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Biomass and carbon stored estimation in a harvested primary forest of "El Rodeo" protected zone, Costa Rica

Estimación de la biomasa y carbono almacenado en un bosque primario intervenido de la zona protectora"El Rodeo", Costa Rica

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ABSTRACT

Costa Rica's National Climate Change Strategy stressed the importance of forest ecosystems in the absorption and fixation of CO2, as a mechanism to achieve carbon neutrality. This research sought to estimate the biomass and carbon stored in the different components of the forest of three sites belonging to the "El Rodeo" Protected Zone, located west of San José, Costa Rica (geographic coordinates 9º 52' 9.56'' N and 84º 14' 84.20'' W). Twelve temporary plots were installed, where the following components were inventoried: stem (>10 cm d), latissimus (5-9.9 cm d), necromass, herbaceous vegetation and litterfall, to determine the concentrations of carbon in each one, components that together represent the potential amount of carbon that can be released into the atmosphere or conserved and fixed on a given surface. With respect to the volume of carbon in the forest, it was determined that the average accumulated in all components analyzed is 230.38 Mg/ha, so it is estimated that the approximate carbon stock for the entire protective zone "El Rodeo" is 541 400.23 Mg. However, the study evidenced a high variability in biomass and carbon content between sites and established plots, due to the wide matrix of the landscape that generates heterogeneity in the forest.

Keywords: aerial biomass; humid forests; carbon in soil; protective zone "El Rodeo".

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RESUMEN

En la Estrategia Nacional de Cambio Climático de Costa Rica se recalcó la importancia de los ecosistemas boscosos en la absorción y fijación de CO_2, como un mecanismo para lograr la carbono-neutralidad. Esta investigación buscó estimar la biomasa y el carbono almacenado en los diferentes componentes del bosque, de tres sitios pertenecientes a la Zona protectora "El Rodeo", ubicada al oeste de San José, Costa Rica (coordenadas geográficas 9º 52' 9,56'' N y 84º 14' 84,20'' W). Se instalaron 12 parcelas temporales, donde se inventariaron los componentes: fustales (>10 cm *d*), latizales (5-9,9 cm *d*), necromasa, vegetación herbácea y hojarasca, para determinar las concentraciones de carbono existentes en cada uno, componentes que en su conjunto representan la cantidad potencial de carbono que puede ser liberado a la atmósfera o conservado y fijado en una determinada superficie. Con respecto al volumen de carbono del bosque, se determinó que el promedio acumulado en todos los componentes analizados es de 230,38 Mg/ha, por lo que se estima que el stock de carbono aproximado para toda la zona protectora "El Rodeo" es de 541 400,23 Mg. No obstante, el estudio elaborado evidenció una alta variabilidad en los contenidos de biomasa y carbono entre sitios y parcelas establecidas, debido a la amplia matriz del paisaje que genera heterogeneidad en el bosque.

Palabras clave: biomasa aérea; bosques húmedos; carbono en suelo; zona protectora "El Rodeo".

INTRODUCTION

Tropical forests play an important role in mitigating climate change, as they regulate carbon dioxide (CO_2) concentrations in the atmosphere through capture, storage and fixation in biomass and soil (Honorio and Baker, 2010; FAO, 2010; Fonseca *et al.,* 2013). Hence its role in the global carbon cycle, by reducing the rate of climate change; being an efficient mechanism in offsetting emissions associated with greenhouse gases (Honorio and Baker, 2010; FAO, 2010). Mature forests therefore have the capacity to mitigate the increase in CO_2 in the atmosphere, due to the increase in anthropogenic polluting activities in recent decades (Honorio and Baker, 2010).

By 2001, about 20 % of global CO_2 emissions were caused by deforestation and forest ecosystem degradation (Schlegel *et al.,* 2001); while by 2014, the Intergovernmental Panel on Climate Change (IPCC) indicates that the agriculture, forestry and other land use sector contributes about 25 % of global emissions, with deforestation accounting for most of this. For this reason, Costa Rica, as part of the REDD+ strategy, has shown interest in calculating the carbon stocks contained in its forests, to develop programs and projects aimed at the conservation and sustainable management of them, in order to reduce forest degradation and deforestation, as well as increase carbon stocks.

Some results in Permanent Sampling Plots (PPM) for tropical forests in America and Asia show that these are important carbon sinks for the planet, since on average they maintain an increase in biomass similar to emissions from deforestation (Honorio and Baker, 2010): 0.53 Mg C/ha/year in Amazon forests and 0.71 Mg C/ha/year globally (Laszlo *et al.,* 2016) for the period 2000 to 2007. This allows to visualize the importance of forests in relation to avoided deforestation, as well as to show the relevance of conservation and sustainable management of these ecosystems.

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Short- and long-term monitoring of forest cover is needed to record information on carbon behaviour in forests and to understand the consequences of climate change on populations and ecosystems (Bawa and Dayanandan, 1998; Bustamante *et al.,* 2016). In Costa Rica, data from this type of short-term research allowed calculating the amount of carbon captured by the country's forests, where mature ecosystems are estimated to store approximately 1,261.54 tCO2/ha; while secondary forests store approximately 628.99 tCO_2/ha (SINAC, 2014).

This type of information is basic to know the capacity of compensation of forest cover, since to minimize the impact of climate change, in addition to applying mitigation techniques associated with reducing emissions, it is recommended to work with forests and forest plantations to aim towards neutrality (Directorate of Climate Change, 2017). In 2007, the government of Costa Rica acquired the commitment to become a carbon-neutral country by 2021, which is why it launched the National Climate Change Strategy, which emphasizes the importance of forest ecosystems as mechanisms for absorbing and fixing CO_2, as well as avoided emissions (Granados, 2013). As a result, the University for Peace (UPaz) is interested in learning about the carbon stock accumulated in the forests it owns, which is included in the "El Rodeo" protective zone.

This research aims to estimate the biomass and carbon present in the different components of the forest (necromass, litterfall, herbaceous vegetation, latizales, fustales and soil), as the basis for calculating the carbon stored in three Permanent Monitoring Plots (PPM), in the protective zone "El Rodeo", Ciudad Colón.

MATERIALS AND METHODS

Area of study

The protective zone "El Rodeo" is located in the canton of Mora, province of San José, at geographical coordinates 9°52'9.56''N and 84°14'84.20''W (Figure 1). It has an extension of 2 350 ha, an altitudinal range between 400 and 1 016 masl, with an irregular topography and moderate to steep slopes (Cascante 2012, Sánchez 2012).

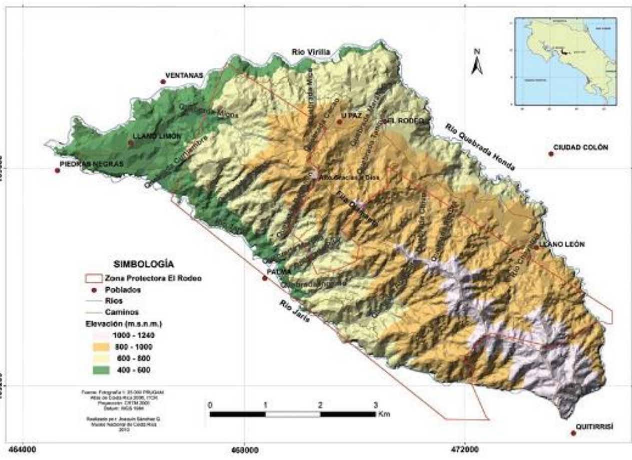

Fig. 1. - Location map of the protective zone "El Rodeo", San José, Costa Rica
Source: Cascante, 2012.

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It has a seasonal climate, with a dry period from January to March, average annual rainfall of 2,467 mm and an average temperature of 23.4 °C (Cascante, 2012; Sánchez, 2012). According to Holdridge's life zone classification, this protected area has three categories: very humid premontane forest in the upper parts of the Fila Diamente, tropical humid forest in the lower parts surrounding the Jaris and Virilla rivers, and tropical humid forest transition to premontane in the foothills of the Fila Diamante (Cascante, 2012).

Sampling

The investigation was carried out during 2014, in three PPM of 10 000 m^2 each, installed by the Herbario Nacional in 1998, in lands of the Universidad para la Paz, within which 12 sub-plots of sampling of 20 x 25 m (500 m2) were established, four in each PPM, located in each corner of the plot. Each subplot was subdivided into four quadrants of 10 x 12.5 m (125 m2) (Figure 2). Biomass and carbon were estimated in these subplot for the different components: bushes, latisses, necromass, litterfall, herbaceous vegetation and soil.

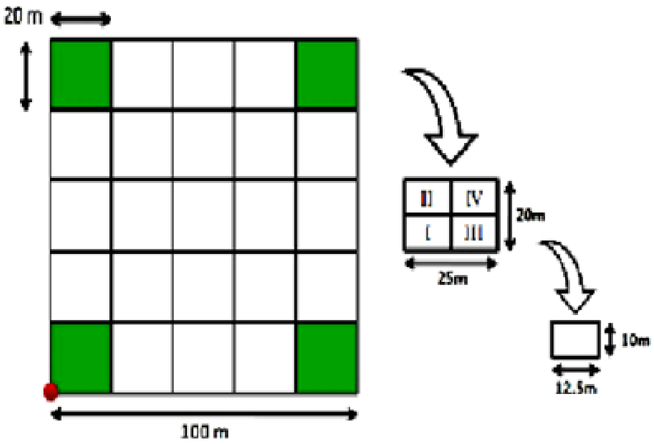

Fig. 2. - Sampling design of plots and sub-plots

Pinelo (2000) defines as fustales the woody plants with D1.30 ≥10 cm, which were sampled in each of the plots of 500 m2. The latizales on the other hand are the vegetation with D1.30 between 2.5 cm and 9.9 cm (Pinelo 2000), which was sampled in quadrant II of the sub-plots of 125 m^2.

In order to estimate the biomass of both components, a non-destructive method was used, in which data of d, height, botanical family and species were taken. The formula 1 for humid forests of Chave *et al.,* (2005) was used, because at the time of sampling there was no specific equation for the area and this is the one that presents the least overestimation (Formula 1).

$$AGBest= 0.0776*(p(d)^2*H)^{0.94} \quad (1)$$

Where:

AGBest: Biomass above ground (kg) estimated
p: specific wood density (g/cm3)
d: represents D1.30 (cm)
H: Height (m)

The necromase was taken from a subplot of 5 x 5 m located in each corner of the plot of one hectare; all dead material with a diameter greater than or equal to 2.5 cm was measured and a representative sample was taken for analysis in the laboratory. When there were sections that could not be weighed, due to their dimensions, they were cubed, a representative sample of the material was weighed in the field and taken to the laboratory to obtain its volume.

Litterfall, which is all the dead organic matter in the forest mulch, was obtained from four 50 x 50 cm nested plots located in the centre of each 125 m^2 quadrant of the 500 m^2 plots. The entire leaf litter collected in the field was weighed and a composite sample was taken for analysis in the laboratory. Herbaceous vegetation, which is all living material less than 2.5 cm in diameter, was sampled in plots of 1 m^2, located in the corners of each quadrant of 125 m^2 of the plot of 500 m^2. All the material was weighed in the field and a composite sample was obtained for the laboratory.

For all biomass components, the results were multiplied by the carbon factor (0.45) to obtain the stored carbon.

The soil sample was obtained from the quarantine of four subsamples taken with a palin, at a depth of 30 cm in the center of each quadrant of 125 m^2. In addition, a soil sample was taken for bulk density analysis at the same depth in quadrant IV.

Analysis of samples in laboratory

The samples were processed in the Laboratorio de Suelos y Foliares del Instituto de Investigacion y Servicios Forestales (INISEFOR) de la Universidad Nacional. In the case of necromase, leaf litter and herbaceous vegetation, were dried at a temperature of 60 °C, until reaching a constant dry weight. The dry weight was calculated, crushed, ground and sieved (1 mm) in order to obtain the necessary sample to perform the analysis of Organic Matter (MO), according to the Walkley and Black (1934) method. The percentage of carbon (% CO) was obtained using formula 2: (Formula 2).

$$\%CO=\%MO/1,72 \quad (2)$$

Where
1.72 is an empirical factor.

The soil was dried at room temperature and sieved 2 mm thick to obtain the sample taken to the laboratory and to perform the same method as above for obtaining the percentage of CO. The apparent density (Da) was calculated according to Forsythe's method (1985). Soil carbon (CS) was calculated using formula 3: (Formula 3)

$$CS= \%C *Da *p \quad (3)$$

Where
p is the depth

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RESULTS AND DISCUSSION

A high variability in biomass and carbon contents was found in all established plots, especially in components with less fixation, such as necromass, herbaceous vegetation and leaf litter; this situation could be associated with the representativeness of the site at landscape scale, being one of the possible sources of error at the time of estimating the biomass in general of natural forests.

When analyzing the necromass component, in the P5 plot the lowest value of carbon in the field was obtained (8 kg in relation to wet weight), which represented 0.48 Mg/ha; on the contrary, the P4 plot presented the highest value, with 81 kg, equivalent to 5.07 Mg/ha of carbon (Figure 3). This can be attributed to the dynamics of mortality within the forest, where the formation of clearings can generate higher necromasses in places where trees or branches fell and lower quantities in areas that do not present these impacts.

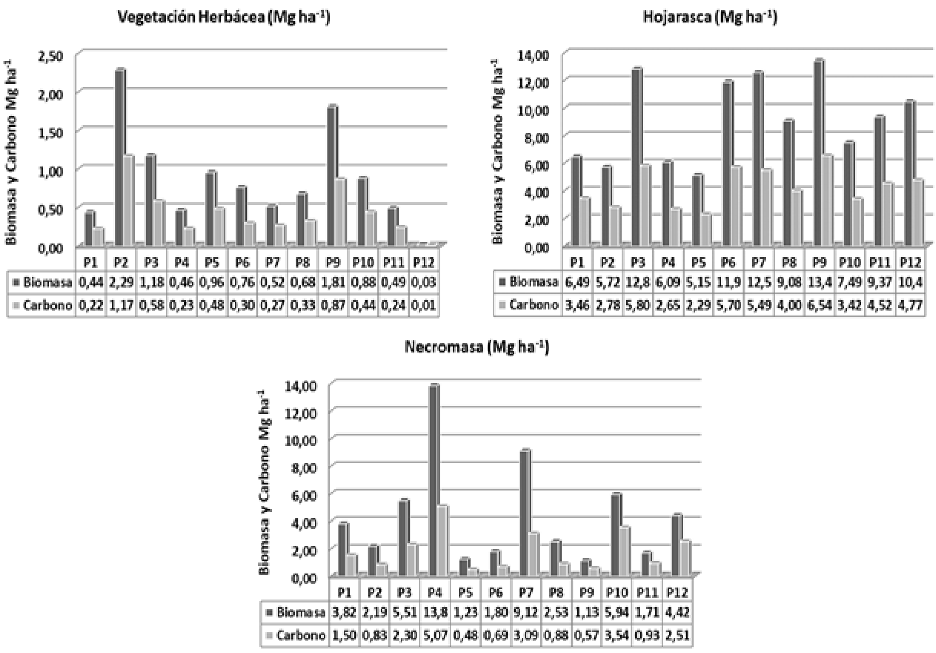

Fig. 3.- Biomass and carbon accumulated in the components of necromass, herbaceous vegetation and litterfall, by plot

This trend was similar to that of leaf litter and herbaceous vegetation. For litterfall, the maximum value found in P9 was 6.54 Mg/ha, corresponding to a field value of 3.9 kg; while the minimum was obtained in P5 and is 1.8 kg, equivalent to 2.29 Mg/ha. For herbaceous vegetation, values ranging from 1.17 Mg/ha in P2 to 0.01 Mg/ha in P12 in terms of maximum and minimum values were also found (Figure 3).

When analyzing the stock of the study site in relation to each component, it was revealed that aerial biomass concentrates 46.35 % of total carbon, corresponding to an average of 103.44 Mg/ha. This coincided with the average recorded by Ulate (2011) for intervened primary forests of the same life zone in Costa Rica (91.56 Mg/ha).

It is known that soil concentrates the largest terrestrial carbon reservoirs, approximately 75 % of carbon in forests (Schoijet, 2008) and for the present study stored 50.79 % of total carbon. If only soil and aerial biomass components are taken into account, they accounted for 97.14 % of total carbon in the study area (Figure 4). The present investigation showed an average value of 117.01 ± 10.10 Mg/ha, with maximum and minimum of 144.71 and 98.27 Mg/ha respectively, which showed little variability in the protective zone (Figure 4). These data agree with the findings of Ibrahim *et al.,* (2007), who indicate that soil carbon for primary and secondary forests can vary on average between 60 and 115 Mg/ha, respectively, so that the value obtained was very similar to those results.

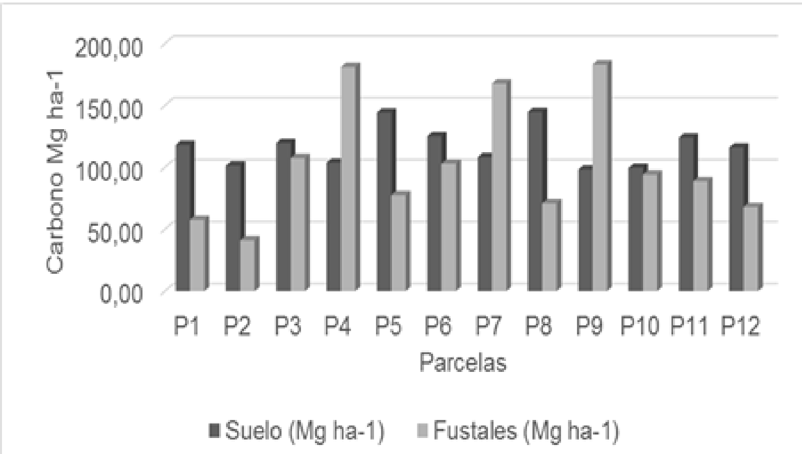

Fig. 4. - Carbon in shafts (>10cm) and soil per plot, "El Rodeo"

When analysing the stock of carbon per plot, the above-mentioned trend was maintained, with the soil being the component with the most CO_2 stored. However, in plots P4, P7 and P9, the stem trees exceeded the amount of carbon in the soil, which could be related to the fact that in them were found individuals of great dimensions.

As for latizales, they corresponded to 1.46 % of the total carbon stock calculated in the study, which showed that this component of vegetation does not have a representative weight within the quantification of this element in the forest. This was specifically observed when comparing the data reported for latizales with that of fustales, which was the second component that generally captured more carbon in the sampling units established in the protective zone "El Rodeo" (Figure 5).

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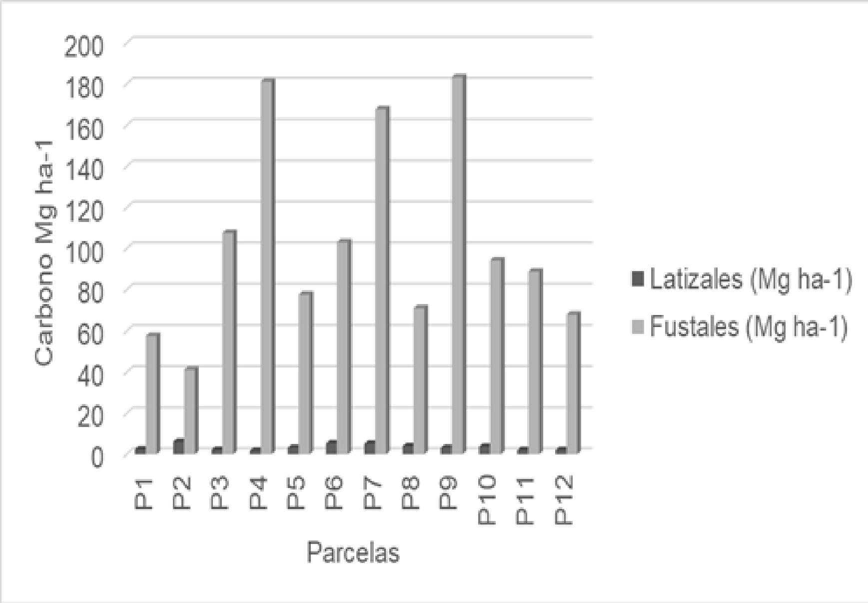

Fig. 5. - Carbon content reported for the components of latizales and fustales per plot, in "El Rodeo"

The data generated for carbon in fustales showed that P9 was the plot that captured the highest volume of CO_2 (183.26 Mg/ha), which is attributed to the fact that P9 is the only plot with more than 20 % of its individuals in diameter classes greater than 40 cm and whose species have wood densities greater than 0.6 g/cm3 (65 %). On the contrary, P2 captured the least amount of CO_2 (41.16 Mg/ha), which presents few individuals with lower categories, in addition to low wood densities of the species present. In this last plot was also found the highest carbon storage by the latizales (6.04 Mg/ha), which could be associated with that, having a smaller amount of fustales, there was a greater opening of light, which allowed the germination and establishment of more trees, with dimensions less than 10 cm d.

Herbaceous vegetation, leaf litter and necromass are the components that stored the least amount of carbon within the ecosystem, which coincided with the results for humid forests in the Costa Rican Caribbean, presented by Fonseca *et al.,* (2008). However, even considering the above and the high heterogeneity of the data obtained, it was determined that the litterfall component is the one that fixed a higher CO_2 content, when comparing with the previous ones (Figure 6). This result could be associated to the fact that the site has a diversity of species similar to that of dry forests (Cascante and Estrada, 2001), which allowed a greater accumulation of leaves in the soil, due to the deciduous characteristics of some of them.

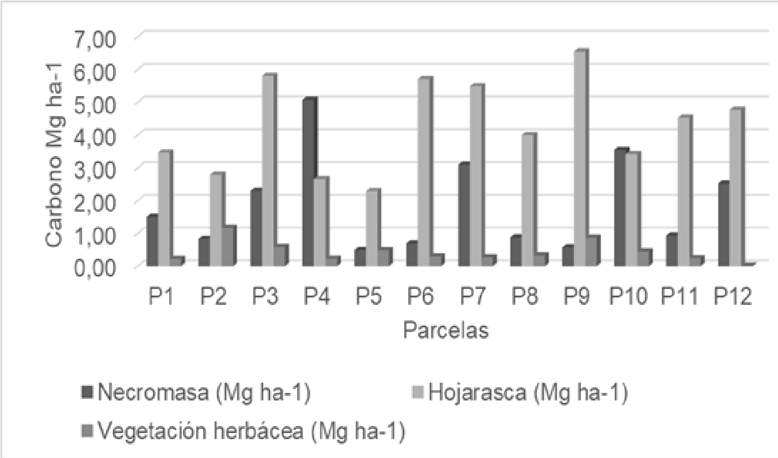

Fig. 6. - Total carbon fixed in the necromass, leaves and herbaceous vegetation by plots, "El Rodeo"

Necromass was the second component with the highest carbon storage, which was superior to that found in litterfall in two plots (P4 and P10), which could be related to the dynamics of forest mortality, where fallen trees are frequently found that generate clearings in the ecosystem, as described by Cascante and Estrada (2001) in their study of the composition and structure of "El Rodeo", when referring to the dynamics of clearings in these sites (Figure 6).

The carbon stock for the three PPMs sampled was approximately 691.14 Mg of carbon, which corresponds to 230.38 Mg/ha. This serves as a baseline for estimating the carbon stored in the "El Rodeo" protective zone. From the five components evaluated, namely necromass, herbaceous vegetation, litterfall, latizales, fustales and soil, the last two present a higher percentage of total carbon (46.35 % and 50.79 %, respectively).

It is important to extend the sampling to other sectors of the Protected Zone, since it is composed of secondary forests and other types of coverage, which were not considered in this study. It is also important to continue with carbon monitoring in each of the components periodically, to know the dynamics and behavior of this element, which provides relevant information for ecosystem management and as a parameter to be taken into account in the framework of the national decarbonization strategy, as well as the carbon neutrality policy.

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