Tropical and Subtropical Agroecosystems, 13 (2011): 149 - 158

THE SPATIAL DISTRIBUTION OF ABOVEGROUND BIOMASS IN TROPICAL FORESTS OF MEXICO

[DISTRIBUCIÓN ESPACIAL DE LA BIOMASA AÉREA EN LOS BOSQUES TROPICALES DE MÉXICO]

José Návar-Chaidez

Professor, Natural Resources Management. CIIDIR-IPN Unidad Durango. Sigma No 119. Fraccionamiento 20 de Noviembre II. Durango, Dgo., México. 34220. Email: jnavar@ipn.mx.
**Corresponding Author*

SUMMARY

Biomass stocks and their spatial distribution remain poorly understood in tropical forests and reliable estimations are critical in the calculations of carbon stocks and fluxes. This report aims to estimate and contrast aboveground biomass (AGB) stocks in tropical forests of Mexico (classified as dry, moist and rainy) by employing three different evaluation techniques. The first method uses a simple mean biomass density value per each forest class multiplied by the area of each forest. The second approach improves the spatial resolution by classifiying forests per each region and a mean biomass density is multiplied by the area of each forest class. The third methodology calculates biomass stocks by developing an empirical model using mean annual precipitation as the independent variable and then applying the equation to the mean annual rainfall of each tropical forest times the area of the forest. Results showed that all three methods of AGB stock estimations are quite consistent since they have mean (confidence interval) values of 3.0 (0.69), 3.0 (0.30), and 2.25 (0.67) Pg estimated by first, second and third approaches, respectively. Deviations between evaluation methodologies did not surpass 0.45 Pg or 16% of the mean AGB stock. Using all three statistics, mean (confidence interval) aboveground biomass stocks for Mexican tropical forests is 2.77 (0.56) Pg. This statistic deviates by more than one order of magnitude when contrasting it with other six independent AGB estimates. However, the mean figure reported in this study or a mean AGB calculated across all estimation methods provides a dataset that is important for conducting carbon stocks and fluxes for Mexican tropical forests.

Key words: Aboveground biomass stocks; precipitation gradients; spatial scales; sources of error.

RESUMEN

Los almacenes de biomasa y su distribución espacial son pobremente entendidos en bosques tropicales y las estimaciones confiables son importantes en los cálculso de los almacenes y flujos de carbono. Este reporte presenta como objetivos la estimación y el contraste de los almacenes de biomasa aérea en pié (AGB) en bosques tropicales de México (clasificados como secos, húmedos y lluviosos) por el empleo de tres metodologías de evaluación. El primer método usa una densidad promedio de biomasa por cada tipo de bosque multiplicado por el área de cada bosque. La segunda técnica mejora la resolución espacial de cada clase de bosque al determinarse para cada Estado y entonces multiplicarse por su densidad de biomasa. El tercer método utiliza el análisis de gradientes al desarrollar una ecuación empírica entre la densidad de biomasa y la precipitación anual y multiplicar el área de cada tipo de bosque por la densidad calculada por medio de esta variable climática. Los resultados mostraron que las tres diferentes estimaciones de AGB son consistentes porque su promedio (intervalo de confianza) fueron 3.0 (0.69), 3.0 (0.30), y 2.25 (0.67) Pg estimadas por los métodos primero, segundo y tercero, respectivamente. Las desviaciones entre metodologías no sobrepasan 0.45 Pg o el 16% del promedio general. Con el uso de los tres estadísticos, la AGB promedio es de 2.77 (0.56) Pg. Este valor se debía por más del 100% cuando se contrasta con otras seis formas independientes de evaluación. Sin embargo, el promedio reportado en este estudio provee datos importantes para evaluar los almacenes y flujos de carbono en bosques tropicales Mexicanos.

Palabras clave: Almacenes de biomasa aérea en pié, gradientes de precipitación; escalas espaciales; fuentes de error.

INTRODUCTION

Estimates of aboveground biomass are critical for studies of: a) the carbon stocks and fluxes of forest communities (Brown, 1997; Návar, 2009ab); b) the amount of primary energy that can be obtained from forests as an alternative to fossil fuels (Richardson *et al*., 2002); and c) the stocks and fluxes of other biogeochemical elements, such as nitrogen (Hughes *et al*., 1999). Regardless of the wide range of studies published on aboveground biomass estimates in tropical forests around the world (Brown, 1997; Houghton, 1999; de Fries *et al*., 2002; Achard *et al*., 2004; IPCC, 2006), the biomass stock of these structurally diverse forests remain poorly understood (Fearnside and Laurance, 2003; Houghton, 2005; Saatchi *et al*., 2007). Indeed, few studies have used proven allometric alternatives coupled with different evaluation methods to contrast AGB values at large spatial scales with the aim of understanding sources of variability intrinsic to biomass stocks.

Tthe reliable estimation of AGB in tropical forest communities remains a key challenge for the successful implementation of international protocols and national strategies. The conventional method for the accurate assessment of AGB is a grid of ground sample plots with very precise location together with a classification of areas according to vegetation types or cover classes (Houghton, 2005; Saatchi *et al*., 2007). Sampling can be improved if an additional dataset is collected by independent techniques such as radar or laser measurements. Several of these techniques have been conducted on worldwide forests (Houghton, 1999; 2005) but there is scarce information on Mexican forests. Neither the sources of error are reported when extrapolating plot AGB data to areas deprived of this information, whose main sources are: a) the lack of a good correlation between ground and remote sensing data, b) the correct location of ground data, and c) temporal variations in the satellite image.

Other simple, alternate methodologies have been employed in preliminary AGB assessments that can result in precise approximations, since land cover/land use datasets are already available in tabular and graphical formats for most places. However, when using already computed maps coupled with ground biomass data, these methods rarely provide error estimates to understand sources of inherent variability (Saatchi *et al*., 2007).

The objectives of this research therefore were: a) to provide AGB estimates for tropical forests of Mexico using three assessment methods, b) to contrast all three methods of AGB evaluation, c) to calculate the error inherent to AGB estimation, and d) to contrast independent AGB evaluations. The null hypothesis was that all three assessment methods would calculate consistent AGB estimates that are compatible themselves as well as with other independent calculations. If Ho is accepted then any evaluation method can be used to calculate AGB for Mexican tropical forests.

MATERIALS AND METHODS

Description of tropical forests of Mexico

The tropcal forests of Mexico occupy an area of between 27 and 32 M ha (Palacios-Prieto *et al*., 2000; De Jong *et al*., 2008). They are distributed in the lowlands of the Pacific, Caribbean and the Gulf of Mexico and they are classified as tropical rain (evergreen), tropical dry (deciduous) and a combination of these two forest classes with different degrees of dryness or wetness. An important portion of these forests are classified as degraded forests, according to the last forest inventory (2004-2006). The disappearance of tropical forests by continous degradation through deforestation practices is a cause of major concern around the world (Houghton, 1995; 2005; Saatchi *et al*., 2007) and Mexico is not the exception to this rule, with varying deforestation rates in several places (Dirzo and García, 1991; Cairns *et al*., 1995; 2000; Trejo and Hernández, 1996; De Jong *et al*., 1999; Trejo and Dirzo, 2000; Ochoa-Gaona, 2001).

Estimations of plot aboveground biomass (SAGB)

Commercial and research forest inventory data reported by several researchers are available for 18 tropical forest communities encompassing the dry (7), moist (6) and rain (5) tropical forests of western and eastern Mexico. Návar *et al*. (2010) reported plot standing aboveground biomass (SAGB) data for the tropical dry forests of Baja California Sur, Sinaloa, and Morelos; the tropical moist forests of San Luis Potosi, Calakmul, Campeche; and the rainy forests of Los Tuxtlas, Veracruz. Jaramillo *et al*. (2003) reported mean values for three sample plots of Chamela, Jalisco for trees with diameter at 1.30 m, D, > 7.5 cm. Cairns *et al*. (2000) reported mean SAGB values for southern Mexico that were classified as tall, medium and short tropical forests for each State of southern Mexico. These researchers also reported a mean value for Los Tuxtlas in Veracruz. De Jong *et al*. (2000) also reported mean statistics for La Selva Lacandona and they were classified as mature and secondary forests. Hughes *et al*. (1999) and Read and Lawrence (2008) reported mean values for Los Tuxtlas, Veracruz and for Calakmul, Campeche, respectively. Mean stand dasometric features of the inventory data collected for this research are reported in Table 1.

Table 1. Stand biomass datasets employed in the assessments of aboveground biomass stocks for Mexican tropical forests.

Location	Classification	Source	Aboveground Biomass ($Mg\ ha^{-1}$)	
			Mean	Confidence Interval
Baja California Sur	Dry	Návar *et al*. (2010)	40.06	6.09
Vado Hondo, Sinaloa	Dry	Návar *et al*. (2010)	47.81	7.42
Tiniaquis, Sinaloa	Dry	Návar *et al*. (2010)	58.15	9.14
Morelos	Dry	Návar *et al*. (2010)	14.13	2.06
Calakmul, Campeche	Moist	Návar *et al*. (2010)	116.37	23.88
La Pila, S.L.P.	Moist	Návar *et al*. (2010)	173.25	39.68
Chuchupe, S.L.P.	Moist	Návar *et al*. (2010)	167.43	39.67
Los Tuxtlas, Veracruz	Rain	Návar *et al*. (2010)	247.09	67.72
Selva Lacandona (Mature)	Rain	DeJong *et al*. (2000)	233.40	NA
Selva Lacandona (Secondary)	Rain	DeJong *et al*. (2000)	116.10	NA
Veracruz (T-M)	Rain	Cairns *et al*. (2000)	265.10	NA
Los Tuxtlas Veracruz	Rain	Hughes *et al*. (1999)	403.00	NA
Chamela, Jalisco	Dry	Jaramillo *et al*. (2003)	47.74	10.52
Calakmul, Campeche	Moist	Read & Lawrence (2008)	136.42	11.57
Guerrero (T-M)	Moist	Cairns *et al*. (2000)	41.10	NA
Campeche, Chiapas, Oaxaca, Quintana Roo, Tabasco, Yucatán (T-M)	Moist	Cairns *et al*. (2000)	133.10	NA
Chiapas,Oaxaca,Tabasco,Veracruz, Guerrero (Dry)	Dry	Cairns *et al*. (2000)	31.60	NA
Campeche,Quintana Roo,Yucatán (Dry)	Dry	Cairns *et al*. (2000)	85.20	NA
Statistics				
	Dry	n=7	46.38	16.42
	Moist	n=6	145.31	21.18
	Rain	n=5	287.15	76.75

Návar *et al*. (2010) tested ten different equations to come up with thwo (a non-destructive and Brown, 1997) allometric functions that consistently calculated SAGB for Mexican tropical forests. Jaramillo *et al*. (2003) used the equation reported by Martinez-Yrizar *et al*. (1992) for evaluating SAGB of Chamela forests in Jalisco. Hughes *et al*. (1999), De Jong *et al*. (2000) and Cairns *et al*. (2000) reported SAGB figures for tropical forests of southern Mexico.

The forest inventory

Palacios-Prieto *et al*. (2000) reported the area covered by tropical forests in the framework of the Mexican forest inventory for the year 2000.

Dry forests include short, deciduous and sub-deciduous trees; moist forests encompass medium deciduous and sub deciduous trees and rain forests contain tall evergreen forests.

Calculations of AGB

Three assessment methods were used to calculate AGB for Mexican tropical forests. The first approach is called the Simple Method since it employs only a mean plot biomass density per hectarea value (SAGB) per forest class that is multiplied by the area covered by the tropical forest, A, and it is expanded for all three forests classes (rain, moist and dry), as in Equation 1.

$$AGB1 = \sum_{i=1}^{n} (SAGB_i * A_i) \qquad [1]$$

Where i = the forest class i (dry, moist and rainy).
The second method is called AGB2 and it expands from AGB1 since a mean plot biomass density per hectare value is multiplied by the area covered by the tropical forest, A, of each region or state, S, as in Equation 2.

$$AGB2 = \sum_{i=1}^{n} (SAGB_{Si} * A_{Si}) \qquad [2]$$

That is, AGB2 multiplies for example for the state of Baja California Sur its reported SAGB by its area covered by tropical forest. For Mexican States with two or three classes of forest types, the estimated SAGB value per forest class was multiplied by the area of the forest class i, A_{Si}. For tropical regions with no recorded SAGB data, mean values were employed for each forest class.

The third approach uses a gradient analysis between mean annual precipitation and SAGB. A simple scatter plot of SAGB and annual precipitation showed an important trend and therefore this approach was adopted. The development of this approach was the following; a mathematical function was fitted to the relationship between SAGB and annual precipitation, P; the model was multiplied by the annual precipitation and the area covered by each forest class for each Mexican State, A_{Si}, as in Equation 3.

$$AGB3 = \sum_{i=1}^{n} (SAGB = f(P) * A_{Si}) \qquad [3]$$

Where si = State i

Data analysis and error estimation

Forest inventory and stand biomass density datasets were displayed in Microsoft Excell and all calculations were conducted in this program. A scatter plot of SAGB versus P was graphed in Sigma Plot and the equation was fitted using SAS ver. 8 software (SAS, 1998). All goodness of fit statistics was recorded for further discussion. In the next step, the mean and confidence interval values were estimated for each tropical forest community.

Confidence interval values were calculated for: a) SAGB datasets and b) methods of AGB estimation. Návar *et al*. (2010) reported the confidence interval values for eight SAGB estimates. Jaramillo *et al*. (2003) and Read and Lawrence (2008) also reported confidence interval values for their estimates. For SAGB datasets with no reported deviation values, mean and confidence figures for all SAGB estimates were calculated and these statistics were employed in further analysis. For the precipitation gradient analysis, the standard error of the estimate given by the equation was transfored into a confidence interval by calculating the standard error multiplied by a t-Student value.

Table 2. Area covered by three classes of tropical forests for each Mexican State.

	Tropical Forest Area (km^2)		
Mexican State	Rain	Moist	Dry
Baja California Sur	0	0	3374
Campeche	37	30657	8828
Chiapas	14186	2226	3898
Chihuahua	0	0	4822
Colima	0	596	1671
Durango	0	67	4711
Mexico	0	0	975
Guanjuato	0	0	208
Guerrero	0	1509	18222
Hidalgo	637	198	146
Jalisco	0	2700	10142
Michoacán	0	1371	13707
Morelos	0	0	1058
Nayarit	0	3677	3585
Oaxaca	10078	5504	12150
Puebla	326	8	5106
Querétaro	3	59	779
Quintana Roo	0	28389	3580
San Luis Potosí	564	883	1743
Sinaloa	0	1021	17584
Sonora	0	0	15616
Tabasco	1048	257	545
Tamaulipas	0	112	6028
Veracruz	6486	1915	784
Yucatán	1	13323	5586
Zacatecas	0	0	1113
Total for Mexico	33366	94472	145961

RESULTS

According to the forest inventory for the year 2000 carried out by Palacios-Prieto *et al*. (2000), tropical forests cover an approximate area of 27.38 M ha, of which, 3.33, 9.45, and 14.60 M ha are classified as rain, moist and dry tree communities (Figure 1). The data depicted in Figure 1 was obtained from Palacios-Prieto *et al*. (2000). De Jong *et al*. (2008) reported an aea of 32 M ha using data from the Mexican forest inventory of 2004-2006. However, more precise information on the classification of tropical forests is not yet available from this latter dataset.

The mean annual precipitation accounted for 59% of the total SAGB variance for 18 ground sample plots evaluated (Figure 2). The three-parameter logistic model fits the recorded SAGB-mean annual precipitation dataset well since the F value was 13.03 with a probability of rejecting the equation (SAGB = $342.26/1+(P/1900.57)^{-2.20}$) of 0.0001. The standard error of the estimate is close to 50% as a function of the mean SAGB value.

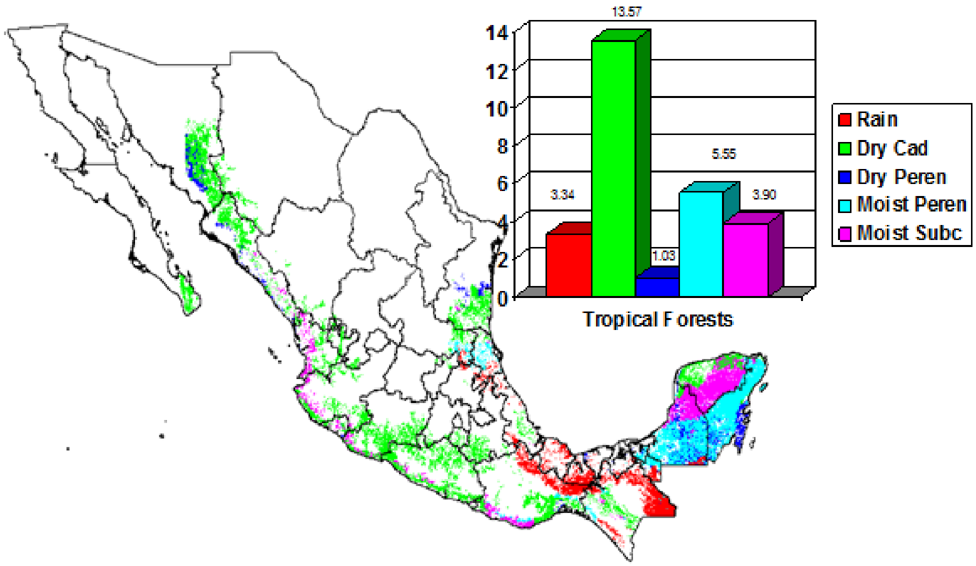

Figure 1: Spatial distribution and area of Mexican tropical forests (Cad = caducifolio; Subc = Subcaducifolio, Peren = perennifolio).

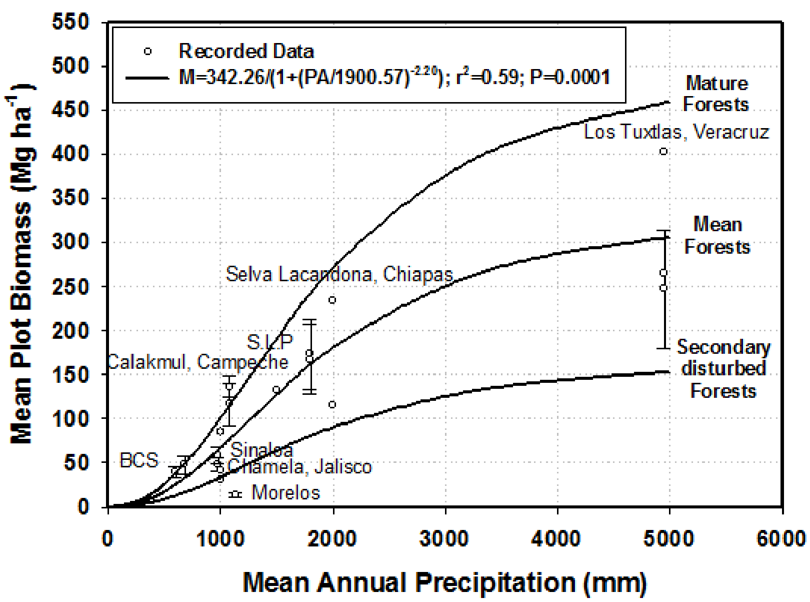

Figure 2: Observed and estimated stand aboveground biomass data for Mexican tropical forests as a function of mean annual precipitation. The model with upper and lower bounds is also depicted.

The large variation noted in this relationship could be adequately modeled by multiplying the equation by a factor of 0.5 since most recorded data lies within these bounds. For example, for tropical trees of Los Tuxtlas, with a mean of 265 Mg ha^{-1} (Cairns *et al*., 2000) as well as a lower mean of 247 Mg ha^{-1} (Návar *et al*., 2010) and an upper mean of 403 Mg ha^{-1} (Hughes *et al*., 1999) bounds are correctly estimated. The model projects somehow low mean values for forest landscapes with rainfall depths within 1000 mm of annual precipitation as several sample plot estimates from the region of Calakmul, Campeche lie beyond the upper bound. However, estimates from Sinaloa and Jalisco are well described by the three-parameter logistic model. That is, tropical forests of eastern Mexico may fit a model with different parameters than tropical forests of western Mexico. However, due to insufficient data, a single mathematical function is employed in further analysis.

The AGB estimates by all three methods per forest class are depicted in Figure 3.

The mean AGB values were not significantly different among forest classes; although dry forests recorded the smallest and moist forests recorded the largest mean figures (Figure 3). There was a tendency for the precipitation gradient method to underestimate AGB values for moist tropical forests. However, it was difficult to separate moist from dry or rain forest classes with the only variable mean annual rainfall.

Methods of assessment produced AGB values that deviated by less than 0.45 Pg or by less than 16% of the mean estimate (Figure 4).

The simple and the improved spatial resolution methods turned out to produce consistent AGB estimates with similar deviations as well. The precipitation gradient appears to underestimate AGB in contrast to the other two approaches. However, all three methodologies result in significantly similar AGB estimates. Using the three statistics, for all Mexican tropical forests, mean aboveground biomass stock estimates would be 2.77 (0.56) Pg. The samples mean (2.77 Pg) deviates only 31% (0.76 Pg) from the theoric population mean.

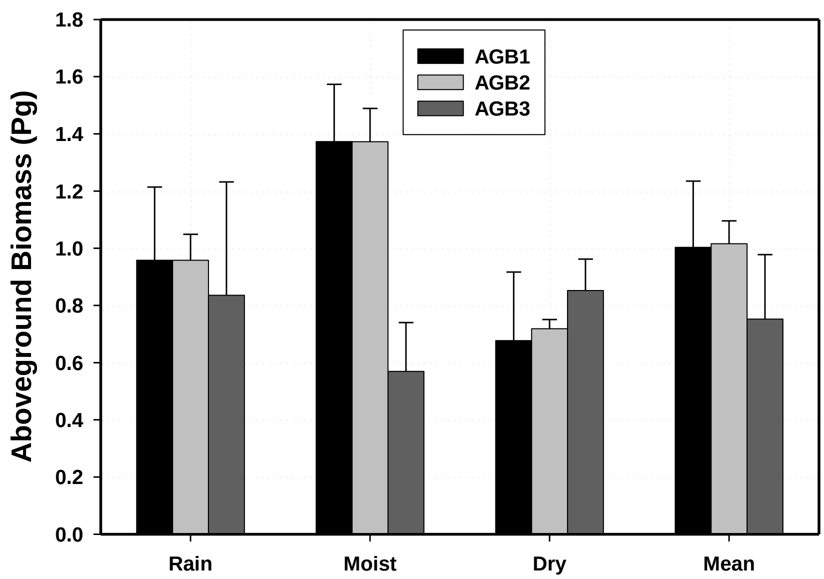

Figure 3. Aboveground biomass estimates per forest class per method of assessment for Mexican tropical forests.

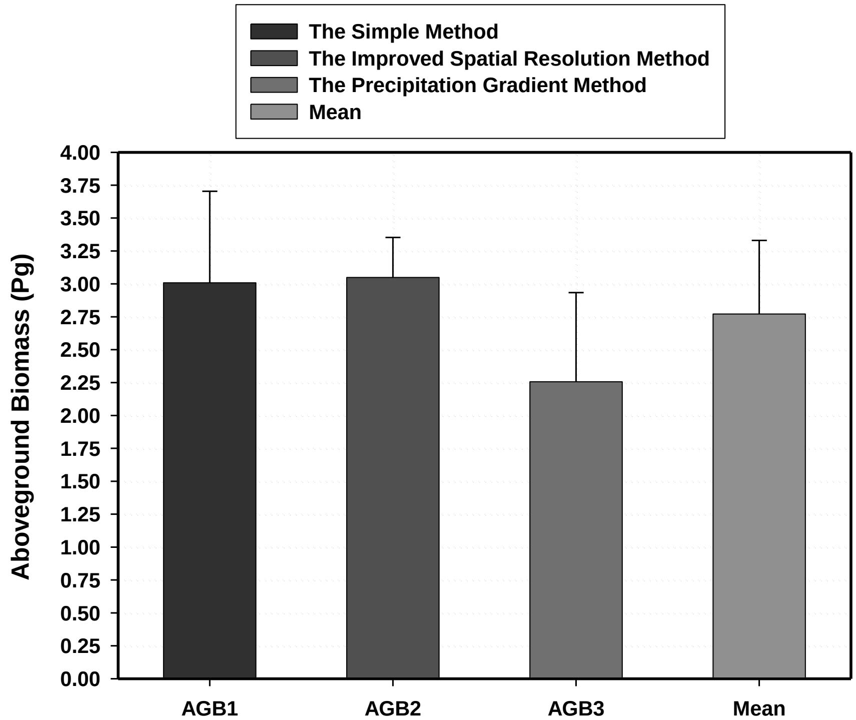

Figure 4: The aboveground biomass values assessed by three evaluation methods for tropical forests of Mexico.

DISCUSSION

Consistent aboveground biomass estimates were produced by all three assessment methods since differences did not surpass a standard deviation of 0.45 Pg and a standard error in percentage as a function of the mean of less than 16%. Other statistics by other independent authors are reported in Table 3.

Other biomass density statistics can be calculated using reported standing volumes by the National Forest Inventory (2004-2006). Tall-medium and short tropical forests record a mean stand standing volume of 50.71 and 19.37 m^3 ha^{-1}, with a total standing volume of 735 and 317 M m^3, respectively. The area covered by these forests was reported as 14.5 and 16.2 M ha, respectively. Návar *et al*. (2010) reported mean wood specific gravity (WSG) values of 0.56 and 0.53 for these forests; multiplying volume by WSG, total aboveground biomass would be 1.16 Pg, (assuming also that branches are 100% of the bole volume). This statistic does not match well with our estimates by any of the three methodologies tested. Návar-Cháidez (2009) reported biomass expansion factors (BEF) for dry tropical forests of Sinaloa, Mexico as 1.46 (0.022) that are quite consistent with the BEF values reported by FAO (2007) for Latin American tropical forests. Using the total standing volume value, biomass expands to 1.54 (0.023) Pg indicating that branch biomass accounts for more than 100% of the bole volume or biomass. Using all these statistics (2.77, 3.84, 4.16, 3.98, 4.34, and 1.54 Pg) a mean (confidence interval) value would be 3.02 (1.36) Pg. However, these individual estimates vary by more than three orders of magnitude as it was also found for Amazonian forests by Houghton *et al*. (2001) when employing different methods of spatial distribution of forest biomass.

Taking the mean AGB statistic as 2.77 (0.56) Pg and considering that tropical forests of Mexico cover an area of 27.37 M ha, according to the forest inventory carried out by Palacios-Prieto *et al*. (2000), the mean weighted SAGB density would be 101 (20) Mg ha^{-1}. De Jong *et al*. (2008) reported biomass (carbon) densities for several forest classes of Mexico; 259, 182, 104, and 110 Mg ha^{-1} for tropical evergreen, tropical evergreen degraded, tropical deciduous, and degraded tropical deciduous forests, respectively. The arithmetic mean reported by these authors is close to 160 Mg ha^{-1} but the weighted mean has to be a bit smaller since the area with the highest biomass density is the smallest of these forest classes. Houghton (1999) and De Fries *et al*. (2002); Brown (1997) and Achard *et al*. (2004); and IPCC (2006) reported mean above and belowground biomass for Latin American tropical dry forests as; 110, 94, and 252 Mg ha^{-1}, respectively. For tropical seasonal and equatorial forests, these reasearchers reported mean values of 280 and 256; and 400 Mg ha^{-1}, respectively.

Other sources of variation involved in this study, as well as in any other project is the error in sampling plots to estimate SAGB. For this research, data from 18 sampling sites were collected and they provide more than 630 sampling plots with over an inventoried area larger than 64 ha. Sampling sites were spatially distributed all over México and encompasses a detailed database that incorporates major intrinsic variations. Most problems with the sampling scheme lie in the randomness criteria since datasets were selected from reported available ground inventory plots that do not meet this criterion across the tropical landscape. Phillips *et al*. (2000) for US Forests and Houghton *et al*. (2001) for Amazonian forests noted that the sampling scheme was an important source of error in AGB or volume estimates. Data from the Mexican forest inventory (a stratified, systematic sampling scheme that covers all the forest landscape) must eventually provide more spatial inventoried data and reduce this uncertainty.

Large deviations in AGB density estimates result from this comprehensive study for Mexican tropical forests. In fact, the mean value calculated for this research (2.77 Pg) is 28%, 33%, 30%, and 36% of the mean values reported by de Jong *et al*. (2008), Houghton (1999) and de Fries *et al*. (2002), Brown (1997) and Achard *et al*. (2004), and IPCC (2006), respectively. That is, deviations are close to one order of magnitude for most estimates. Deviations between my three methodologies and the calculations with either the BEF or the WSG approaches are still large and require other independent approaches to understand other sources of inherent variability. This is a matter of further study.

Large deviations result from variations in plot aboveground biomass estimates. The weighted mean estimates are 101, 140, 200, 191, and 208 Mg ha^{-1} for this study, de Jong *et al*. (2008), Houghton (1999) and de Fries *et al*. (2002), Brown (1997) and Achard *et al*. (2004), and IPCC (2006), respectively. The SAGB statistic used for this study was reported by Návar *et al*. (2010) and they claimed they compared several other methods and allometric equations to come up with this figure. Other studies do not convey any other contrasts or comparisons with other alternatives. They use most of the time a single worldwide allometric equation coupled with forest inventory datasets. Therefore, their statistics may bias SAGB estimates and consequently total AGB for all Mexican tropical forests. Further discussions on this issue should arise later as new data is comes up. Chavé *et al*. (2004) stressed the importance of the error involved in SAGB estimates due to the choice of an allometric model relating SAGB to other tree dimensions. Houghton *et al*. (2001) recommended direct measurements coupled with forest inventories and improved biomass allometry to increase precision between different methods of AGB assessment. For improved tree allometry, Návar (2010) found that several equations when they are used individually would bias biomass estimates when contrasting seven different allometric functions with the physics equation. These researchers noted that SAGB could be biased by more than two orders of magnitude and recommended instead using a mean value resulting from three consistent allometric equations.

Table 3. Aboveground biomass density estimates for Mexican Tropical Forests taking information on stand biomass for Latin American Tropical Forests reported by several researchers and compiled by Gibbs *et al*. (2007).

Tropical Forest	Area (M ha)	Aboveground Biomass Density (Pg) deJong *et al*. (2008)	Houghton (1999) DeFries *et al*. (2002)	Brown (1997) Achard *et al*. (2004)	IPCC (2006)
Rain	3.34	0.74	1.33	1.33	1.33
Moist	9.45	1.55	2.53	2.53	2.53
Dry	14.60	1.56	1.61	1.37	1.84
Total AGB		3.84	4.16	3.98	4.34

Note: De Jong *et al*. (2008) reported statistics for evergreen and degraded evergreen as well as for deciduous and degraded deciduous. A mean value was taken for evegreen (rain) and for deciduous (dry) and a second mean between these two means for moist forests. For tropical seasonal forests (moist), Houghton (1999) and de Fries *et al*. (2002) reported one SAGB figure of 280 Mg ha^{-1} and IPCC (2006) reported a second one of 256 Mg ha^{-1}. A mean value was taken for these calculations. For equatorial rain forests, IPCC (2006) reported a mean SAGB statistic of 400 Mg ha^{-1} and this value was taken for all other estimates. The mean root:shoot ratio reported by Cairns *et al*. (1997) for all tropical forests was 0.24.

CONCLUSIONS

This paper aimed at estimating and contrasting biomass stocks in tropical forests of Mexico by employing three different evaluation techniques. Results showed that methods of AGB stock estimations are quite consistent since they have mean (confidence interval) values of 3.0 (0.69), 3.0 (0.30), and 2.25 (0.68) Pg estimated by the methodologies employed. Deviations between evaluation methodologies did not surpass 0.45 Pg or 16% of the mean aboveground biomass stock. Using all three statistics, mean (confidence interval) AGB stocks for Mexican tropical forests is 2.77 (0.56) Pg. This information appears to deviate notoriously when contrasted with other statistics and other methodologies by more than one order of magnitude. Therefore, a mean value for seven different assessment methods could be a better estimate that can be preliminary employed in further analysis of carbon stocks to comply with national and international protocols or to develop sustainable management projects for these forests. When further research is conducted on this issue, *i.e.*, coupling the Mexican Forest Inventory data with satellite imagery information and proved allometric equations to precisely estimate SAGB, better AGB estimates would come up to improve precision on carbon stocks and fluxes.

ACKNOWLEDGEMENTS

I thank anonymous reviewers for improving the readability and technical content of this manuscript.

REFERENCES

Achard, F., Eva, H. D., Mayaux, P., Stibig, H.J. and Belward, A. 2004. Improved estimates of net carbon emissions from land cover change in the tropics for the 1990s Glob. Biogeochem. Cycles 18 GB2008 doi:10.1029/2003GB002142

Brown, S. 1997. Estimating biomass and biomass change of tropical forests. Forest Resources Assessment Publication. Forestry Papers 134. FAO, Rome, 55 pp.

Cairns, M.A., Dirzo, R. and Zadroga, F. 1995. Forests of Mexico: a diminishing resource? Journal of Forestry 93: 21-24.

Cairns, M.A., Brown, S., Helmer, E.H. and Baumgardner, G.A. 1997. Root biomass allocation in the world' s upland forests Oecologia 111 1–11.

Cairns, M.A., Haggerty, P.K., Alvarez, R., De Jong, B.H.J. and Olmsted, I. 2000. Tropical Mexico's recent land use and change: a region´s contribution to the global carbon cycle. Ecological Applications 10: 1426-1441.

Chavè, J., Condit, R., Aguilar, S., Hernández, A., Lao, S. and Perez, R. 2006. Error propagation and scaling for tropical foret biomass estimates. Phil. Trans. R. Soc. London B. 359: 409-420.

Chavè, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Folster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.-P., Nelson, B.W., Ogawa, H., Puig, H., Rie´ra, B., Yamakura, T., 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia 145 (1), 87–99.

De Jong, B.H.J., Cairns, M.A., Haggerty, P.K., Ramirez-Marcial, N., Ochoa-Gaona, S., Mendoza-Vega, J., Gonzalez-Espinosa, M. and March-Mifsut, I. 1999. Land-use change and carbon flux between 1970's and 1990's in central highlands of Chiapas, Mexico. Environmental Management 23: 373-385.

De Jong, B.H.J., Ochoa-Gaona, S., Castillo-Santiago, M.A., Ramirez-Marcial, N. and Cairns, M.A. 2000. Carbon flux and patterns of land-use/land-cover change in the Selva Lacandona, Mexico. Ambio 29: 504-511.

De Jong, B.H.J., Iglesias-Gutiérrez, L., and Alanís de la Rosa, J.A. 2008. Advances of Mexico in preparing for REDD. UNFCC Workshop. Tokyo, Japan.

DeFries R S, Houghton, R.A., Hansen, M.C., Field, C.B., Skole, D. and Townshend, J. 2002. Carbon emissions from tropical deforestation and regrowth based on satellite observations for the 1980s and 1990s Proc. Natl Acad. Sci. USA 99 14256–61.

Dirzo, R. and Garcia, C. 1991. Rates of deforestation in Los Tuxtlas, a netropical area in southeast Mexico. Conservation Biology 6: 84-90.

FAO. (2007). Food and Agricultura Organization. State of the World's Forests. Rome, Italy.

Fearnside, P.M. and Laurance, W.F. 2003. Comment on 'determination of deforestation rates of the world's humid tropical forests'. Science, 299, 1015a.

Gibbs, H.K., Brown, S. Niles, J.O. and Foley, J.A. 2007. Monitoring and estimating tropical forests carbon stocks: making REDD a reality. Environmental Research Letters doi 10.1088/1748-9326/2/4/045023.

Houghton, R.A. 1999. The annual net flux of carbon to the atmosphere from changes in land use 1850–1990 Tellus B 51 298–13.

Houghton, R.A., Lawrence, K.T., Hackler, J.L., and Brown, S. 2001. The spatial distribution of forest biomass in the Brazilian Amazon: A comparison of estimates. Global Change Biology 7: 731-746.

Houghton, R.A. 2005. Aboveground biomass and the global carbon balance. Global Change Biology 11 945–958.

Hughes, R.F., Kauffman, J.B., Jaramillo, V.J. 1999. Biomass, carbon, and nutrient dynamic of secondary forests in a humid tropical region of Mexico. Ecology 80: 1892–1907.

IPCC. 2006. Guidelines for National Greenhouse Gas Inventories. Prepared by the National Greenhouse Gas Inventories Programme ed H S Eggleston, L Buendia, K Miwa, T Ngara and K Tanabe (Japan: Institute For Global Environmental Strategies).

Jaramillo, V.J., Kaufmann, J.B., Rentaría-Rodríguez, L., Cummings, D.L., and Ellingson, L.J. 2003. Biomass, carbon and nitrogen pools in Mexican tropical forest landscapes. Ecosystems 6: 609-629.

Martínez-Yrızar, A., Maass, M., Pérez-Jiménez, L.A. and Sarukhán, J., 1996. Net primary productivity of a tropical deciduous forest ecosystem in western Mexico. Journal of Tropical Ecology 12: 169–175.

Návar, J., 2009a. Allometric equations for tree species and carbon stocks for forests of northwestern Mexico. Forest Ecology and Management 257: 427-434. doi:10.1016/j.foreco.2008.09.028

Návar, J., 2009b. Biomass component equations for Latin American species and groups of species. Annals of Forest Science 66: 208-216.

Návar, J. 2010. A non-destructive approach for tree biomasa estimation. Submitted to Forest Ecology and Management.

Návar, J., Pérez, G. and González-Elizondo, M. 2010. Stand biomass estimation in tropical forests of Mexico. Submitted to Forest Ecology and Management.

Návar-Cháidez, J.J. 2009. Allometric equations and expansion factors for tropical dry trees of eastern Sinaloa, Mexico. Tropical and Subtropical Agroecosystems 10: 45-52.

Ochoa-Gaona, S. 2001. Traditional land-use systems and patterns of forest fragmentation in the highlands of Chiapas, Mexico. Environmental Management 27: 571-586.

Palacio-Prieto, J.L., Bocco, G., Velázquez, A., Mas, J.F., Victoria, A., Luna-González, L., Gómez-Rodríguez, G., López-García, J., Palma, M., Trejo-Vázquez, I., Peralta, A., Prado-Molina, J., Rodríguez-Aguilar, A., Mayorga-Saucedo, R. and González, F. 2000. La condición actual de los recursos forestales en México: resultados del Inventario Forestal Nacional 2000. Investigaciones Geográficas (43): 183-203.

Phillips, D.L., Brown, S., Schroeder, P.E., and Birdsey, R.A. 2000. Toward error analysis of large-scale forest carbon budgets. Global Ecology and Biogeography 9: 305-313.

Read, L. and Lawrence, D. 2008. Recovery of biomass following shifting cultivation in dry tropical forests of the Yucatan. Ecological Applications 13: 85-97.

Richardson, J., Bjorheden, R., Hakkila, P., Lowe, A.T. and Smith, C.T. 2002. Bioenergy from Sustainable Forestry: Guiding Principles and Practice- Kluwer Academic Publishers. Dordrecht, The Neederlands. 344 p.

SAS. 1998. Statistical Analysis System. V. 8.0. Raleigh, N.C. USA.

Saatchi, S.S., Houghton, R.A., Dos Santos Alvala, R.C., Soarez, J.V., and Yu, Y. 2007. Distribution of aboveground live biomass in the Amazon Basin. Global Change Biology 13: 816-837.

Trejo, I. and Dirzo, R. 2000. Deforestation of seasonally dry tropical forest: a national and local analysis in Mexico. Biological Conservation (94): 133-142.

Trejo, I. and Hernández, J. 1996. Identificación de la selva baja caducifolia en el estado de Morelos, México, mediante imágenes de satélite. Investigaciones Geográficas (5): 11-18.

Submitted December 09, 2009 – AcceptedMay 25, 2010
Revised received May 31, 2010