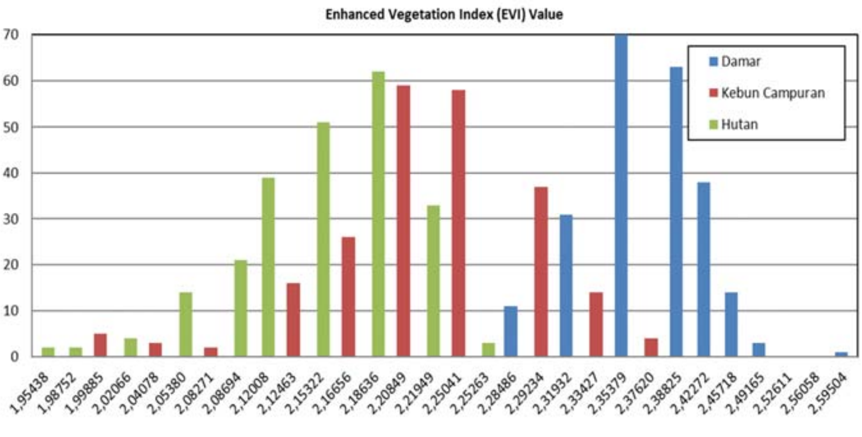
Figure 4. Difference in parameter scale: (a) Scale 25, (b) Scale 30 and (c) Scale 50.



(a)



(b)



(c)

Figure 5. Histogram of sample points of forest (green), Repong Damar (blue) and mixed garden (red) in (a) NDWI, (b) NDVI and (c) EVI.

This is possible because EVI can minimize cloud disturbances (atmosphere) and also the EVI algorithm is designed to be more resistant to soil color disturbances [9] Whereas for NDVI according to [10] NDVI values are influenced by several factors, including the sun angles indicated to affect the reflectance of red and infrared rays, atmospheric effects, and cloud conditions. In contrast to EVI and NDVI, NDWI has a negative value (-) because NDWI shows more dominance of regions that have water content in the region recorded using reflectance ratios from NIR and green channels for absorption calculations and light penetration on soil surfaces that have moisture content [11].

The EVI algorithm was then used to determine the most accurate threshold calculation in detecting the Repong Damar. Thresholds are applied to identify changes in vegetation over time including increases, decreases, and areas that have not changed [12]. According to [13] there is no theoretical foundation on how the threshold value is obtained, but assessed it through accuracy assessment.

5.1.4. Accuracy assessment. This accuracy value is used to determine which method is better able to detect the distribution of Repong Damar. The results of the accuracy values of the three detection methods are presented in table 1. The accuracy value (overall) of the 2016 MLC method shows a value of 75 % and for 2018 it shows a value of 92.16 %.

The tabulation results show that OOC has the highest overall accuracy than the others. The value of accuracy between the OOC method and MLC is not much different. This difference in value is 0.11 %. This is because MLC has a weakness, particularly "salt and pepper" result.

5.2. Repong damar cover changes

The results of the processing of satellite images from 1990 to 2018 to determine the changes in the area of Repong Damar are shown in figure 6.

Table 1. Accuracy assessment

No.	Method	Accuracy value		
		Overall	Producer (Damar)	User (Damar)
1.	OOC	92.27 %	89.35 %	64.33 %
2.	MLC	92.16 %	90.13 %	67.00 %
3.	EVI with 2 standard deviation threshold	83.33 %	78.40 %	92.00 %

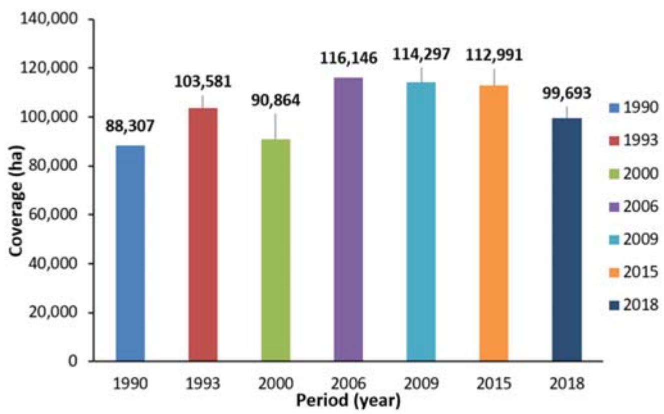


Figure 6. Historical coverage of Repong Damar in the study area.

Repong Damar experienced an increase and a reduction in the coverage. The increase or reduction in area can be caused by many factors. [14] states that repong is a tree-based farming system that has been traditionally cultivated by West Lampung Coastal communities. The hereditary culture that is strongly held by the community is the cause of increasing cover of Repong Damar.

5.3. *Estimated emissions levels of repong damar*

The results of monitoring Repong Damar coverage changes from 1990 to 2018 showed that the trend of deforestation in Repong Damar is not clearly visible. Therefore, the reference value used was the Forest Reference Level (FRL). Forest Reference Level (FRL) is a benchmark for assessing the performance of REDD+ scheme. In addition to the FRL, the Forest Reference Emission Level (FREL) is commonly used to assess the performance of forest emission levels. The most common understanding to distinguish these two forest emission level baselines is that FREL only includes gross emissions from deforestation and forest degradation, while the FRL includes emissions from sources and absorption by sinks, so that includes conservation of forest carbon stocks, management sustainable forest and enhancement of forest carbon stocks [15].

The estimated FRL Repong Damar was carried out by taking into account the history of Repong Damar cover from 1990 to 2015. The average value of Repong Damar cover from 1990 to 2015 was used as the FRL, which was 104,364 ha. The 2018's Repong Damar cover was used to see GHG emissions performance. Once the area of Repong Damar in 2018 is above the average, then the performance of Repong Damar is classified as good. However, the coverage of Repong Damar in 2018 was 99,693 ha, which means below the average. To this, the performance of Repong Damar in maintaining its area is classified as underperformance.

5.3.1. Repong Damar carbon stock. The calculation of Repong Damar carbon stock in 23 plots in Gunung Kemala and Pahmungan Pekon is estimated at around 318 tC/ha. The overall data from each plot are shown figure 7.

Table 2 shows a comparison figures of carbon stock in other area. This study showed Repong Damar in Pesisir Barat District has a greater carbon stock value compare to other study. According to [16], high carbon stock in Repong Damar was caused by the composition of vegetation in Repong Damar resembling natural forest, so that the carbon stored was quiet similar to the tropical natural forests.

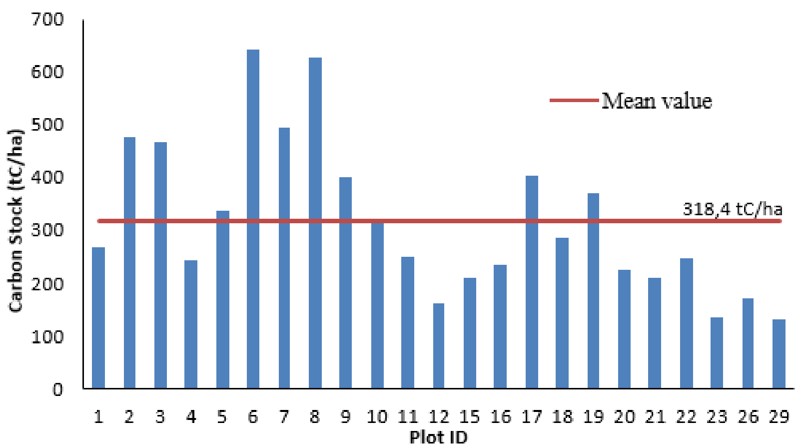


Figure 7. Calculation of carbon stock of Repong Damar in each plot of measurement.

Table 2. Carbon stored in various regions.

No.	Location	Land cover types	Allometric equation	Carbon stock (tC/ha)
1.	Repong Damar in Pesisir Barat Districts (this study)	Agroforestry (Repong Damar)	Moist tropical forest [8]	318.4
2.	Repong Damar (Pahmungan Village) [16]	Agroforestry (Repong Damar)	Various Specific Species Allometric Equation	174.22–254.09
3.	Meru Betiri National Park [17]	Natural Forests, Secondary Forests, Mixed Gardens, Agricultural Areas, Shrubs, Grasslands and Reeds, and Rubber Plantations.	[18]	20.31–120.93
4.	Dungus Iwul Natural Reserve [19]	Lowland Forest	Various Specific Species Allometric Equation	211.67
5.	Pemerihan Resort (Bukit Barisan Selatan National Park) [20]	Natural Forest	Various Specific [21]	277.64
6.	Nunukan Regency, East Kalimantan (Natural Forest) [22]	Natural Forest	Various Specific Species Allometric Equation	230.10
7.	Tambling Wildlife Nature Conservation (Bukit Barisan Selatan National Park) [23]	Natural Forest	Various Specific Species Allometric Equation	178.44
8.	Kelungu Village Community Forest, Tanggamus [24]	Agroforestry	Various Specific Species Allometric Equation	101.61

5.3.2. Repong Damar performance. The Repong Damar FRL value is 33,187.752 tC/year which is obtained from the mean of Repong Damar cover (104,364 ha) multiplied by the average value of the Repong Damar carbon stock (318 tC/ha). In the same way the value of Repong Damar carbon stock in 2018 is 31,702,374 tC. Therefore, the Repong Damar's emission performance in 2018 was calculated as -1,485,378 tC. The negative value showed that Repong Damar emitted carbon as much as 1,485,378 tC in 2018.

6. Conclusion

The best method for detecting the distribution of Repong Damar is object-based method (OOC). By using this method, the area of Repong Damar from 1990 to 2018 can be monitored and it experienced deforestation and reforestation. The coverage of Repong Damar in 2018 was 99,693 hectares. FREL of Repong Damar cannot be built because Repong Damar has decreased and increased trend from 1990 to 2018. The replacement of FREL that can be used is FRL, because FRL pays attention to the ability of Repong Damar to absorb carbon. Repong Damar emitted carbon as much as 1,484,378 tC in 2018. In conclusion, all technical procedure for measuring REDD+ performance from Repong Damar was able to be done, so from technical perspective, agroforestry such as Repong Damar has a significant potential for implementing REDD+.

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