Forest Ecology and Management 329 (2014) 195–205

Contents lists available at ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

A new insight in the structure, composition and functioning of central African moist forests

Adeline Fayolle [a,b,*], Nicolas Picard [b], Jean-Louis Doucet [a], Michael Swaine [c], Nicolas Bayol [d], Fabrice Bénédet [b], Sylvie Gourlet-Fleury [b]

[a] *Laboratoire de Foresterie des Régions Tropicales et subtropicales – Unité de Gestion des Ressources Forestières et des Milieux Naturels – Gembloux Agro-Bio Tech, Université de Liège, Passage des Déportés 2, 5030 Gembloux, Belgium*

[b] *CIRAD, UPR BSEF, Biens et Services des Ecosystèmes Forestiers tropicaux, TA C-105/D, Campus international de Baillarguet, 34398 Montpellier Cedex 5, France*

[c] *Institute of Biological and Environmental Sciences, University of Aberdeen, Aberdeen AB24 3UU, United Kingdom*

[d] *Foret Ressources Management, Espaces Frejorgues Ouest, 60 rue Henri Fabre, 34130 Mauguio, France*

A R T I C L E   I N F O

Article history:
Received 10 June 2014
Accepted 11 June 2014

Keywords:
Deciduousness
Forest management and conservation
Mixed species forest
Monodominant forest
Pioneer
Wood specific gravity

A B S T R A C T

The greater part of the semi-deciduous moist forests of the Congo basin has been given to logging companies for exploitation. In the next decades, very few of these forests will remain intact. In this paper, we aimed to identify large-scale variations in the structure, composition and functioning of African moist forests that could serve as a baseline for both management and conservation purposes. Commercial forest inventory data were assembled for 49,711 0.5-ha plots, covering an area of more than six million hectares, crossing the borders of Cameroon, Central African Republic and Republic of Congo. Floristic composition was analyzed for a subset of 176 genera reliably identified in the field. Three key functional traits of tropical trees: regeneration guild, leaf phenology, and wood specific gravity, were collected at the species level from various sources, and assigned at the genus level. We first investigated the main variations in forest structure and composition, and identified seven forest types based on these variations. Differences in the percentage of pioneer and deciduous stems, and mean wood specific gravity were tested between forest types. Most of the study area was composed of a mosaic of the structural variations of the forests characterized by the occurrence of *Celtis* (Ulmaceae) species, which are mostly composed of frequent and abundant genera that formed the common floristic pool of the region. Secondary *Musanga* (Moraceae) forest is located in repeatedly disturbed areas, along roads and around main cities; mixed *Manilkara* (Sapotaceae) forest covers a huge area in the southern Central African Republic and in the northern Republic of Congo; and monodominant *Gilbertiodendron* (Fabaceae) forest is sparsely distributed along rivers. The contrasted structure, composition, and functioning of the forest types imply pronounced differences in population and ecosystem processes, and call for adapted management and conservation strategies.

1. Introduction

The need to manage and conserve tropical forests has never been greater, with a unique challenge to develop strategies that are suitable for sustainable timber production, biodiversity conservation and carbon storage. The tropical forests of central Africa comprise the second largest continuous block of tropical forests in the world, possibly harbouring up to 20,000 different plant species including c. 8000 species of trees (White, 1983) and storing more than 200 t of carbon per hectare in live trees (Lewis et al., 2009, 2013).

Patterns of diversity and endemism are now well established for sub-Saharan Africa (Küper et al., 2004; Linder, 2001). In central Africa, high rates of diversity and endemism in the Cameroon–Gabon (Lower Guinea) and Kivu areas have been generally recognized (Linder, 2001; White, 1983), and these hotspots of biodiversity have been considered as priorities for conservation (Küper et al., 2004). In between these centres of diversity and endemism, immense areas are covered by lowland semi-deciduous moist forests that are not particularly species-rich and mostly composed of widely distributed species (White, 1983). Since the

* Corresponding author at: Gembloux Agro-Bio Tech, Laboratoire de Foresterie des Régions Tropicales et subtropicales, Passage des Déportés, 2, B-5030 Gembloux, Belgium. Tel.: +32 (0)81 62 22 98; fax: +32 (0)81 62 23 01.

E-mail address: adeline.fayolle@ulg.ac.be (A. Fayolle).

http://dx.doi.org/10.1016/j.foreco.2014.06.014
0378-1127/

1950s most of these forests, with the exception of the Democratic Republic of Congo, have been granted to private logging companies and impacted by selective logging (Nasi et al., 2012; Ruiz Pérez et al., 2005). In the next decades, very few of the forests outside protected areas will remain intact, yet they have never received particular attention as a whole.

Information on the composition, and to the lesser extent the structure, of these forests are available from phytogeographical maps at the national (Boulvert, 1986 in the Central African Republic; Caballé, 1978 in Gabon; Lebrun and Gilbert, 1954 in the Democratic Republic of Congo; Letouzey, 1985 in Cameroon) and continental (Aubréville et al., 1958; De Namur, 1990; White, 1983) scales. Thematic (e.g. carbon maps) or land use maps have also been obtained by remote sensing techniques (e.g. Baccini et al., 2008; Mayaux et al., 2004; Verhegghen et al., 2012). On the one hand, phytogeographical maps have mainly been based on expert knowledge and basic statistical analyses of forest inventory data. On the other hand, remote sensing maps generally distinguish between only a few broad forest types, without additional details. Maps derived from MODIS imagery, which take advantage of canopy phenology, are likely to bridge the gap between phytogeographical maps and remote sensing (Gond et al., 2013; Viennois et al., 2013). To date, however, no work has been attempted that integrates detailed forest inventory data with ecological knowledge on forest structure, tree species composition and functioning to produce a comprehensive forest map for decision makers.

The lack of such a comprehensive map of the Congo basin forests has limited their management on a sound ecological basis as discussed in Gourlet-Fleury et al. (2013b). At the same time, extensive areas of forests have been sampled by logging companies to quantify the timber resource and its spatial variations, providing a unique opportunity to study these forests in detail and at a large scale. Data from commercial forest inventories have generally been regarded as imprecise or incomplete by academic standards, despite the quantitative information they contain. However, since diameters of all trees are measured in plots of known areas, following similar protocols, they provide accurate quantitative information for the analysis of structural variations (Couteron et al., 2003). Moreover, it has been demonstrated that commercial forest inventory data are suitable to detect compositional gradients (Réjou-Mechain et al., 2011). We here hypothesize that large-scale commercial forest inventories combined with species functional traits and modern statistical techniques are an efficient and more detailed alternative to remote sensing to define informative forest types over large areas using ground-based information.

In this paper we used the spatially extensive data collected by logging companies to identify large-scale variations in structure and both floristic and functional composition of the semi-deciduous moist forests of the Congo basin. To do so, we used three key functional traits for tropical trees that influence the forest's response to disturbance, soil fertility and climate: shade tolerance, leaf phenology and wood specific gravity (Fayolle et al., 2012; Maharjan et al., 2011; Slik et al., 2008). We specifically aimed to (i) detect large scale variations in forest structure and composition; (ii) identify and label forest types with regards to their structural, compositional and functional characteristics; and (iii) produce a distribution map of these forest types that could serve as a baseline for forest management (including conservation) and sampling (e.g. to estimate carbon stocks) purposes. We also discussed how the combined information on forest structure, composition and function gained from this work might help orientate future management options in the study area.

2. Material and methods

2.1. Study area

The study area covers more than 6 million ha of lowland moist forests located in southeastern Cameroon, in southern Central African Republic and in northern Republic of Congo. A humid tropical climate prevails in the area with a dry season of up to 3-months. Mean annual rainfall varies between 1400 and 1700 mm. Altitude ranges from 300 to 800 m a.s.l. The vegetation belongs to the mixed, moist, semi-deciduous forests of the Guineo–Congolian region where the Malvaceae, Ulmaceae (now Cannabaceae), Sapotaceae and Meliaceae families are abundant (Boulvert, 1986; Harris, 2002; Letouzey, 1985; White, 1983).

2.2. Inventory data

In this study, we used data from large-scale forest inventories from 22 logging concessions (six in Cameroon, six in the Central African Republic, and ten in the Republic of Congo) completed by logging companies prior to the implementation of forest management. The sampling design was systematic, irrespective of forest types. It consisted of parallel transects 2 or 3 km apart, and divided into consecutive rectangular plots (25×200 m or 20×250 m, i.e. 0.5 ha). Due to restricted access to data in five Congolian concessions, we only used half of the inventoried plots (i.e. every other plot). Within each plot, all trees with a diameter at breast height (dbh) $\geqslant 30$ cm were measured and identified. Trees with diameters up to 140 cm were assigned to 10 cm wide dbh classes and larger trees were grouped in the dbh $\geqslant 150$ cm class. Vernacular names were converted to species-level scientific names when possible. Taxonomy was revised and homogenized according to the African plant database (available online http://www.ville-ge.ch/musinfo/bd/cjb/africa/recherche.php).

The analyses were conducted at the genus level because vernacular names are more reliable at the genus level than at the species level (Réjou-Mechain et al., 2011), and because the genus resolution captures most of the floristic variation in tropical forests (Higgins and Ruokolainen, 2004; Slik et al., 2003; ter Steege et al., 2006). A total of 343 genera were identified in the 49,711 inventoried plots. The unidentified trees represented between 0 and 5 stems, and between 0 and 0.92 m^2 basal area per plot, with a mean of 0.6 stem (1.7% of total stem number) and 0.1 m^2 (1.3% of total basal area) per plot. Within the 49,711 inventoried plots, a total of 35,930 plots (72% of plots) did not contain any unidentified tree at genus level. We further restricted the analyses to a set of 176 tree genera for which we had confidence in the identification across the study area following a set of rules. The selected genera should (1) be present in at least two logging concessions and represented by at least 30 trees across the study area; (2) show a mean diameter distribution across the study area in agreement with the genus biology (genera known to contain only understory species should not reach large diameter); and (3) show a coherent spatial pattern across the study area (no major gap in the distribution, absence in one concession while present in all the neighboring concessions, and that could correspond to the local misidentification by tree spotters). Despite an extensive check of data and taxonomy, minor misidentifications may have persisted. The set of genera analyzed represented, on average, 85% of plot stem number and 88% of plot basal area. Among the 49,711 plots, we only considered the 38,363 plots for which the 176 genera contributed to more than 80% of plot total stem number.