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Estimation of mangrove carbon using drone images

Firman Farid Muhsoni*, Indah Wahyuni Abida, Dyah Ayu Sulistyo Rini, Aditya Januar Putera

Water Resources Management, Faculty of Agriculture, Trunojoyo Madura University, Bangkalan, Indonesia.

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ABSTRACT

Mangrove has numerous ecological functions, such as a habitat for various biota, a place of care and rearing, with a microclimate regulator and spawning. This ecosystem can store the highest carbon compared to tropical, subtropical, and boreal forests. This research aimed to model the estimation of mangrove carbon stocks using drone images. The method used consists of several steps as follows: (1) Taking and analyzing drone images, (2) Identification and estimation of biomass with carbon stocks, (3) Modeling of mangrove carbon stock using drone and field data. The results of mangrove carbon estimation using logarithmic regression of drone images were the best, by the equation $y = 0.0455\ln(x) + 0.244$. Therefore, the results showed that the R^2 value was 0.7454, with the RMSE accuracy-test being 689.9 kg, at 35.4%.

Introduction

Mangrove is a coastal forest with numerous ecological functions, such as a habitat for various biota, a place of care and rearing, with a microclimate regulator and spawning (Kauffman and Donato, 2012; Donato *et al.*, 2012). Presently, 50% of the world's mangroves are being damaged by various activities, while 35% of 50% are due to land conversion, cultivation, and coastal area development (Feller *et al.*, 2010). Furthermore, a total of 70 mangrove species (16%) are observed to be under the threat of extinction (Polidoro *et al.*, 2010). Also, the mangrove vicinity in the world is observed to be 2% of the coastal area. However, it has a 5% primary production function, 12% respiration, and about 30% carbon absorption (Alongi and Mukhopadhyay, 2015). This research aimed to find an estimation model for mangrove carbon stock using UAV (Unmanned Aerial Vehicle) aircraft/drones.

The next-generation drone users for aerial imaging and mapping are found to be increasingly used for mapping. As the field repeatedly seeks new mapping methods, the practical aspects of drone imaging and grading are detected to be the most applicable (Kullmann, 2018; Sanfourche *et al.*, 2015). In Indonesia, drones are also used to produce high-quality maps and resolve land conflicts between the government and the community (Radjawali *et al.*, 2017). Furthermore, it overcomes the scale gap between remote sensing and the airfield, providing high-resolution and multi-temporal data. Drones are easy to use, flexible, and transmits data in cm-scale resolution. The imagery is very prominent and has been used successfully in precision agriculture and photogrammetry (Jakob *et al.*, 2017; Shofiyanti, 2011). A flexible, inexpensive, and high-resolution remote sensing system in drones is an important platform for filling data gaps and enhancing manned aircraft capabilities with satellite remote sensors. Furthermore, it also can map forest canopies while explaining patterns of local biodiversity (Tang and Shao, 2015; Zhang *et al.*, 2016)

Unmanned Aerial Vehicle (UAV) or drones also produce high-resolution imagery for mapping small islands. The resulting data were analyzed using object-based digital analysis (GEOBIA). Furthermore, this analysis improves the mapping results' efficiency and accuracy, compared to visual interpretation with 94.4% incisiveness, and a kappa index of 0.92, because it has a large spatial resolution (Ramadhani and Susanti, 2015).

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* Corresponding author.
Email address: firmanfaridmuhsoni@trunojoyo.ac.id

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The drone in this research was used for mangrove mapping. The distribution and mangrove forest area observations obtained better accuracy, using drones for mapping its dynamics than Geo Eye 1 satellite imagery, with an incisiveness of 77.3% and a kappa coefficient value of 0.62 (Salim *et al*., 2018). The object-based classification of drone images with dominant land cover features provides the highest accuracy of 94.0±0.5%. Furthermore, pixel-based classification (using the maximum possibility algorithm) of drone imagery provides better accuracy of 90.0±1.9% (Ruwaimana *et al*., 2018). However, the drone provides higher temporal resolution images, even on cloudy days, and a tremendous benefit when working in humid tropical climates. In terms of cost, drone users are more advantageous than those utilizing satellite data for long-term monitoring of a small area. However, mangrove mapping based on drone aerial photographs provided unprecedented results and proved to be a viable alternative (Ruwaimana *et al*., 2018). The method of estimating mangrove carbon stocks using satellite images is rare, and for drone images, this method does not yet exist. The purpose of this study was to obtain an estimation method for mangrove carbon stock using drone images. The hypothesis is that carbon stock estimation can use a non-linear regression approach.

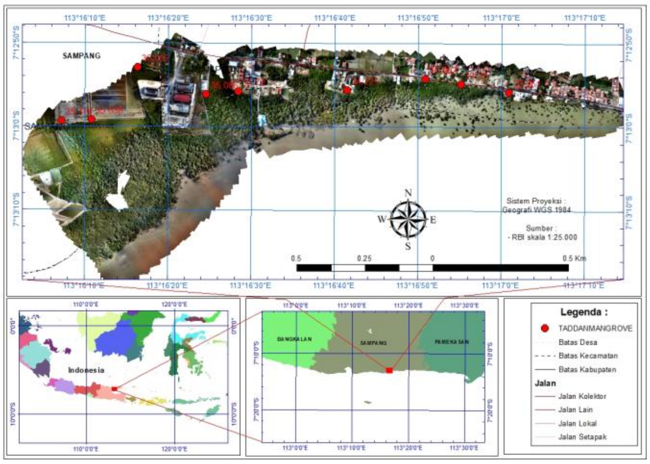


Figure 1. Drone image of mangrove area in Taddan Village, Sampang Regency.

Materials and Methods

Research location and time

This research was conducted in Taddan Village, Camplong Subdistrict, Sampang Regency, Madura. Image data were collected from the mangrove area using the Mavic pro drone on September 2, 2020. The mangrove location from the drone image results is shown in Figure 1. The image generated from the drone was 829 photos, 108 m height, 3.27 cm/pix resolution, 0.881 km^2 area, error estimates of 5.38m, 2.37m, 8.056 m, 5.88 m, 9.98 m, for X, Y, Z, XY, and the total error, respectively. The DEM resolution of 6.54 cm/pix and a point density of 234 points/m2 were also recorded. The photos were then analyzed using the Agisoft Metashape Professional software.

Data analysis

The measurement of mangrove biomass used SNI 7724:2011, regarding the analysis and calculation of carbon stock (Kauffman and Donato, 2012; Bismark *et al*., 2008; Dharmawan and Siregar, 2008; Dharmawan, 2010). The stages of measuring mangrove carbon in terrestrial are as follows (Kauffman and Donato, 2012):

a. Measurement of above-ground biomass consisting of tree and understorey components.
b. Biomass measurement of dead trees and wood (necromass),
c. Measurement of soil organic carbon content on mangrove mineral soils (Lugina *et al*., 2011; BSN, 2011)
d. The below-ground biomass measurement is calculated using the method formula in Kauffman and Donato (2012). The general equation is as follows (Kauffman and Donato, 2012; Komiyama *et al*., 2008):

$$B = 0{,}199 * \rho^{0{,}899} * (DBH)^{2{,}22}$$

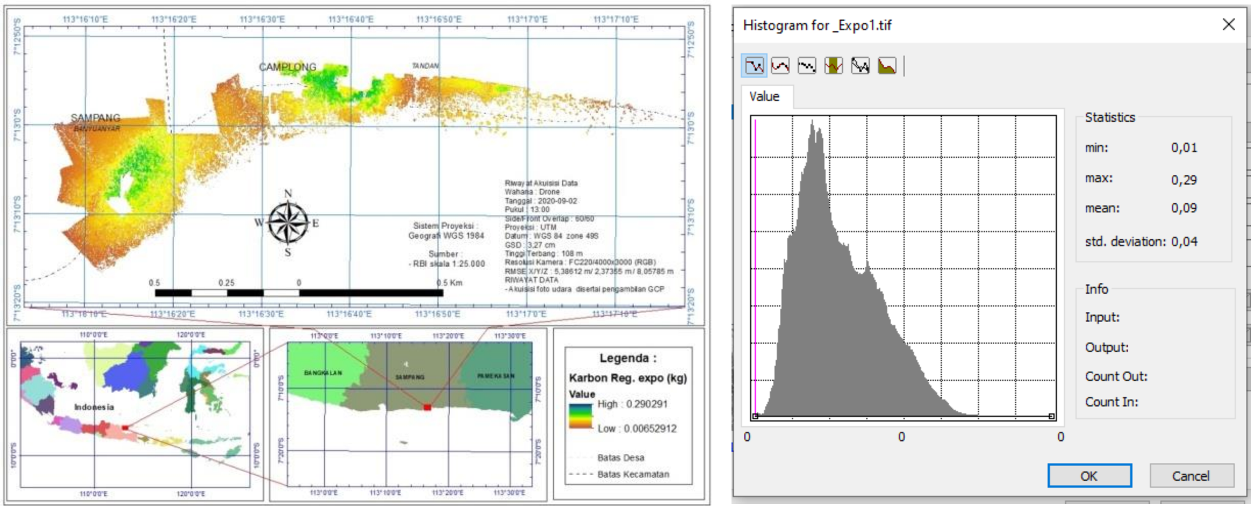
Note: B=underground biomass (kg), ρ= density of wood (g.cm^{-3}), DNH diameter at breast height (cm).

The calculation of carbon stock was based on SNI 7724:2011. Furthermore, the carbon calculation based on SNI 7724:2011 includes the following stages:

a) Carbon calculation from biomass,
b) Carbon calculation from dead organic matter (litter, deadwood, and trees),
c) Soil carbon calculation

DBH (diameter at breast height) to estimate the carbon stock content in mangrove biomass. Estimation of biomass using an allometric equation model. DBH measurements were taken at the chest height of an adult (1.3 m). DBH measurements are only carried out on trees>5 cm in diameter. This study's measurement of biomass and carbon stock refers to SNI 7724 (National Standardization Agency for Indonesia, 2011).

The DEM and orthomosaic data generated by the drone linear and non-linear regression at the mangrove carbon stock modeling stage were tested to obtain the best method. This modeling was to obtain estimates of mangrove carbon stock in the research area (Muhsoni *et al*., 2018a; Muhsoni *et al*., 2018b).



Statistics
min: 0,01
max: 0,29
mean: 0,09
std. deviation: 0,04

Info
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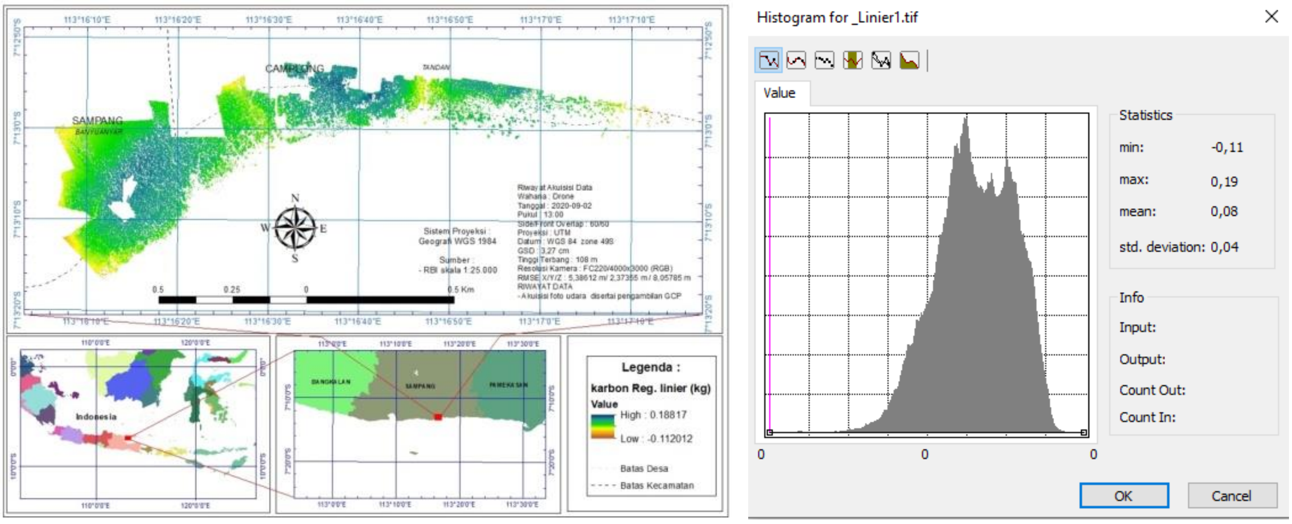
Figure 2. Total mangrove carbon stock using the Exponential regression equation.



Statistics
min: -0,11
max: 0,19
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std. deviation: 0,04

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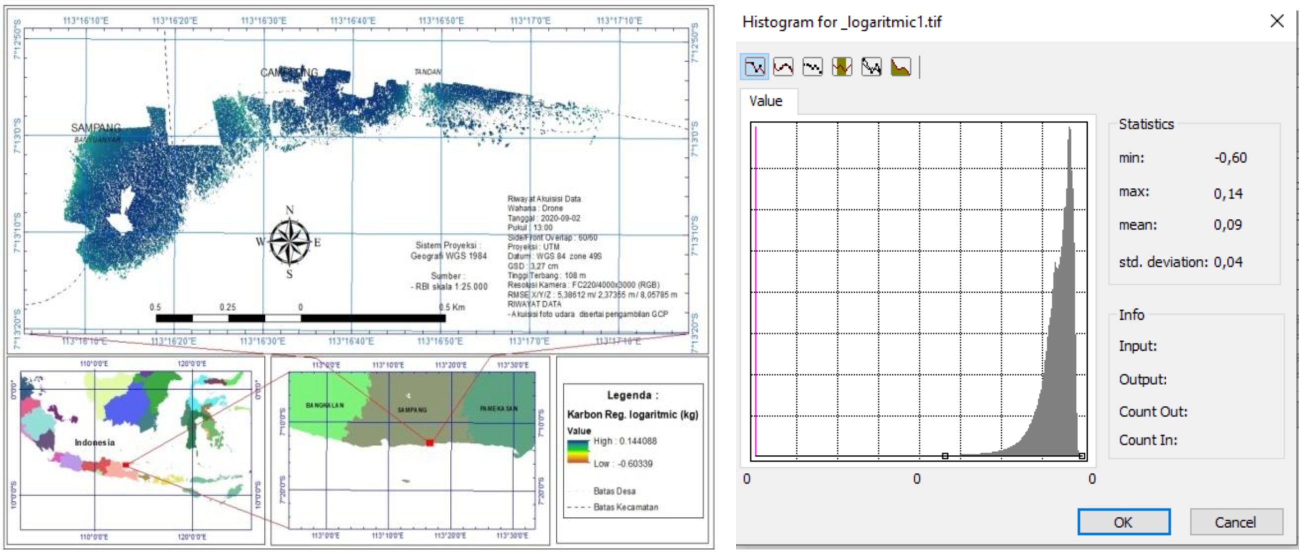
Figure 3. Total mangrove carbon stock using the Linear regression equation.



Statistics
min: -0,60
max: 0,14
mean: 0,09
std. deviation: 0,04

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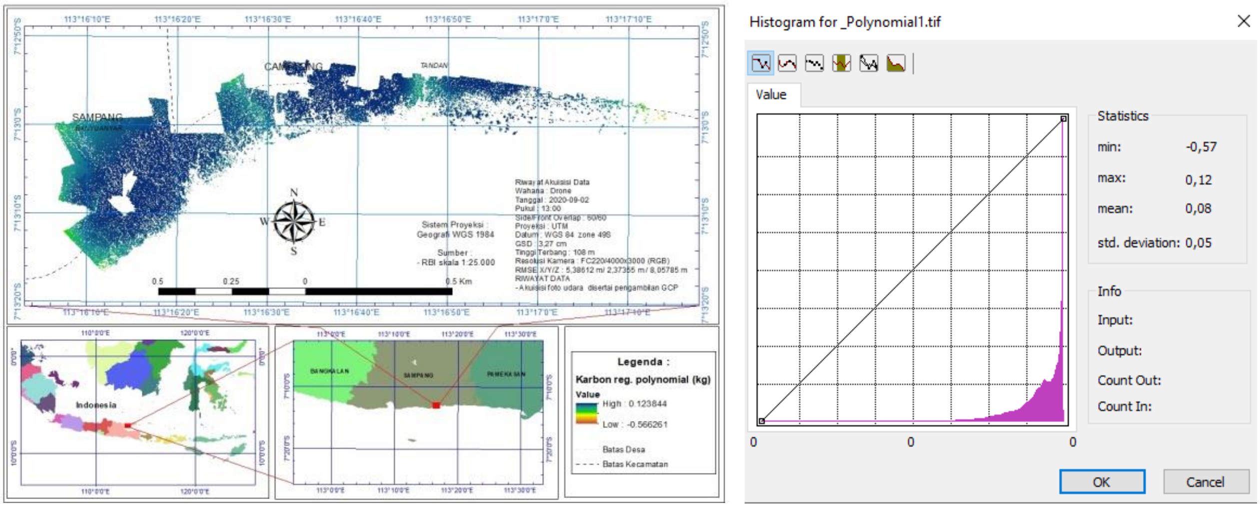
Figure 4. Total mangrove carbon stock using the Logarithmic regression equation.



Statistics
min: -0,57
max: 0,12
mean: 0,08
std. deviation: 0,05

Info
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Figure 5. Total mangrove carbon stock using the Polynomial regression equation.

Results

Mangrove biomass

The biomass measurement stage began with measuring the diameter at breast height (dbh=±1,3 m) for all mangrove tree types in each plot at all stations. Furthermore, it uses allometric equations to estimate the weight of above-ground mangrove biomass. The calculation of understorey biomass was carried out, by weighing mangrove sampling, in each understorey plot. The measurement of below-ground/root biomass in this research used equations from Kauffman and Donato (2012) and Komiyama *et al*., (2008). Calculations using this equation required the wood density value for each mangrove type.

The calculation of litter biomass was neglected because mangrove land was strongly influenced by seawater tides, which causes litter can not be measured thoroughly (Kauffman and Donato, 2012). The calculation of the dead trees and wood biomass at the research location was also ignored because of its observation to be very small in the study area. The analysis results of the average mangrove biomass, at the research location, on all measurement plots, reached 171 tonnes/ha, i.e., 101.9 tonnes/ha (60%) for above-ground, and 69,1 tonnes/ha (40%) for that of the root/below ground.

Calculation of mangrove carbon stock

Mangrove carbon stock calculations were carried out for each plot, at all stations, within the field. The mangrove carbon stock value consisted of (1) Surface carbon stock or tree biomass, which was also combined at the same time with that of the understorey due to its mangroves in the research not being too large. (2) Subsurface carbon stocks or root biomass, and (3) Soil carbon stocks.

Soil carbon calculations were carried out for each plot at all stations. Parameters measured for each plot were sediment depth and soil organic C (Kauffman and Donato, 2012). The average mangrove sediment depth was 24.74 cm, with that of the soil organic C stock being 4.87%.

The results of carbon calculations in each plot were then converted into ton per hectare. Furthermore, the calculation of mangrove carbon stock in this research was estimated from biomass carbon (above-ground, below-ground, and understorey) and added with that of the soil (with sediment depth). The analysis results of the average carbon stock for mangroves reached 194.7 tonnes/ha, i.e., tree and understorey carbon for the above-ground of 47.9 tonnes/ha (24%), root for below ground of 32.5 tonnes/ha (17 %), and soil of 114.4 tonnes/ha (59%). Therefore, when comparing biomass carbon stocks (trees, roots, and understorey) with soil carbon, it attains a ratio of 1:1.4.

Mangrove carbon stock modeling from drone image data

In this analysis, several stages were carried out, such as (1) Calculating the volume of the field measurement location at each plot on the DEM from the drone image analysis; (2) Comparing the results of the volume with carbon calculations in the field data; (3) Furthermore, modeling with both linear and non-linear regression was carried out; (4) The regression results were recorded into the map, with the best accuracy being searched for.

Obtaining the best model for estimating mangrove carbon was carried out by regressing the volume of the drone image analysis results (x) with the carbon of mangrove vegetation and the soil from field measurements (y). The best model was observed by regressing both linear and non-linear regression at this stage, with the results shown in the equation below. Also, the carbon estimation map results for each regression model, were shown in Figures 2, 3, 4, and 5 as well. The results of the regression equation are as follows:

1. Exponential Regression, $y = 0.0432e^{17.164x}$, $R^2 = 0.6481$, RMSE (n : 21) = 873.9 kg , % RMSE = 44.9%
2. Linear Regression, $y = 1.3578x + 0.0371$, $R^2 = 0.6992$, RMSE (n : 21) = 820.1kg , % RMSE = 42.1%
3. Logarithmic Regression, $y = 0.0455\ln(x) + 0.244$, $R^2 = 0.7454$, RMSE (n : 21) = 797.9kg , % RMSE = 41.0%
4. Polynomial Regression, $y = -20.252x^2 + 3.0288x + 0.0106$, $R^2 = 0.7576$, RMSE (n : 21) = 797.3kg , % RMSE = 40.9.

Discussion

Dharmawan (2010) observed that above-ground biomass in the Purwakarta mangrove area was 77.2 tonnes/ha. This value was almost close to this research results for mangroves (79.4 tonnes/ha). However, Hartoko *et al.* (2015), observed that mangrove biomass in Karimunjawa reached 128.29 tonnes/ha, with the results almost the same as this research (111.5 tonnes/ha).

This research is the same as Donato *et al.* (2011), which obtained the highest C stock at the top of the soil profile. The results showed that the estuary mangroves were on average 3.0%, compared to the mangroves in the sea (2.8%). The calculation of soil carbon required data on depth, density, and percentage of soil carbon. While using the research results by Muhsoni *et al.* (2020), the bulk density showed that the average soil frequency of mangroves was 1.02 g/cm^3. The calculation results in each plot were converted into tonnes per hectare. The average soil carbon stock for mangroves was 114.40tonnes/ha, with a minimum and maximum of 43.82 tonnes/ha, and 239.63 tonnes/ha (39.3%), respectively.

Imiliyana *et al.* (2002), observed that an average mangrove carbon stock in the Pamekasan area was 196.85 tonnes/ha. This value is almost close to the average stock produced by this research (154.1 tonnes/ha). However, Donato *et al.* (2011), also obtained mangrove carbon stock in the tropics, at 1.023 tonnes/ha.

Alongi *et al.* (2016), further obtained mangrove carbon stock in Java, for above-ground carbon at 311.8 ± 77.2 tonnes/ha (± 24%), underground at 27.9 ± 4.4 tonnes/ha (± 2%), and soil at 979.5 ± 152.4 tonnes/ha (± 74%). Therefore, the ratio of carbon stock from biomass (trees, roots) to soil C is 1:2.9. Furthermore, Donato *et al.* (2011), obtained subsurface carbon stocks for estuary mangroves at 71%-98%, and that of the marine at 49%-90%. Kauffman and Donato (2012) explained the ratio between biomass and soil carbon in the Kalimantan region to be 1:8, almost corresponding with this research, for estuarine mangroves 1:9.1. The carbon in the sediment is high because much organic material is carried away from the river flow.

The best equation for estimating mangrove carbon stock, used Logarithmic regression, with the equation $y = 0.0455\ln(x) + 0.244$. Furthermore, the equation had an R^2 value of 0.7454, RMSE accuracy test at 689.9 kg, with the RMSE percentage at 35.4%. The mangrove area of Taddan Village used the above equation, with an area of 24.97 ha, 0.088 kg/pix (with a pixel area of 0.0043 m^2), a standard deviation of 0.038, and total carbon stock of 515.3 tonnes.

Conclusion

The analysis results of the average biomass were approximately 171 tonnes/ha. This consisted of 101.9 tonnes/ha (60%) for the above-ground biomass (tree and understorey) and 69.1 tonnes/ha (40 %) for below ground. The analytical results of the average mangrove carbon stock, in the field measurement of 154.1 tonnes/ha, consisted of the carbons obtained from tree and underground vegetation of 47.9 tonnes/ha (31%), root 32.5 tonnes/ha (21%), and soil 73.7 tonnes/ha (48%). The estimation of mangrove carbon, with the best drone images, used Logarithmic regression, with the equation $y = 0.0455\ln(x) + 0.244$. This equation had an R2 value of 0.7454, RMSE accuracy of 689.9 kg, at 35.4%. The average carbon stock mangrove was 0.088 kg/pixel (with a pixel area of 0.0043 m2), with a standard deviation of 0.038, and a total of 515.3 tonnes.

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