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Carbon stocks and tree allometries in the savannahs of the Plateau Batéké, central Africa

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ABSTRACT

Tree allometric equations that are used to predict the biomass of a tree from its dendrometrical characteristics are key elements for the estimation of forest carbon stocks. Few equations compared to the diversity of forest ecosystems are currently available for the tropical forests of the Congo Basin. Pantropical equations are available but a pending question is whether they remain valid for all types of forest ecosystems in central Africa. The Plateau Batéké that covers a large area across Congo, Gabon and the Democratic Republic of Congo is dominated by savannahs that contrast with the dense rain forest often found under this tropical wet climate. Four 1-ha plots were inventoried in a savannah of the Plateau Batéké in Congo. Ninety trees from the five most abundant species were destructively sampled for aboveground biomass, while belowground biomass was measured for a subsample of 36 of these trees. The relationship between height (H in m) and diameter at breast height (dbh, D in cm) was modelled by a Mitscherlich model: $H = 6.755–5.570 \exp(-0.0946\ D)$. The relationship between biomass (B in kg) and D, H and wood density (ρ in g cm^{-3}) was modelled as: $B = 0.6229 \times (\rho D^2 H)^{0.7031}$. This locally fitted allometric model had a bias of -2%, while a commonly used pantropical equation had a bias of -38%. Nevertheless, the bias of the pantropical equation at the Batéké site was of the same order as the bias of this pantropical equation at other sites used to establish it. The shoot-root ratio was 0.272. The savannah of the Plateau Batéké had a basal area of 6.32 m^2 ha^{-1} and an aboveground woody biomass of 11.7 Mg ha^{-1} while belowground woody biomass accounted for an additional 3.4 Mg ha^{-1}. The estimate of the aboveground woody biomass dropped by 50% when using the pantropical allometric equation. Insofar as site differences in biomass allometry are negligible in the pantropical equation, so is the difference between the pantropical equation and the locally fitted biomass equation. Nevertheless, the difference between the estimate of aboveground biomass using the locally fitted equation and the pantropical equation is large enough to call for a further examination of site differences in pantropical approaches.

1. Introduction

Savannahs cover massive areas in Africa, not only in drylands but also, even though more marginally, under equatorial climate (Bastin et al., 2017). Better assessing the carbon stocks and dynamics in savannah ecosystems is important given their role in Africa's carbon cycle. Despite massive efforts to improve the estimates of forest and savannah carbon stocks, large uncertainties in emission and carbon sink estimates are still present (Bouvet et al., 2018; Mitchard et al., 2014). When using field inventory plots and allometric equations, landscape-level estimates of forest carbon stocks have an error (IPCC, 2006) that can be broken into two main components (van Breugel et al., 2011): (i) sampling error, that is dependent on landscape heterogeneity, plot size and shape, and the number of plots, and (ii) model error which follows from the differences between the true plot biomass values and the model predictions. One bottleneck to improve estimates lies in the

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model error from allometric equations (Picard et al., 2015). In central Africa, tree biomass data used to develop tree allometric equations are still scarce compared to the diversity of ecosystems found in this region, and the determinants of allometric variability remain poorly understood. At the local level, such as for a few dozen thousands hectare that is the typical scale of forest-based carbon projects in central Africa, a pending question is whether a local allometric equation should be developed and used, or whether a pantropical equation should be preferred. The implicit trade-off is between the bias of local predictions and the prediction error due to uncertain model coefficients and residual model error.

One of the most widely used pantropical allometric equation today is the equation by Chave et al. (2014) that predicts tree biomass from the quantity $\rho D^2 H$ with ρ the specific wood density, *D* tree diameter at breast height (dbh), and *H* tree height. Chave et al. (2014) have proposed that the allometry between tree biomass and $\rho D^2 H$ is universal, i.e. with a relationship that is the same across different species, sites, climates, or soil conditions, and that environmental variability only results in variation in the height-diameter allometry. As a default when the local relationship between height and diameter is unknown, Chave et al. (2014) have also defined a pantropical height-dbh model that depends on a climatic index *E*. Even if the *E* index correctly captures the main trends in height-dbh allometry variation at the global level, its dependence on climate alone may locally bring some inconsistencies when non-climate environmental factors are the drivers of height-dbh allometry variation.

In Congo, the Plateau Batéké is an illustration of how soil conditions can influence height-dbh allometry. Soils of the Plateau Batéké are deep and sandy, which results in low water availability even if the climate is tropical wet (Makany, 1976). Together with other factors like wildfires, these soil conditions result in a vegetation that dominantly consists of savannahs with a physiognomy similar to the savannahs found in the Sahel region under dry climates and that contrasts with the dense forest usually found at these latitudes (Lanfranchi and Schwartz, 1990; White, 1983). The *E* index by Chave et al. (2014) that is calculated from climatic factors varies between −0.05 and 0.10 in the Plateau Batéké (Fig. 1), which contrasts with the values of $E > 0.75$ that are predicted for the savannahs of the Sahel under dry climate. Therefore, the calculated *E* value may not reflect the architecture of trees in the Plateau Batéké and is expected to overestimate tree height and biomass. When biomass is to be directly predicted from tree height without requesting the *E* index, and because they are a dry-looking ecosystem under an equatorial humid climate, the savannahs of the Plateau Batéké are a good study case to test the proposition of Chave et al. (2014) that the allometry between tree biomass and $\rho D^2 H$ is universal.

Correctly predicting the biomass of trees in the Plateau Batéké is all the more important as savannahs occurring on deep sandy soils cover large areas of Congo (7.5 Mha; Fig. 1), but also of neighboring countries. These specific ecosystems thus matter for carbon accounting at the national level in these countries. However, to our knowledge, no specific allometric equation has been developed so far for the savannahs of the Plateau Batéké.

Based on the inventory of all trees with diameter at the base ≥1 cm in four 1-ha plots in some savannah of the Plateau Batéké in Congo, on the measurement of height and diameter for 3397 trees, on the destructive measurement of the aboveground biomass of 90 trees, and on the additional measurement of the belowground biomass for a subsample of 36 trees, the current study aims at building height-diameter and biomass allometric equations for the savannahs of the Plateau Batéké and to derive estimates of the aboveground and belowground biomass of this ecosystem. Estimates of wood density, of shoot-root ratios and of biomass expansion factors are also provided. The locally fitted allometric models were compared to the pantropical equations of Chave et al. (2014). Hence, the objective of this study is twofold: (1) to test the proposition formulated by Chave et al. (2014) of universal allometry based on $\rho D^2 H$ using data from the savannahs of the Plateau Batéké; (2) to provide allometric equations and carbon stocks for the savannahs of the Plateau Batéké that will be useful for the forest

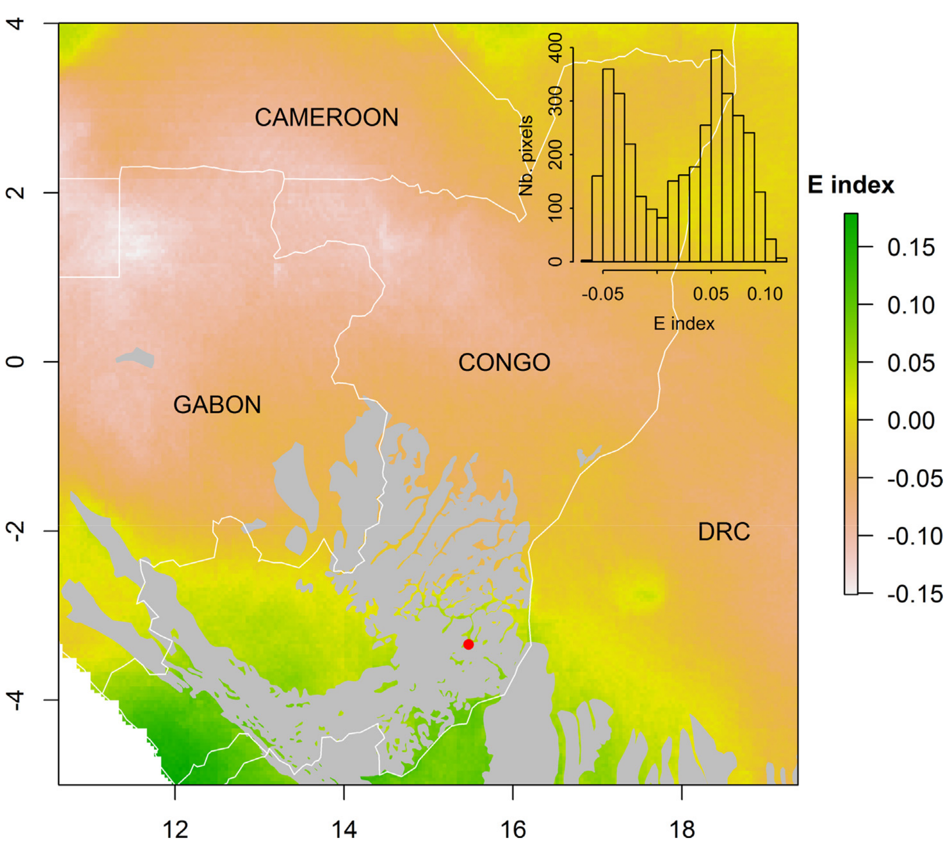

Fig. 1. Location of the study site (red dot) in Congo. The grey area shows the spatial distribution of savannahs according to Descoings (1969) for Congo, Caballé (1983) for Gabon and Devred (1958) for the Democratic Republic of Congo (digitalization of the phytogeographic maps by the University of Maryland). The background shows the map of the *E* index defined by Chave et al. (2014). The histogram in the upper right part of the figure shows the distribution of the *E* index in the savannahs of Congo. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)