IGARSS 2023 - 2023 IEEE International Geoscience and Remote Sensing Symposium | 979-8-3503-2010-7/23/$31.00 ©2023 IEEE | DOI: 10.1109/IGARSS52108.2023.10282442

INDIVIDUAL TREE CROWN DELINEATION AND BIOMASS ESTIMATION FROM LIDAR DATA IN GORGONA ISLAND, COLOMBIA

Yady Tatiana Solano-Correa[1,2], Yineth Viviana Camacho-De Angulo[2,3], Fernando Oviedo-Barrero[3], Michele Dalponte[4], Edgar Leonairo Pencue-Fierro[2]

[1] Universidad Tecnológica de Bolívar, Parque Industrial y Tecnológico Carlos Vélez Pombo Km 1 Vía Turbaco, 130010 Cartagena, Colombia.
[2] Universidad del Cauca, Calle 5 #4-70, 190001 Popayán, Colombia
[3] Centro de Investigaciones Oceanográficas e Hidrográficas del Pacífico - DIMAR, Capitanía de Puerto Tumaco, 528501 San Andrés de Tumaco, Colombia
[4] Research and Innovation Centre, Fondazione Edmund Mach, via E. Mach 1, 38098 San Michele all'Adige, Italy.

ABSTRACT

Biomass estimation is a crucial component in the areas of carbon storage and forest management. Biomass can be analyzed rather at forest or at Single Tree Level (STL) and studies in both directions can be found in literature. Nevertheless, working at STL provides more accurate estimations. Such a level of information can be obtained by means of LiDAR data, but this type of data is usually expensive and not available for all Countries. Thus, few studies at STL can be found in developing countries and tropical forests. This study presents one of the first works for biomass estimation in tropical forest located in Gorgona Island, Colombia. Adaptations have been made to state-of-the-art methods for them to properly work in a complex forest, where trees sizes vary a lot from one area to another. Preliminary results are shown for some areas, allowing to see the capabilities of the adaptation.

Index Terms— Individual Tree Crowns, Biomass Estimation, LiDAR data, Gorgona Island, Tropical Forest.

1. INTRODUCTION

Forest biomass estimation is the base for both forest management and timber industry [1]. From the research viewpoint, it is very interesting to analyze forest biomass distribution at tree level. Thus, a key point is to accurately identify Individual Tree Crowns (ITC). ITC identification is done by delineation of tree crowns by means of Very High spatial Resolution (VHR) [2]–[5] or by means of LiDAR data [6]–[8]. Accessing any of the two types of data implies high costs that not all countries can afford. That is a particular case for Colombia, where official institutions are the ones who have the financial capacity. Unfortunately, the most detailed data for forest management only arrives to a scale of 1:51000, which is not enough for properly mapping forest, neither for ITC delineation.

The DIMAR ([9] in Spanish Dirección General Marítima) is the Colombian maritime authority in charge of executing government's policy in this matter. Over the last 5-10 years, DIMAR has collected LiDAR data over the pacific coastline of Colombia focusing also on small islands such as the Gorgona one. The Gorgona island (GI) is of great interest because it became a National Natural Park (NNP) in 1983, thus representing a large area of preservation for the Country. GI is home to a diverse range of flora and fauna, it is covered by a tropical forest, which provides important ecosystem services such as carbon sequestration, water regulation, and soil stabilization. Thus, estimating the biomass of such forest can help: (i) to identify areas that require special attention for forest management, such as areas that are experiencing deforestation or areas that need reforestation; (ii) conservationists and scientists to understand the distribution and abundance of different species and their habitats, which is crucial for developing effective conservation plans [10], [11]. Biomass is a crucial component of carbon storage, as it represents the amount of carbon stored in living organisms such as trees, shrubs, and other vegetation. Mapping the biomass on GI can help to quantify the amount of carbon stored on the island, which is important for monitoring the impact of climate change on the island's ecosystem [11]. Finally, GI is a popular destination for ecotourism, and biomass mapping can provide valuable information for tourists who want to learn more about the island's ecology and biodiversity. It can also help tour operators and other stakeholders develop sustainable tourism practices that minimize the impact on the island's natural resources [10].

Even though GI is an area of great interest, few/nonofficial data can be found at national level where details are offered at ITC level. This is due to the lack of detailed data to perform such an analysis and the availability of tools to process the

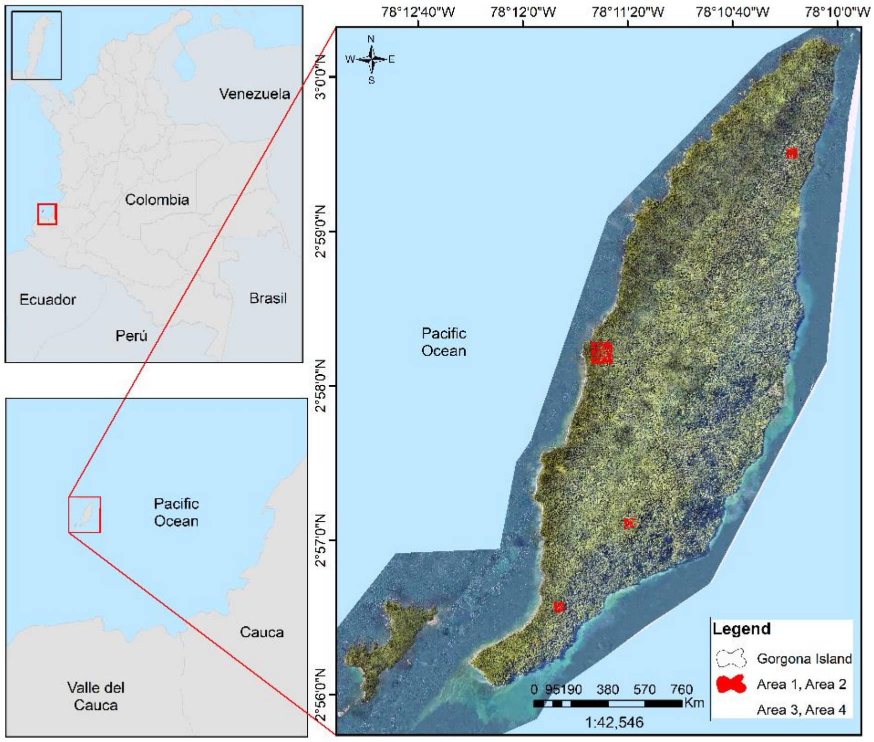

Figure 1. Gorgona island location in Colombia, right panel: real color airborne image with validation areas highlighted in red.

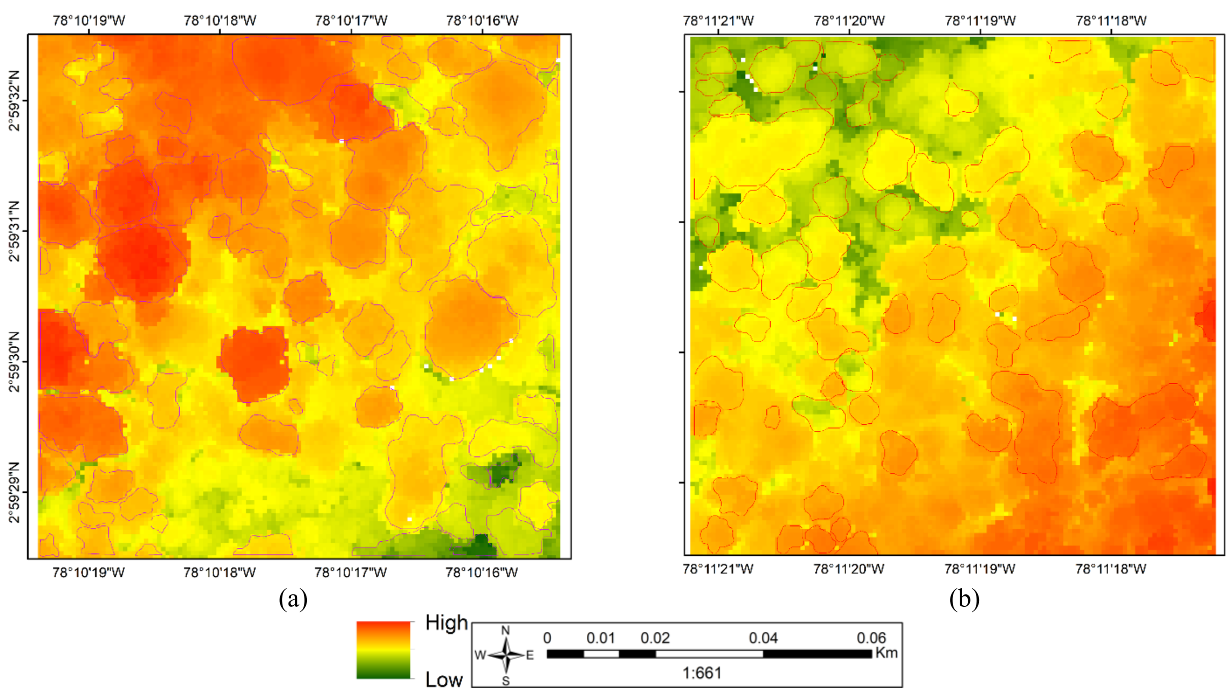

Figure 2. DTM map for Gorgona Island in (a) area 1 and (b) 2. Red lines indicate ITC delineated by photointerpretation.

corresponding data. This research presents one of the first works (to the best of our knowledge) on automatic ITC delineation in the NNP of GI in Colombia, where adaptations have been made to existing algorithms in literature, such that they can work for the complexity of tropical forest. Taking advantage of the ITC map, biomass has also been calculated.

2. STUDY AREA AND DATA

The study area for this research is the Gorgona island, located in the Cauca region to the South-West of Colombian Pacific coast (see Figure 1). The total extension is 61687.5 ha that includes insular territory and marine area. Gorgona island has a relative humidity of 100%, high rainfall of nearly 7000 mm per year and a temperature over 28°C. It has volcanic and intrusive rocks and the vegetation present corresponds mostly to secondary forest with remnants of primary forest on the ridges, with small to medium-sized trees, followed by juvenile trees and shrubs [12], [13].

LiDAR used in this study were collected in 2019 with a Leica ALS50-II recording system mounted on a fixed-wing aircraft with a point density of 2px/m^2. Up to four returns per pulse were recorded. The LiDAR data covers the entire area shown in Figure 1 and was accompanied by an RGB orthophoto. In order to validate the results, and due to the lack of any similar data in Colombia, ITC delineation was made by photointerpretation (over the 4 areas shown in red squares in Figure 1) considering both the DTM map derived from this research and the RGB orthophoto. Figure 2 shows the detailed DTMs for areas 1 and 2, where it can be seen the complexity of the studied areas. Green to Red shades indicate different trees' altitude, showing the large variability, even in a small area. It is important to note that due to the area's complexity, only the clearest trees were delineated (shown in red lines), trying to keep the most of them. This will affect the final quantitative evaluation but does not penalize the effectiveness of the presented method.

3. METHODOLOGICAL WORKFLOW

In order to perform the automatic ITC delineation for the entire Gorgona island, the package itcSegment [14] inside the software R (www.r-project.org) was used. The ITC delineation approach finds local maxima within a rasterized Canopy Height Model (CHM), designates these as treetops and then uses a decision tree method to grow individual crowns around the local maxima. In order to properly delineate the ITCs, different parameters must be set up. This is valid for any type of forest, in particular for the tropical one, since the algorithm has not been developed for tropical forest. The selection of these parameters strongly depends on the expected tree's size and the fact that this size should remain homogeneous across the entire study area. This is not the case here, where large variability can be seen. Since no ground truth is available in order to validate the results, automatic selection of the best ITCs delineation parameters that would work over the entire area was carried out based on four validation areas. This process was carry out on an iterative matter and making use of the Jaccard Index (JI) [15]. JI is a statistic used for comparing the similarity and diversity of two sets, and is calculated like:

$$JI(A,B) = \frac{|A \cap B|}{|A \cup B|} \qquad (1)$$

where: $JI(A,B)$ represents the Jaccard index between sets A and B; $|A \cap B|$ denotes the size (cardinality) of the intersection of sets A and B, i.e., the number of elements they have in common; and $|A \cup B|$ represents the size (cardinality) of the union of sets A and B, i.e., the total number of distinct elements present in both sets.

JI ranges from 0 to 1, where 0 means the sets have no common elements and 1 means the sets are identical. The JI is commonly used in data analysis, information retrieval, and pattern recognition [15]. The mean JI per size and per area over each of the validation areas was confronted obtaining the best parameters that comply from both a qualitative and quantitative perspective. Once ITCs were delineated, biomass was calculated using the equation published in Jucker et al. [16] that relates height and crown radius with biomass.

4. PRELIMINARY RESULTS AND CONCLUSIONS

A preliminary result for both automatic delineation and biomass calculation for one of the validation areas can be seen in Figure 3. The average Jaccard Index differed across each area (area 1: JI = 0.35; area 2: JI = 0.46; Area 3: JI = 0.48; Area 4: JI = 0.52) and splitting the ITCs of all the four areas by size (small: JI=0.44; medium: JI = 0.47; big: JI = 0.55). As we needed to delineate ITCs over the entire island, we chose the combination of parameters with the highest average JI over all the manually delineated crowns (JI= 0.45), which is considered as a good trade-off, considering the complexity of the study area (see left panel in Figure 2). Using the best parameters found, it was possible to generate the entire ITCs and biomass map for Gorgona Island, which is a relevant and unique map for this Region.

It is important to note that JI is smaller than 0.5, but this small value does not indicate a wrong detection. The reader is reminded that the delineation by photointerpretation did not include every single tree in the studied areas due to complexity and large variability in the area. Nevertheless, while comparing with the true color image in the left panel of Figure 3, it is possible to notice the good detection capabilities of the presented method. As future developments, it would be interesting to consider a hierarchical approach to further help the ITCs delineation with different tree sizes.

5. REFERENCES

[1] D. Xu, H. Wang, W. Xu, Z. Luan, and X. Xu, "LiDAR Applications to Estimate Forest Biomass at Individual Tree Scale: Opportunities, Challenges and Future Perspectives," *Forests*, vol. 12, no. 5, Art. no. 5, May 2021, doi: 10.3390/f12050550.

[2] B. Santiago et al., "Which Pixel is a Forest? Tree Crown Delineation Using VHR Images to Estimate Tree Cover in Landsat Based Classification," in *2021 IEEE International*

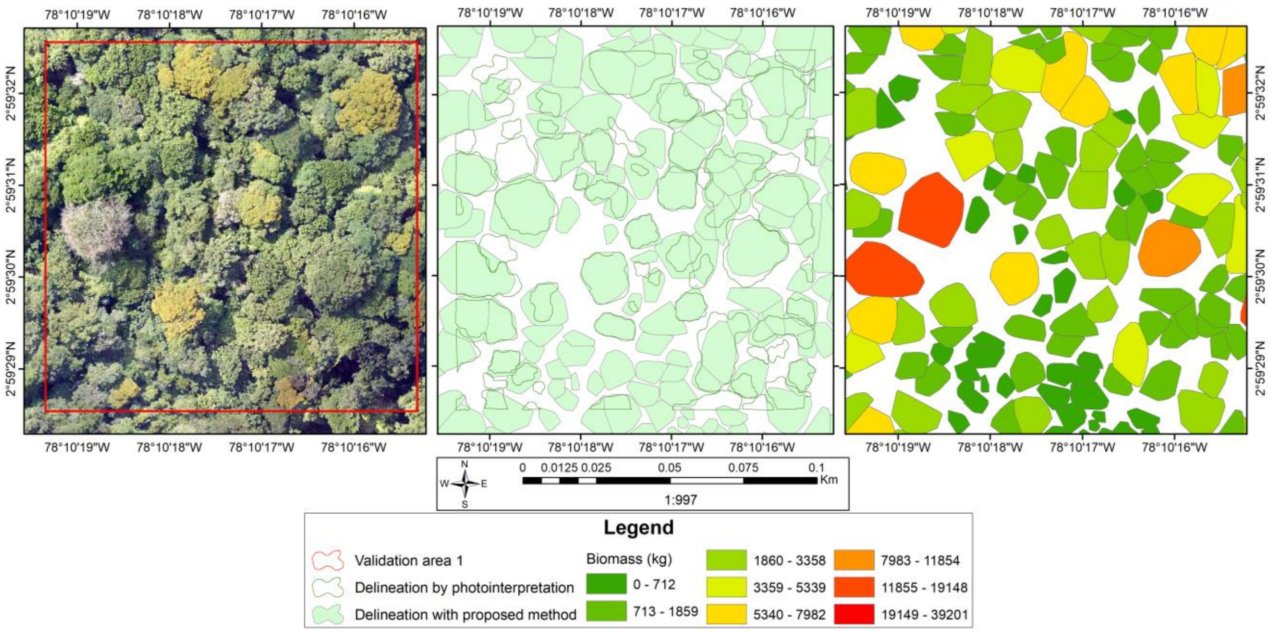

Figure 3. ITCs delineation and biomass for validation area 1. Left: RGB orthophoto. Middle: ITCs delineation with photointerpretation and proposed method. Right: Biomass.

Geoscience and Remote Sensing Symposium IGARSS, Jul. 2021, pp. 1600–1603. doi: 10.1109/IGARSS47720.2021.9553173.

[3] F. A. Gougeon and D. G. Leckie, "The Individual Tree Crown Approach Applied to Ikonos Images of a Coniferous Plantation Area," *Photogrammetric Engineering & Remote Sensing*, vol. 72, no. 11, pp. 1287–1297, Nov. 2006, doi: 10.14358/PERS.72.11.1287.

[4] D. Pulido, J. Salas, M. Rös, K. Puettmann, and S. Karaman, "Assessment of Tree Detection Methods in Multispectral Aerial Images," *Remote Sensing*, vol. 12, no. 15, Art. no. 15, Jan. 2020, doi: 10.3390/rs12152379.

[5] G. Lassalle, M. P. Ferreira, L. E. C. La Rosa, and C. R. de Souza Filho, "Deep learning-based individual tree crown delineation in mangrove forests using very-high-resolution satellite imagery," *ISPRS Journal of Photogrammetry and Remote Sensing*, vol. 189, pp. 220–235, Jul. 2022, doi: 10.1016/j.isprsjprs.2022.05.002.

[6] M. Dalponte and D. A. Coomes, "Tree-centric mapping of forest carbon density from airborne laser scanning and hyperspectral data," *Methods in Ecology and Evolution*, vol. 7, no. 10, pp. 1236–1245, Oct. 2016, doi: 10.1111/2041-210X.12575.

[7] L. Beese, M. Dalponte, G. P. Asner, D. A. Coomes, and T. Jucker, "Using repeat airborne LiDAR to map the growth of individual oil palms in Malaysian Borneo during the 2015–16 El Niño," *International Journal of Applied Earth Observation and Geoinformation*, vol. 115, p. 103117, Dec. 2022, doi: 10.1016/j.jag.2022.103117.

[8] T. Yun *et al.*, "Individual tree crown segmentation from airborne LiDAR data using a novel Gaussian filter and energy function minimization-based approach," *Remote Sensing of Environment*, vol. 256, p. 112307, Apr. 2021, doi: 10.1016/j.rse.2021.112307.

[9] "¿Qué es Dimar ?- Misión y Visión | Portal Marítimo Colombiano - Dimar." https://www.dimar.mil.co/que-es-dimar-mision-y-vision (accessed Jan. 12, 2023).

[10] Instituto de Hidrología, Meteorología y Estudios Ambientales 2018. IDEAM, PNUD, MADS, DNP, CANCILLERÍA, FMAM. Bogotá D.C., Colombia, IDEAM, PNUD, and MADS, Eds., *Segundo Informe Bienal de Actualización de Colombia a la Convención Marco de las Naciones Unidas para el Cambio Climático (CMNUCC)*. Bogotá: IDEAM, 2018.

[11] Ministerio del Medio Ambiente, "Resultados de monitoreo de deforestación." MINAMBIENTE $ Instuto de Hidrología, Jan. 2020. Accessed: May 31, 2023. [Online]. Available: chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://www.minambiente.gov.co/wp-content/uploads/2021/10/Informe_gestio%CC%81n_MINAMBIENTE_2019-2.pdf

[12] P. N. N. de Colombia, "Gorgona National Natural Park," *Parques Nacionales Naturales de Colombia*. https://www.parquesnacionales.gov.co/portal/en/ecotourism/pacific-region/gorgona-national-natural-park/ (accessed Jan. 12, 2023).

[13] A. I. Vásquez-Vélez, "Estructura y diversidad de la vegetación del Parque Nacional Natural de la Isla Gorgona, Colombia," *Revista de Biología Tropical*, pp. 13–26, Feb. 2014, doi: 10.15517/rbt.v62i0.15976.

[14] M. Dalponte, "itcSegment: Individual Tree Crowns Segmentation." Mar. 23, 2018. Accessed: May 31, 2023. [Online]. Available: https://cran.r-project.org/web/packages/itcSegment/index.html

[15] R. Real and J. M. Vargas, "Probabilistic Basis of Jaccard's Index of Similarity | Systematic Biology | Oxford Academic," *Systematic Biology*, vol. 45, no. 3, pp. 380–385, Sep. 1996.

[16] T. Jucker *et al.*, "Allometric equations for integrating remote sensing imagery into forest monitoring programmes," *Global Change Biology*, vol. 23, no. 1, pp. 177–190, 2017, doi: 10.1111/gcb.13388.