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Estimations of total ecosystem carbon pools distribution and carbon biomass current annual increment of a moist tropical forest

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ABSTRACT

With increasing CO_2 in the atmosphere, there is an urgent need of reliable estimates of biomass and carbon pools in tropical forests, most especially in Africa where there is a serious lack of data. Information on current annual increment (CAI) of carbon biomass resulting from direct field measurements is crucial in this context, to know how forest ecosystems will affect the carbon cycle and also to validate eddy covariance flux measurements. Biomass data were collected from 25 plots of 13 ha spread over the different vegetation types and land uses of a moist evergreen forest of 772,066 ha in Cameroon. With site-specific allometric equations, we estimated biomass and aboveground and belowground carbon pools. We used GIS technology to develop a carbon biomass map of our study area. The CAI was estimated using the growth rates obtained from tree rings analysis. The carbon biomass was on average 264 ± 48 Mg ha^{-1}. This estimate includes aboveground carbon, root carbon and soil organic carbon down to 30 cm depth. This value varied from 231 ± 45 Mg ha^{-1} of carbon in Agro-Forests to 283 ± 51 Mg ha^{-1} of carbon in Managed Forests and to 278 ± 56 Mg ha^{-1} of carbon in National Park. The carbon CAI varied from 2.54 ± 0.65 Mg ha^{-1} year^{-1} in Agro-Forests to 2.79 ± 0.72 Mg ha^{-1} year^{-1} in Managed Forests and to 2.85 ± 0.72 Mg ha^{-1} year^{-1} in National Park. This study provides estimates of biomass, carbon pools and CAI of carbon biomass from a forest landscape in Cameroon as well as an appropriate methodology to estimate these components and the related uncertainty.

1. Introduction

Terrestrial ecosystems play an important role in the global carbon cycle and hence modify the atmospheric CO_2 mixing ratio as they can act as carbon sink due to net carbon uptake during vegetation growth and as carbon source through deforestation or forest degradation (Schulze, 2006). Forests in the tropics are particularly in focus due to the potential high plant productivity on the one hand and a high level of deforestation and forest degradation as a consequence of land use intensification and population pressure on the other hand. The true level of tropical deforestation and forest degradation and its geographical extend is, however, subject to many debates. The amount of carbon accumulated or released from forest ecosystems in the tropics is poorly quantified (Achard et al., 2004).

Increment of carbon biomass of trees which includes photosynthesis and autotrophic respiration and thus represents aboveground and belowground (fine and coarse roots) biomass growth is one of the important components of the carbon budget in tropical forests (Malhi et al., 1999; Clark et al., 2001). The comparison of different biomes of the world (Malhi et al., 1999) shows that the highest mean annual increment occurs in the tropics (Clark et al., 2001). Accurate estimates of current annual increment (CAI) from tropical forests are necessary in order to reduce uncertainties in net carbon budgets of the tropics and to provide constraints on global biogeochemical models with data sets from typically underrepresented tropical sites.

One of the difficulties for ecologists, policy makers, scientists, etc. is to provide a true estimate of forest biomass and hence of CAI. For instance Fang et al. (1998) state that there is a significant discrepancy between early and recent studies concerning estimations of forest biomass and of carbon emissions and absorption from forest ecosystems. This difference may be attributed to uncertain data and different methodologies for estimating forest biomass and carbon fluxes (Brown and Lugo, 1982, 1984; Brown et al., 1989; Dixon et al., 1994; Cohen et al., 1996; Brown, 1997; Chave et al., 2004; Ibrom et al., 2008). Early studies derived from direct field measurements on small plots resulted in overestimations of biomass density

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and pools (Whittaker and Likens, 1973; Busing et al., 1992; Birdsey et al., 1993; Dixon et al., 1994; Siccama et al., 1994). Recent studies derived from forest inventory data provide biomass data at national and regional level (Brown, 1997; Malhi et al., 1999; Nasi et al., 2009). An appropriate methodology for estimating forest biomass is required to reduce uncertainties on carbon estimates. The use of allometric equations to estimate biomass density of large plot inventories is gaining the favour of many ecologists (Brown, 1997; Fang et al., 1998; Houghton et al., 2001; Chave et al., 2004).

Knowing how tropical forests have grown in the past is very important for policy makers and scientists to assess past environmental variations and/or changes and can also be used to reconstruct the stand history (Worbes et al., 2003). For example, when trees form annual rings, the growth patterns can be used in many ways to assess the past environmental changes (Fichtler et al., 2003). Tree rings, which are physiological responses of trees on seasonal variations of atmospheric parameters can be used to evaluate tree growth and therefore to estimate the production of individual trees in the forest. Several authors have studied and proved the existence of tree annual rings in the tropics (Worbes, 1999; Dünisch et al., 2002; Fichtler et al., 2003; Worbes et al., 2003; Brienen and Zuidema, 2006) and also in Cameroon (Détienne, 1989; Worbes et al., 2003).

Very few studies have attempted to estimate carbon biomass in tropical forests in Africa and particular in Central Africa, even though substantial rates of deforestation and forest degradation were reported. Nasi et al. (2009) estimated between 1990 and 2005 an annual deforestation rate of 0.16% corresponding to a total area of 43,000 km^2 of forest lost in tropical forests in Central Africa during this period. For the same time, these authors estimated annual forest degradation areas to be 0.09%. In Cameroon, Nasi et al. (2009) estimated annual deforestation areas to be 0.12% and annual forest degradation to be 0.02%. In Africa, most studies estimated biomass from pan allometric equations, i.e. relationships between biomass and stem diameter at breast height, based on biomass data collected outside Africa (e.g. Brown et al., 1989; Brown, 1997; Chave et al., 2005). From inventory data collected by the Forest Tropical Technical Centre (CTFT) in 1969, Brown (1997) estimated a total aboveground biomass of 310 Mg ha^{-1} in primary moist forests in Africa. Nasi et al. (2009) estimated an aboveground carbon pool of lowland moist forests in Central Africa of 216 Mg ha^{-1} from sample plot field data, 126 Mg ha^{-1} from forest inventory data. The total carbon pool of Cameroon is estimated to 5043 millions Mg with more than half (3162 millions Mg) in lowland moist forests (Nasi et al., 2009).

Geographical Information System (GIS) technology coupled with field information offers a possibility to improve accuracy in estimating biomass and carbon densities and pools in large areas (Roy and Ravan, 1996; Brown, 1997; Magcale-Macandog et al., 2006). GIS allows incorporating different vegetations and other heterogeneity of the landscape such as topography in estimates of carbon pools. It offers therefore a possibility to produce biomass pool maps at local or regional level (Magcale-Macandog et al., 2006). Through this process, the result of ecological features can be extended with more confidence to areas for which there is lack of data.

This study aims (a) to estimate the total aboveground biomass of a moist tropical forest in South-Western Cameroon based on locally developed mixed-species allometric equations (Djomo et al., 2010) and compare the result with other allometric equations (e.g. Brown et al., 1989; Brown, 1997; Chave et al., 2005), (b) to estimate carbon pools and their spatial distribution at the study site, (c) to allocate carbon pools to different land uses and strata using GIS and (d) to estimate the CAI at the study site and compare the values with other investigations.

2. Materials and methods

2.1. Study site

The study was conducted within the Campo-Ma'an area in South Western Cameroon located between latitudes 2°08′33″–2°53′59″N and longitudes 9°49′09″–10°57′17″E. It is an area of 772,066 ha, incorporating a National Park (264,064 ha, 34%), a protected forest (11,968 ha, 1.6%), a forest management zone with five logging concessions (241,809 ha, 31.4%), an agro-forestry area where local population have controlled access for multi-purpose uses (196,155 ha, 25.5%), a rubber and an oil plantation (57,750 ha, 7.5%) and a coastal area (320 ha). The Campo-Ma'an forest is bordered in the western part by the Atlantic Ocean and in the southern part by the river Ntem and Equatorial Guinea. Most of the land is covered by lowland tropical moist forests that extend from Southeast Nigeria to Gabon and the Mayombe area in Congo (Letouzey, 1968, 1985). The area is subdivided in different vegetations types which have been recently described by Tchouto et al. (2009). According to this description, the coastal area (Cosaca, Cosaga and Cosas vegetations) is dominated by coastal species. In this study we use only Cosaca for coastal vegetation. Caesalp are lowland evergreen forests rich in Caesalpinioideae. Caesalpcasa are lowland evergreen forest rich in Caesalpinioideae in association with *Calpocalyx heitzii* and *Sacoglottis gabonensis*. Mixevergreen is the vegetation dominated by mixed evergreen species. Mixsemideci is the vegetation type dominated by semi-deciduous species. Swamp forest is found along rivers or river basins and is permanently or seasonally inundated (Fig. 1).

Campo-Ma'an area is situated on the Precambrian shield constituted of metamorphic and volcanic rocks. Metamorphic rocks such as gneisses, migmatites, schists and quartzites dominate the geologic underground in the area. Sedimentary rocks of the Cretaceous can also be found in the Campo basin. The topography ranges from undulating to rolling in the lowland area and, to steeply dissect in the more mountainous areas. The western part of the park, which reaches the coast, is generally flat, with altitudes ranging between 0 m and 300 m. In the eastern part, which is quite mountainous, the altitude varies between 400 m and 1100 m and the rolling and steep terrain has more variable landscape (Tchouto et al., 2009). The climate is typical equatorial with two distinct dry seasons (December–February and June–August) and two wet seasons (March–May and September–November). The average annual

Table 1
Allometric regression equations used for aboveground biomass estimations. CF represents the correction factor of each allometric equation, *N* the number of sample trees.

No.	Allometric equation	Type	*N*	dbh range	CF
1	$M = \exp(-2.05 + 2.33\ln(dbh))$	Site specific	71	1–79	1.056
2	$M = \exp(-3.03 + 0.91\ln(dbh^2H))$	Site specific	71	1–79	1.055
3	$M = \exp(-2.29 + 0.17(\ln dbh)^2 + 0.66\ln(dbh^2H) + 0.13\ln(\rho))$	Site specific	71	1–79	1.043
4	$M = \exp(-2.36 + 0.29(\ln dbh)^2 - 0.04(\ln dbh)^3 + 0.74\ln(dbh^2H) + 0.28\ln(\rho))$	Pan moist tropical	274	1–138	1.100
5	$M = \exp(-3.11 + 0.97\ln(dbh^2H))$	Pan moist tropical	168	10–130	1.007
6	$M = \exp(-2.41 + 0.95\ln(dbh^2H\rho))$	Pan moist tropical	168	10–130	1.002
7	$M = \exp(-2.98 + \ln(dbh^2H\rho))$	Pan moist tropical	1505	5–156	1.051

Sources: Eqs. (1)–(4): Djomo et al. (2010); Eqs. (5) and (6): Brown et al. (1989); Eq. (7): Chave et al. (2005).