Carbon pools of an intact forest in Gabon

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Abstract
Quantitative and qualitative loss of tropical forests prompted international policy agendas to slow down forest loss through reducing emissions from deforestation and forest degradation (REDD+), ensuring carbon offset payments to developing countries. So far, many African countries lack reliable forest carbon data and monitoring systems as required by REDD+. In this study, we estimate the carbon stocks of a naturally forested landscape unaffected by direct human impact. We used data collected from 34 plots randomly distributed across the Mount Birougou National Park (690 km²) in southern Gabon. We used tree-level data on species, diameter, height, species-specific wood density and carbon fraction as well as site-level data on dead wood, soil and litter carbon to calculate carbon content in aboveground, belowground, dead wood, soil and litter as 146, 28, 14, 186 and 7 Mg ha⁻¹, respectively. Results may serve as a benchmark to assess ecosystem carbon loss/gain for the Massif du Chaillu in Gabon and the Republic of Congo, provide field data for remote sensing and also may contribute to establish national monitoring systems.

Key words: biomass, inventory, mosaic cycle, REDD+ tropical forests

Resume
Les pertes qualitatives et quantitatives de forêt tropicale ont ouvert les calendriers politiques internationaux à ralentir la perte de forêts au moyen des mécanismes REDD+, qui garantissent le paiement compensatoire des émissions de carbone aux pays en développement. Jusqu’à présent, de nombreux pays africains ne disposent pas encore de données fiables sur le carbone forestier, pas plus que de systèmes de suivi exigés par les REDD+. Dans cet article, nous estimons les stocks de carbone d’un paysage de forêt naturelle non affecté par des impacts humains directs. Nous avons utilisé les données provenant de 34 parcelles réparties au hasard dans le Parc National du Mont Birougou (690 km²), dans le sud du Gabon. Nous avons utilisé trois niveaux de données pour les espèces, le diamètre, la hauteur et la densité spécifique du bois par espèce, et la fraction de carbone ainsi que des données au niveau du site sur le carbone du bois mort, du sol et de la litière pour calculer le contenu en carbone au-dessus du sol, dans le bois mort, le sol et la litière, à savoir, respectivement, 146, 28, 14, 186 et 7 mg ha⁻¹. Ces résultats peuvent servir de données de référence pour évaluer la perte ou le gain de carbone de l’écosystème pour le Massif du Chaillu, au Gabon, et en République du Congo, constituer des données de terrain pour la détection à distance et aussi contribuer à établir des systèmes de suivi au niveau national.

Introduction
The alarming rate of loss in quantity as well as quality of carbon-dense tropical forests has prompted international policy agendas to suggest additional carbon crediting mechanisms. The negotiations first initiated Reducing Emissions from Deforestation in Montreal, 2005 (FCCC/CP/2005/MISC 1) and expanded it to Reducing emissions from Deforestation and forest Degradation (REDD) in the Bali Action Plan (Decision 1/CP. 13). In Copenhagen (COP 15, 2009) and Cancun (COP 16, 2010), REDD was extended to REDD+ considering forest conservation, sustainable forest management and enhancement of forest carbon stocks. COP 17 (Durban, 2011) further emphasized the earlier decisions on reference emission and forest reference levels.

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For implementation, the establishment of reliable national forest monitoring systems (Decision 4/CP. 15) is essential. Combinations of remote sensing- and ground-based carbon inventories are suggested to estimate anthropogenic greenhouse gas emissions and removals [Decision 4/CP. 15 Paragraph 1(d)]. According to Decision 1/CP. 16 III C, forest-related emission reductions need to be systematically measured, reported and verified including carbon stocks in five pools: (i) aboveground biomass (AGB), (ii) belowground biomass (BGB), (iii) dead wood, (iv) litter and (v) soil.

Estimates for Africa show a wide range between 76 and 231 MgC ha\(^{-1}\) (Brown & Lugo, 1984; Brown, Gillespie & Lugo, 1989; Brown, Gaston & Daniels, 1996; Clark et al., 2001; FAO, 2007; Ramankutty et al., 2007; Saatchi et al., 2011). One of the reasons for the uncertainty in the estimated biomass carbon of tropical forests is the lack of standard models to calculate AGB from field measurements (Chave et al., 2005). For Gabon, no validated biomass equation exists so far (Maniatis, 2010). Estimates based on basic information collected in the field [diameter at breast height (DBH), height, wood density, carbon fraction of wood, litter mass and litter carbon fraction and soil density and soil carbon fraction] are still the best means to provide reliable results.

In this work, we provide an example to calculate carbon stocks in the undisturbed forest of the Mount Birougou National Park in the Massif du Chaillu, Gabon. We thereby provide ground-truthing data for remote sensing and provide a benchmark for the potential carbon stocks of unmanaged forests located within the area of 35,000 km\(^2\) of the Massif du Chaillu.

Materials and methods

Study area

The study area was located in the vast intact block of evergreen rain forest of Monts Birougou National Park covering an area of 690 km\(^2\). Common tree species include Dacryodes macrophylla (Oliv.) H.J.Lam, Aucoumea klaineana Pierre, Centroplacus glaucinus Pierre, Coelocaryon preussi Warb., Plagiostyles africana Prain ex De Wild, Santiria trimera (Oliv.) Aubrév., Scorodophloeus zenkeri Harms and Uapaca guineensis Müll.Arg. Mean annual precipitation and temperature are 1800 mm (Maloba Makanga, 2010) and 22°C, respectively (Service de Climatologie – unpublished March 04, 2005). The rainy season extends from mid-September to June with lower and less interspersed rainfall during December and January, and the dry season lasts almost 3 months from mid-June to mid-September (Fig. 1). Soil type is Ultisol containing Kaolinite (60%), Goethite (11%), Gibbsite (8%) and 20% other minerals (Chatelin, 1968).

Today, the national park is uninhabited, but in colonial times a few villages existed along a migration route crossing the eastern edge of today’s park from north to south. Among these villages, only one (i.e. Kuendji – situated on a hilltop aside the headwater of the Lolo river) was located inside the park and was given up before 1900 (Ilembi Makinda Léon-Paul 2005, personal communication, March 14). For sampling, we excluded a buffer zone of 3 km along the migration route.

Data

Thirty-four sampling plots (fifteen in August 2004 and nineteen in March 2005) were randomly selected across the forest. In this study, we applied the point sampling inventory method (Bitterlich, 1948; Avery & Burkhart, 1983) using a gauge with a 2-cm-wide opening plate and a 65-cm-long string. Basal area factor (BAF) of the instrument was calculated as 2.37 m\(^2\) ha\(^{-1}\) (Eq. 1) and corrected for slope (BAF\(_{corr}\)), if necessary (Eq. 2).

\[
BAF = \left( \frac{w * 50}{R} \right)^2
\]  

\( (1) \)
BAF_{cor} = \frac{BAF}{\cos(z)} \tag{2}

Where \(w\) is opening width of instrument (cm) and \(R\) is distance between eye and opening gauge (cm), and \(\cos(z)\) is cosine of slope angle.

For each tallied tree, the tree species, the orientation and distance from the plot centre, DBH and tree height were recorded with diameter tape and Vertex III hypsometer (Haglöf, Sweden), respectively. Herbarium samples of 37 tree species were taken to the ‘Herbier National du Gabon’ for species verification. If buttress or stilt roots were present at 1.3 m, diameter was measured immediately above the buttresses or stilt roots. Basal area of a tree (BA_{tree}), number of representative trees per hectare (\(N_{rep}\)), tree volume (Volume_{tree}) and total volume (Volume_{total}) were calculated according to Eqs. 3–6. An average form factor (FF) of 0.6 (Cannell, 1984) was used.

\[
BA_{tree} = \pi \frac{DBH^2}{4} \tag{3}
\]

\[
N_{rep} = \frac{BAF}{BA_{tree}} \tag{4}
\]

\[
Volume_{tree} = BA \times \text{height} \times \text{FF} \tag{5}
\]

\[
Volume_{total} = Volume_{tree} \times N_{rep} \tag{6}
\]

In point sampling, each tallied tree represents a specific virtual nested circular plot area with borderline radius \(R_{plot}\) (Eq. 3).

\[
R_{plot} = \frac{DBH \times 50}{\sqrt{BAF}} \tag{7}
\]

The mean of the virtual areas of all tallied trees gives virtual plot size, for our 34 plots ranging from 212 to 1227 m\(^2\) with a mean of 610 m\(^2\).

One to three stem cores were recovered from 55 species until the corer broke in a stem of *Swartzia fistuloides* Harms. Cores were oven dried for 24 h at 105°C, and part of each sample was sent to the University of Vienna for carbon fraction determination. For trees with no values, we used the weighted mean derived from the trees with assigned values. For wood density determination, cores collected from 43 species were equilibrated (4°C, 12% relative humidity) for constant weight, separated into 5–18 subsamples and each of which was analysed for density using the submerge method. Wood density for trees not cored was taken from literature [Dahms, 1999; Société National des Bois du Gabon – unpublished September 9, 2004; Wood Density Database, 2009 http://www.worldagroforestry.org/sea/products/AFDbases/WD/Index.htm (accessed on September 4–October 30, 2009)] ranging from 400 kg m\(^{-3}\) (*Funtumia africana* Stapf) to 1200 kg m\(^{-3}\) (*Afzelia bipindensis* Harms). For trees with no values, we assigned the weighted mean density (WD_{avg}, Eq. 8). Specific wood density (WD_{0%}) of corresponding tree species was calculated (Eq. 9, Kollman & Cote, 1968).

\[
WD_{avg} = \frac{\sum_{i=1}^{n} N_i \rho_i}{\sum_{i=1}^{n} N_i} \tag{8}
\]

\[
WD_{0%} = WD_{mc} \left( \frac{100 + \left( \frac{VS}{30} \times mc \right)}{(100 + mc)} \right) \tag{9}
\]

Where \(N_i\) is the number of trees in \(i\)th tree species, \(\rho_i\) is the wood density of \(i\)th tree species, WD_{mc} is the wood density (kg m\(^{-3}\)) at moisture content (mc%), mc is the moisture content in wood while measuring wood density, and VS is the volumetric shrinkage of the tree species taken from Dahms (1999).

Considering the heterogeneity and species diversity in the tropics, the biomass of each tree recorded in the plot was calculated using the corresponding tree-specific measurement. AGB of each tree was obtained by multiplying tree volume with respective WD_{0%}. AGB of each tree within the plots were summed to obtain AGB density in the corresponding plot. BGB was estimated from AGB using the relationship derived for the tropics by Cairns et al. (1997):

\[
BGB = e^{(-1.0587 + 0.8816 \ln AGB)} \tag{10}
\]

Aboveground carbon content of each tree was derived by multiplying tree biomass with the corresponding wood carbon fraction. For trees with no observation, we used the mean of all observed data weighted for individual abundance within all 34 plots. AGB carbon of each tree was summed to obtain AGB carbon density at the plot level. BGB carbon content was derived from AGB carbon content using Eq. 10.

Dead wood includes tallied standing dead trees, and dead and down trees if and only if the distance from the
plot centre to the re-erected tree fell within the border line radius of the tree ($R_{plot}$, Eq. 7). With this criterion, dead wood observations were only made on 18 of 34 plots. Dead wood volume was calculated as given in Eqs. 3–6 and converted to dead wood biomass and dead wood carbon using the weighted averages of WD0% and carbon fraction.

Soil consisted two layers: humus rich top soil and a clayey lower soil layer with a maximum depth of 11 m observed on an eroded bank of Makanga River. Soil profiles were taken in 2005 in three replicates per plot using a single gauge soil auger made for collecting soil profiles up to 1 m depth. The high water content of the soil (sampling was during the rainy season) and the clayey soil texture resulted in a mixture zone between top and lower soil within the collected soil profile. Two soil samples were collected from each profile: One in the middle of the top soil layer and one at 0.5 m soil depth or 0.1 m below the mixture zone of top and lower soil layer if the mixture zone reached below 0.48 m soil depth, resulting in an average sampling depth for top and lower soil of 0.1 and 0.54 m. Soil density was determined from two samples collected with a soil sample ring with 8 cm diameter and 5 cm height.

Few soil samples were treated with hydrochloric acid to test the presence of CaCO$_3$, but no evidence of it was found in any samples. The soil samples were oven dried at 105°C for 24 h, and weight of both samples was recorded before further processing. The soil samples were sieved with 2-mm sieve and roots and wooden parts removed, if present. Next samples were milled with a mixer mill (Retsch MM 200), and carbon content was determined at the University of Vienna, Austria.

Soil carbon content (SC) in the top soil layer and up to 1 m soil depth in Mg ha$^{-1}$ was calculated according to Eqs. 11 and 12.

$$SC_{tl} = \frac{\rho_s \times C_{\%ts} \times D_{ts}}{10}$$  \hspace{1cm} (11)

$$SC_{1m} = \frac{\rho_s \times (C_{\%ts} \times D_{ts} + C_{\%ls} \times (1 - D_{ts}))}{10}$$  \hspace{1cm} (12)

Where $\rho_s$ is soil density in kg m$^{-3}$, $C_{\%ts}$ is carbon per cent in top soil, $C_{\%ls}$ is carbon per cent in the lower soil layer and $D_{ts}$ is depth of top soil layer in m, measured as the distance from the soil surface to the beginning of the mixture zone to avoid overestimation from profile collection artefacts, that is, the mixture of top and lower soil layers within the soil auger.

In the case of litter, on each of the 34 plots three litter samples were randomly collected from a soil surface of 50.26 cm$^2$ using the same sample ring. The three samples collected per plot were mixed before analyses. Samples were oven dried at 105°C for 24 h, weighed, milled and analysed for carbon content as described for soil samples.

### Results

#### Floristic composition

On the 34 sampling plots, 85% of tallied trees were taxonomically identified to 91 species. Of these, 34 species were abundant with a single tree and eighteen with two trees, while seven of the species contributed more than 57% to the total stem number. The plant identification rates varied from 31% to 100% of the trees in each plot.
with only two plots exhibiting an identification rate of <75% (Fig. 2). Among the trees identified, Caesalpinaceae was the most diversified family with eleven tree species, followed by Annonaceae and Burseraceae with seven tree species. Burseraceae, Caesalpinaceae and Euphorbiaceae were the three most common tree families holding 23%, 10% and 8% of total basal area (Table 1) in the forest, respectively. Of 36 recorded families, six families were only represented by a single tree (Table 1), and together, their contribution to basal area was 1.4%. By tree number, Dacryodes macrophylla (Oliv.) H.J.Lam was the most abundant tree species (approximately 10%). By diameter and height, Aucoumea klaineana Pierre (Buraseraceae), Afzelia bipindensis Harms (Caesalpiniaceae) and Erythrophleum ivorense A.Chev. (Caesalpinaceae) were the biggest three trees.

Table 1 Summary of species count (SC), tree count (TC), diameter at breast height (DBH, cm) and total tree height (m) by family

| Family              | SC | TC   | DBH            | Height          |
|---------------------|----|------|----------------|-----------------|
| Caesalpinaceae      | 12 | 44 (10.05) | 40.2 (9.9–129.5) | 22.8 (8.0–40.0) |
| Annonaceae          | 7  | 20 (4.57)  | 31.2 (5.4–63.3)  | 22.0 (6.0–40.0)  |
| Burseraceae         | 7  | 100 (22.83) | 41.1 (3.8–135.3) | 23.1 (8.5–43.0)  |
| Apocynaceae         | 5  | 8 (1.83)   | 21.6 (6.9–41.0)  | 14.6 (7.5–26.5)  |
| Olacaceae           | 5  | 16 (3.65)  | 44.0 (8.3–85.3)  | 25.5 (11.9–35.0) |
| Mimosaceae          | 4  | 15 (3.42)  | 54.8 (5.6–90.4)  | 28.1 (10.4–40.0) |
| Sapindaceae         | 4  | 4 (0.91)   | 19.0 (4.3–38.0)  | 16.6 (4.5–23.2)  |
| Anacardiaceae       | 3  | 4 (0.91)   | 20.0 (4.1–33.7)  | 13.9 (9.0–20.5)  |
| Euphorbiaceae       | 3  | 34 (7.76)  | 49.9 (4.1–82.0)  | 23.7 (8.5–37.0)  |
| Meliaceae           | 3  | 8 (1.83)   | 40.2 (5.5–93.3)  | 22.4 (6.0–35.1)  |
| Moraceae            | 3  | 5 (1.14)   | 16.1 (8.6–20.7)  | 13.2 (8.6–20.0)  |
| Papilionaceae       | 3  | 9 (2.05)   | 21.6 (6.9–41.0)  | 14.6 (7.5–26.5)  |
| Rubiaceae           | 3  | 10 (2.28)  | 20.6 (8.0–39.5)  | 16.8 (8.0–31.0)  |
| Rutaceae            | 3  | 8 (1.83)   | 44.9 (9.5–84.4)  | 23.8 (14.5–33.5) |
| Guttiferae          | 2  | 6 (1.37)   | 26.0 (16.0–38.8) | 19.5 (15.0–24.0) |
| Myristicaceae       | 2  | 21 (4.79)  | 43.5 (17.5–84.0) | 25.3 (15.5–37.0) |
| Myrtaceae           | 2  | 2 (0.46)   | 37.1 (7.3–66.8)  | 19.5 (7.5–31.5)  |
| Sapotaceae          | 2  | 4 (0.91)   | 48.6 (40.0–68.4) | 25.2 (7.4–33.0)  |
| Anisophylleaceae    | 1  | 5 (1.14)   | 38.9 (16.1–76.4) | 24.6 (17.0–31.0) |
| Chrysobalanacaceae  | 1  | 3 (0.68)   | 36.1 (26.2–47.0) | 20.9 (17.4–26.1) |
| Clusiaceae          | 1  | 8 (1.83)   | 38.6 (7.2–71.3)  | 22.0 (8.0–31.0)  |
| Ebenaceae           | 1  | 2 (0.46)   | 37.1 (16.2–58.0) | 20.2 (13.6–26.7) |
| Erythroxylaceae     | 1  | 4 (0.91)   | 20.2 (16.6–24.2) | 21.8 (19.5–25.0) |
| Fabaceae            | 1  | 1 (0.23)   | 46.0              | 21.3             |
| Flacourtiaceae      | 1  | 1 (0.23)   | 4.2               | 4.8              |
| Irvingiaceae        | 1  | 2 (0.46)   | 12.8 (9.9–15.7)  | 14.1 (11.6–16.5) |
| Lamiaceae           | 1  | 3 (0.68)   | 19.2 (12.4–22.9) | 17.8 (15.0–21.0) |
| Lecythidaceae       | 1  | 8 (1.83)   | 51.3 (22.9–68.0) | 25.9 (18.0–39.0) |
| Loganiaceae         | 1  | 1 (0.23)   | 29.9              | 24.5             |
| Pandaceae           | 1  | 5 (1.14)   | 17.8 (10.5–26.1) | 18.9 (11.0–25.0) |
| Rhizophoraceae      | 1  | 2 (0.46)   | 19.3 (4.5–34.0)  | 11.7 (4.0–19.3)  |
| Simaroubaceae       | 1  | 3 (0.68)   | 59.8 (29.2–89.1) | 26.2 (15.2–34.0) |
| Sterculiaceae       | 1  | 1 (0.23)   | 31.0              | 11.2             |
| Tiliaceae           | 1  | 1 (0.23)   | 26.0              | 21.1             |
| Ulmaceae            | 1  | 1 (0.23)   | 39.8              | 33.0             |
| Violaceae           | 1  | 3 (0.68)   | 22.4 (19.1–25.8) | 15.3 (12.0–19.0) |
| Unidentified        | 66 | 15 (0.07)  | 33.7 (6.9–75.1)  | 21.2 (2.8–41.0)  |

Values in parenthesis give the per cent of the corresponding family’s representation for TC and the range of measurements for DBH and Height.
| Family            | Species                          | Local name         | C (%) | WD 0% |
|-------------------|----------------------------------|--------------------|-------|-------|
| Anacardiaceae     | *Sorindeia oxyandra* Bourobou & Breteler | Tsaghessa          | 47.46 | 653   |
| Anacardiaceae     | *Sorindeia Thouars*              | Mutoumbu           | 48.28 | 737   |
| Anacardiaceae     | *Trichoscypha acuminata* Engl.   | Amvut/Mulli        | 47.85 | 729   |
| Anisophylleaceae  | *Poga olesia* Pierre             | Ovoga              | 50.88 |       |
| Annonaceae        | *Aneulophus africanus* Benth.    | Mutoumbu           | 48.28 | 737   |
| Annonaceae        | *Cleistopholis patens* Engl. & Diels | Mukundzu          | 47.78 | 691   |
| Annonaceae        | *Enantia letestui* LeThomas      | Moambe             | 48.97 |       |
| Annonaceae        | *Greenwoodiodendron sauvelensis* Verdc. | Otunga         | 49.20 |       |
| Annonaceae        | *Isolona zenkeri* Engl. & Diels  | Isolona            | 52.19 |       |
| Annonaceae        | *Xylopia aethiopica* A. Rich     | Okala              | 48.93 | 715   |
| Apocynaceae       | *Alstonia congensis* Engl.       | Ekuk/Mukuku        | 49.14 | 641   |
| Apocynaceae       | *Picralima nitida* Th. & H. Dar. | Ghundu             | 49.08 | 938   |
| Burseraceae       | *Anonidene klaineana* Pierre     | Okoume             | 48.41 | 467   |
| Burseraceae       | *Aucryodes buettneri* (Engl. H.J.Lam) | Ozigo           | 47.95 | 789   |
| Burseraceae       | *Aucryodes klaineana* (Pierre H.J.Lam) | Adjouba      | 48.88 |       |
| Burseraceae       | *Aucryodes macrophylla* (Oliv.) H.J.Lam | Atom            | 47.19 | 764   |
| Caesalpinaceae    | *Amphiinus ferrugineus* Pierre ex Harms | Ikodiakodi    | 48.77 | 980   |
| Caesalpinaceae    | *Bikinia letestui* (Pellegr.) Wieringa | Mubungi       | 48.76 | 836   |
| Caesalpinaceae    | *Diallum pachyphyllum* Harms     | Eyoum              | 47.27 |       |
| Caesalpinaceae    | *Scropholobus zenkeri* Harms     | Divida             | 48.16 | 894   |
| Caesalpinaceae    | *Swartzia fistuloides* Harms     | Pao Rosa           | 790   |       |
| Caesalpinaceae    | *Tessmania africana* Harms       | Nkagha             | 53.05 |       |
| Chrysobalanaceae  | *Magnistipula tessmanii* (Engl.) Prance | Efot           | 50.43 |       |
| Clusiaceae        | *Allanblackia* Oliv.             | Nsangom            | 47.19 | 802   |
| Clusiaceae        | *Garcinia kolh Heckel*           | Mboudi             | 47.28 | 800   |
| Ebenaceae         | *Diospyros* L.                   | Envila             | 45.14 |       |
| Euphorbiaceae     | *Plagioptyles africana* Prain ex De Wild. | Boulou/Essoula | 45.99 | 726   |
| Euphorbiaceae     | *Unapoa guineensis* Müll Arg.    | Rikio/Bodjahambe  | 52.79 |       |
| Lamiaceae         | *Vitex* L.                       | Ipate              | 47.61 | 456   |
| Lecythidaceae     | *Petersianthus macrocarpus* (P Beauv.) Liben | Essia       | 49.98 |       |
| Loganiaceae       | *Anthocleista vogelli* Planch.   | Aynbe              | 47.87 | 463   |
| Meliaceae         | *Carapa procer* D.C.             | Crabwood           | 48.39 | 805   |
| Mimosaceae        | *Albizia Durazz.*                | Tsele              | 48.22 | 646   |
| Moraceae          | *Chlorophora excelsa* Benth. & Hook.f. | Mbounga        | 47.82 | 603   |
| Myristiciaceae    | *Pycnanthus angolensis* (Welw.) Exell | Ilomba         | 45.93 | 499   |
| Myristiciaceae    | *Coelocarpon preussi* Warb.      | Ekoune/Lombe      | 46.22 | 550   |
| Myristiciaceae    | *Syzygium staudtii* (Engl.) Mildbr. | Szygium       | 48.38 | 781   |
| Olacaceae         | *Engomegosa gordonii* Breteler   | Engomegoma        | 49.92 |       |
| Olacaceae         | *Heisteria pavilhia* Sm.          | Nsombo             | 47.42 | 646   |
| Olacaceae         | *Ongokea gore* Pierre             | Mungeke            | 47.29 | 855   |
| Olacaceae         | *Strombosiopsis tetandra* Engl.   | Vendi              | 47.41 | 881   |
| Pandaceae         | *Centroplacus gaulactus* Pierre   | Mbesse             | 48.51 | 837   |
| Rubiaceae         | *Corpanythe maqambensis* (R.D. Good) N. Hallé ‘eH. | Mussuli     | 49.16 | 915   |
| Rutaceae          | *Zanthoxylum heitzii* (A.& P.) P.G.W. | Olon          | 48.20 | 557   |
| Rutaceae          | *Zanthoxylum tessmanii* (Engl.) A. | Bong              | 48.14 | 1051  |
| Sapindaceae       | *Ganophyllium giganteum* (A.Chev.) Hauman | Bilinga   | 49.67 | 707   |
| Simaroubaceae     | *Odyndea gabonensis* Pierre      | Bundjeghe         | 48.31 | 461   |
| Violaceae         | *Rinoreax Aubl.*                  | Issoka             | 48.35 | 553   |

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Tree-level data

The tree-level information was developed from species, DBH, total tree height and corresponding WD0% of trees in 34 plots (Fig. 2). Diameters ranged from 4.1 to 135 cm and heights from 2.8 to 43 m (Table 1).

Stem cores of 54 tree species exhibited wood carbon contents of 45.14–53.05% with a mean of 47.95% (Table 2). For trees without observed wood carbon fractions, weighted mean carbon of 48.27% was assumed.

Wood density analysis of stem cores from 43 species revealed WD0% of 456–1051 kg m\(^{-3}\) with a mean of 726 kg m\(^{-3}\) (Table 2) close to the average 690 kg m\(^{-3}\) reported for 268 tropical tree species (Fearnside, 1997).

Measured wood densities of 49% of species and literature values for another 26% species resulted in an average weighted WD0% of 680 kg m\(^{-3}\) for the remaining 25%.

For diameter–height relationship, a logarithmic DBH versus height model (Fig. 3) was fitted, explaining two-thirds of height variation by diameter (\(r^2 = 0.67\)), excluding broken top trees (1.6%).

Stand-level data

Because of the diversified species composition, the analyses of species-specific tree volume, biomass and carbon content for each plot was omitted. Stand-level information on these variables revealed Burseraceae, Caesalpinioideae and Euphorbiaceae as holding 23%, 11% and 8% of total AGB of 302 Mg ha\(^{-1}\), respectively, and 16% attributable to unidentified trees (Table 3). Most families exhibited the highest percentage of AGB within the diameter classes from 20 to 50 cm (Table 3), which contributed 56% to total biomass (Table 4). The highest shares of basal area (21%), tree volume (21%), AGB (22%) and AGB carbon (22%) were found within 30–40 cm (Table 4). In this diameter class, tree height was 22.6 ± 4.5 m, which was 35% lower than the highest mean height by diameter class (Table 4).

Without considering tree species and family, plot-level means were given as follows: Lorey’s height, 27 ± 4 m; volume, 447 ± 171 m\(^3\) ha\(^{-1}\); AGB, 302 ± 122 Mg ha\(^{-1}\); and AGB carbon, 146 ± 58 Mg ha\(^{-1}\) (Table 5). Average BGB and carbon were estimated as 53 ± 19 and 28 ± 10 Mg ha\(^{-1}\), respectively and average dead wood volume, biomass and carbon were 44 ± 20 m\(^3\) ha\(^{-1}\), 29 ± 14 Mg ha\(^{-1}\) and 14 ± 7 Mg ha\(^{-1}\), respectively (Table 5).

Figure 4 shows that the carbon fraction in top soil (3.21 ± 0.81%) was significantly higher (paired t-test: \(t = 12.46, P < 0.001, df = 18\)) than in the lower soil layer (1.38 ± 0.37%). Top soil exhibited an average thickness of 20 cm (16–29 cm) holding a total of 66 ± 20 Mg ha\(^{-1}\) carbon. Including the lower soil up to...

Table 2 (continued)

| Family | Species | Local name | C (%) | WD0% |
|--------|---------|------------|-------|-------|
| Bukulu | 47.68   | 692        |
| Mbanza | 47.97   | 963        |
| Mololongo | 48.50 | 713        |
| Ndombela | 46.76  | 628        |
| Pula Tsulbatseki | 47.40 | 975        |
| Tombdika | 47.17  | 827        |
1 m depth resulted in a total soil carbon content of 186 ± 41 Mg ha\(^{-1}\) (Table 5). None of the soil samples from our plots exhibited traces of charcoal or other indicators of human habitation, clearance or cultivation (Willis, Gilson & Brncic, 2004).

Litter samples collected in August 2004 exhibited a mass of 14.1 ± 6.0 Mg ha\(^{-1}\), a mean carbon fraction of 40 ± 5% and a corresponding total litter carbon stock of 2.8 ± 1.3 Mg ha\(^{-1}\). Samples collected in March 2005 exhibited a mass of 27.5 ± 9.5 Mg ha\(^{-1}\), a carbon fraction 35 ± 6% and a litter carbon stock of 10.3 ± 3.0 Mg ha\(^{-1}\). Samples from August 2004 exhibited a significantly higher carbon fraction (\(t\)-test: \(t = 2.31; P = 0.02; df = 32\)) but a highly significant lower mass (\(t\)-test: 

Table 3 Mean distribution of biomass (in per cent, except the first column) at family level by diameter classes

| Family         | TB  | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| Burseraceae    | 69.6| 1.4 | 6.5 | 13.2| 32.0| 21.7| 12.1| 4.9 | 1.0 | 2.9 | 2.1 |
| Caesalpiniae   | 35.1| 1.3 | 4.8 | 26.7| 23.1| 11.0| 9.4 | 9.5 | 3.6 | 4.0 | 6.7 |
| Euphorbiaceae  | 21.8| 4.5 | 6.1 | 18.3| 19.1| 12.4| 22.0| 6.1 | 8.0 | 3.6 |
| Olacaceae      | 15.0| 2.9 | 5.0 | 14.1| 12.2| 8.5 | 19.8| 23.7| 7.2 | 6.7 |
| Mimosaceae     | 13.4| 1.8 | 3.5 | 19.6| 14.9| 10.4| 17.9| 19.1| 5.6 | 6.5 |
| Myristicaceae  | 12.8| 3.5 | 12.2| 21.7| 23.2| 21.9| 5.5 | 6.5 | 5.5 |
| Annonaceae     | 12.0| 6.7 | 4.8 | 14.6| 24.7| 23.8| 16.6| 8.8 |
| Lecythidaceae  | 6.7 | 9.8 | 10.6| 9.1 | 12.2| 58.4|
| Clusiaceae     | 6.6 | 10.2| 15.4| 42.7| 16.7| 15.0|
| Meliaceae      | 6.1 | 3.3 | 10.9| 21.1| 15.0| 16.8| 14.6|
| Papilionaceae  | 6.0 | 10.8| 7.7 | 19.1| 21.4| 13.1| 15.9| 12.1|
| Rutaceae       | 5.3 | 8.5 | 32.2| 9.4 | 10.4| 10.6|
| Rubiaceae      | 4.9 | 17.8| 24.6| 11.6| 46.0|
| Pandaceae      | 3.9 | 46.7| 53.3|
| Apocynaceae    | 3.8 | 11.7| 34.6| 48.8| 4.9 |
| Guttiferae     | 3.5 | 11.8| 60.4| 27.8|
| Erythroxylaceae| 3.2 | 51.0| 24.1| 24.9|
| Sapotaceae     | 2.8 | 71.7| 28.3|
| Anisophyllaceae| 2.7 | 11.4| 17.0| 39.0| 32.7|
| Sapindaceae    | 2.7 | 3.6 | 27.5| 68.9|
| Moraceae       | 2.4 | 12.8| 13.2| 50.3| 23.7|
| Chrysobalanaceae| 1.9 | 30.8| 30.5| 38.7|
| Anacardiaceae  | 1.7 | 12.4| 21.0| 23.5| 43.1|
| Simaroubaceae  | 1.7 | 19.9| 39.9| 40.2|
| Ebenaceae      | 1.2 | 36.6| 63.4|
| Myrtaceae      | 1.2 | 20.9| 79.1|
| Violaceae      | 1.0 | 26.5| 73.5|
| Lamiaceae      | 1.0 | 38.8| 61.2|
| Ulmaceae       | 1.0 | 100.0|
| Irvingiaceae   | 0.9 | 41.3| 58.7|
| Tiliaceae      | 0.8 | 100.0|
| Rhizophoraceae | 0.7 | 15.3| 84.7|
| Fabaceae       | 0.6 | 100.0|
| Loganiaceae    | 0.6 | 100.0|
| Sterculiaceae  | 0.2 | 100.0|
| Flacourtiaclae | 0.1 | 100.0|
| Unidentified   | 47.0| 1.7 | 13.3| 24.3| 17.6| 12.5| 8.3| 4.3|

The columned name with tree biomass (TB, in Mg ha\(^{-1}\)) gives the total amount for the corresponding family. In the table, 1 represents diameter class with diameter at breast height <10 cm, and 2, 3, 4, 5, 6, 7, 8, 9, 10 and 11 represent diameter class of 10 cm–100 cm at 10-cm interval, respectively, and the last eleven represents for diameter class with larger than 100 cm.
Table 4 Number of observation (Obs.), total tree height (m), basal area (BA, m² ha⁻¹), tree volume (TV, m³ ha⁻¹), aboveground biomass (AGB, Mg ha⁻¹) and aboveground biomass carbon (AGBC, Mg ha⁻¹) by 10 cm diameter classes

| Dbh | Obs | Height | BA | TV | AGB | AGBC |
|-----|-----|--------|----|----|-----|------|
| <10 | 32  | 9.9 (2.8–29.0) | 2.45 | 15 | 9.4 | 4.6 |
| 10–20 | 54  | 15.7 (8.0–26.0) | 4.07 | 38 | 26.4 | 12.7 |
| 20–30 | 91  | 19.3 (9.0–35.0) | 6.95 | 81 | 56.0 | 27.0 |
| 30–40 | 93  | 22.6 (10.4–33.0) | 6.99 | 95 | 66.9 | 32.2 |
| 40–50 | 59  | 25.6 (7.4–40.0) | 4.42 | 68 | 47.2 | 22.7 |
| 50–60 | 49  | 27.8 (5.5–41.0) | 3.73 | 63 | 40.4 | 19.6 |
| 60–70 | 28  | 29.6 (16.0–39.0) | 2.27 | 40 | 25.8 | 12.5 |
| 70–80 | 12 | 32.8 (28–40.0) | 0.89 | 17 | 11.3 | 5.5 |
| 80–90 | 11 | 33.4 (28–40.0) | 0.79 | 16 | 9.7 | 4.7 |
| 90–100 | 4 | 35.1 (32.0–36.5) | 0.31 | 6 | 4.2 | 2.0 |
| >100 | 5 | 34.5 (25.1–43.0) | 0.36 | 7 | 4.7 | 2.2 |
| Total | 438 |        | 33.23 | 447 | 302.0 | 145.8 |

\[ t = -4.76; P < 0.001; \text{df} = 32 \] resulting in highly significant lower litter carbon stocks (\( t \)-test: \( t = -7.21; P < 0.001; \text{df} = 32 \)), as compared to samples from March 2005 (Fig. 5).

Discussion

Compared to other regions in Gabon, where pioneer species like *Aucoumea klaineana* Pierre account for 30 to >80% of BA (Fuhr, Nasi & Minkoué, 1998; Fuhr, Nasi & Delegue, 2001), the abundance of *Aucoumea klaineana* Pierre evident in our plots (mean BA: <6%; min: 0%; max: <16%) is attributable to natural gap dynamics (Wostl, 2000). This, together with the observed structural diversity in terms of diameter and tree height (Table 1), the presence of a large number of climax trees in the forest and the absence traces of fire in the soil samples indicates a lack of major human impacts like logging or slash and burn agriculture in recent centuries. Moreover, the high presence of Caesalpiniaceae tree species in the forest suggests that it was a forest refuge during last glaciations (Maley, 1989; Rietkerk, Ketner & De Wilde, 1995; Leal, 2009).

Observed basal area (33 m² ha⁻¹) matched the published values (26–35 m² ha⁻¹ Chave et al., 2003; 29–38 m² ha⁻¹ Djuikouo et al., 2010; 29–42 m² ha⁻¹ Swamy et al., 2010; 12–43 m² ha⁻¹ Feldpausch et al., 2011). Similarly, observed volume (447 m³ ha⁻¹) was within the published data (402 m³ ha⁻¹ Sist & Saridana, 1998; 641 m³ ha⁻¹ Riswan, Kenworthy & Kartawinata, 1985).

Aboveground biomass (302 Mg ha⁻¹) was in agreement with AGB densities of tropical forests ranging between 152 and 596 Mg ha⁻¹ (Brown & Lugo, 1984; Brown, Gillespie & Lugo, 1989; Brown, Gaston & Daniels, 1996; Clark & Clark, 2000; Clark et al., 2001; FAO, 2007; Ramankutty et al., 2007; Baccini et al., 2008; Hertel, Hartevedl & Leuschner, 2009; Djuikouo et al., 2010) and close to lower bound estimates for Gabon (312–333 Mg ha⁻¹ Maniats et al., 2011; 343–554 Mg ha⁻¹ Lee White – cited in Saatchi et al., 2011 – Table SO2; 483–617 Mg ha⁻¹ Lewis et al., 2009). AGB estimates derived from Eqs. 3–6 did not differ from estimates derived with a more recent allometric equation (e.g. Chave et al., 2005: \( \ln (\text{AGB}) = -3.027 + \ln (D^2 H_D); \) paired \( t \)-test: \( t = -0.783, P = 0.4391, \text{df} = 436 \)). Tree height, however, may explain the lower AGB, because mean Lorey’s height of 27 m (Table 5) was lower than that reported for Gabon in the literature (34 m: Lee White – cited in Saatchi et al., 2011; 38 m: Lewis et al., 2009). Consequently, observed AGB carbon (146 Mg ha⁻¹) is lower than the reported 160 Mg ha⁻¹ (Saatchi et al., 2011) and 200 Mg ha⁻¹ (Lewis et al., 2009).

Belowground biomass, calculated as a fraction of AGB (Cairns et al., 1997), was 53 ± 19 Mg ha⁻¹, comparable to 48 and 54 Mg ha⁻¹ found for tropical rainforests in Ivory coast and Ghana (Swamy et al., 2010). BGB holds 28 ± 10 Mg ha⁻¹ of carbon. Observed dead wood 29 ± 14 Mg ha⁻¹ matched the estimates for tropical moist forests (22–55 Mg ha⁻¹ Delaney et al., 1998) and contained 14 ± 7 Mg ha⁻¹ of carbon.

Observed 2.3% mean soil carbon fraction (i.e. top and lower layer) was comparable to 2.4% for tropical forests (Hertel et al., 2009). Total soil carbon contents given in the literature range from 51 Mg ha⁻¹ (top 20 cm, Hertel et al., 2009) to 57 Mg ha⁻¹ (top 30 cm, Henry, Valentini & Bernoux, 2009) and from 123 to 125 Mg ha⁻¹ (top 100 cm, Dixon et al., 1994; Henry, Valentini & Bernoux, 2009). Our observations were higher, with top soil (depth 16–29 cm) and the top 100 cm containing a mean 66 and 186 Mg ha⁻¹, respectively (Table 5).

Observed 2.8 Mg ha⁻¹ litter carbon (end of dry season 2004) and 10.3 Mg ha⁻¹ (rainy season 2005) with an average of 7.0 Mg ha⁻¹ were comparable to 0.9–9.3 Mg ha⁻¹ published for tropical forests (Clark et al., 2001). Seasonal differences in (i) litter fall intensity, that...
is, the higher litter mass in 2005 versus 2004, and (ii) decomposition activity, that is, lower litter carbon fraction in 2005 versus 2004 (Fig. 5) may explain the range of observations. Besides intra-annual variation (Proctor et al., 1983; Spain, 1984; Valenti, Cianciaruso & Betalha, 2008; Averti & Dominique, 2011), interannual variation (Chave et al., 2008; Averti & Dominique, 2011) complicates the reliable estimates of litter carbon from single-point measurements. The inclusion of litter carbon in REDD+ is questionable because of (i) its rapid turnover (ii) intra- and interannual variation and (iii) its low (1.8%) contribution to total carbon (Table 5).

**Table 5** Lorey’s height (H, m), basal area (BA, m² ha⁻¹), tree volume (TV, m³ ha⁻¹), biomass in aboveground (AGB, Mg ha⁻¹), belowground (BGB, Mg ha⁻¹) and dead wood (DWB, Mg ha⁻¹), carbon content in aboveground biomass (AGC, Mg ha⁻¹), belowground biomass (BGC, Mg ha⁻¹), dead wood (DWC, Mg ha⁻¹), top soil layer (SC-TL, Mg ha⁻¹), soil up to 1 m (SC-1 m, Mg ha⁻¹) and litter carbon (LC, Mg ha⁻¹) in 34 sampling plots

| Plot | H  | BA  | TV  | AGB | BGB | DWB | AGC  | BGCCCI | DWC  | SC-TL | SC-1 m | LC    |
|------|----|-----|-----|-----|-----|-----|------|--------|------|-------|--------|-------|
| 1    | 23 | 26.52| 338 | 213 | 40  | 43  | 103.5| 20.9   | 20.9 |  4.4  |
| 2    | 27 | 23.87| 314 | 201 | 38  | 24  | 97.1 | 19.8   | 11.6 |  2.0  |
| 3    | 26 | 51.78| 713 | 461 | 78  | 221.4| 21.4 | 41.0   |      |       |
| 4    | 22 | 35.53| 391 | 263 | 48  | 23  | 128.6| 25.3   | 11.1 |  2.5  |
| 5    | 21 | 22.97| 231 | 145 | 28  | 71.1 | 15.0 |        |      |       |
| 6    | 29 | 26.04| 359 | 215 | 40  | 103.4| 20.9 |        |      |       |
| 7    | 20 | 30.23| 313 | 199 | 37  | 20  | 95.2 | 19.4   | 9.7  |  1.8  |
| 8    | 21 | 26.04| 294 | 199 | 37  | 23  | 95.9 | 19.6   | 10.9 |  1.2  |
| 9    | 28 | 27.89| 409 | 249 | 45  | 30  | 125.7| 24.8   | 14.3 |  2.7  |
| 10   | 21 | 20.28| 174 | 104 | 21  | 28  | 50.0 | 11.0   | 13.3 |  6.0  |
| 11   | 23 | 41.00| 469 | 297 | 53  | 49  | 144.1| 28.0   | 23.7 |  1.7  |
| 12   | 27 | 26.04| 321 | 211 | 39  | 8   | 102.5| 20.8   | 3.7  |  3.5  |
| 13   | 23 | 31.04| 356 | 225 | 42  | 108.8| 21.9 |        |      |  2.5   |
| 14   | 22 | 37.89| 438 | 303 | 54  | 45  | 149.0| 28.9   | 21.5 |  2.9  |
| 15   | 19 | 29.70| 294 | 196 | 37  | 93.3 | 19.1 |        |      |  1.8   |
| 16   | 31 | 51.06| 697 | 453 | 77  | 218.0| 40.4 |        |      |  9.3   |
| 17   | 32 | 40.86| 679 | 463 | 79  | 221.8| 41.0 |        |      | 13.1   |
| 18   | 28 | 34.01| 517 | 424 | 73  | 201.8| 37.7 | 7.5    |      | 11.7   |
| 19   | 31 | 36.93| 560 | 387 | 67  | 186.5| 35.2 |        |      |  8.2   |
| 20   | 29 | 26.04| 349 | 209 | 39  | 28  | 103.5| 20.9   | 13.3 |  6.9   |
| 21   | 29 | 26.18| 431 | 300 | 54  | 145.1| 28.2 |        |      |  7.9   |
| 22   | 21 | 19.04| 212 | 146 | 28  | 26  | 71.3 | 15.0   | 12.5 |  9.4   |
| 23   | 35 | 36.59| 600 | 442 | 75  | 213.3| 39.6 |        |      |  6.1   |
| 24   | 26 | 40.24| 506 | 344 | 61  | 163.4| 31.3 | 29.7   |      |  9.9   |
| 25   | 24 | 23.67| 234 | 179 | 34  | 17  | 85.2 | 17.6   | 8.3  | 12.8   |
| 26   | 32 | 41.14| 595 | 407 | 70  | 194.3| 36.5 |        |      |  3.7   |
| 27   | 33 | 31.71| 476 | 304 | 54  | 146.4| 28.4 | 6.5    |      | 16.1   |
| 28   | 28 | 26.62| 412 | 276 | 50  | 135.5| 26.6 |        |      | 11.3   |
| 29   | 27 | 47.42| 719 | 512 | 86  | 247.7| 45.2 |        |      |  7.1   |
| 30   | 31 | 54.06| 868 | 558 | 93  | 269.7| 48.8 | 13.4   |      | 12.5   |
| 31   | 27 | 47.45| 706 | 517 | 87  | 248.6| 45.4 | 17.5   |      | 11.3   |
| 32   | 26 | 26.07| 342 | 236 | 43  | 113.9| 22.8 |        |      |  2.0   |
| 33   | 36 | 34.78| 531 | 388 | 67  | 187.4| 35.3 |        |      | 12.0   |
| 34   | 21 | 29.15| 336 | 240 | 44  | 115.1| 23.0 |        |      | 10.1   |
| Avg  | 27 | 33.23| 447 | 302 | 53  | 145.8| 28.1 | 13.9   |      |  7.0   |
| SD   | 4  | 9.39 | 171 | 122 | 19  | 58.3 | 10.0 | 6.6    |      |  4.8   |
| Max  | 36 | 54.06| 868 | 558 | 93  | 269.7| 48.8 | 29.7   |      | 21.3   |
| Min  | 19 | 19.04| 174 | 104 | 21  | 50.0 | 11.0 | 3.7    |      | 1.2    |

Values in the parenthesis give top-layer thickness in cm. SD gives one standard deviation for corresponding values.
After litter, deadwood carbon (3.6%) and BGB carbon (7.4%) resemble smaller, soil (48.9%) and AGB (38.3%) the largest carbon pools (Table 5). Variation in soil carbon estimates may result from (i) differing top-layer thickness, (ii) different sampling depths, (iii) soil bulk density, texture and aeration and (iv) bedrock material (Trumbore, 1997). Variation in AGB carbon estimates are attributable to (i) the methodology used (harvest or volume estimates, Brown & Lugo, 1984; Detwiler & Hall, 1988; Chave et al., 2004), (ii) the use of allometric equations developed from inconsistent data sets (Fearnside, 1985; Brown, Gillespie & Lugo, 1989; Dixon et al., 1994), (iii) the application of equations to regions not included in the validation data sets (Chave et al., 2003; Gourlet-Fleury et al., 2011), (iv) the number of parameters (dbh, dbh and height, dbh height and WD0%) used in the equations (Keller, Palace & Hurtt, 2001) and (v) measurement errors in dbh, WD0% and height with decreasing order of importance (Chave et al., 2005).

Another important source of variation in AGB carbon estimates is the natural dynamics of undisturbed forest ecosystems. Undisturbed in this context refers to (i) the absence of human exploitation of forest resources and (ii) the absence of silvopastoral, pathogen or game management practices. Traditionally, such forests were thought to be in climax (Clements, 1916), that is, stable conditions. This concept changed towards a climax vegetation that is ‘varying continuously across a varying landscape’ (Spies, 1997). Today, it is widely accepted that single stands experience periodic declines due to disturbances from endogenous and exogenous dynamics (Wostl, 2000) which maintain ecosystem productivity (White, 1979). On a larger scale, a mosaic of different stages – including breakdown and recovery – shifts over time, but the abundance of all stages remains constant if the area is large enough (Heinselman, 1973). Such ‘mosaic cycles’ (Remmert, 1991) include five successional stages (regeneration, adolescence, optimum, old growth and breakdown, c.f. Pietsch & Hasenauer, 2009) but maintain an overall steady state at the landscape level with local disequilibria attributed to differing vegetation dynamics. If a sampling strategy fails to cover all the stages of the mosaic cycle, biomass estimates may give biased results at the landscape level. The data from 34 plots distributed randomly across the 690 km² of the Monts Birougou National Park resemble a snapshot of a mosaic cycle. The observed variation in AGB (104–558 Mg ha⁻¹) and dead wood (8–62 Mg ha⁻¹) (Table 5) indicates that our data cover all five successional stages occurring in virgin forests (Pietsch & Hasenauer, 2009). The random selection of the plots ensures that all stages contribute to the overall mean according to their relative abundance. Hence, our sample resembles a mosaic cycle with mean values representing the steady state at the landscape level.

Conclusions

Considering the commonly reviewed sources of errors, the direct use of ground-based information on diameter, height, species-specific wood density and wood carbon
fraction, thickness of top soil layer, carbon fraction of top and lower soil, soil density, litter mass and corresponding carbon fraction resembles the best currently available means to estimate carbon pools in forests. In our case, data from 34 plots distributed across 690 km² of the Mount Birougou National Park exhibited 146, 28, 14, respectively, and provide a benchmark for the potential biomass density of the 35,000 km² of the Massif Du Chaillu (CBFP, 2007). Results may serve as ground-truthing data for remote sensing and may assist in establishing national monitoring systems for measuring, monitoring and verifying emission reductions.

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