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Full Length Research Paper

Is there a relationship between floristic diversity and carbon stocks in tropical vegetation in Mexico?

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Tropical vegetation plays an important role in the terrestrial carbon stocks, and Mexico has a considerable amount of this vegetation that may store a large amount of carbon. However, an important variable of vegetation is its floristic diversity. Floristic diversity influences in a great extent the biomass of an ecosystem and hence carbon stocks. The purpose of this study was to determine whether there is a relationship between floristic diversity and carbon stocks in the case of tropical vegetation in Mexico. Floristic species richness, Shannon´s index and above-ground biomass were estimated for eight localities with arboreal and herbaceous vegetation. The biomass in the humid and sub-humid tropical forests was estimated using two specific allometric formulas for trees. In the case of grassland, it was estimated by harvesting the vegetation. A positive relationship was observed by a straight line (r^2 = 0.82, *P* = 0.001) and a significant relationship was observed in the inverse U polynomial model (r^2 = 0.84, *P* = 0.002) between species richness and carbon stocks. The diversity estimated by Shannon´s index also presented a significant relationship (r^2 = 0.65, *P* = 0.05). This proves what was expected and indicates that there is a relationship between floristic diversity and carbon stock in these ecosystems. The conservation of floristic diversity may represent an important factor in the mitigation of global warming, through the storage of large amounts of carbon.

Key words: Biomass, carbon budget, diversity index, global warming, species richness, sub-humid forest, tropical rain forest.

INTRODUCTION

Among terrestrial plant ecosystems, tropical systems are the most diverse, productive and, at the same time, vulnerable to land use change (Sala et al., 2000; Siche and Ortega, 2008). Nowadays, and worldwide, they play a main role in the reduction of atmospheric CO_2 concentrations through carbon sequestration (Brown et al., 1989).

Mexico still has a considerable amount of tropical ecosystems that may function as carbon sinks. These ecosystems differ, among many other aspects, in their floristic diversity as a result of natural or anthropogenic conditions. In view of all the implications of the management and conservation of terrestrial plant ecosystems, it is important to determine the relationship there is between floristic diversity and carbon stocks, in order to provide a useful tool for decision makers. The way in which the diversity of species affects the productivity of an ecosystem will in turn, affects the assets and services it can provide. This will be important to determine whether ecosystems in future, be less productive and effective as carbon sinks, should a progressive reduction in global biodiversity occur. The above-ground biomass of an ecosystem constitutes a basic indicator of its productivity (Pearson et al., 1989). The organic carbon in vegetation represents half its dry biomass (Pearson et al., 2005). The amount and variability of the above-ground biomass, and thus of the carbon that an arboreal ecosystem may store, respond to the diversity and relative abundance of the species (Tilman et al., 1996; Hector et al., 1999; Bunker et al., 2005). Despite many theoretical and experimental studies carried out to date, the relationship between species

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diversity and ecosystem productivity continues to be one of the most controversial subjects in Ecology (Garnier et al., 1997; Guo and Berry, 1998; Mittelbach et al., 2001). In the case of plant communities, this relationship has been studied mostly for grassland and temperate forests. In the case of grassland, Tilman et al. (1996) and Hector et al. (1999) found that a reduction in biodiversity causes a reduction in productivity (biomass). In the case of temperate forests, An-ning et al. (2008) found a negative relationship between species richness and biomass for two communities of *Quercus* in China. Regarding to humid tropical forests, to date there are not yet documented case studies.

The diversity-biomass relationship is affected by the environment (Guo and Berry, 1998). When environments are homogeneous, lineal relationships are present, and when environments are heterogeneous, inverted U-type curvilineal relationships occur. Lineal relationships may be positive or negative (Pianka, 1967; Silvertown, 1980). Guo and Berry (1998) found that the species richness-biomass relationship in homogeneous environments characterised by shrubs was positive, negative or not related. Mittelbach et al. (2001) found positive relationships between species richness and biomass of vascular plants, however, the inverted U-type curvilineal relationship was more frequent (65%). Tropical humid forests include relatively homogeneous environments that may be compared, and in which a linear relationship between species diversity and biomass may be expected.

It is a fact that at present it is necessary to conserve forest areas as carbon stocks, and it will always be important to conserve areas with the greatest possible diversity. But, what is the magnitude of the total carbon storage considering the actual diversity in the ecosystems that are available for this purpose?

The questions of this study were: what is the relationship between the floristic diversity of tropical plant ecosystems and the carbon storage? The more diverse plant ecosystems store more carbon than the less diverse ecosystems?

METHODS

Eight localities were selected (Table 1). Plot replicates were randomly selected throughout in all localities. The above-ground biomass in the grasslands was harvested from ten 2 × 2 m sub-plots in each plot, dried at 70° C for 72 h, and the dry weight was estimated. The above-ground species in the localities of Rieles de San Jose and Veteranos de la Revolución were identified by the local people and verified with herbarium vouchers. The names of the species were obtained from Magaña (2006) and Ochoa-Gaona et al. (2008). The identification of the species in Yumka was carried out at the Universidad Juárez Autónoma de Tabasco. For La Cuchilla and Los Tuxtlas, leaf samples were collected and identified with the aid of herbarium specimens. The non-identified species were considered as morpho-species.

In the case of the arboreal vegetation, the above-ground biomass of each tree was calculated (>10 cm dap) for each plot with the formulas for humid (total annual rainfall >3,500 mm) and sub-humid (total annual rainfall 1,500 to 3,500 mm) forests, and the lowest value of mean error, according to Chave et al. (2005). The formulas used were, for the sub-humid tropical forest:

$$\ln(AGB)= -1.562 + 2.148 \ln(D) + \ln(D)^2 + \ln(D)^3 + \ln(q) \quad (1)$$

For the humid tropical forest:

$$\ln (AGB) = -1.302 + 1.98 \ln (D) + 0.207(\ln(D))^2 - 0.0281(\ln(D))^3 + \ln(q) \quad (2)$$

Where AGB = above ground biomass, D = diametre at breast height (cm) and q = wood density of 0.6 g/cm^3.

For the case of palms, lianas and *Cecropia obtusifolia*, the following formulas were used (Pearson et al., 2005):

$$\text{Palms: } AGB = 6.666 + 12.826 / \text{height } [0.5(\ln(\text{height}))] \quad (3)$$

$$\text{Lianas: } AGB = \exp[0.12 + 0.9(\log (\text{Basal area at } D))] \quad (4)$$

$$\textit{C. obtusifolia}\text{: } AGB = 12.764 + 0.2588 [D(2.0515)] \quad (5)$$

The species richness (total number of species ha^{-1}), Shannon´s diversity index (Krebs, 1998), and the above-ground biomass were obtained for each locality. Data were checked out for normality and homogeneity of variances. The regression models between diversity (species richness and diversity index) and above-ground biomass were obtained with the values of the seven localities. Simple and polynomial (inverse U) regressions were tested. The use of the polynomial regression was accordingly to the most approximate regression model to the inverse U line previously discussed. Statgraphics Plus 4.0 was used for the analyses.

RESULTS

The sub-humid tropical forest 1 presented a total of 20 species per hectare, with an above-ground biomass of 135 t/ha. The sub-humid tropical forest 2 and 3 (regeneration site) presented a total of 41 and 30 species per hectare, with an above-ground biomass of 199.7 and 79.4 t/ha respectively. The humid tropical forests presented a range from 62 to 88 tree species per hectare and a biomass from 198.8 to 261.4 t/ha. Shannon´s index for the sub-humid tropical forests ranged from 3.7 to 4.0, and for the humid tropical forests from 4.08 to 5.31 (Table 2). The grasslands presented 12 and 10 herbaceous species per hectare (> 20% area coverage), with a biomass of 4.5 and 5.5 t/ha respectively. The dominant species were the grasses *Brachiara decumbens* and *Paspalum notatum* respectively.

Biomass distribution amongst the families and species of the sites

Species biomass of the grasslands could not be obtained. Overall dominant families in biomass in the arboreal vegetation of all the localities were Moraceae (four communities), Bombacaceae (two communities), Tiliaceae (two communities), Anacardiaceae and Caesalpinaceae (Table 3). These families dominated

Table 1. Characteristics of the study sites in Mexico.

Site	Locality	Vegetation type	Location	Annual average temperature (°C)	Annual average rainfall (mm)	Number (and size) of sampled plots	Sampled area (ha)
Sub-humid tropical forest 1	Yumka, Villahermosa, Tab.	40-year old Sub-humid tropical forest	17° 59' - 18° 00' N, 92° 47' - 92° 49' W	26.9	2,159.3	3 (50 × 50 m)	0.75
Sub-humid tropical forest 2	La Cuchilla, Balancan, Tab.	20-year old Sub-humid tropical forest	17° 47' N, 91° 13' W	28.0	1,500.0	25 (10 × 10 m)	0.25
Sub-humid tropical forest 3	La Cuchilla, Balancan, Tab.	Mature Sub-humid tropical forest	17° 47' N, 91° 13' W	28.0	1,500.0	25 (10 × 10 m)	0.25
Humid tropical forest 1	Rieles de San Jose, Tenosique, Tab.	Mixture of mature forest and 10-20 year-old Humid tropical forest	17° 19' 00'' N, 91° 21' 15'' W	26.0	3,300.0	13 (30 × 30 m)	1.17
Humid tropical forest 2	Veteranos de la Revolución, Tenosique, Tab.	Mixture of mature forest and 10-20 year-old humid tropical forest	17° 23' 30'' N, 91° 21' 00'' W,	26.0	3,300.0	13 (30 × 30 m)	1.17
Humid tropical forest 3	Los Tuxtlas, Ver.	Mature Humid tropical forest	18° 34' - 18° 36' N, 95° 04' - 95° 09' W	25.1	4,487	3 (50 × 50 m)	0.75
Grassland 1	Yumka, Villahermosa, Tab.	Grassland	17° 59' - 18° 00' N, 92° 47' - 92° 49' W	26.9	2,159.3	30 (2 × 2 m)	0.012
Grassland 2	Yumka, Villahermosa, Tab.	Grassland	17° 59' - 18° 00' N, 92° 47' - 92° 49' W	26.9	2,159.3	30 (2 × 2 m)	0.012

Table 2. Values of diversity and above-ground biomass for six arboreal communities and two grasslands in southeastern Mexico.

Site	No. of species ha^{-1}	Shannon index	Biomass (t/ha)
Sub-humid tropical forest 1	27	4.00	135.0
Sub-humid tropical forest 2	30	3.7	79.39
Sub-humid tropical forest 3	41	3.9	199.7
Humid tropical forest 1	66	4.55	198.8
Humid tropical forest 2	62	4.08	196.85
Humid tropical forest 3	88	5.31	261.4
Grassland 1	12		4.5
Grassland 2	10		5.5

almost with the same species elsewhere. In the sub-humid tropical forest 1, only two species accounted for more than 60% of the total biomass. In contrast, in the humid tropical forest 1 for example, tree biomass spread over many species with small values. In all the communities biomass dominant species were not strictly tree density dominant species. Species with the highest tree densities had intermediate or low biomass values.

The relationship between species richness (number) and biomass in these plant communities was significant with a positive linear relationship, and for the inverted U curve polynomial model (Figure 1a and b). The relationship for diversity and biomass obtained with Shannon´s index as an estimator of diversity may also be considered as significant (Figure 2).

DISCUSSION

A possible minor baized could occur in the species and biomass values owing to the different plot size used throughout the localities in the present study. However this baized may be negligible. In the grassland 30 × 30 m plots were set up. This was because the herbs are small-size plants and large trees that require large sampling plots were almost absent. In the secondary forests, the baized could be greater owing to the relatively small sampling plots (10 × 10 m). However due to the larger number of plots sampled this could be sufficiently over-compensated (Gentry, 1990). Two grassland localities were considered sufficient owing to the low biomass variation of this vegetation type. A second biased in the study could be owing to the use of a mean value of wood density (0.6 g/cm^3, Pearson et al., 2005) to obtain the tree biomass. Since many particular species from these localities do not have a literature value yet and the reported mean value is obtained from a larger sample of species and worldwide accepted, it was decided to maintain it.

Site biomass tended to concentrate in species of large trees. However, it seems that overall, biomass values among the vegetation types differ more because of species richness than because of species composition. Dominant species of the topical humid forests accounted for the highest community biomass values, but there were a large number of species with lower biomass values that overall, accounted more for the community total biomass than dominant species.

A relationship was found between floristic diversity and biomass (carbon stocks) in the tropical plant communities. This relationship was positive and slightly more significant for the species richness than for the Shannon´s diversity index. It may be that a greater number of localities would also have provided a more significant result with the diversity index. These relationships were slightly more significant with the lineal regression model than with the inverted U quadratic model. A complete inverted U line was not observed, surely because a greater number of localities are required. As Guo and Berry (1998) indicated, ecosystems in homogeneous climates tend to present a lineal relationship between diversity and productivity. Tropical ecosystems have a homogeneous climate with relatively homogeneous temperature and rainfall values throughout the year.

Given that carbon stocks is half of the biomass, the linear regression between biodiversity and biomass in the tropical ecosystems indicates that the conservation of biodiversity deserves the main importance, when considering a tropical ecosystem or a forest area with the purpose of carbon storage. This may contribute to the management of natural areas by simplifying decision making.

In natural communities, the positive relationship between species diversity and productivity has been proved by many experiments, mainly for herbaceous species, aided by the advantage of a faster growth and easy manipulation (Wardle, 1999; Schwartz et al., 2000; Diaz and Cabido, 2001; Loreau et al., 2001; Schmid et al., 2002; Hooper et al., 2005; Spehn et al., 2005; Fargione et al., 2007). Positive relationships occur principally when there are new species that increase productivity (Mittelbach et al., 2001).

A tendency may also be seen (P = 0.03, F = 9.52) towards the commonly accepted inverse U relationship that is observed in most plant communities, probably because this type of relationship is more common in heterogeneous than in homogeneous environments (tropical areas) (Guo and Berry, 1998). In this case, the sub-humid tropical forest represents the greatest value of the slope by having, with only 20 and 41 species (Yumka and La Cuchilla, Table 1), a slightly smaller or equal biomass than that of humid tropical forests, where the number of species is much greater. This also indicates the importance of conserving the presently reduced sub-humid tropical forests. The basic difference between these two types of tropical forests is the shorter dry season and greater rainfall in the humid tropical forest, compared with the sub-humid tropical forest.

It has been proposed that the non-observation of the peak in the inverted U relationship (straight line) in natural communities responds to the absence of a wide availability of resources (Marrs, 1999; Mittelbach et al., 2001). In the case of natural communities, Gough et al. (2000) proposed that the inverted U relationship occurs after long ecological processes such as the colonization of new species, for which reason, in general, only the ascending part of the curve may be seen. However, Whittaker and Heegaard (2003) said that this widely accepted biomass-diversity relationship has been overestimated

Table 3. Biomass dominant species and families in the sites.

Site	Dominant families	Dominant species	Contribution of total biomass (%)
Sub-humid tropical forest 1	Moraceae	*Brosimum alicastrum* Sw.	41.0
	Caesalpinioidae	*Dialium guianense* (Aubl.) Sandw.	20.7
Sub-humid tropical forest 2	Bombacaceae	*Ceiba pentandra* (L.) Gaertn.	21.0
	Combretaceae	*Bucida buceras* L.	19.1
	Moraceae	*Ficus* sp	16.5
Sub-humid tropical forest 3	Combretaceae	*Bucida buceras*	9.6
	Mimosoideae	*Acacia* sp	8.0
	Anacardiaceae	*Spondias mombin* L.	7.9
Humid tropical forest 1	Moraceae	*Brosimum alicastrum*	6.8
	Bombacaceae	*Pseudobombax ellipticum* (Kunth) Dugand	6.3
	Tiliaceae	*Trichospermum mexicanum* (DC.) Baill.	5.4
Humid tropical forest 2	Tiliaceae	*Trichospermum mexicanum*	16.2
	Moraceae	*Psuedolmedia oxyphyllaria* Donn. Sm.	14.4
	Bombacaceae	*Pachira aquatica* Aubl.	9.8
	Bombacaceae	*Pseudobombax ellipticum*	8.0
Humid tropical forest 3	Moraceae	*Nectandra ambigens* (S.F. Blake) C.K. Allen	18.8
	Anacardiaceae	*Spondias radlkoferi* Donn. Sm.	11.2
Grassland 1	Poaceae	*Bachiaria decumbens* L.	n.d.
		Axonopus compresus Sw.	
		Cynodum dactylon (L.) Pers	
		Eulosine indica	
		Paspalum notatum Flugg	
	Fabaceae	*Mimosa pigra*	
Grassland 2	Poaceae	*Paspalum notatum* Flugg	n.d.
		Panicum 5aximum	
		Andropogon bicornis L.	
	Euphorbiacea	*Euphorbia harta*	
	Fabaceae	*Phaseolus latyroides*	

n.d. = not determined.

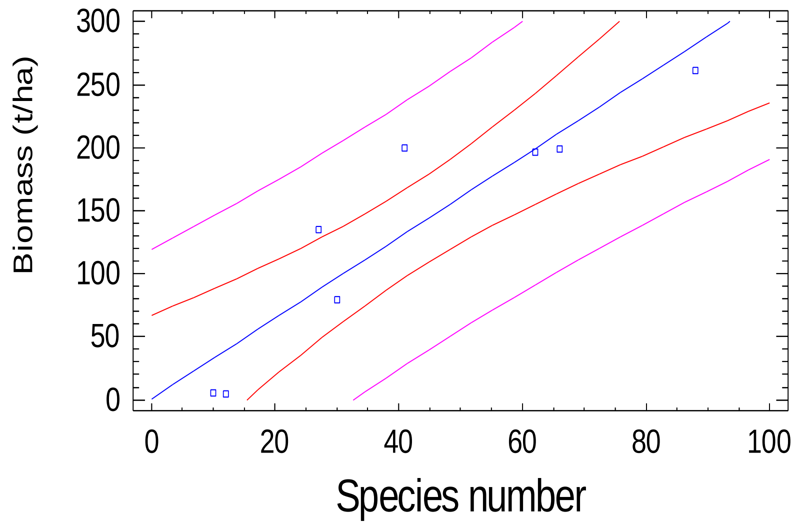

Figure 1a. Linear relationship of the number of species per hectare and above-ground biomass in two tropical grasslands and six tropical forests. r^2 = 0.82, *P* = 0.001, F = 34.0. Model: Biomass = 0.675896 + 3.20147 * No. of species.

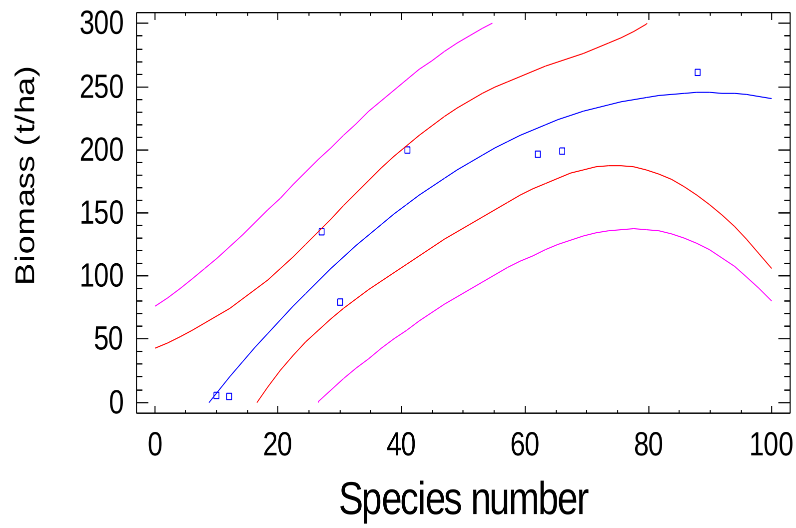

Figure 1b. Polynomial relationship of the number of species per hectare and above-ground biomass in two tropical grasslands and six tropical forests. r^2 = 0.84, *P* = 0.002, F = 25.5. Model: Biomass = -56.875 + 6.77745* No. of species - 0.03801 * No. of species ^ 2.

by data analysis. Grime (1973) proposed that the descending part of the inverted U responds to environmental stress and a high inter-specific competition that decrease the productivity of a wide variety of species.

The fact that the arboreal biomass increases progressively with an increase in the diversity of arboreal species has important practical implications, as for example: it is advisable to maintain an ecosystem with its greatest diversity to ensure a greater productivity and profit for the ecosystem. The more diverse an ecosystem, the more effective in providing important environmental services, as is the specific case of the carbon stocks. The relationship between greater ecosystem productivity and greater diversity has two possible explanations (Aarsen, 1997; Huston, 1997; Tilman et al., 1996, 1997; Loreau, 2000). One is “the sampling effect” in which a greater productivity responds to the greater probability of occur-

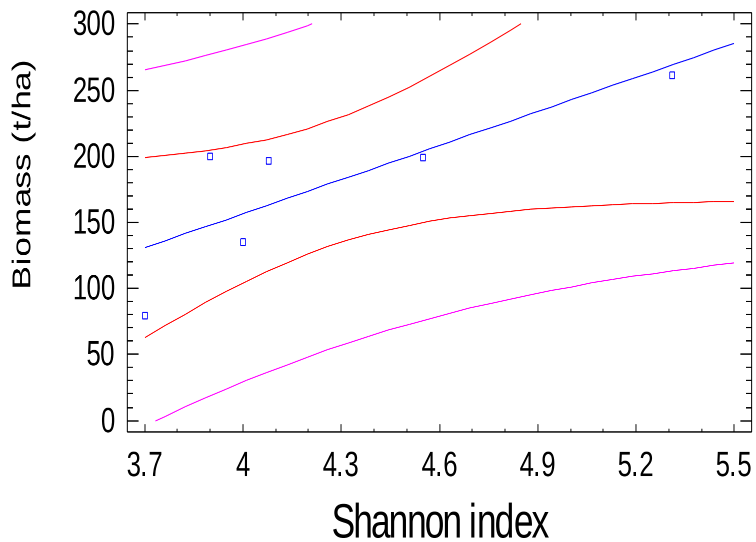

Figure 2. Linear relationship for diversity (Shannon Index) and above-ground biomass in tropical grassland and six tropical forests. $r^2 = 0.65$, $P = 0.05$, F = 7.34. Model: Biomass = -187.69 + 86.032 * Shannon index.

ence of one or several dominant species in the sampling units. The other is "the complimentarily of the niche" in which the sharing of resources by the different species results in a greater productivity in the community. The possibility of use of the same resource by more species (sharing) gives the possibility of a higher number of species in the community and then of biomass. If the polynomial regression (inverted U curve) is considered the one that best explains this relationship in arboreal communities, the greatest value of the positive slope (lower number of species and higher arboreal biomass) was recorded for the sub-humid tropical forest in Yumka. This may indicate that the sub-humid tropical forests have a relatively greater productivity with a lower number of species, in comparison with the humid tropical forests. This is of great importance in the conservation of tropical ecosystems also as, in the case of Mexico, the sub-humid tropical forests cover at present the smallest area and has been strongly eradicated from their original distribution (Rzedowski, 1978). From the point of view of arboreal ecosystems as carbon stocks, the sub-humid tropical forests are of great importance.

It may be concluded that, as the theory states, a relationship between diversity and productivity was recorded for the humid tropical vegetation of Mexico. This relationship was directly proportional (ascending straight line) as predicted for homogeneous environments. This means that carbon stocks in these highly productive terrestrial ecosystems will be more efficient when there is a greater diversity of arboreal species, and that the environmental service of carbon sequestration will be markedly favored by the preservation of a greater floristic diversity.

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