Estimating mangrove biomass using drone in Karimunjawa Islands

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Abstract. Research on mangrove forest biomass using drones was conducted in Karimun Jawa Islands in August 2018. Karimunjawa Islands is a conservation area under the management authority of the Ministry of Environment and Forestry (KLHK). However potential environmental stress due to increasing numbers of tourists and aquaculture activities concerned to degrade mangrove ecosystem in the area. The method used in this study includes aerial photography work using drones and field data collection of forest ecosystems. Aerial photography work consists of stages of preparation, aerial photography and aerial photo processing in the form of photos mosaicking and DSM generating. The mangrove field data obtained were tree diameter (DBH), tree height and mangrove genus. To find out the mangrove biomass, the equation Saenger & Snedaker (1993) is used. The results show that the number of branches of mangrove trees are 853 branches with heights varying between 1 to 15.5 meters and an average height of 4.4 meter. The estimated mangrove biomass in the study site is 82,154 tons/hectare. This study successfully demonstrated that by using relatively low operational cost consumer-grade drone and can help map the characteristics of mangrove vegetation. However, drone technology still has some limitations, including the need to use GPS Geodetic for accurate positioning. Using this supporting technology, it is expected that the position and height of the tree can be measured more accurately.

1. Introduction

The use of satellite imagery for mapping the dynamics of mangrove forests has been carried out by several researcher such as by Suwargana [1] and Suprakto [2]. Several institutions, both government and private requiring spatial data for their works have also used these technologies. This is due to several advantages on temporal and spatial resolution capabilities offered by satellite technology [3] for monitoring the surface of the earth at a certain level of detail. Moreover, prices of the images are relatively cheap or even free and can cover a large area [4,5]. Some websites provide free remote sensing data, for example USGS, and for high resolution can be obtained from Google Earth.

Besides using satellite imagery, aerial photography has also been frequently used for land use mapping [6]. Aerial photography is a photographic image obtained from an aerial survey using either manned or unmanned aircraft that fly above the earth's surface at low altitudes [7]. Due to the low altitude, the photo resolution obtained can be very detail, even less than 25 cm [8].

Data obtained from satellite imagery and aerial photography are still in form or basic data that need to be processed and integrated into a system that can be managed, analyzed and displayed as spatial information called Geographic Information Systems [9]. Spatial information can be in the form of various thematic elements called layer(s). These layers are normally displayed during analysis and
spatial analysis is carried out to these layers to produce new information concerning spatial objects on the surface of the earth.

One of the applications of satellite imagery and aerial photography that can be integrated with geographic information systems is mapping mangrove forests dynamics. Mangrove forests as part of land cover, describes human activities on the earth's surface in relation to land use [10]. This relationship is not directly visible from satellite imagery. Land cover mapping activity is closely related to the study of vegetation, agricultural crops and soil from the surface of the earth. In addition, it also relates to the results of human culture of artificial elements such as settlements and land utilities [11].

Land use and land cover data are very important for planning [12]. The data are very useful for identifying land suitability, alternatives and better land use selection, even for land-use change planning. The uniqueness of land use in an area must also be considered, because different regions will have different characteristics. So that the development planning process will be different. Accurate spatial data can be obtained through integration between remote sensing data and geographic information systems [13]. Several studies show that the integration can increase the accuracy of the data [14].

The study took place in Karimunjawa Island. The location is a conservation area under the management authority of the Indonesian Ministry of Environment and Forestry through its Marine National Park Authority. The mangrove area in Karimunjawa Island is relatively dense and healthy. The purpose of this research is to estimate the biomass of mangrove area in Karimunjawa Island using aerial photographs taken by UAV, which is then integrated into a Geographic Information System.

2. Methods

2.1 Description of the study area
Karimunjawa National Park is located in Jepara Regency, Central Java Province. Astronomically, Karimunjawa Subdistrict is located at coordinates 5°40' S - 5°57' LS and 110° 04' - 110° 40' BT. Karimunjawa National Park is 45 nautical miles from the Capital of Jepara Regency and 60 nautical miles from Semarang, the Capital City of Central Java Province. Karimunjawa Subdistrict is located in the north of Java Island, the boundary of Karimunjawa Subdistrict to the West, East, North and South is the Java Sea. The typical ecosystems in Karimunjawa National Park are ecosystems of lowland tropical rainforests, mangrove forests, coastal forests, seagrass beds and coral reef ecosystems. Mangrove ecosystem in Karimunjawa is relatively natural and spread throughout Karimunjawa National Park. The dominant mangrove species in Kemujan and Karimunjawa are Exocarica agallocha, while the most widespread species is Rhizophora stylosa.

Mangroves area at National Park are divided into 2 parts, which are separated by asphalt roads and separating them. On the west part it borders the sea, the mangrove has a height of less than 15 meters and towards the seaward becomes shorter because it is a new plant. Whereas in the east part mangrove height is relatively high reaching height of more than 20 meters with a very high density. This makes the color / tone of mangroves in the eastern locations are relatively darker than the locations in the west when viewed from satellite imagery.

2.2 Acquisition of aerial imageries
In general, aerial photo acquisition requires several stages, i.e preparation stage, the acquisition stage and the data processing stage. During the preparation phase, it has to be identified the area or scope to be mapped in hectare unit. Also the desired pixel resolution or ground sample distance (GSD) needs to be determined. For a height of 130 meters it produces a resolution of 5.84cm, a height of 100 meters resulting in a GSD of 4.43cm, a height of 50 meters producing 2.26 cm and a height of 15 meters resulting in 0.789 cm. The percentage of overlapamong photos is determined at 80% due to variation in vegetation reliefs. The type of drone used is a DJI Phantom 3 Pro type drone with a 12 MP camera resolution with the ability to fly for 15 minutes per battery. Next, Pix4DCapture, an Android-based
application is used to estimate the number and duration of flight based on these parameters so that the number of flight information is obtained.

Installation of benchmarks for georectification purposes is required. The benchmark is made of materials that are weather resistant and can be seen from drones. Benchmark coordinates are then obtained using GPS Geodetics with a maximum accuracy of 0.5 cm. These coordinates are ground control points (GCP) which will later be used for georectification. The next stage is the stage of acquisition of aerial photography. Time to take photos around 8:00 to 10:30 and 14:00 to 16:30. The timing of the time is usually sunny and the wind blows calmly.

The acquired aerial photographs are then selected. Blurry, tilted photos or angled from upright 90° are set aside for further processing. Aerial photos are processed using the trial version of Pix4D Mapper software. At this stage some steps are implemented: aligning photos, building dense cloud, texturing, orthomosaicking, DSM building and finally exporting photos into ortho map format. The resulting map is then further processed using Global Mapper software for compression and storage in smaller ecw format. The orthophoto map was then processed to generate DSM information using Geographical Information System, particularly neighborhood and focal statistic analysis. The results obtained from this process are height information, number of the tree and biomass estimation.

2.3 Estimation of Mangrove Tree Biomass
Mangrove biomass can be estimated using specific allometric equations that have been published in several references [15]. Almost all of the equation need tree diameter as the main parameter beside wood density and tree height. Since data that can be extracted from aerial photographs is only tree height, we use the equation by Saenger & Snedaker [16] that only use height as the main parameter. The tree height and the number of tree branches was derived from Digital Surface Model (DSM) corrected by DEM which is assumed to have a value of 0. The Saenger & Snedaker equation as follows:

\[ \text{BIOMASS (t.ha}^{-1}) = 10.8 \times \text{Height (m)} + 34.994 \] (1)

3. Result and Discussion
3.1 Western part of National Park
A total of 444 photographs were taken. Not all photos were aligned due to the density and position of mangrove vegetation and the drift by the wind so that the software did not succeed in finding the connection points among the photos. The study site is focused on the coastal area near the watchtower with mangrove vegetation density varies, showing variation between sparse and moderately-denses. A 3D view and a mosaic map of the study site were obtained (Figure 1 and Figure 2). Furthermore, based on mosaic data and aerial photographs using Agisoft PhotoScan software, Digital Surface Model (DSM) data or digital surface models can be obtained which can show the height of the earth's surface in meters (Figure 3). On the DSM map, it can be seen that the average height of a certain object such as the tower height is around 18 meters and vegetation is less than 10 meters. In the south, there are height distortions due to the position of the camera that is perpendicular to the bottom so that the edge area has increased height.
There were 853 tree branches with varying heights counted in this location (Figure 4). The height of the tree varies from 1 to 15.5 meters with an average height of 4.4 meters. The average of tree height at the study site is around 4.4 meters, resulting in the estimation of biomass at the study site of 82,154 tons / hectare.
Figure 4. Mangrove tree estimation map of the western part of national park
3.2 Eastern part of National Park
The study site is across the first location and separated by a road. Located in the east, this location is overgrown with mangrove vegetation with relatively high trees. The height of the tree ranges up to 19 meters high. The acquisition of aerial photographs at this location successfully obtained 295 photographs, where a total of 290 photos (98%) successfully calibrated. The obtained Ground Sample Distance is 1.11 cm and managed to map area of 2.92 hectares. The 3D profile of the study site is presented in Figure 5. For the purposes of this study, the area is then cropped and selected in an area that has the smallest distortion, namely in the middle area. The new focused area is 1,716 m² as shown in Figure 6.

![Figure 5. 3D Model of research location at eastern part](image)

Furthermore, Digital Surface Model (DSM) data was produced using Inverse Distance Weighted (IDW) method with the Pix4DMapper cloud trial software (Figure 7). Based on the subsequent DSM data processing using ArcGIS, location estimation and the number of trees in the area are generated. The tools used are tools Neighborhood, namely focal statistics. These tools are useful for determining the highest point in an area in this case the number of pixels is limited to 100 pixels or the area per 1 meter will get the highest value. Furthermore, to limit the results of each meter, tools are used "con" or conditional. This tool determines which point will be determined as the highest peak of a tree and it is assumed that the point is the height of the tree and or the height of the tree branch. The results of tree analysis are presented in Figure 8. The average of the tree height at the location was around 14.6 meters, resulting the estimation of biomass of 192,674 tons / hectare.
Based on the calculation results, it can be seen that the location to the east of the National Park has larger biomass than the location to the west. That means the biomass on the east side is bigger than the west side. This was allegedly due to environmental conditions that did not support mangrove growth on the west side of the road, as seen from the difference in tidal hydrodynamics between the two sides. The environmental conditions of the mangrove ecosystem on the east side are relatively supporting for mangrove growth, characterized by regular tidal circulation and inundation.
The results of the field visit revealed that the location of the west side of the road has *Xylocarpus mollucensis* mangrove which is the largest contributor to biomass, followed by *Rhyzophora mucronate* [17]. Interestingly, the simultaneous presence of both species were found only on the east side (right of the road). These results also support the previous assumption that the environmental conditions of the mangrove ecosystem on the east side are still quite good for supporting the growth of various types of mangroves.
4. Conclusion
Drone technology can be used more effectively to map the areal extent and the biophysical parameters of mangrove, such as biomass, in a more detail resolution than using satellite imagery. Drone technology in this study succeed to fill the mangrove data gaps in Karimunjawa that are not achievable from satellite imagery. This study successfully demonstrated the ability of consumer-grade drones and relatively low-cost mapping activity to support mapping the characteristics of mangrove vegetation, including its size, height, number of trees and biomass.
Future improvement can be attempted by using Geodetic GPS for improving positioning of the drone-based map and the tree height calculated from the drone images. Weather factors such as sun-glint, tree shadow and wind condition needs be taken into account for calculation and consideration as these factors impact the accuracy of mosaicking and classification results.

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