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Article

Biomasa en acahuales de tres unidades ecogeográficas del estado de Tabasco

Biomass of secondary vegetation of three ecogeographic units of the state of *Tabasco*

Antonio García-Domínguez[1], Luisa del Carmen Cámara Cabrales[1*], Johannes Cornelis Van der Wal[2] y Pablo Martínez Zurimendi[2]

Resumen

La escasa información sobre los atributos de los acahuales en Tabasco contribuye a que no se les dé la debida importancia a esos ecosistemas en programas de conservación y como reservorios de carbono. El presente trabajo contribuye a subsanar el poco conocimiento que se tiene de la magnitud de la biomasa existente en acahuales. En tres unidades ecogeográficas, se establecieron 18 conglomerados de cuatro parcelas (10 × 40 m), en un arreglo de Y invertida, con un total de 28 800 m^2. Los años de abandono en las áreas de estudio fueron de 15, 20, 30 y 100; en cada uno se tomaron parámetros dasonómicos para determinar rasgos básicos estructurales y su biomasa. Los acahuales con menor tiempo de abandono mantuvieron mayor densidad de individuos, distribuidos principalmente en dos clases diamétricas (2-10 y 10-18 cm, DN) y tres estratos de altura (2-7, 7-12 y 12-17 m). El área basal y la biomasa no cambiaron, proporcionalmente, con respecto a la etapa sucesional. A pesar de la variabilidad en su estructura, estos ecosistemas mostraron tener un potencial de captura y reservorio de carbono importante, en relación a la vegetación primaria en menores lapsos de tiempo; por lo que, si se siguen manteniendo hacia etapas avanzadas de sucesión pueden ser una alternativa de vegetación estable que genere servicios ambientales de captura de carbono y biodiversidad.

Palabras claves: Áreas abandonadas, área basal, biodiversidad, densidad, estructura, reservorio de carbono.

Abstract

The lack of sufficient information on the attributes of the secondary vegetation in *Tabasco* contributes to obscure the importance of these ecosystems in conservation programs and as carbon reservoirs. The present study contributes to fill in the knowledge gaps regarding the magnitude of the existing biomass in fallow lands. In three eco-geographic units, 18 clumps —each consisting of four 10 × 40 m plots— with an inverted Y arrangement were established in secondary forests aged 15, 20, 30, and 100 years, covering a total surface area of 28 800 m^2. In each study area, mensuration parameters were taken to determine the plant biomass and the basic structural characteristics. Results showed that younger secondary forests support a higher density of individuals, which are mainly distributed in two diameter classes (2-10 and 10-18 cm, ND) and three height levels (2-7, 7 -12 and 12-17 m). The basal area and biomass did not change proportionally to the age or successional stage. In spite of their variability, these ecosystems have been shown to have a high potential for carbon capture and accumulation in a shorter period compared to the primary vegetation. Therefore, if these abandoned areas continue to grow to advanced successional stages, they will be an alternative strategy for such environmental services as carbon sequestration and biodiversity.

Key words: Abandoned areas, basimetric area, biodiversity, density, structure, carbon reservoirs.

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[1]Universidad Juárez Autónoma de Tabasco. México.
[2]Departamento de Agricultura, Sociedad y Ambiente, Ecosur. México.
[*]Autor por correspondencia; correo-e: lcamara27@hotmail.com

Introduction

Changes in land use in the tropics transform forests and jungle landscapes into secondary forests (FAO, 2010), whose surface has expanded at the global level. In Mexico, these are known as *acahuales*, and their number is increasing, as a consequence of the degradation of over 300 thousand hectares of forests per year; therefore, they have recently become the dominant forest cover in the tropics (Semarnat, 2012; Mukul and Herbohn, 2016).

In general, secondary forests are regarded as plants systems that lack value. As a result, the policies for their conservation evidence little interest on the part of the governmental agencies (Sánchez-Sánchez *et al.,* 2007). Certain studies have shown that, depending on its successional stage, this vegetation maintains a degree of variability in its productive capacity, which can be multi-functional, as a source of food, medicine and supplies of forest products, in addition to providing significant environmental services, such as protection of the soil and carbon storage (Alayon-Gamboa *et al.,* 2016). All this renders it vital to the rural economy, since in many cases it manages to replace basic functions of primary forests and remove pressures from them (Schulze *et al.,* 2000; del Valle *et al.,* 2011).

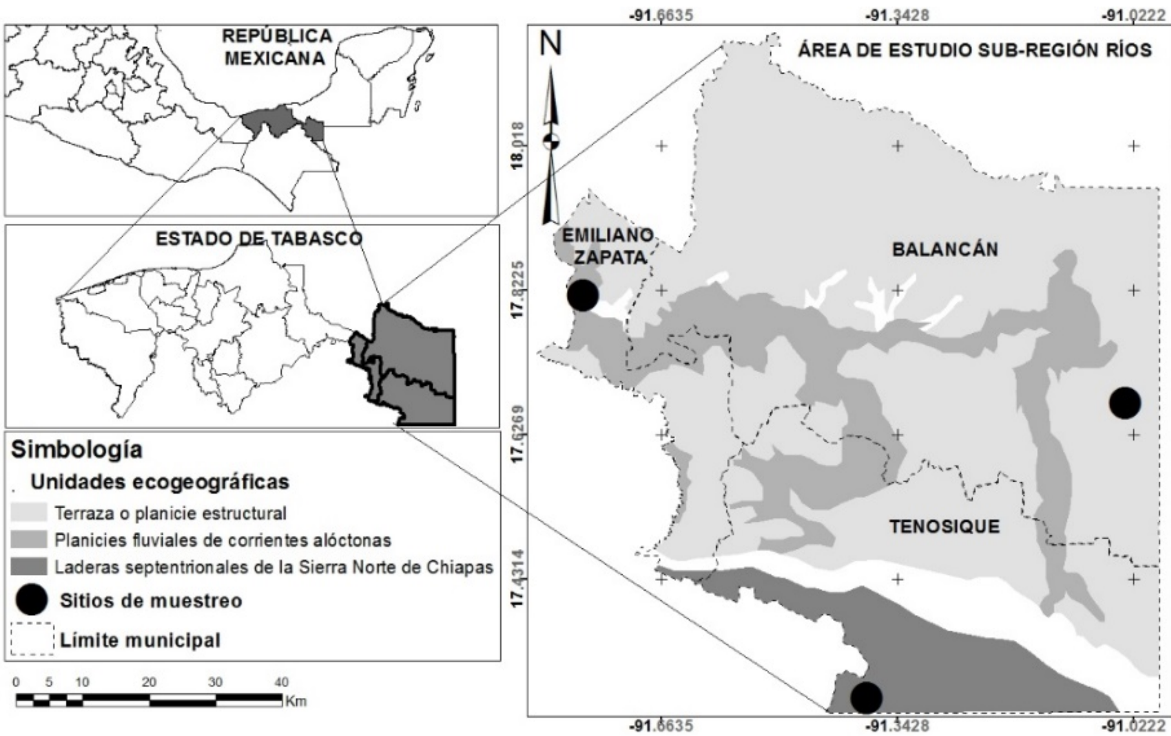
Due to their size and level of increase in biomass, secondary forests have the potential to mitigate the raising of atmospheric CO_2 concentrations. For example, it is known that at different ages of neglect they function as large reservoirs of carbon (C) that exceed 190 Mg C ha^{-1} (Johnson *et al.,* 2000); however, the scarce importance that has been given to their study, both in Mexico and worldwide, results in a lack of information and a lack of knowledge of the potential and contribution of these ecosystems to the global carbon cycle.

In Mexico, secondary forests with productive potential maintain a coverage of 3 % (Semarnat, 2012), but the lack of quantitative and qualitative knowledge of their attributes renders their conservation unviable. For this reason, basic structural and biomass data were estimated at different ages of abandonment for two components: the juvenile trees (*Ajuv*) and the mature trees (*Amad*) of three eco-geographic regions in *Tabasco*. The main objective of this work was to demonstrate the potential of secondary forests in terms of the environmental service of carbon capture, and thereby to help demonstrate that they can be considered in the scheme of payments for environmental services leading to the improvement of the planning strategy for the biomass resource as a method of conservation of the biodiversity in order to minimize the deterioration of the natural capital in the humid tropics.

Materials and Methods

Study area and data collection

The research was carried out in the sub-region of *Los Ríos, Tabasco*, between the coordinates 17°16'00'' and 18°12'00'' N, and 90°56'00'' and 91°52'00'' W, in three eco-geographic units (EUs) (Ortiz-Pérez *et al.,* 2005): the Northern slopes of the Northern *Sierra* of *Chiapas* (*LSSNCh*) in *Tenosique*; the *Terrazas* in *Balancán* (T), and the River Plains of Allochthonous Flows (*PFCA*) in *Emiliano Zapata*, which exhibit a geological-structural arrangement with an altitudinal gradient of 250 m in the part of the sierra, 6 masl toward the coast of the Gulf of Mexico, and 50 masl in its central part (Figure 1). Precipitations on the slopes (3 000 mm) favor a warm humid climate with rains year round (Af(m)); while in the areas of low and medium altitude, the mean annual precipitation is 1 500 mm, with a warm, humid climate and summer rains (Am(fz)) INEGI (1986).



Áreas de studio subregión Ríos = Study área Ríos sub-region; *Simbología* = Symbology; *Unidades ecogeográficas* = Eco-geographic units; *Terraza o planicie estructural* = *Terraza* or structural plains; *Planicies fluviales de corriente alóctona* = River Plains of Allochthonous Flows; *Laderas septentrionales de la Sierra Norte de Chiapas* = Northern Slopes of the Northern *Sierra* of *Chiapas; Sitios de muestreo* = Sampling sites; *Línite municipal* = Municipal limit.

Figure 1.Eco-geographic units (EUs) and sampling sites in the Ríos sub-region; Northern Slopes of the Northern *Sierra* of *Chiapas* (*LSSNCh*) in the *Tenosique* municipality, *Terraces* (T) in the *Balancán* municipality, and River Plains of Allochthonous Flows (*PFCA*) in *Emiliano Zapata* municipality, in *Tabasco*, Mexico.

Six clusters of 1 600 m^2 with an inverted-Y array, each consisting of four plots of 10 × 40 m, were established (Conafor, 2011); the sites were selected based on the mapping of the regional study of *Umafor Ríos* (Cámara-Cabrales *et al.*, 2011). The ages of abandonment of the secondary forests were determined *in situ*, from field knowledge of the owners of the land. The age of abandonment was 100 years in the *PFCA*; 15 to 20 years in *T*, and 20 to 30 years in *LSSNCh*. Moreover, two samples of forest in *LSSNCh* were considered as a reference for mature vegetation.

The variables for the structure were normal diameter (ND), total height and wood specific density; in addition, both the common and the scientific names were recorded, (Zanne *et al.,* 2009). The values for density (Equation 1), basal area (Equation 2) and biomass (Equation 3) were estimated based on this information. Using the Normal Diameter (ND) as a basis, two components were catalogued: mature trees, with a ND of ≥10 cm, and juvenile trees, with a ND of ≥ 2.5 cm and ≤ 9.9 cm. This categorization was applied to the allometric biomass equation proposed by Chave *et al.* (2005) for humid rainforests (1 500 to 35 00 mm), in conjunction with the specific allometric equations for each available species in Rojas-García *et al.* (2015).

$$Density = \frac{No.\ of\ individuals}{sampled\ area}$$ (Equation 1)

$$BA = \frac{\pi}{4}D^2 = 0.7854 * D^2$$ ....(Equation 2)

Where:

BA = Basal area per tree (cm^2)

π = 3.1416

D = Normal Diameter (cm)

$$Y = \exp\left(-2.977 + \mathrm{nl}\,(\rho\, D^2\, h)\right) \qquad \text{(Equation 3)}$$

Where:

Y = Biomass (kg $tree^{-1}$)

nl = Natural logarithm

p = Density of each species (g cm^{-3})

D = Normal diameter (cm)

h = Height (m)

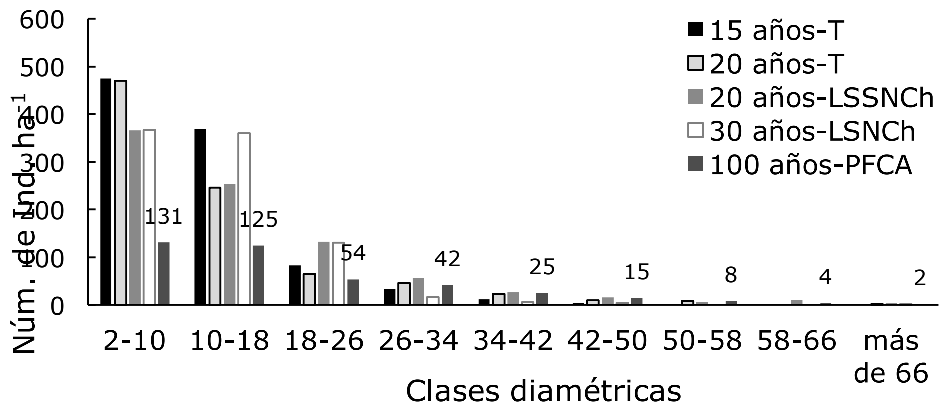
The variance analysis and the Tukey-Kramer HSD mean comparison test were carried out using the statistical package JMP™ 2008. *A posteriori* tests were used to observe the statistical differences between the basal area and the biomass for the times of abandonment of the secondary forests as the main source of variation, ($p < 0.05$).

Results

Structural attributes and biomass

It was noted, in general, that the longer the time of abandonment, the lower the total number of individuals. In the River Plains of Allochthonous Flows (*PFCA*) the age of 100 years registered a lower density of mature trees (406 Ind. ha^{-1}) and of juvenile trees (131 Ind. ha^{-1}). The percentage difference between the density of mature trees and that of juvenile trees was more evident in the *PFCA*, where the number of mature trees remained above 35 %, compared to the juvenile trees; in *T*, the difference was less than 2 %, while in the *LSSNCh*, the proportion was up to 28 % (Figure 2).

As for the diametric distribution, the highest concentration of Ind. ha^{-1} in each period of abandonment occurred only in two diameter classes: the category of 2 to 10 cm, known as juvenile trees, and that of 10 to 18 cm, consisting of mature trees. Both classes are best represented in all treatments, since up to 52 % of the total Ind. ha^{-1} remain in the first, and up to 38 % of the total, in the second. In the subsequent diameter classes, the number of Ind. ha^{-1} decreases progressively as the normal diameters increase with an inverted-J behavior for all periods of abandonment. In these secondary forests, the presence of diameters of over 50 cm is consistent for all periods of abandonment; however, the absence of certain diameter classes at certain times is also noticeable. The 20 year-old sites of *LSSNCh* and the 100 year-old sites in the *PFCA* presented all diameter classes, up to a ND of 66 cm (Figure 2).

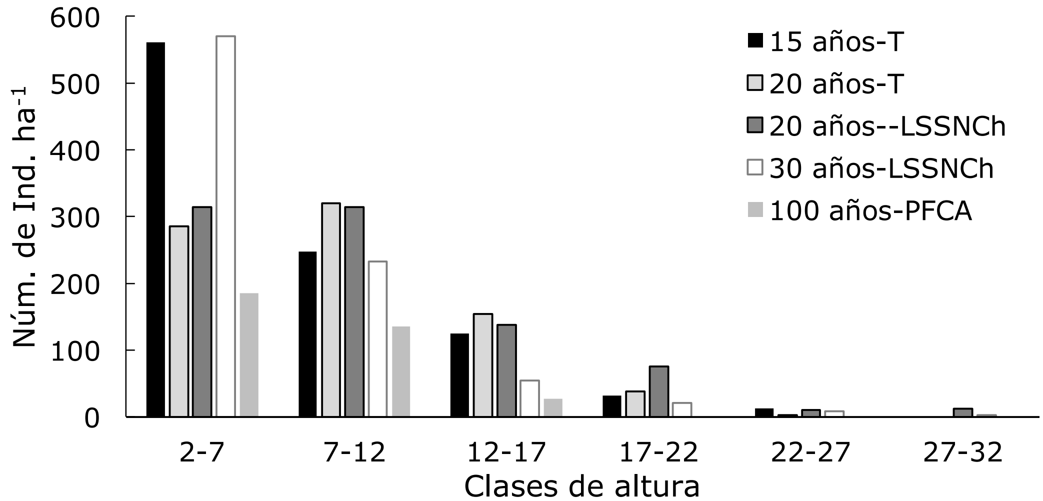


Núm. de Ind. ha^{-1} = Number of individuals per hectare*; Clases diamétricas* = Diameter class; *Años* = Years.

Figure 2. Number of individuals per hectare (No. of Ind. ha^{-1}) per diameter class (cm) in secondary forests at different ages, in each of the eco-geographic units (EUs) identified in the lower basin of the *Usumacinta, Los Ríos Region, Tabasco,* Mexico*.*

The existence of three tree strata is evident in the distributions of height: low (2 to 7 m); medium (7 to 12 m), and high (12 to 17 m). The class of 2 to 7 m consists of 36 to 64 % of the total number of individuals in each period of abandonment (Figure 3).

The 30 year-old secondary forest in *LSSNCh* exhibited the highest percentage of individuals in the height class of 2-7 m, which included 64 % of the total Ind. ha^{-1} for this period of abandonment. In the 20- and 30-year old secondary forests in *LSSNCh*, emergent trees of up to 30 m in height were observed. The tendency was for the number of individuals to be inversely proportional to the height; also, at certain ages these diameter classes tend to disappear. In the River Plains of Allochthonous Flows (*PFCA*), the height reaches a maximum of 17 m. As in the case of the diameters, the behavior of the heights after the class of 7 to 12 m evidences an inverted-J behavior, in which the number of individuals decreases toward the next higher classes in each period of abandonment (Figure 3).

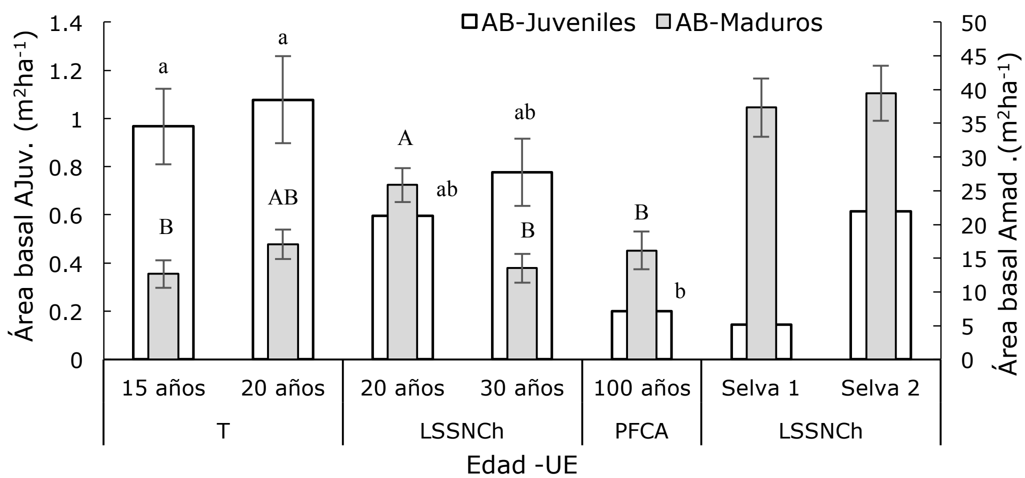


Núm. de Ind. ha^{-1} = Number of individuals per hectare; *Clases de altura* = Height class; *Años* = Years.

Figure 3. Number of individuals per hectare (Ind. ha^{-1}) by height class (m) in secondary forests at different ages, in each of the eco-geographic units (EU) identified in the lower basin of the *Usumacinta,* in the *Los Ríos Region, Tabasco,* Mexico.

The basal area (BA) of the mature trees ranged between 12.6 ± 2.10 m^2 ha^{-1} and 25.84 ± 2.34 m^2 ha^{-1}. The largest BA occurred in the 20 year-old secondary forest (25.84±2.34 m^2 ha^{-1}), located in the *LSSNCh* eco-geographical unit. The variance analysis (ANOVA) exhibited a statistically significant difference between these BAs in all successional stages ($p \leq 0.0016$). The Tukey-Kramer HSD test (TKHSD) indicated that only the 20 year-old secondary forest in *LSSNCh* is significantly different ($p \leq 0.05$) with regard to the age of abandonment in the other EUs. In the eco-geographic unit *T*, an increase was observed depending on the successional age; i.e. the size of the basal area increases in direct proportion to the period of abandonment. In *LSSNCh*, this behavior is expressed in the opposite way, due to the fact that the BA did not increase with a more advanced successional stage.

The BAs in juvenile trees were within the range of 0.20 ± 0.06 to 1.07 ± 0.18 m^2 ha^{-1}. The variance analysis showed no statistically significant differences between the ages ($p \leq 0.0008$). The *a posteriori* test shows a significant difference only for 15 and 20 year-old secondary forests in *T*, with respect to the 100 year-old secondary forest in the *PFCA*. There is a tendency for the BAs of juvenile trees in each eco-geographic unit to increase with longer periods of abandonment; the same applies to the basal area of mature trees (Figure 4).



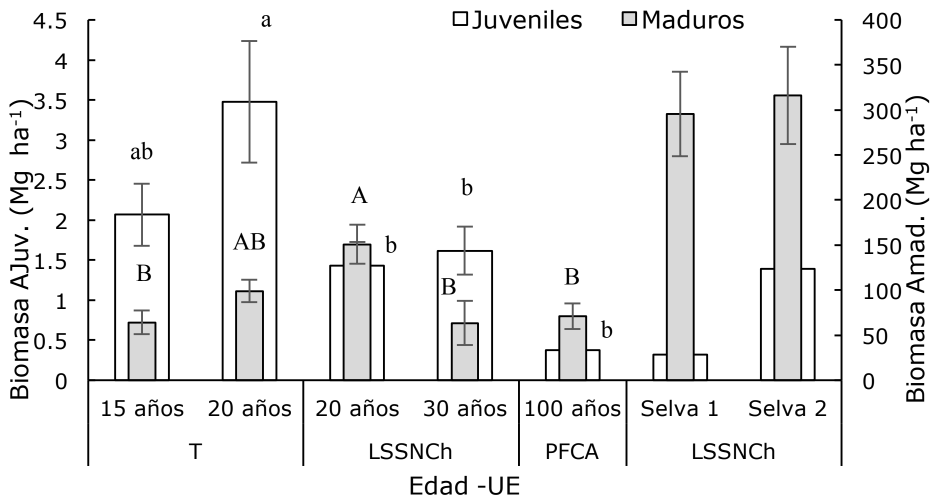
Área basal = Basal area; *AB-Juveniles* = AB juvenile trees; *AB- Maduros* = AB mature trees; *Años* = Years; *Edad* = Age; *UE* = Eco-geographic units.

The vertical lines represent the standard error. Different letters —upper case for mature trees and lower case for juvenile trees— indicate significant differences between ages ($\alpha \leq 0.05$). This is also the case in the basal areas of two medium forest samples.

Figure 4. Left. - Basal area (m^2 ha^{-1}) of the juvenile tree component (*AJuv*) of secondary forests at different ages in the eco-geographic units (EUs). Right. - Basal area (m^2 ha^{-1}) of the mature trees (*Amad*).

In the abandonment periods with the presence of mature trees, the registered aboveground biomass ranged between 150.90 ± 21.79 and 63.51 ± 24.57 Mg ha^{-1}. The highest concentration was determined at the age of 20 years of abandonment, within the eco-geographic unit *LSSNCh*. The ANOVA revealed a significant difference ($p \leq 0.0045$) between the contents of aerial biomass for these abandonment periods. The Tukey-Kramer HSD test ($\alpha \leq 0.05$) showed that the biomass content of the 20 year-old secondary forest in *LSSNCh* is similar to that of the 20 year-old one in *T* and differs from that of other abandonment periods in the eco-geographic units. In the eco-geographic unit *T*, the biomass increased in direct proportion to the time of abandonment; while the opposite occurred in *LSSNCh* (Figure 5).

In juvenile trees (Figure 5), the maximum value registered for biomass was 3.47 ± 0.76 Mg ha^{-1}, and the minimum, 0.375 ± 0.13 Mg ha^{-1}. The ANOVA showed a statistically significant difference between the biomass contents according to the age of abandonment ($p \leq 0.0004$). The a *posteriori* test ($\alpha \leq 0.05$) revealed that the two secondary forests in *T* have similar biomass contents. The 20 year-old secondary forest in *T* revealed a significant difference between the ages of abandonment of 20 and 30 years in *LSSNCh* and for the age of 100 years in the *PFCA*. The juvenile trees in *T* exhibited an increase in direct proportion to the length of the abandonment period in *T*, and in inverse proportion in *LSSNCh*.



Biomasa AJuv= Biomass in the juvenile trees; *Biomasa Amad* = Biomass in the mature trees; *Años* = Years; *Edad* = Age; *UE* = Eco-geographic units; *Juveniles* = Juvenile trees; *Maduros* = Mature trees.

The vertical lines represent the standard error. Different letters indicate significant differences between the ages (α ≤ 0.05) —upper case letters for mature trees and lower case letters for juvenile trees. The biomass of two samples of middle-sized forests is equally represented by vertical lines.

Figure 5. Left. - Biomass (Mg ha^{-1}) in the juvenile trees component of secondary forests at different ages in the eco-geographic units (EUs). Right. - Biomass (Mg ha^{-1}) in the mature trees component.

Discussion

In general, the shorter the time of abandonment, the higher the density of individuals. This suggests that the species that make up these successional stages respond positively to a high availability of resources that, in a way, favors the growth and survival, given the absence of a great competition for nutrients and light, whose primary characteristic is to maintain a large number of individuals in small diameter classes (Smith *et al.,* 1997; Ajbilou *et al.,* 2003). Moreover, Morales-Salazar *et al.* (2012) and Puc (2014) point out that, for tropical secondary forests, the tree density has a tendency to increase with a longer time of abandonment, contrarily to what is shown by the results of this research, in which the density of individuals on sites with longer abandonment periods decreased progressively; this would be accounted for by the incidence of some climatological phenomenon or by selective harvesting, although there is no record of either.

Along the chronosequence, the density of juvenile trees in a longer abandonment period agreed with what was naturally expected, because it decreases as the successional stage advances, as a result of the intrinsic qualities of the life history of the species (Chazdon *et al.,* 2007); however, it has been determined that the density decreases with a less open canopy, affecting the survival and growth of the trees of certain groups (Muñiz-Castro, 2008). Nevertheless, if there is another behavior that alters the generality, it is probably due to an episodic disturbance (Ajbilou *et al.,* 2003) that increases regeneration, and, consequently, the number of juvenile trees. Examples of this are the 30 year-old secondary forest and forest number 2, where the canopy was observed to have been opened by the selective logging of timber species; this may have caused the emergence of species that are dependent on the openings in the canopy.

In the *PFCA* (100 years), the low density of juvenile and mature trees is influenced by the characteristics of the site, rather than by the age of abandonment: the fact that it is a temporary flood zone may account for the low density registered in it; Cortés-Castelán and Islebe (2005) suggest that the tree density tends to be lower in these areas than in high reliefs. Moreover, flooding does not allow regeneration, mainly due to the presence of seeds that decay in the water, resulting in a low germination rate for the establishment of seedlings that might otherwise enrich the densities of juvenile and mature trees. Also, it has been observed that the flooding reduces the availability of oxygen to the roots, and thereby causes senescence and mortality (Moreno and Fischer, 2014), which favor a low density.

The pattern of distribution of individuals per diameter class has the shape of an inverted J regardless of the age of abandonment, with a trend toward a reduction in the number of individuals in the larger-diameter categories (Figure 2) —as quoted by Morales-Salazar *et al.* (2012) for secondary forests under and over the age of 30 years—, resulting from the abandonment of pastures in Costa Rica. Like Carreón-Santos and Valdez-Hernández (2014) and Puc (2014), we observed that many of the individuals are grouped into two diameter categories of less than 20 cm of ND —the first, of 2-10 cm (juvenile trees), and the second, of 10 to 18 cm (matures tree); therefore, these secondary forests are at an optimal regeneration phase (Guariguata, 1998; Ajbilou *et al.,* 2003), which will ensure the persistence of the forest and the balance of the same through the succession process (Lamprecht, 1990; Higuchi *et al.,* 2008). It was also noted that there are more individuals per hectare at successional stages of lower-age groups, *i.e.* of 30 or less years, than among older age groups.

The diametric distribution, based on two classes of less than 20 cm of ND, regardless of the abandonment period in the EUs, may respond to the history of land use and to the impacts that modify the diameter distributions, since in the secondary forests of *T*, for example, there have been fires that favor repopulation by juvenile trees—, while in *LSSNCh* (30 years) we observed a use that eventually changes the canopy and results in the presence of small diameter classes. The existence, after the slash-and-burn, of extreme values that form larger-diameter classes not corresponding to early ages of abandonment (if an average annual increase of 1 cm is assumed is accounted for by the history of the use of the land), as it is a common practice in these areas to preserve shade trees or trees with any commercial value, and therefore the presence of large trees was observed.

The distribution of individuals by height, for different ages, shows that three strata are prevalent. A similar behavior is cited by Díaz *et al.* (2002) and Carreón-Santos and Valdez-Hernández (2014). Individuals of both the secondary vegetation and the forests were arranged in low height classes, of less than 10 m, which amount to 80 % more than the other classes. According to Carreón-Santos and Valdez-Hernández (2014), the inverted-J feature indicates that these are forest masses with a good repopulation. Ajbilou *et al.* (2003) document that a higher density of young individuals in lower strata is a feature that reveals a higher level of disturbance. This condition is observed in the region of *LSSNCh* and *T* for the 30 and 15 year-old secondary forests, in both of which the use of the resources appears to be relative, while fires have occurred recently in *T*.

As for the heights in the EUs, not more than three strata (17 m) are observed; these trees are small because they have been subject to conditions of high flooding (Cortés-Castelán and Islebe, 2005), for in those areas of *Tabasco* with flooded forests the canopy does not exceed 20 m in height (Rzedowski, 1979).

The basal areas (BA) for mature and juvenile trees varied according to the time of abandonment. Only in *T* did mature trees with a longer time of abandonment have a larger BA. In general, there is a tendency of the juvenile tree component to increase with a longer time of abandonment in each of the eco-geographic units.

Only the BAs for the mature trees exceed those considered by the legislation in force in Mexico for the secondary vegetation, of 4 m^2 ha^{-1}; this underestimation can lead to the absence of actions for the conservation or restoration of these forest ecosystems. In particular each time of abandonment exhibits a BA close to that of the primary forests, as indicated by Plonczak (2005) for a dry tropical forest in Venezuela (DN ≥ 10 cm) whose BA was approximately 21.4 m^2 ha^{-1}, and by Cuello (2002), for a cloud forest in Venezuela where the lowest value was 26.6 m^2 ha^{-1}

(ND ≥ 2.5 cm). Secondary vegetation with a fraction of the age of the medium-sized forests in this study might attain, in a short time, a BA with similar values to those estimated for medium-sized forests, as well as to those registered for the forest areas with protection status within the eco-geographic unit *LSSNCh*, of 40 m^2 ha^{-1}. The BAs estimated for the secondary forests are greater than those cited by Puc (2014), for similar ages.

In the present study, the BAs did not increase from one abandonment period to the next, due to factors such as the effects of selective felling for domestic use, observed mainly in the 30 year-old fallow land in *LSSNCh*, where the BA is larger for juvenile than for mature trees and for a 20 year-old secondary forest in the same EU. This applies equally to the BA of the juvenile tree component of forest 2, where selective felling for local or domestic use is practiced, unlike in forest 1, where no significant selective felling appears to be carried out, and therefore the BA of the juvenile tree component exhibits low values.

In general, the accumulation of biomass exhibited a variability in content commonly related to the ages of abandonment (del Valle *et al.,* 2011). These biomass values were within the range of 190 Mg C ha^{-1} for secondary forest masses less than 100 years old (Johnson *et al.,* 2000; Puc, 2014). Read and Lawrence (2003) and Puc (2014) point out that the secondary vegetation aged 5 to 80 years contributes between 20 Mg ha^{-1} and 39.75 Mg ha^{-1}, with diameters smaller than 7.5 cm (juvenile trees), and 179 ± 7 Mg ha^{-1} in a secondary vegetation whose trees, with a ND ≥ 7.5 cm, are considered as adult, in southern *Quintana Roo*. Therefore, the biomass of the two studied components is within the expected range for the biomass contents at different ages of abandonment.

The amount of biomass in secondary forests with an abandonment period of 15 years was superior to those estimated by Urquiza-Haas *et al.* (2007) for a similar age in seasonally dry forests in *Yucatán* and *Quintana Roo*. However, mature stands with 100 years of abandonment in the *PFCA* have a lower biomass (70.9 Mg ha^{-1}) than that estimated by these authors (191 Mg ha^{-1}).

In general, the biomass accumulation potential for abandonment periods of less than 30 years is observed to be of 100 to 150 Mg ha^{-1}, which is more than the 100 Mg ha^{-1} considered by Brown and Lugo, (1990) and Silver *et al.* (2000) for ages under 20 years. Furthermore, if these stands are maintained, they may reach similar biomass values to those attained by rainforests in half the time, of up to 300 Mg ha^{-1}, which would be within the general range indicated for different types of primary tropical forest, of 200 to 400 Mg ha^{-1} (Sarmiento *et al,.* 2005; Yepes *et al.,* 2010).

The variability in the contents of biomass that have been documented for similar ages responds to factors specific to each ecosystem, allowing these contents of biomass to be expressed worldwide as maximum or minimum (Ngo *et al.,* 2013; Rutishauser *et al.,* 2013; Puc, 2014). Although the contribution of biomass between mature and juvenile trees showed a difference of 95 %, their values agree with those estimated by Read and Lawrence (2003) for southern Mexico. Dupuy *et al.* (2012) mention that this larger proportionality of the mature tree component is due to the fact that, in principle, juvenile trees have small diameters and heights despite their abundance; for reasons of competence, this disproportionality is maintained through all successional stages.

Conclusions

The studied secondary forests show significant differences in their structural attributes, depending on the time of abandonment, as well as on factors specific to each EU. Although the chronosequence in the eco-geographic units does not follow a pattern of widespread increases with the age, in certain EUs it seems to conform to what has been pointed out by several authors in regard to both the structural increases and the increases in biomass. Those cases in which it does not conform are accounted for by the relationship between the vegetation and factors derived from natural and anthropogenic phenomena that determine the intrinsic characteristics of the secondary forests and promote a structural variability which influences the accumulation of biomass. Since secondary vegetation is a global trend due to changes in land use, it can maintain a C sequestration potential thanks to its rapid accumulation of biomass —a positive sign for the mitigation of the global climate change resulting from greenhouse gas emissions.

Secondary forests with a shorter time of abandonment have a potential for biomass accumulation and, to a large extent, are also the most vulnerable because their owners attach little importance to them and thereby render them susceptible to being constantly intervened. Secondary vegetation with less than half the age of the forests has similar structural attributes, with a considerable accumulation of carbon; if handled properly, it may afford a significant benefit by contributing to mitigate the increase in atmospheric CO_2.

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Conflict of interests

The authors declare no conflict of interests.

Contributions by author

Antonio García Domínguez: writing and integration of the article, field data analysis, design of maps and methodology; Luisa del Carmen Cámara Cabrales: coordination of the crew and the project, support in field work, methodological information and review of drafts; Johannes Cornelis Van der Wal: data analysis, review of drafts and coordination of the project; Pablo Martínez Zurimendi: data analysis and review of drafts.

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