SSD

SCIENCE FOR A SUSTAINABLE DEVELOPMENT

SUSTAINABILITY OF TROPICAL FOREST BIODIVERSITY AND SERVICES UNDER CLIMATE AND HUMAN PRESSURE

"BIOSERF"

A. Hambuckers, M.-C. Huynen, F. Trolliet, R. Jamar-Beudels, R.-M. Lafontaine, H. Robert, P. Van Damme, A. Baert, N. Dendoncker, C. Fontaine, C. Halleux, L. François, M. Dury, A.-J. Henrot

ENERGY
TRANSPORT AND MOBILITY
AGRO-FOOD
HEALTH AND ENVIRONMENT
CLIMATE
BIODIVERSITY
ATMOSPHERE AND TERRESTRIAL AND MARINE ECOSYSTEMS
TRANSVERSAL ACTIONS

.be

SCIENCE FOR A SUSTAINABLE DEVELOPMENT
(SSD)

"Terrestrial Ecosystems, Biodiversity"

FINAL REPORT

SUSTAINABILITY OF TROPICAL FOREST BIODIVERSITY AND SERVICES UNDER CLIMATE AND HUMAN PRESSURE
"BIOSERF"

BIOSERF

Promotors
A. HAMBUCKERS & M.-C. HUYNEN, University of Liège, Behavioural Biology Unit,
Quai Van Beneden 22, 4020 Liège
R. JAMAR-BEUDELS, Royal Belgian Institute of Natural Sciences, 29 rue Vautier, 1000 Brussels
P. VAN DAMME, Universiteit Gent, St-Pietersnieuwstraat 25, 9000 Gent
N. DENDONCKER, Facultés Universitaires Notre Dame de la Paix, 61 rue de Bruxelles,
5000 Namur
L. FRANÇOIS, Unité de Modélisation du Climat et des Cycles Biogéochimiques, Université de
Liège, Place du 20-Août 7, 4000 Liège

Authors
F. TROLLIET, University of Liège, Behavioural Biology Unit, Quai Van Beneden 22, 4020 Liège
R.-M. LAFONTAINE &, H. ROBERT, Royal Belgian Institute of Natural Sciences, 29 rue Vautier,
1000 Brussels
A. BAERT, Universiteit Gent, St-Pietersnieuwstraat 25, 9000 Gent
C. M. FONTAINE & C. HALLEUX, Facultés Universitaires Notre Dame de la Paix,
61 rue de Bruxelles, 5000 Namur
M. DURY & A.-J. HENROT, Unité de Modélisation du Climat et des Cycles Biogéochimiques,
Université de Liège, Place du 20-Août 7, 4000 Liège

Université de Liège

museum

UNIVERSITEIT GENT

FUNDP NAMUR

Published in 2015 by the Belgian Science Policy
Avenue Louise 231
Louizalaan 231
B-1050 Brussels
Belgium
Tel: +32 (0)2 238 34 11 – Fax: +32 (0)2 230 59 12
http://www.belspo.be

Contact person: Georges Jamart
+32 (0)2 238 36 90

A. Hambuckers, M.-C. Huynen, F. Trolliet, R. Jamar-Beudels, R.-M. Lafontaine, H. Robert, P. Van Damme, A. Baert, N. Dendoncker, C. Fontaine, C. Halleux, L. François, M. Dury, A.-J. Henrot. ***Sustainability of tropical forest biodiversity and services under climate and human pressure - "BIOSERF"***. Final Report. Brussels: Belgian Science Policy 2015 – 125 p. (Research Programme Science for a Sustainable Development)

Contents

SUMMARY

A. Context

It is today established that tropical forests are currently disappearing or being degraded at worrying rates. It is commonly believed that the main threat for these forests is deforestation. Yet, more than just logs, forest ecosystems produce many other services of prime importance to man (the so-called ecosystem services or ES). Agroforestry, hunting or collection of plant products furnish numerous resources to the society and contribute a lot to the well-being and livelihood of local people. Excessive consumption of ES constitutes another major threat to forest survival owing to shifts in traditional practices. Indeed, socio-economical conditions are changing due to increases in population, demand for forest products by cities (bushmeat, ivory, medicinal plants, etc.), road constructions to facilitate trade, etc. These changes induce increased pressure on forest. Canopy cover becomes fragmented; soils lose their fertility; animal density and plant diversity decrease. These conditions might ultimately lead to the disappearance of some ES and to the rarefaction of other ones beyond threshold under which they can no longer regenerate.

The question arises to know whether it is possible to make predictions on the optimal evolution of a forest system under human pressure to preserve biodiversity and services for human communities. To answer such a question, one has to consider, on the one hand forest growth and its regeneration and, on the other hand, the use of the forest by man. In relation to the first aspect, one of the main issues is recruitment (i.e., establishment and growth of juvenile plants) of forest tree species. Indeed, large seeds (> 1 cm diameter) or diaspores of the main climax tropical trees have to be carried from trees remaining in the environment to the deforested areas. Seed dispersal, however, becomes limited in fragmented habitats or in the absence of frugivore vertebrates (due to excessive hunting). Besides, future ecosystems will also have to face global warming. The response of African ecosystems to future climate change remains under-investigated and existing dynamic global vegetation models were not specifically designed and tested for tropical grass–tree systems. With regard to the latter point, the mathematical models currently used in predicting future use patterns usually do not take into account human pressure or else they only do so in a superficial way.

B. General objectives

The general objectives of the BIOSERF project were to explore the evolution of a socio-ecological system, with a focus on ecosystem services and to assess their sustainability in an area of evergreen tropical forest under increasing human pressure and climate change. For this purpose, we aimed at adapting two dynamic spatial models, one dynamic vegetation model (CARAIB) simulating various aspect of vegetation development and an agent-based model (ABM) simulating land-use by people. The study area was a stretch of forest and savannah in the Congo Basin also known as the WWF Lake Tumba landscape in the Democratic Republic of Congo.

C. Results and conclusions

In the work-package 1 (WP1 – Socio economic analysis), we studied people of local communities in the Ngiri area in order to estimate demographic variables and relationships between people and nature. The multifaceted human-forest interactions, leading to information on subsistence farming, hunting, informal logging, fishing, and the collection of non-timber-forest products was to be analyzed.

The objective of WP1 was to establish a stakeholder typology by characterization of the demographic situation of the communities present in our study area. Seventy-two villages in the Ngiri triangle were selected for sampling, resulting in information obtained from 1,766 households.

Villages are concentrated on the riverbanks, camps occur wherever certain resources are seasonally available. People hold on to a traditional way of living. They rely on water resources not only as a source of food and primary economic gain, but also for transportation, through the rivers that connect them to villages and markets of the region.

Agriculture and fishing are the most important daily subsistence activities. Many villages live largely on cassava and maize. To a lesser extent sugarcane, plantain and different tubers are grown both for self-consumption and market purposes. Traditional slash-and-burn agriculture is the rule. Variation in total field area among households is very high. Figures vary between 0.1 ha to 1 ha. Fields outside of this range are exceptional, yet on average total household field area is close to 1 ha. As a rule of thumb, one should count ¼ ha per person. Variation in length of fallow is less pronounced. Most villages indicate fallow duration of less than 4 years. The exact conditions and parameters steering farmers into the decision to create new fields instead of returning to old ones are of great importance. Results of surveys of tropical deforestation support the view that population growth is never the sole and often not even the major underlying cause of change in forest-cover. Fields and fallows may extend up to 5 km and sometimes up to 10 km away from the village, but fishing, gathering and trapping might extend for 20 km. The extent of 'territories' used and claimed by agricultural communities are generally quite fixed but not necessarily static. Fish is predominantly caught as a means to generate income. Some 90% of the catch is sold. Similarly so, bushmeat is an important source of cash with rising demand from urban markets.

The lack of commercial value associated with non-timber forest products (NTFPs) may impact decision-making around land transformation from forest to agricultural land because the need to open farmland may take precedence over the importance of NTFP as a subsistence activity. The Ngiri triangle is not very well represented on the Mbandaka markets. Agricultural products and NTFPs from that area are basically auto-consumed and traded on local markets only, while fish and bushmeat are being sold to large pack boats bound for Kinshasa.

Semi-industrial/industrial logging is totally absent. All forest exploitation is confined to either the collection of fuel-wood and small-scale forest exploitation of hardwood trees for construction timber both consumed locally. Charcoal production and sales are not important in the Ngiri reserve, unlike what happens around large urban centres at the other side of the Congo River.

Our focus group discussions indicated quite clearly that local populations are aware that certain practices and trends threaten the sustainability of their livelihoods through the overexploitation or misuse of resources. Given that there are few current alternatives to resource extraction, it is fair to assume that current trends of land use will continue into the coming years, exercising more pressure on local resources, unless policy changes.

WP2 (Vegetation analysis) focused on forest regeneration, more particularly on the problem of seed dispersal by animals and on the adaptation of the DVM. For the seed dispersal study, we achieved evaluation of primary seed dispersal of *Staudtia kamerunensis* (24 trees dispersed among five sites with a maximum distance between them of 30 km). Those sites situated in the western part of the Landscape Lake Tumba (Bandundu province), had contrasted level of fragmentation, hunting pressure, faunal density, *S. kamerunesis* abundance, and fertility. There were several species of dispersers, but most of the time (> 95 %), trees were visited only by the white-thighed hornbill, *Bycanistes albotibialis*. Dispersal failure considerably varied among trees (from 17.6% up to 180 %). Statistical analysis revealed that the only significant drivers of seed dispersal failure were the percentage of forest around the focal trees (in a radius of 3,000 m, linear negative effect) and the intensity of hunting (linear and quadratic effects giving a rather positive hollow curve).

In rather intact tropical ecosystems, dispersal failure is generally very low (0 or some percents) because the dispersers were competing for food resources and very large proportion of the mature fruits is consumed with their seeds, which are later deposited. Here, human disturbance (maintenance of savannahs and hunting) seemed to control the biological process of zoochory, which now relied more and more on a limited number of animal species. The behavior particularities of the remaining species may additionally skew the patterns of seed deposition as probably observed with the more than 100 % of seed dispersal failure estimated for 4 trees. We highly suspected this to be the result of inter-conspecific seed dispersal. Such contagious seed dispersal has been reported to be particularly strong in bird-dispersed tree species. Small forest fragments could tend to confine hornbill's movements within a limited area and induce repeated flights between fruiting trees.

The data collected on *S. kamerunensis* seed dispersal allowed the construction of a seed dispersal/plant regeneration module for simulating the dispersion of this species. The module was first run off-line and then integrated within CARAIB DVM. It allowed evaluating the characteristic time and efficiency of regeneration for this particular tree species in a savanna-forest mosaic located in the southern part of the WWP Lake Tumba Landscape. The DVM was also upgraded to simulate major attributes of forest (species potential distribution, net primary productivity, biomass, etc) at the species, rather than at the plant functional type (PFT) level (as usually done in most DVMs). A total of 78 African tree species were implemented into this upgraded model. Simulations were then performed on the recent period for validation purposes with the use of field or satellite data.

In WP3 (Fauna analysis), we investigated how a large mammal species, the bonobo played in the regeneration of the forest. The study was also conducted in the West of the Landscape Lac Tumba. It had two components. By collecting the feces of the animals, we were able to identify the consumed plant species and evaluated the service of seed dispersal. By comparing ingested and fresh seeds for their germination characteristics, we determined the animal effect on the ecophysiology of the seeds.

We found that the bonobos consumed fruits from 78 different identified species, among which 16 were important (in more than 50 % of samples for at least 1 month) and 5 preferred (consumed disproportionately relative to their abundance in the habitat). The bonobos selected particular forested habitats for building their nests but they had no preferences for their other activities (travelling, feeding). They dispersed species representative of the different successional stages of the forest (41 % of shade bearers, 19 % of non-pioneers light demanding, 25 % of pioneers and 14 % of savannah species). Seed gut passage may enhance or reduce initial delay, germination rate, and speed.

We finally concluded that the bonobo, thanks to its behavior, is likely to disperse seeds of all light guilds in all habitats, including forests at different successional stages (primary and secondary), with varying understory conditions, at the interface between forest and savannahs, and further from forest patches within the savannah matrix. Passage of the seeds in the gut was likely to favour forest regeneration at early and late successional stages. Thus, the lost of large species like the bonobo may threat the resilience of old primary forests.

In the second study conducted in WP3, we realized faunal surveys of birds and mammals. We travelled in four zones of the Lac Tumba Landscape, in the Natural Reserve of the Ngiri Triangle, in the northern part of the Natural Reserve of Tumba-Lediima, in the unprotected forests located between the River Bambou, and finally in the southern part of the Nature Reserve of Tumba-Lediima. Birds were searched and recorded following mist net stations, camera traps, and direct observations around base camps and along recces. Data on mammal presence were collected either by direct observation, search for evidence (faeces, tracks, burrows) and by interviewing local villagers, trackers and hunters.

Important species of mammals have been encounters (bonobo, chimpanzee, black mangabey, Allen swamp monkey, Wolf's monkey, forest elephant, hippopotamus, red-river hog, etc.) but for most of them in very limited numbers. This attested intensive hunting. Three hundred and forty-three bird species were observed. This number represented 75 % of the potential list of species present in the landscape. Additionally, we signalled 12 new species for the areas. Only 80 species were considered as widespread and observed within each prospected area. Between 180 and 190 bird species were observed in pristine or semi-pristine habitats during each of the field trip, sometimes in abundance particularly for the small species but not for the larger ones. The grey parrot or the hornbill species achieving the service of large seed dispersal were rare. While dispersal of small seeded species seemed guaranteed, the dispersal of the large seeded climax species was obviously threatened. From direct observations, we attested that large birds with weight as low as 1 kg became targets of hunters.

As a general conclusion, for the area in which our inventories have been performed, we can say on the one hand that, at this stage of exploitation and human density, the vertebrate richness of the natural habitats including those of larger species remained quite high (at least in the protected areas which often serve as the last refuges for the fauna). On the other hand, we noticed that the densities of large mammals and large birds were surprisingly low. This conclusion had to be put in perspective with growing population attested by traces of human activities at large distance of villages or even in the heart of protected areas as well as with the growing number of new settlements along routes, rivers or in savannahs.

Linking biodiversity management with human needs would yield better-integrated policy and management plans at a landscape-scale and be more firmly directed towards human well-being. Therefore, the links between biodiversity and benefits that people derive from nature, i.e. ES, must be clearly set out before their valuation and modelling for the present and the future. In WP4 (Valuation of ecosystem services), we first identified qualitatively the most prevalent services and the associated levels of revealed threat for associated species. Second, we estimated current population figures in order to evaluate a pseudo-average level of services usage per person. Spatial disaggregation was limited to a distinction between official villages, settled along the riverbanks.

The selection of the subarea to study, in the northern part of the Lake Tumba- (the Ngiri triangle), was suggested by a local NGO partner (WWF-Congo). The infield work provided evidence of marginal spatial impact of agriculture practices. Hence, the picking activities, for survival, have the greatest impact on ecosystem services. In other words, the degradation of ecosystem services provided by evergreen forest are most probably to be related directly to population change rather than farming activities. Considering the remoteness of the subarea investigated, only partial and revealed population estimates are available.

Amongst the ca. one hundred plant species encountered in the Ngiri subarea, around 40 were considered as vital and/or strategic by local communities of which half was estimated to have less than 15 individuals per hectare in a 2006 inventory. In terms of ecosystem services, production services are prevalent. The wood of these species is largely used for a variety of craft productions, whilst the others parts are dedicated to medicinal products. Relating this importance of service with species considered at risk of overexploitation gives some evidence of over-exploitation.

From the outputs of a DVM simulation run over the historical period (1901-2012), we plotted the present-day spatial distribution of net primary productivity and biomass of 78 African tree species (from WP2), as well as other results, such as soil water, runoff, fire occurrence and extent, etc. These results were then used to map the current distribution of a set of ecosystem services associated with the studies species.

Finally, in WP5, we selected some climate scenarios for the future from the CMIP5 database (IPCC AR5) by evaluating the ability of the available models to reproduce the present-day observed variability of surface temperature and precipitation in central Africa. Five CMIP5 climate models (CMCC-CM, CNRM-CM5, HadGEM2-CC, MIP-ESM-MR and MPI-ESM-LR) were selected using this criterion. Their climate reconstructions of the historical period (1950-2005) and their projections for the future (2006-2100) according to the RCP4.5 and RCP8.5 scenarios were downscaled to a common longitude-latitude resolution of 0.5°x0.5°. The DVM was then run under all of these climate reconstructions/projections. In view of the uncertainty on the impact of increasing atmospheric CO2 on vegetation primary productivity and growth (the so-called CO_2 fertilization), each of these climatic scenarios was run within the DVM under the assumptions of increasing CO_2 (RCP4.5 or RCP8.5 CO_2 projections) or constant CO_2 (330 ppmv).

The DVM results show that the net primary productivities (NPP) of most studied species tend to increase in the future when CO_2 fertilization is included (increasing CO_2 hypothesis). By contrast, when CO_2 fertilization is not considered, many species see their productivity decrease throughout their current range. This latter situation is probably the most likely in view of the generally low availability of nutrients in tropical soils. This decrease of productivity of the tree species corresponds to a significant reduction in the ecosystem services they provide. Maps are thus provided showing the expected future change in the availability ecosystem services associated with the studied species. Three main services are considered: production of food, production of timber and other wood materials, production of medicinal services. The future evolution of other output variables of the DVM (runoff, burned area, soil turnover time) is also studied and is used with the projections of species abundance and NPP to build an index for the risk of severe impacts ("ecosystem disruption") of climate change on the tropical forest ecosystem. Under the most likely "no CO_2 fertilization" hypothesis, the risk is not negligible and appears to be significantly higher in the southern part of the WWP Lake Tumba Landscape.

It must be stressed that many uncertainties remain on such projections due to (1) the uncertainties on the climatic scenarios, (2) the scarcity of autoecological and ecophysiological data for most African tree species that constrain their response to climatic variations, (3) the possible acclimation and adaptation of the species to their future climate and environment, (4) our poor quantitative knowledge of seed dispersal and rainforest regeneration processes, (5) the largely unstudied/unmodeled interactions between fauna and flora, and (6) the uncertainties on future forest management practises and use of the forest products. Much more research is needed to reduce these uncertainties, both from the data acquisition and the modelling sides, as well as from both the natural sciences and the social science perspectives.

D. Contribution of the project in a context of scientific support to a sustainable development policy

For the short term (years to decade), we can conclude from many sights that the studied ecosystems in DR Congo are under high pressure and might collapse. The observed perturbations would probably intensify if the way people acquire their basic resources remains unchanged and the urban centres continue to consume forest products. For the long term (several decades), another threat might come from climate change. Reduction of the services provided by forest species can be expected. Nevertheless, many of the studied species could spread outside their present range, but this would depend on seed dispersal efficiency, which relies mainly on the threatened large animals.

There is urgency of actions in the short term to adapt agricultural practices to reach sustainability. In the same time, governance may be reinforced to increase shelter of nature in protection area. These actions may have the highest. However, it is also important to develop plans to face the effects of climate change on a longer term because the risk of severe perturbations of the forest ecosystem (disruption), by climate change only, is quite significant. Thus, the important species for provisioning ecosystem services should be favoured through forestry management and particularly, care should be taken to the regeneration processes including the important step of seed dispersal by animals.

E. Keywords

Dynamic vegetation model, agent-based model, man-nature interactions, climate change, socio-economic changes, forest regeneration, zoochory

1. INTRODUCTION

Slash-and-burn agriculture in tropical evergreen forests is sustainable when space is unlimited and fallow can regenerate soil fertility. Land cleared of forest can be cropped for a limited number of years (typically 3 years in tropical humid forests), after which spontaneous forest regeneration is possible. According to Mazoyer & Roudart (1997), sustainability and good yields (equivalent to *ca.* 2 t/ha cereals) could be maintained as far as the time between successive forest clearing is longer than *ca.* 50 years (also see the R factor proposed in Ruthenberg, 1977). In such conditions, shifting agriculture results in a mosaic of agricultural, secondary and primary ecosystems that resemble somewhat natural disturbance regimes and can serve biodiversity conservation. Human communities benefit in this more productive environment from ecosystem services deriving from hunting, fishing and plant collection for various uses (*e.g.* construction purposes, food and medicines). However, mostly due to increasing human population pressure, time between different forest clearing events is reduced or else land is converted into permanent cropping or pasture land, and pressure increases. Useful forest plant densities and yields decrease with land conversion, leading to impoverishment of local users (Fujisaka *et al.*, 1997). In some places, the yield of the new agricultural practices (crops) remains sufficient because they are well-adapted to local conditions (*e.g.,* high initial soil fertility). However, it will quickly develop into progressive ecosystem degradation when demography increases. In Rwanda, for example, forest cover has been almost entirely destroyed (Fisher & Hinkel, 1992) and converted into agro-ecosystems since the population increase fourfold over the 1970 – 2010 period, with the exception of the protected areas where human settlements and exploitation are excluded. In such conditions, biodiversity degradation leads to loss of ecosystem, hence of the services they provide to human communities. In places where yields decrease, older cultivated lands are progressively abandoned and new forest patches are cleared. Here, when plant and animal populations have declined because of overexploitation, and when soil fertility has been depleted owing to long-term cultivation, forest regeneration through natural processes becomes difficult. The question now arises to know whether it is possible to make predictions on the evolution of a forest system under human pressure. One has to consider, on the one hand, forest growth and its regeneration and, on the other hand, the use of the forest by man. In relation to the first aspect, one of the main issues is lower recruitment (i.e., establishment and growth of juvenile individuals) of forest trees. Indeed, large seeds of the main climax trees have to be carried from trees remaining in the landscape to the fallows. Seed dispersal, however, becomes limited in fragmented habitats or in the absence of frugivore vertebrates and particularly of primates (Wunderle Jr, 1997; de Melo *et al.*, 2006; Nuñez-Iturri & Howe, 2007). In addition, density of (young) individuals of the same species near the remaining parent trees might not increase because of a negative plant-soil feedback induced by previous attraction of specific enemies by adult trees (e.g. Mangan *et al.*, 2010). The decline in tree diversity and of their commensal wildlife populations might also and ultimately lead to the disappearance of some ecosystems services and to the reduction of the availability of other ones. This example illustrates the close link existing between the functional aspects of forest ecology and the sustainability of forest use by man.

Besides an intensification of human pressure, future ecosystems will also have to face global warming. The response of African ecosystems to future climate change remains under-investigated (Cao et al., 2001; Grace et al., 2006; Hély et al., 2006; Williams et al., 2007). Some studies have been carried out with dynamic vegetation models, specifically developed to simulate carbon cycle and vegetation distribution, but these are not frequent and only take place at global, continental or biome scales (Cramer et al., 2001; Woodward & Lomas, 2004; Bond et al., 2005; Scheiter and Higgins, 2009). Aga Alo and Wang (2010) analyse the impacts of structural vegetation feedbacks on simulated climate and hydrological processes in Western Africa using a dynamic vegetation model asynchronously coupled to a regional climate model. Some studies consider the role of fire disturbances in vegetation dynamics in Africa (Arora and Boer, 2005, Scheiter and Higgins, 2009). However, existing dynamic global vegetation models were not specifically designed and tested for tropical grass–tree systems (House et al., 2003). Moreover, these models usually do not take human pressure into account or only in a relatively crude way. Some analyses of the impacts of increasing human pressure in Africa have been conducted with agent-based simulations. These researches focus on local case studies, *e.g.*, the CLOUD model (Climate Outlooks and Agent-based Simulation of Adaptation in Africa), which has been applied to small subsistence farming villages in Southern Africa (Bharwani et al., 2005, Ziervogel et al., 2005). Other agent based models deal with conflicts for natural resources in Africa (Kennedy et al., 2010). A promising approach for the modelling is the integration of dynamic vegetation models with agent-based models, in order to represent the complex interactions between man and ecosystems in a fully coupled mode. This approach is currently being developed for case studies on other continents (Murray-Rust et al, 2014), but to our knowledge has not been applied in Africa yet.

The general objectives of the BIOSERF project were to explore the evolution of socio-ecological system, with a focus on ecosystem services and to assess their sustainability in an area of evergreen tropical forest under increasing human pressure and climate change. To reach these objectives, we used mathematical models. The project had the objective to integrate two spatial-dynamic models, the CARAIB dynamic vegetation model DVM and an agent-based model (ABM). The models would have to be adapted to the local human community's situation (demography, land use, ecosystem services, ethnobotany, see WP1) and to particularities of the forest ecosystem (plant main traits, plant autoecology and functional ecology. The models had to be upgraded and to be fed with locally gathered data on plant-animal interactions, on human-nature interaction and on human behaviors related to land use. Integrated in the general scheme, the specific objectives of the project were as follows:

- Study the physical and biological processes that govern the natural regeneration of the forest ecosystem, especially the dispersal pattern of selected tree species, which (partially) depends on the animal community (frugivores). This dispersal capacity becomes limited if hunting increases (thus reducing natural disperser numbers), if the habitats of the dispersers are/become fragmented or if the collection of diaspores is too intensive.
- Identify and evaluate quantitatively some ecosystem services currently provided by the forest to the local human communities, under the present socio-economic context (WP1). The selection of ES to be studied has been made based on cartography including participatory GIS and socio-economic survey among stakeholders.

- Explore, with the use of the coupled DVM-ABM model, possible scenarios for the future evolution of the forest ES over the whole area covered by the WWF Lake Tele – Lake Tumba Landscape, under different climate, demographic and socio-economic scenarios of change, specifically developed for this area. A sustainability assessment has been conducted for each of these scenarios.

The project had focused on the lowest latitude zone of the Congo Basin, on the WWF Lake Tumba Landscape, the largest area of swamp and flooded forest in Africa, and more specifically on the DR Congo part of the Landscape, spreading over ca. 78,972 km² in the Equateur Province. The huge biological value of the Lake Tumba Landscape is widely recognized. WWF Belgium, WWF Congo, the Belgian Development Agency, and CARPE (Central African Regional Program for the Environment) supported by USAID (United States Agency for International Development), finance and manage biodiversity conservation, community-based development, and environmental research programs in the region. The Landscape contains various habitats ranging from terra firma and swamp forests to grasslands, savannahs, and prairies along the Congo River and its numerous tributaries. Partial biodiversity surveys have taken place in the last few years but much remains to do especially at the vegetation/plant use level. Huge and increasing human pressure is threatening the sustainability of the ecosystems through ill-adapted practices, including slash-and-burn or shifting cultivation, forest product harvesting and commercial fishing and hunting (primate, crocodile, bushpig, and elephant for ivory).

The project was developed in five main work-packages (WP1 – Socio-economic analysis, WP2 – Vegetation analysis, WP3 - Fauna analysis, WP4 – Valuation of ecosystem services, WP5 – Sustainability assessment). Owing to field constraints, some of the methodologies has been adapted or upgraded.

WP1 SOCIO-ECONOMIC ANALYSIS

The objective of WP1 was to establish a stakeholder typology by characterization of the demographic situation of the communities present in the study area. We studied people of local communities in order to estimate demographic variables and relationships between people and nature. The multifaceted human-forest interactions, leading to information on subsistence farming, hunting, informal logging, fishing, and the collection of non-timber-forest products was to be analyzed.

The survey of people activities has been conducted in the Ngiri reserve protected area. This 1,000 km^2 triangular-shaped zone extends northwards from the confluence of the Congo River and the Ubangi River. The Ngiri River - a tributary of the Ubangi - snakes through the center of the reserve before joining the Ubangi. A wide zone bordering the Ngiri consists in alternating marshy grassland-savannahs, swamp forests and seasonally flooded forests (Fig. 1). As no other elaborate socio-economic data was available for the Ngiri region, the choice was made to concentrate WP1 study efforts in that zone, rather than in the southern dryland area of the landscape.

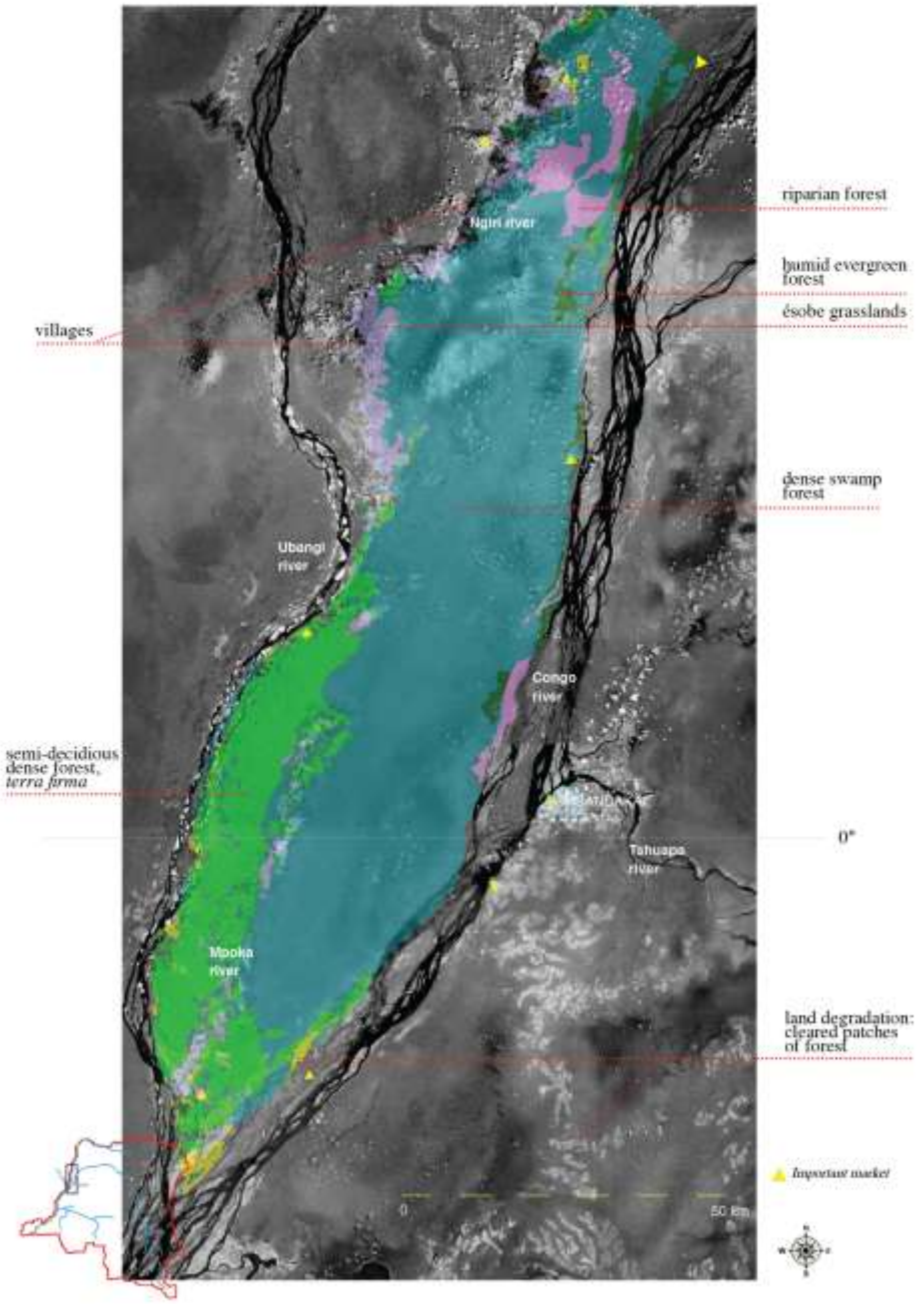


Fig. 1 The Ngiri triangle featuring the dominant habitat types as well as the main rivers: the Congo, Ubangi, Mpoka and Ngiri.

WP2 VEGETATION ANALYSIS

As emphasized in the introduction section, the future of ES in tropical forests and their sustainability mainly relies on the ability of forest to regenerate. The regeneration process is linked with the activities of animals and their function as seed dispersers. The main objective of WP2 was to gather data on vegetation and to prepare tools that would allow to make projections of the forest regeneration process for the present and future conditions by combination with results of WP3. The projections will allow assessment of ecosystem sustainability (WP5). The WP2 objectives have been achieved by gathering vegetation information required for the computation of the potential recruitment of focused tree species and by upgrading CARAIB vegetation model to the simulation of the processes in the context of sustained human pressure assessed in WP1.

Data were (i) assembled from the literature, with, most of the data assembling efforts focusing on the seed dispersal mechanisms and (ii) collected in the field to better constrain seed dispersal rates of the selected tree species. The initial plan was to collect data on five tree species. However, due to field constraints and the difficulties to conduct data collection on a set of different species (i.e fruit production and seed dispersal rates) with the chosen methodology, we decided to collect data on one model species, *Staudtia kamerunensis* (Myristicaceae). Focusing on one species allowed us to gather thorough autecological data for ultimately being able to compute seed dispersal kernel at spatial scale. While the submitted project underlined the pivotal role of primates in seed dispersal, the observations revealed that their presence in the canopy of *S. kamerunensis* was marginal. Information from WP3 might indicate that intensive hunting of the large species (> 1 kg) and among others of the primates would be the cause of their rarity.

Since the exposed methodology limited our ability to understand the functioning of the whole ecosystem, we therefore also focused observations on two other processes in the ecosystem to complement our understanding of the regeneration mechanisms at the community level and to orientate final objectives towards generalization. Firstly, we conducted botanical survey to investigate the composition (abundance and diversity) of the seedling community. The data were intended to report on the effect of anthropogenic pressures (as for the previous investigation on *S. kamerunensis*) on the regeneration capacity and future of the plant community of the whole tree community and more particularly on zoochorous species. Secondly, we investigated the ecological role of a model frugivore species, the bonobo (*Pan paniscus*), on the regeneration of tropical forest. It has to be noted that in some villages, *P. paniscus* is protected from hunting by a taboo and was abundant. In WP2, we gathered data on the selected plant species (tree density, seed production rate), while data on dispersing animal community were collected in WP3 (Fauna analysis).

WP2 has also also deal with the necessary adaptations of the dynamic vegetation model to the studied tropical humid zone. Owing to collaborations with J.-L. Doucet's team of the *Laboratoire de Foresterie des régions tropicales et subtropicales* – ULg (Gembloux), we can make use of a large database of tree species occurrences to derive the bioclimatic thresholds and it was not necessary to define the Bioclimatic Affinity Groups, as initially planned in the project. In such a way, the output of the model (e.g. net primary productivity) has the advantage also to apply to separated species. The model outputs were validated using for instance satellite data.

WP3 FAUNA ANALYSIS

The first objective of WP3 was to gather autecological data for selected tree species. These data were then used for functional analysis and for computing seed dispersal kernels for the tree species selected in WP2. Within the southern part of the Lac Tumba Landscape, we recorded data on the wildlife species visiting the selected tree species, and estimated their relative contribution to primary and secondary seed removal. We conducted specific faunal inventory in order to investigate the effect of the abundance of different large frugivorous species near the focal tree species on seed removal rates (see WP2).

As introduced in WP2 section, the regeneration process of the forest was studied through one single tree species, which limited our capacity to generalize to the whole ecosystem. We therefore investigated the ecological role of a keystone and flagship frugivorous species, the Bonobo (*Pan paniscus*), on the regeneration of tropical forest. This study had two major advantages. Firstly, looking at the zoochorous regeneration process through the animal perspective allowed us to consider a large set of dispersed plant species. Secondly, we improved our database on the ecological role of the Bonobo in a forest-savannah mosaic, a unique ecosystem allowing us to take into account environmental pressures such as the impact of forest degradation, a common reality around the study site.

More generally, we classified the main seed dispersers (large vertebrates) in different functional groups and estimated the quantitative contribution of each faunal group to the dispersal of tree species and others ecosystems services in the "Lac Tumba" Landscape. For this purpose, we collected presence/absence and distribution data during three campaigns of wildlife inventories within the two existing protected areas (PAs) of the Landscape (Natural Reserve of the Ngiri Triangle and Natural Reserve of Tumba-Lediima).

Main dispersers daily travelled distances and seed retention times for each functional group were extrapolated from literature. This information was then used to derive the spatial seed dispersal kernel for the tree species used by the CARAIB vegetation model in WP2.

Within WP3, general distribution and relative abundance of large vertebrate species was extracted from the data collected in the field, to feed a simple sub-model to be developed and implemented into CARAIB. The aim of this sub-model was to estimate the abundance of animal functional groups (including the main dispersers of the tree species) as a function of remaining vegetation coverage and pressure exerted by humans through hunting/poaching, habitat fragmentation, etc.

WP4 VALUATION OF ECOSYSTEM SERVICES

Linking biodiversity management with human needs would yield better integrated policy and management plans (cf. WP6) at a landscape-scale and be more firmly directed towards human well-being (Haines-Young & Potschin, 2012). Therefore, the links between biodiversity and benefits that people derive from nature, i.e. ecosystem services, must be clearly set out (cf. WP1) before their valuation and modelling for the present (WP4) and the future (WP5).

The initial method was to progress in two steps: first, isolate from WP1 results those ecosystem services that can be measured. Second, model the socio-ecological system (SES) in its current state for a subarea, i.e. to the spatial extent of a group of villages, identified during WP1, 2 and 3.

The reality of the field of study counteracted these plans. The methodology was thus adapted as follow. First, identify qualitatively the most prevalent services and the associated levels of revealed threat for associated species. Second, estimate current population figures in order to evaluate a pseudo-average level of services usage per person (WP4). Spatial disaggregation was limited to a distinction between official villages, settled along the river banks. Third, build projection of population change in order to estimate future changes in services usage (WP5).

Despite these difficulties with field works, we were able to use the dynamic vegetation model upgraded in WP2 and WP3, to evaluate present-day ecosystem services associated with the modeled species in the landscape, or at a larger spatial scale (i.e., within most forest ecosystems of Africa). Species were grouped according to the ecosystem services they provide: production of food, production of timber or other materials, production of medicinal plants. The current availability of these services calculated by the model was then mapped over central Africa.

WP5 SUSTAINABILITY ASSESSMENT

The objective of WP5 was to explore a set of climate and socio-economic scenarios for the future and assess the sustainability of the forest ecosystem and the associated production and availability of ES. First, available climate change scenarios from the Climate Model Intercomparison Project Phase 5 (CMIP5, Taylor et al., 2012), developed for the 5th Assessment Report (AR5) of the IPCC, have been acquired and downscaled over the studied area. The methodology used to derive these scenarios is explained in the task description section below. We mostly focused on scenarios corresponding to RCP 4.5 and RCP 8.5 (Moss et al., 2010) of the IPCC. All climate models having simulated these RCP scenarios were evaluated against their skill to reproduce observed climate data (mostly surface temperature and precipitation) in central Africa over the historical period. The five best models were selected to use their downscaled climatic fields as forcing of the CARAIB dynamic vegetation model (DVM). Fully transient simulations of the DVM were performed over the period 1950 to 2100, using these downscaled climatic fields. The outputs of these simulations were then used to assess the evolution of African forest ecosystems in the future. As in WP4, we focused on a set of tree species, which allowed evaluating the change related their ES production through time from the model-predicted change of their net primary productivities (NPP). Other outputs of the DVM were also analysed, such as the soil hydrological budget or the fire occurrence and the estimated burned area. Unfortunately a full coupling of the DVM with the Agent-Based Model has not been possible, in view of the difficulties encountered in WP4, as well due to lack of time. Anyway, spatial maps have been produced for the distribution of some key species, their NPPs and other biological/physical variables. These maps are the basis for the sustainability assessment of ecosystems and their services. Finally, potential rates of ecosystem regeneration after disturbances, due for instance to slash-and-burn agriculture, have been studied with the seed dispersal/species migration module developed in WP2 and implemented in the DVM, but this was limited to *S. kamerunensis*, the focal tree species studied in the field within WP2.

2. METHODOLOGY AND RESULTS

WP1 SOCIO-ECONOMIC ANALYSIS

Authors: A. Baert, P. Van Damme (UGENT)

Introduction

A first specific objective was to establish a stakeholder typology by characterization of the demographic situation of the communities present in our study area. In continuation the multifaceted human-forest interactions, leading to information on subsistence farming, hunting, informal logging, fishing, and the collection of non-timber-forest products (NTPF) was to be analyzed. Socio-economic data was collected on a continuous basis in the period of April - May 2012. This is a somewhat drier period of the year, thus improving field conditions for the research team. More dry land allows for less demanding campsites and easier entry into the forest. Data was collected by means of questionnaires, interviews and through personal observations.

Two types of questionnaires were prepared: A 153-question household survey and a 109-question focus group survey. The household questionnaire inquired on such topics as household composition, recent migration, and group membership. Household subsistence and economic activities, specifically those with some potential environmental impact such as agriculture, hunting, fishing, and the collection of NTFP were studied into more detail. This instrument was used to collect quantitative information to enable the identification of trends and to make comparisons across the landscape. The questionnaire also included qualitative, open-ended questions regarding perceived changes in the availability of resources. However, most household questions were of the closed-multiple choice type to limit interpretation errors. Focus groups are moderated discussions leading a group of people in the discussion of a specific topic. These do not substitute surveys, but rather complement the information collected.

Seventy-two villages in the Ngiri reserve were selected for sampling (Fig. 2). A regional sampling rate of approximately 10-15 % was set forward as an objective. After a 3-day training session, a gender-mixed team of twenty-four people was brought to the Ngiri reserve for the field work *in situ*.

After digitalization, data cleaning and data transformation of the survey results, information from 1,766 households sampled from 72 villages remained. R open source statistical programming software (RStudio) was used for certain calculations and operations. R is a free software programming language and software environment for statistical computing and graphics, accessed through a command-line interpreter.

Demographic typology for parameterization (Task 1.1)

The Ngiri triangle, squeezed between the Ubangi, Ngiri and Congo rivers, is an isolated, poor and generally neglected stretch of land. Dense swamp forests constitute the most-dominant vegetation type. As Fig. 2 depicts, Villages are concentrated on the riverbanks, camps occur wherever certain resources are seasonally available. The people there hold on to a traditional way of living. They rely on water resources not only as a source of food and primary economic gain, but also for transportation, through the rivers that connect them to villages and markets of the region. Table 1 presents a breakdown of the major land-related activities according to geographical entity/river. Attesting village focus group information, only villages close to the Ngiri River, keep cattle as domesticated animals. Data suggests that villages bordering the Lobengo channel connecting the Ngiri and Congo rivers house more hunters than what is considered an average percentage for the region (39% as compared to 20% of households). All other substantial land use activities in the region are on a similar level as the regional average.

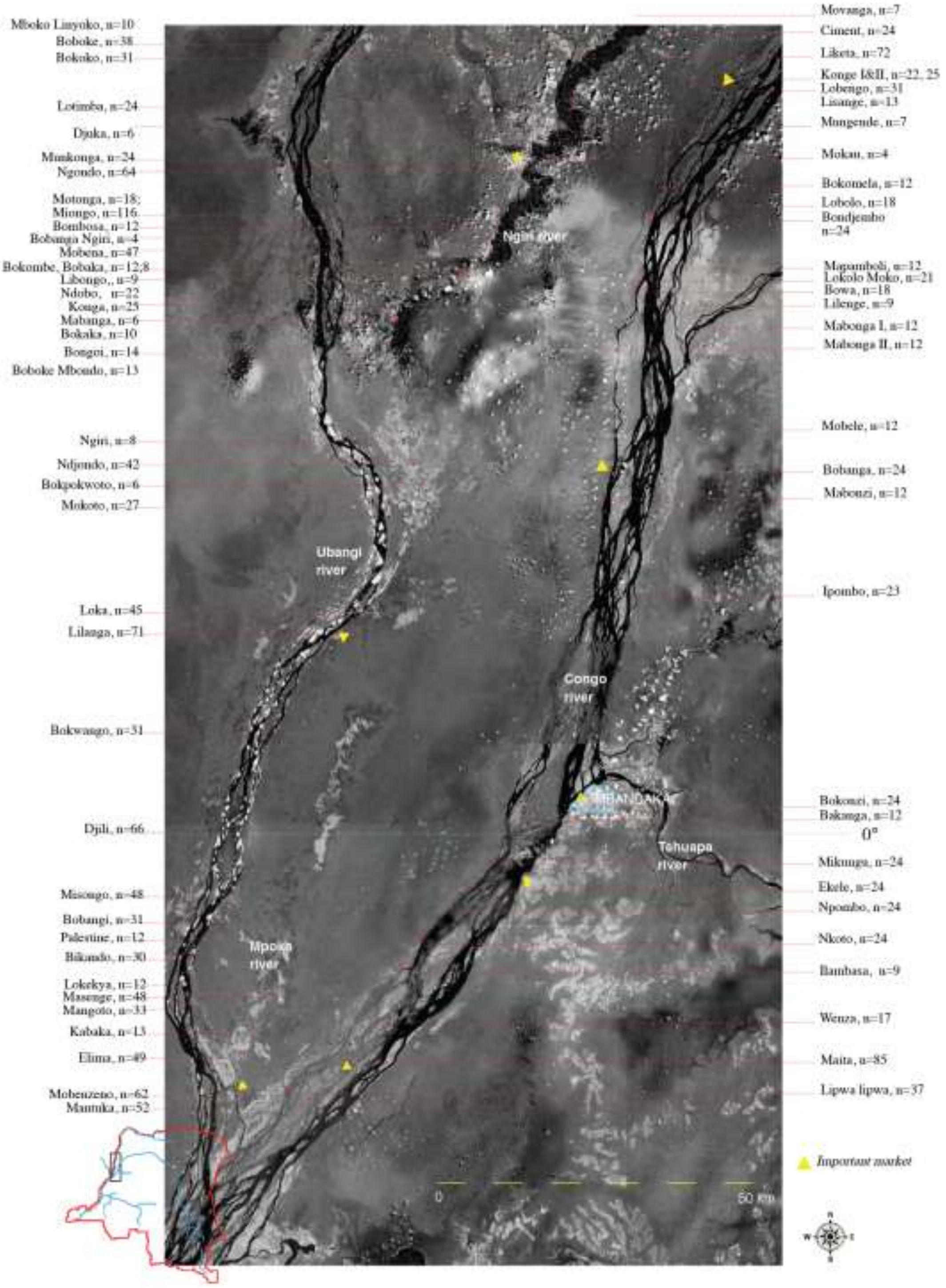


Fig. 2. The Ngiri Triangle featuring The Congo, Ubangi, Mpoka and Ngiri rivers, with 72 sampled villages (red), Mbandaka urban complex (blue) and main market hubs in the region (yellow). The figure (n) associated with each village refers to the number of socio-economic surveys taken in the respective locations, adding to 1,766.

Table 1 Confirmed activity (%, as opposed to confirmed non-activity and no answer) per geographical entity/river.

Geographical entity	**n**	**agriculture**	**fishing**	**collecting/ gathering**	**firewood collecting**	**cattle**	**hunting**
Congo	457	0.82	0.88	0.69	0.98	0.00	0.22
Lobengo	192	0.89	0.89	0.83	0.99	0.02	0.39
Ngiri	514	0.89	0.92	0.69	0.98	0.09	0.20
Ubangi	379	0.85	0.83	0.69	0.98	0.01	0.20
Monyotu/Mpoka	224	0.79	0.81	0.53	0.96	0.00	0.11
	1766						

Table 2 General demographic characteristics of the interviewed households.

		Male	**Female**	**no answe**
Age (year)		41 ± 12	35 ± 11	
Head of household gender (#		1550	154	62
Education (%)	*none*	2.7	7.9	
	primary, not finished	11.2	28.7	
	primary	6.0	11.3	
	secondary, not finished	44.6	36.0	
	secondary school diploma	19.2	4.2	
	higher education	3.5	0.5	
	0/no answer	12.7	11.4	
Primary/secondary activity (%	*fishing*	43.7/14.2	11.4/10.3	
	agriculture	31.3/57.5	56.3/39.1	
	hunting	0.8/2.9	0.1/0.1	
	commerce	2.6/4.6	10.6/13.7	
	others	18.8/12.1	9.3/14.0	
	0/no answer	2.7/8.8	12.3/22.8	
# Children		4 ± 3		
Household size		8		

*CLDC: 'Comités Locaux de Développement et de Conservation' are specific organizations or groups of people united voluntarily to push development in a village on one front or another. They often act as an intermediary between the community and official NGO's and/or the government.

Table 2 presents some general demographic characteristics of the interviewed households. Fishing was quoted as the most important activity for the men (43.7%), followed close by agriculture (31.3%). However, as the second most important daily activity or profession, agriculture was quoted by 57.5% of the respondents against

14.2% for fishing. So we can conclude that most 'fishermen' also practice some subsistence agriculture as a second activity, yet this is not as pronounced as the other way round.

Commercial activities were found to be the third most important activity (7.2% 1st and 2nd activity combined), teaching was fourth (6.8% combined). Hunting and animal husbandry were quoted respectively by 3.7 and 3.2 % of the household heads as either the first or second preferred daily activity. Women are around 35 years old and are predominantly active in agriculture (95.5% combined), small commerce (24.3%), fishing (21.7%), and cooking (13.3%). Actually, all women cook, but apparently 13.3% of woman claimed it to be the first or second most important activity of the day.

Table 3 Information on camps derived from focus group discussions. Camp seasonality and type are given per geographical entity.

	Geographical entity (# villages)					**TOTAL**
	Congo (25)	**Mpoka/ Monyotu (5)**	**Ubangi (10)**	**Ngiri (27)**	**Lobengo (5)**	
CAMPS DURATION						
seasonal	50	8	24	55	15	152
permanent	17	0	3	1	1	22
unknown	4	3	0	3	0	10
CAMP TYPE						
agriculture (A)	2	0	0	1	0	3
fishing (F)	41	8	24	47	2	122
hunting (H)	3	0	1	4	0	8
A+F	6	0	0	1	0	7
A+H	0	0	0	1	1	2
H+F	16	3	2	4	11	36
A+F+H	3	0	0	0	2	5
animal husbandry	0	0	0	1	0	1
TOTAL	71	11	27	59	16	**184**

The village is the central entity of community life, yet many people have lived in a camp or multiple camps in the past and continue to do so today. Table 3 presents some results from the focus group discussions concerning the phenomenon of camps. It can be confirmed from this table that most camps are seasonal fishing camps, sometimes in combination with some hunting and trapping of animals. Agricultural camps are the exception. Each village is on average linked to at least 2 to 3 camps, sometimes many more. Although a camp usually consists of little more then a few very basic huts made from sticks and palm leaves for sleeping and storage, some of them tend to become small villages. Especially on the banks of the Congo River, some larger camps can be found.

Many villages live largely on cassava and maize (Table 4). To a lesser extent sugarcane, plantain and different tubers are grown both for self-consumption and market purposes. Vegetables such as tomatoes, eggplant, peppers, beans and onion are grown at home. Traditional slash-and-burn agriculture is the rule. A more diverse and permanent-plot agriculture could potentially reduce malnourishment and reduce the continued clearing of older forests for shifting cultivation.

Table 4 Focus group discussion results on crop-preference ('1' signifies the preferred crop, '2' signifies the second most preferred crop and so on)

product	**1**	**2**	**3**	**4**	**5**	**share consumed/sold**
cassava	64	4	1			0.58/0.42
maize	1	27	21	11	4	0.32/0.68
plantain		27	17	7	5	0.41/0.59
sugarcane	2	7	17	14	4	0.35/0.65
yam			2	4	4	0.74/0.26
potato/tubers			1	4	4	0.71/0.29
sweet potato (mabenge)				2	5	0.66/0.34
pineapple				1	7	0.50/0.50
others (peppers, tomato, rice, cocoa,	3	3	10	15	14	0.34/0.66
fallow length (years)						4.9 ± 2.3
size largest field (ha)						1.8 ± 1.4
time distance furthest field (minutes)						110 ± 60

Variation in total field area among households is very high. Figures vary between 0.1 ha to 1 ha. Fields outside of this range are exceptional, yet on average total household field area is close to 1 ha. As a rule of thumb, one should count ¼ ha per person. Villages bordering the many bends of the Ngiri River tend to have total household field sizes somewhat smaller than the global average (that is between 0.54 - 0.75 ha instead of 1 ha). Perhaps the bigger reliance on cattle and sheep in these villages because of the presence of large swatches of grassland is one of the reasons. Most households (nearly 80%) interviewed claimed their respective total field area does not suffice. This thus could announce more pressure on the surrounding forests. Literature states that many fields are abandoned even before fertility drops, for instance due to invasive grassy species such as Imperata cylindrica (Poaceae) taking over.

Variation in length of fallow is less pronounced. Most villages indicate fallow duration of less than 4 years. There is a slight correlation between large villages and length of fallow in the sense that such villages tend to wait even less time on average to return old fields into production. It is anticipated that populated villages are more likely to open new forest plots into the system. The exact conditions and parameters steering farmers into the decision to create new fields instead of returning to old ones are of great importance. Results of surveys of tropical deforestation support the view that population growth is never the sole and often not even the major underlying cause of change in forest-cover (Geist and Lambin, 2001). Socio-economic triggers such as devaluation of national currency, price changes of agricultural commodities, social conflicts, and the introduction of contract farming might be of influence (Lambin et al., 2001). Either way, it is clear that monitoring rural population dynamics such as growth rates and in-out migration will be key to better understand rural land use trends.

Fertilizer use is very low. The presence of livestock (as around the Ngiri river) could increase soil nutrient provision around villages, improving agricultural production.

Fields and fallows may extend up to 5 km and sometimes up to 10 km away from the village, but fishing, gathering and trapping might extend for 20 km (focus group discussions). The extent of ‘territories’ used and claimed by agricultural communities are generally quite fixed but not necessarily static. Rights to cultivate certain parts of the forest might only be granted to individuals by the community as a whole until the forest reaches a certain stage in regeneration, at which point it reverts to the community. Colonial and post-colonial governments added to the traditional tenure complexity by agglomerating smaller communities together, such that individuals within any given community might now, through their lineage connections into other communities, retain rights to cultivate land far from their own villages and closer to others.

Each of these arrangements is complex enough, but they are often superimposed on top of each other, creating an enormously complex system that is likely to shift in both time and space. It is sometimes even further complicated by the fact that one ethnic group might at least partly define their own ‘territories’ in terms of another groups’ land use. Conflicts over resources and territories have occurred in the past, and will likely continue to do so.

Seasonal camps do move, so the already complex system of access rights is also constantly moving. As said, along the borders of the Congo River many of these camps are in the process of becoming permanent settlements. Perhaps the possibility of direct sales of fish to passing boats is part of the explanation. Fish is predominantly caught as a means to generate income. Some 90% of the catch is sold. Similarly so, bushmeat – especially higher valued, larger animals – is an important source of cash. With rising demand from urban markets, bushmeat is no longer caught for reasons of subsistence (as it used to be), but again predominantly sold.

The primary and basically only source of energy is wood. Wood is collected in the forests and adjacent fields and fallows, generally not too far from the village. Any dry wood will do, but the most frequently mentioned species are *Guibourtia demeusei* (Leguminosae), *Lophira alata* (Ochnaceae), *Diospyros laurentii* (Ebenaceae), *Uapaca guineensis* and *U. Heudelotti* (both Phyllanthaceae). On average, one household consumes about one bundle or one basket of firewood per day. In contrast to areas south of Mbandaka, charcoal production, use and/or sale is not significant in the Ngiri triangle. Only 6.3 % of households claimed to produce or use charcoal for energy purposes. So, while on the other side of the Congo River woodfuel is charred and bagged for trade on markets, in the Ngiri region consumption is immediate.

Surprisingly, over 90% of households said to put more faith in modern allopathic medicine for the treatment of diseases than in traditional healing methods. This fact was confirmed during focus group discussions as 52 of the villages claimed they preferred modern treatment methods to traditional ones (1 village); 16 villages use both types of treatment. For 3 villages, the answer is unknown. Drugs/medicines are state-provided (56.9% of respondents), distributed through NGOs (11.6%) or available on the market (23.5%). This is rather strange, as in a survey conducted by Ndoye and Awono (2005) in the Equateur and Bandundu provinces of DRC, 85% of households interviewed used medicinal plants to cure common ailments.

Common fruit trees encountered in the villages are banana, papaya, orange, guava and avocado among others. Quite often, some badly attended, derelict cocoa or mango plantations are present. Oil palm (*Elaeis guineensis* - Arecaceae) is also very important as a source of cooking oil. Honey, caterpillars, *Gnetum* spp., insect larvae, kola nuts, palmoil, alcoholic drinks are the most important NTFPs in the region in terms of financial benefits. Charcoal production is important in areas relatively close to urban centers and/or access routes to those centers. On a subsistence level, in addition to NTFPs marketed, lianas, palm leaves, wrapping leaves, some medicinal plants and some fruits/spices are important.

Although the trade in certain products extends across Central Africa, and for a few, as far as Europe and the US (*Gnetum africanum* - Gnetaceae, *Cola nitida* - Malvaceae, caterpillars, larvae) in many remote areas NTFPs are generally self-consumed. The lack of commercial value associated with NTFP may impact decision-making around land transformation from forest to agricultural land because the need to open farmland may take precedence over the importance of NTFP as a subsistence activity for households looking for ways to generate income.

Semi-industrial/industrial logging is totally absent in the water-rich landscape of the Ngiri triangle. All forest exploitation is confined to either the collection of fuelwood (46.4% of respondents), small-scale forest exploitation of hardwood trees for construction timber (2.3%) or a combination of both (29.4%). Harvested firewood and timber are consumed locally and are generally not intended for market purposes.

Our focus group discussions indicated quite clearly that local populations are aware that certain practices and trends threaten the sustainability of their livelihoods through the overexploitation or misuse of resources. Nearly all villages (94.9%) stated that resources are declining. While local perception isn't directly concerned with 'conservation' per se, many of the issues raised by participants are ultimately linked to the state of local ecosystems: declining numbers of species, less fish, eroding river banks, river sedimentation, etc. Major drivers or root causes of biodiversity decline in the landscape need also to be seen in a wider national and political context. Given that there are few current alternatives to resource extraction, it is fair to assume that current trends of land use will continue into the coming years, exercising more pressure on local resources, unless policy changes.

Forests, particularly tropical rainforests, are among the most complex and most productive ecosystems on earth, providing a wide range of direct and indirect ecological, economical, and socio-cultural services on different scales of time and place. Biodiversity is integral to sustainable ecosystem functions and, therefore, vital for maintaining the availability of ecosystem services. Conservation of forest biodiversity therefore appears as a prerequisite for the conservation of the complete array of forest ecosystem functions. However, from a human viewpoint, a very high diversity is not necessarily linked to more useful or valuable forest goods and services. Less species do not necessarily mean less importance.

Stakeholder based valuation of plant-use – a species list (Task 1.2)

The usefulness of plants to humans is a variable concept. Depending on the point of view taken – be it an ecological or a utilitarian perspective - all plants have an unmistakable role to play in ecosystem functioning and represent an enormous gene pool from which humans can take direct benefit. Throughout this project, the concept of plant usefulness must be understood in a more direct fashion, i.e. from a local ethnic perspective. More specifically, it represents the usefulness of plants as perceived by the participants interviewed and reflects the importance of different plants and NTFPs in satisfying daily needs in a practical and/or cash-generating way.

The basis for the following information originates from the same 2012 field-campaign. In that survey, local communities were asked about what plants they preferred for a range of different purposes. Plants were not sampled or photographed. Only oral survey information was collected. The complexity and extent of the mission would render it nearly impossible to gather, dry, prepare and seal good specimen, as no central workspace was installed in the field. The survey-teams were always moving locations.

Our methodology counted the total number of times a certain plant species was cited in different categories. Since for each category and question and for all species all citations of all participants were summed, information on individual participant level was sacrificed. It is thus not possible to know how many different participants cited a certain plant. Only the total number of citations per category remains. Local dialects are inherent to remote places. Many 'species' remain unidentified because of a lack of local knowledge. Collective names could refer to a single species, to a family or an even broader range of species all used for the same purpose; sometimes a local name is used for different species depending on the plant part or use it refers to. Therefore, it is best to discard temporarily the precondition that every single answer allies with a particular species. Instead, it seems to be a safer bet to talk in terms of '*articles*'. Some of these were identified; many others – usually quite scarcely cited –are still awaiting a final identification at this moment unfortunately.

Several quantitative and qualitative indicators were calculated for the 'articles' cited, based on the total information we gathered from the field surveys. Table 5 summarizes some general statistics about the total relevant information obtained. It is split in two parts to separate the information based on the question it was obtained from. The total amount of use reports (*Tur*) sums all use reports found for a particular category or plant part including those 'articles' that were cited only once over all categories/parts; in contrast with the use reports (*ur*) that were retained for further calculations. The difference between the two is the information that is lost because of misspellings, lack of consensus, or because a nonsensical answer was given. The number of participants that answered the question out of the total of 1766 is reflected in the statistic *p*. When the number of retained use reports (*ur*) is divided by *p,* the mean number of responses per participant (response ratio) is obtained. The informant consensus ration (*ICR*) reflects the general agreement that exists for the use and/or importance of certain species. A high ratio (close to 1) signifies that many people pointed to the same species for a certain purpose as opposed to a value close to 0, signifying a very broad number of different species are used for that purpose. A suitable weighing factor (*Wf*) to put a certain importance ranking on the use categories for calculating QUV$_s$ is also given.

A total list of 580 'articles' supposedly referring to botanical species, honey, general plant parts, insects and mushrooms among others resulted from the inquiries made in the field. A total figure of 27,731 use reports (responses or citations) were recorded. A response or citation is defined here as an answer from a participant with regard to a use of a particular plant species/event.

Table 5 General information on use reports (ur), total use reports, thus including articles cited only once (Tur), responses (p), response rate (ur/p), number of unique 'events/species' and informant consensus factor (ICF).

		ur	**Tur**	**Lost (Tur-ur)**	**%**	**p**	**ur/p**	**events / / sp.**	**ICF**	**Wf**
PRODUCT NATURE	leaf	1939	2110	171	0,92	1228	1,6	46	0,98	0,70
	roots	616	800	184	0,77	561	1,1	60	0,90	0,32
	fruits	1580	1894	314	0,83	1042	1,5	91	0,94	0,59
	lianas	1559	1894	211	0,88	1199	1,3	57	0,96	0,68
	weeds/herbs	430	585	155	0,74	448	1,0	41	0,91	0,25
	caterpillar	499	628	129	0,80	469	1,1	42	0,92	0,27
	snails	455	544	89	0,84	469	1,0	22	0,95	0,27
	mushrooms	699	820	121	0,85	628	1,1	43	0,94	0,36
USE-CATEGORIES	food	3487	3744	257	0.93	1338	2,6	73	0,94	0,76
	animal food	1459	1624	129	0,90	600	2,4	35	0,94	0,34
	medicine	2165	2507	342	0,86	969	2,2	71	0,92	0,55
	ritual/social uses	501	592	91	0,85	222	2,3	26	0,86	0,13
	environmental uses	1065	1158	93	0,92	517	2,1	29	0,94	0,29
	poison	737	840	103	0,88	306	2,4	15	0,95	0,17
	construction	3750	4259	509	0,88	1447	2,6	158	0,88	0,82
	materials	1911	2389	478	0,80	856	2,2	106	0,85	0,48
	fuel	4846	5128	282	0,95	1734*	2,8	113	0,93	0,98

* Specifically high response rate. This information was derived from a different question than the remaining use-categories.

The basis for these indicators is thoroughly described in Albuquerque et al (2006), Phillips and Gentry (1993a,b), Byg and Balsev (2001), Carretero (2005) and Paniagua Zambrana (2005).

The 50 most useful species/'articles' were ranked according to decreasing use values (UV_s), together with the total number of use reports (ur_t), quality use value (QUV_s), and use diversities (Uds). The difference *d* between the simple use value index (UV_s) and the quality use value (QUV_s) was also reported. A negative d-value reflects that a lesser weight was given to the use-categories that particular species was cited in. A ranking based on QUVs values largely coincide with one based on UVs values, which in turn largely coincides with the total use reports. Ranking of useful plant species based on use diversity (UDs) values behaves differently. This implies that species with high use values are not necessarily used within most use categories, nor that the different use categories contribute evenly to the total usefulness of a species.

The list reflects the most commonly known and used wild and cultivated plant species and plant parts sharing similar purposes. According to the answers given in our socio-economic survey, large understory leaves such as those from the species *Megaphrynium macrostachyum* (Marantaceae) are among the most widely used and appreciated plant parts. Such leaves are used for wrapping food (for instance cassava sticks before cooking), packing and thatching. Leaves in general (*kasa*), are widely used be it as a source of food, a medicine or a material. Smaller leaves (*Thaumatococcus daniellii* - Marantaceae) also function as hygienic paper. *Guibourtia demeusei* (Fabaceae) is the most cited type of hardwood in the region, used for timber, as a fuelwood and for its resin, which can be used as lightning when ignited. Other important construction and fuelwood species are *Xylopia aethiopica* (Annonaceae), *Uapaca* spp., *Allanblackia floribunda* (Garcinieae), *Oubanguia africana* (Annonaceae), *Lophira alata, Nauclea diddericchi* (Rubiaceae), and *Cynometra sessiliflora* (Fabaceae) among others. Straight trunks of *Chlorofora excelsa* (Moraceae) are especially important for the construction of canoes. Different types of lianas are widely recognized as important sources of building material (ropes, etc.). Next to some further unspecified weeds and herbs, the vine *Morinda morindoides* (Rubiaceae) was cited as the most important medicinal plant. *Gnetum africanum* is a popular wild food plant, as are different kinds of mushrooms and mollusks. *Eleies guineensis* serves as a multifunctional tree, oil being its primary product used to cook and to thicken sauces. *Synsepalum dulcificum* (Sapotaceae), *Mammea africana* (Calophyllaceae) and *Afromomum* spp. (Zingiberaceae) are among popular wild fruit sources.

Value and origin of market commodities (Task 1.3)

As the largest city in an otherwise scarcely populated province, Mbandaka is the main trading and transportation hub of the region. . To assess the 'usefulness' of certain plant and animal products in contributing to household incomes, 5 important markets were sampled. Information on pricing, availability, seasonality, quantities traded and origin of products was collected here. Ideally a beginning of an understanding of product origin and fluxes in the wider region could begin to settle. Charcoal, for instance, is typically produced not only within cities, but also imported from along transport axes to city centres. Prices for charcoal can triple once it reaches urban markets, as is often the case for bushmeat. Data collection took place in April 2014. The most important markets for trade in natural products around Mbandaka were selected. This information was made available via a Congolese consultant specialized in socio-economic market survey research in the region, who was hired for data-collection on those markets. Each market was visited for a whole day on that market's busiest day. Stall vendors were selected in a random fashion. As every market was visited only once, representativeness is not guaranteed. Ideally, a market should be visited several times in the timeframe of one month, several times per year to account for seasonal variability. Prior to any interview, the research objectives and methods were clearly presented to the respondent. To be able to focus on the desired information, we used a to-the-point questionnaire with open-ended questions.

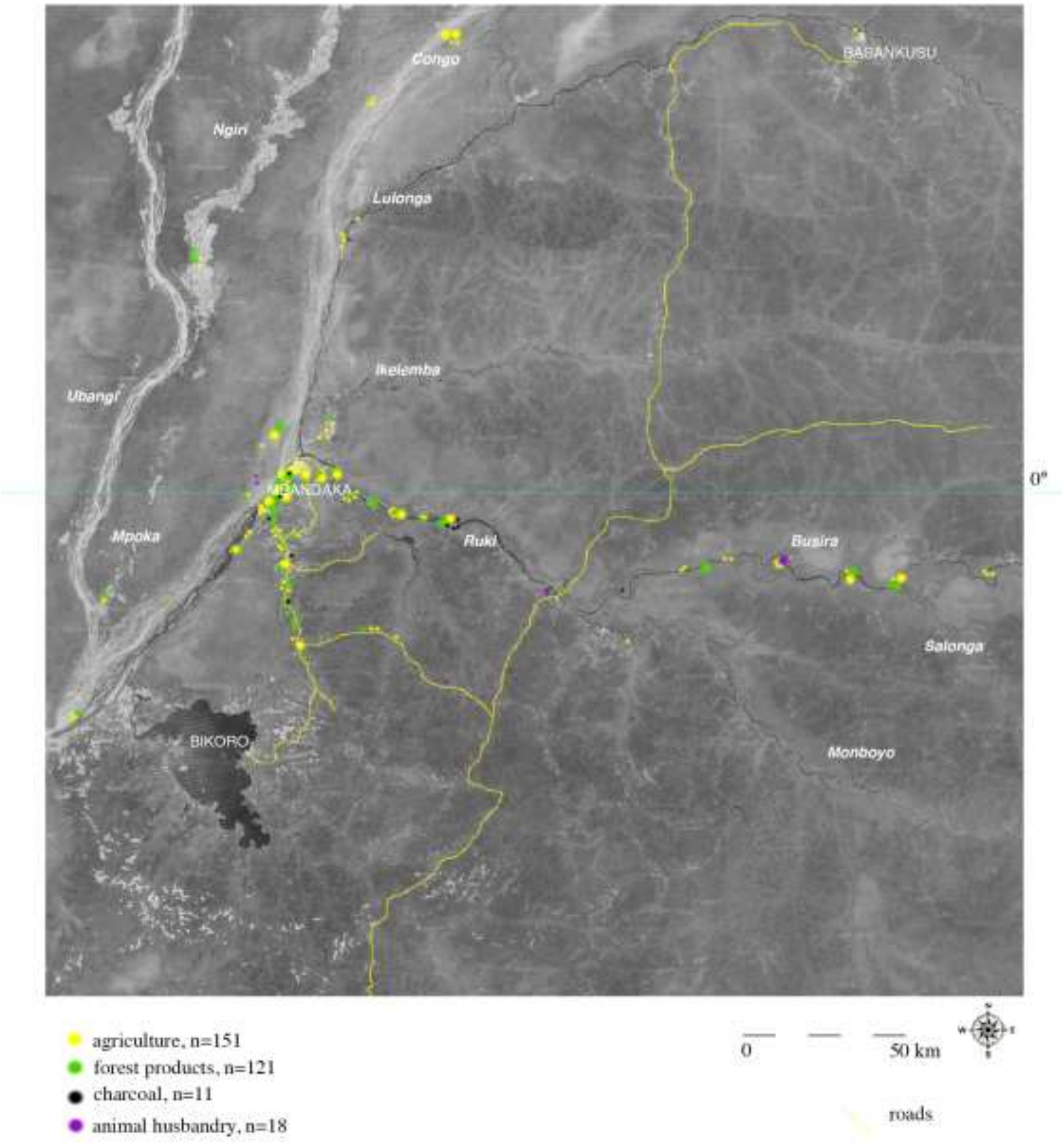


Fig. 3 Origin of plant products (agriculture, forest products, charcoal) and domesticated animals surveyed on 5 markets in and around Mbandaka.

Fig. 3 and 4 present the geographical distribution of the source sites/markets of products sold on the Mbandaka markets from vegetative and animal origin, respectively. Agricultural produce, charcoal and forest products are sourced from predominantly three axes: (*i*) the outskirts of Mbandaka; (*ii*) the Mbandaka – Bikoro axis and all the villages and communities along that road (Bolenge, Wangata, Iyonda, Lofosola, Ilema, Itipo, Bogonde, Buya, Kolikoli, etc.); and (*iii*) the communities along the Ruki river.

Quite the contrary, nearly all bushmeat found on the Mbandaka markets during the time of survey originates from the Busira/Salonga region. Markets and villages along the Busira River such as Lingunda, Boleke, Bokote and Loolo are important trading places not only for wild animals, but also for forest products coming from the nearby Salonga national park. Sometimes riverine species like crocodiles and turtles are caught in fishing nets in the Congo River as a by-catch. Varans and snakes are usually not sought for, but killed opportunistically when encountered to sell on local markets. Smaller monkeys (*Cercopithecus* spp. and *Colobus* spp.) are the most important type of bushmeat. They are often offered charred and smoked beyond recognition.

The Ngiri triangle is not very well represented on the Mbandaka markets. Agricultural products and NTFPs from that area are basically auto-consumed and traded on local markets only, while fish and bushmeat are being sold to large pack boats bound for Kinshasa which thus generally neglect Mbandaka as a stop-over place. Additionally, much of the wildlife has been severely reduced in numbers to the point that some species have been locally exterminated around village influence zones and are now found only in the swampier areas which are harder to access. There is also an important market situated somewhere at the southern edge of Lake tumba. Via the Iberu channel connecting this lake and the Congo river, products brought to this market go straight down to Kinshasa.

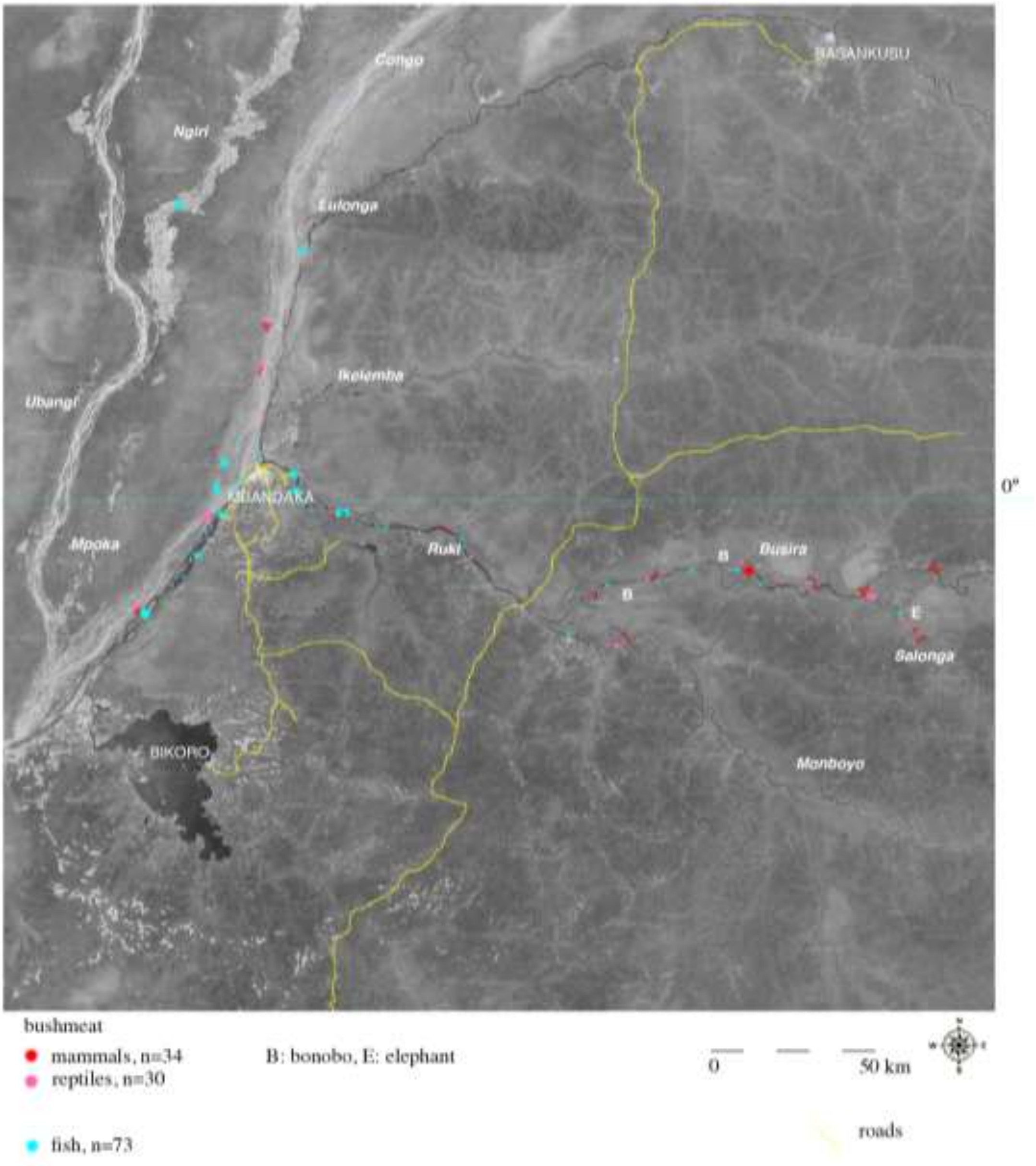


Fig. 4 Origin of wild animal products (bushmeat and fish) surveyed on 5 markets in and around Mbandaka.

A list of the 438 products surveyed on the Mbandaka markets including information on product, availability and average pricing was produced. As bushmeat, *Cercopithecus* and *Colobus* monkeys, dwarf crocodile (*Osteolaemus tetraspis*), small turtles and red river hog (*Potamocherus porcus*) are the more common animals found. However, protected animals such as bonobo (*Pan paniscus*) and forest elephant (*Loxodonta africana cyclotis*) were also encountered. *Clarias buthopogon* and *Channa obscurus* are the most important resources of fish. Cassava, peppers, yams and maize are frequently found agricultural products while lianas, palmoil and palm nuts (*Elaeis guineensis*), larvae and kola nut (*Cola acuminata* - Malvaceae) are frequently found NTFP. Charcoal is also readily available on urban markets.

Identification of Key ES services (Task 1.3)

Tropical rainforests are among the most complex and most productive ecosystems on earth, providing a wide range of direct and indirect ecological, economical and socio-cultural services on different scales of time and place (Table 6). On the most local of scales, the Ngiri forests form the habitat and life support system of the local populations living in and around their confines near dusty roads and wide rivers. It is their primary source of energy, food, medicine, shelter, water, and frequently adds to their small incomes by providing bushmeat, charcoal (near urban centra), fruits, and larvae, etc. to sell. It is also their land reserve for agricultural expansion. However, tropical forests also provide a set of less tangible services and benefits, often operating on a larger, regional scale, such as soil formation, climate and hydrological regulation, moderation of temperature and water flow, etc. On a global scale, it is hard to underestimate the importance of tropical rainforests in stocking global terrestrial carbon. Balancing the inherent trade-offs between satisfying immediate needs and maintaining general ecosystem functioning is of great importance and requires knowledge about ecosystem responses to changes in land use (Defries et al., 2004). In the end this balance depends on societal values and political and economical orientations.

Table 6 A summary of ecosystem services in the Congo Basin (based on the division of categories as introduced by the Millennium Ecosystem Assessment (2005)

SERVICE TYPE	**Category**	**Congo Basin Ecosystem Services**	
		Water Resources	***Forest resources***
PROVISIONING	food	fish, turtle, etc.	wild animals, fruits, insects, wild honey, weeds, vines, herbs, etc.
	water (quantity)	water for drinking, washing, toilet, etc.	vegetation influence
	materials		fibers, timber, fertilizer, wax, colors for dyes, etc.
	energy	hydropower potential	woodfuel
	genetic res.		botanic potential
	medicinal res.		medicinal plants, bark, biochemical potential, etc.
	ceremonial res.		skins, fetish objects, etc.
	fodder		animal food
	ornamental res.		flowers, plumage, animal parts, etc.
	transportation	boat transport, navigation	
REGULATING	climate		C-stock, effect on cloud formation, rainfall and temperature, etc.
	moderation of extreme events		*Flood control? scale matters*
	erosion prevention		effect ground and vegetation cover
	pollination		animal vectors required
	seed dispersal		animal presence required
	water quality/purification		buffer, sediment load, biological purity
	water flow		seasonal distribution, timing
	natural pest control		pests controlled by natural enemies: birds, bats, beetles,

			fungi, etc.
CULTURAL/ AMENITY	recreation & tourism	non-consumptive tourism (Pure Congo, travel companies, etc.)	
	spiritual, inspirational experience		sacred forest, forest cemetery
	educational		
	cultural heritage/ identity		
SUPPORTING/ HABITAT “make all other ecosystem services possible”	nutrient cycling		filter; storage, processing, acquisition of nutrients
	maintaining soil quality		nutrient cycles, chemical and biological transformations, accumulation of organic material, etc.
	maintenance of life-cycle of migratory species	The Ngiri savanna corridor constitutes an important migration flyway.	
	maintenance of genetic diversity		

WP2 VEGETATION ANALYSIS

Introduction

This section is constituted of 4 subsections. The first one is the final selection of tree species to be studied (Task 2.1). The second one exposed the adapted Task 2.2 i.e. Collecting ecological data on the five tee species (it used data coming from Task 3.1). For this study, we benefited of the close collaboration of P.-M. Forget (Muséum d'Histoire Naturelle de Paris) and will be soon submitted to an ecology journal. The third part exposes the methodology applied to collect information on regeneration community (adapted Task 2.2). The two last parts expose the upgrade of the DVM for studying local forest production and regeneration (Task 2.3) and the validation of the present situation using remote sensing and field data (Task 2.4).

Selection of five ecosystem services related tree species indicators of forest change (Task 2.1)

The species were selected according to abundance in the study area, existence of data about their dispersers and reported uses (Table 7).

Table 7 Selected species in the study site for their abundance and ES

Name	Family	Dispersers	Uses
Staudtia kamerunensis	Myristicaceae	*Ceratogymna sp.*[2,3,4] *Civettictis civetta*[5]	logs; medicines
Annonidium manni	Annonaceae	*Pan paniscus*[7]	Fruits[6]; medecines[1]
Chrysophyllum lacourtianum	Sapotaceae	*Loxodonta cyclotis*[9,10]	logs ; fruits
Myrianthus arboreus	Moraceae	*Loxodonta cyclotis*[9, 10] *Cercopithecus*[11]	Fruits; medecines[8]
Annickia chlorantha	Annonaceae	*Pan paniscus*	Medecines[12]

[1]Betti, 2004 ; [2]Holbrook & Smith, 2000; [3]Whitney et al., 1998; [4]Clark et al., 2001 ; [5]Pendje, 1994 ; [6]Termote et al., 2011; [7]White, 2005; [8]Biapa et al., 2007 ; [9]Danquah & Oppong, 2007 ; [10]Theuerkauf et al., 2000 ; [11]Hladik & Hladik, 1969 ; [12]Adesokan et al., 2007

Hunting pressure and forest fragmentation increase seed dispersal failure of Staudtia kamerunensis (Myristicaceae) in forest-savanna mosaic of northern DR Congo (Task 2.2 and 3.1)

<u>Authors</u>: F. Trolliet, M.-C. Huynen, P.-M. Forget, A. Hambuckers (ULG-ENV)

Introduction

It is now widely recognized that the regeneration of tropical forests highly depends on the action of frugivores which disperse seeds away from parent plants (Howe & Smallwood, 1982; Wang & Smith, 2002). However, there is a raising number of studies proving the harmful effects of anthropogenic pressures on ecological functions such as animal-mediated seed dispersal. Studies have shown that bushmeat hunting

(Beckman & Muller-landau, 2007; Wang et al., 2007; Holbrook & Loiselle, 2009; Markl et al., 2012; Abernethy et al., 2013) and forest fragmentation (Cordeiro & Howe, 2003; Galetti et al., 2003; Galetti et al., 2006; Kirika et al., 2008; Jesus et al., 2012; Kurten, 2013) alter the animal community susceptible to interact with plants and can disrupt different components of the seed dispersal processes. For instance, a decrease in frugivore abundance and diversity can be associated with a lower frequency of visitation rate and a decrease in the number of seeds removed, as well as shorter seed dispersal distances (Markl et al., 2012). Also, other components of the seed dispersal loop can be affected by hunting such as pre and post-dispersal seed predation (Beckman & Muller-landau, 2007). Through a meta-analysis, Markl et al. (2012) showed however that fragmentation was not associated with a reduction in the number of seeds removed.

Yet, while a significant amount of work dealing with those problematic have been conducted in the neo-tropics (see Markl et al., 2012 for a non-exhaustive list of studies), relatively few studies have investigated the impact of either hunting (Kirika et al., 2008a; Wang et al., 2007; Babweteera & Brown, 2009; Babweteera, 2009) or habitat fragmentation (Cordeiro & Howe, 2003; Farwig et al., 2006; Kirika et al., 2008b ; Neuschulz et al., 2011) on primary or secondary dispersal in Africa (Aliyu et al., 2014). Moreover, rare studies have considered and proved the effect of those two major threats together (but see Galetti et al., 2006). The African continent holds however the largest frequency of large frugivores on Earth (Forget et al., 2007), including four of the six great ape species (*Pan paniscus*, *Pan troglodytes*, *Gorilla gorilla* and *Gorilla beringei*) and the forest elephant (*Loxondonta cyclotis*). Also, the threat to Afro-tropical frugivore communities is substantial, with a rate of bushmeat extraction much greater than in the Neo-tropics (Fa et al., 2002) and affecting primarily larger species (Fa et al., 2005). The four great ape species are for that matter classified as either endangered or critically endangered on the IUCN redlist (IUCN 2015). It is therefore particularly important to investigate the consequences of anthropogenic threats on seed dispersal and seedling establishment capacities of zoochorous plants in Afro-tropical forests.

The family Myristicaceae is of increasing scientific interest and ideal to study zoochorous seed dispersal (Queenborough et al., 2013): it has characteristic fruits allowing efficient estimates of seed production and removal (see Material & Methods) and an arillate seed known to attract large frugivorous birds and primates and of relatively large size (Queenborough 2013), thus allowing to detect more easily the impact of defaunation on seed dispersal (Markl et al. 2012). As a pan-tropical family having a consistent fruit morphology across tropical regions it allows easy inter-continental comparisons. Still, the family is a good example of this inter-continental imbalance: seed dispersal process of Myristicaceae species has been widely studied across the Neo-tropics (e.g. Howe, 1981; Forget, 1991; Forget et al., 2000; Russo, 2005; Forget & Cuijpers, 2008; Ratiarison & Forget, 2013; Boissier et al., 2014) compared to the paleo-tropics. In Africa, it has only been studied in the lowland rain forest of the Dja Reserve, Cameroon, on *Staudtia kamerunensis* (Whitney et al., 1998; Holbrook & Smith, 2000; Clark et al., 2001; Clark et al., 2004; Clark et al., 2005) and the effects of human disturbances on seed dispersal have not yet been investigated.

Several studies show that the quantity of fruit available might influence frugivores visitation rate and the quantity of fruit removed at both the tree scale (crop size) and the neighborhood scale (Korine et al., 2000; Saracco et al., 2005; Ortiz-Pulido et al., 2007; Blendinger et al., 2008; Blendinger & Villegas, 2011 ; Prasad & Sukumar, 2010; Flörchinger & Braun, 2010; Bravo, 2012). Also, two of the African hornbill species

(*Ceratogymna atrata* and *C. cylindricus*) known to disperse the seeds of *S. kamerunensis* (Clark et al., 2005), are able to track fruit resources over large areas (Whitney & Smith, 1998) and thus likely to move between forest patches.

Here we investigated how forest fragmentation, hunting pressure, abundances of large frugivores and fruit availability influence seed dispersal capacities of *S. kamerunensis* in contrasted sites across a forest-savanna mosaic landscape in Democratic Republic of the Congo.

Material and methods

Study area and forest sites

The study took place in western D.R. Congo, around the WWF-Malebo research station, in the Bandundu province, (2°27′ S, 16°28′ E). Annual rainfall averages 1500mm. The main dry season occurs between June to August and is followed by the main rainy season between September to January, itself followed by the consecutive small rainy and dry seasons between January to May. The study area is situated in a forest-savanna mosaic, an ecosystem characterized by a mix of tropical semi-evergreen lowland rain forests and herbaceous savanna matrix, representing respectively around 60 and 40% of the total area (Inogwabini et al., 2008). The forest cover is highly fragmented, characterized by a system of patches and corridors of variable sizes and shapes, mainly associated with the hydrographic network of brooks and small rivers. This landscape can be considered as semi-natural ecotone. It reflects the transitory vegetation between the extensive lowland rain forests of the central Congo Basin (the "Cuvette Centrale") and the savannas expending in the South. Still, cattle ranching activity and the associated yearly fire regimes maintain the fragmented structure and prevent the re-colonization of forest. Slash-and-burn agriculture largely encroaches on forest patches.

We conducted field work in five forested study sites in a section of about 300 km² within the mosaic landscape (Fig. 5). The two most distant sites are spaced by 30 km. The Mbanzi and Nkombo sites are situated in an extensive forest bloc (>500 km²) whereas the tree others are situated 9 km lower in a more fragmented area: Minkalu is a forest patch of 4,6 km², Nkala N. and Nkala S. are both located in a forest patch of 17.6 km². The 5 sites have therefore contrasting levels of surrounding forest cover. Mbanzi village, originally founded in 1982 as a hunting camp, and is now home to around 600 people and still inhabited by many hunters. Therefore, the forest around is supposed to be subject to relatively high hunting pressure. The Nkombo forest is located further away from human settlements and anthropogenic pressure is probably more limited compared to the other sites, which are all parts of nearby village's community are where subsistence hunting activities and slash-and-burn agriculture take place. The Nkala-North, Nkala-South (respectively Nkala-N. and Nkala-S. hereafter) and Minkalu are located in a more densely populated area where hunting pressure is high, yet home to an ethnic group which do not hunt bonobos following a traditional taboo. As part of the conservation programs of the WWF-RDC (World Wide Fund) and MMT (Mbou-Mon-Tour) NGO's, the Nkala forest (including the two sites Nkala N. and Nkala S.) has a community-based conservation status and hunting pressure is theoretically limited.

Study species

Staudtia kamerunensis var. gabonensis (Myristicaceae) is a common emergent tree found in afro-tropical rainforests. It produces dehiscent berries composed of two valves and a large seed (28.2 x 17.7mm) surrounded by a bright red-colored fleshy aril, which mature during the dry season (June-August). Dispersal of *S. kamerunensis* seeds seems to depend a lot on hornbills (Clark et al., 2001; Clark et al., 2005), even though the lipid-rich berries are known to attract bonobos (Idani et al., 1994; Beaune et al., 2013), chimpanzees (Head, 2011) as well as other primates (Gautier-Hion et al., 1985 ; Poulsen et al., 2001; Poulsen et al., 2002).

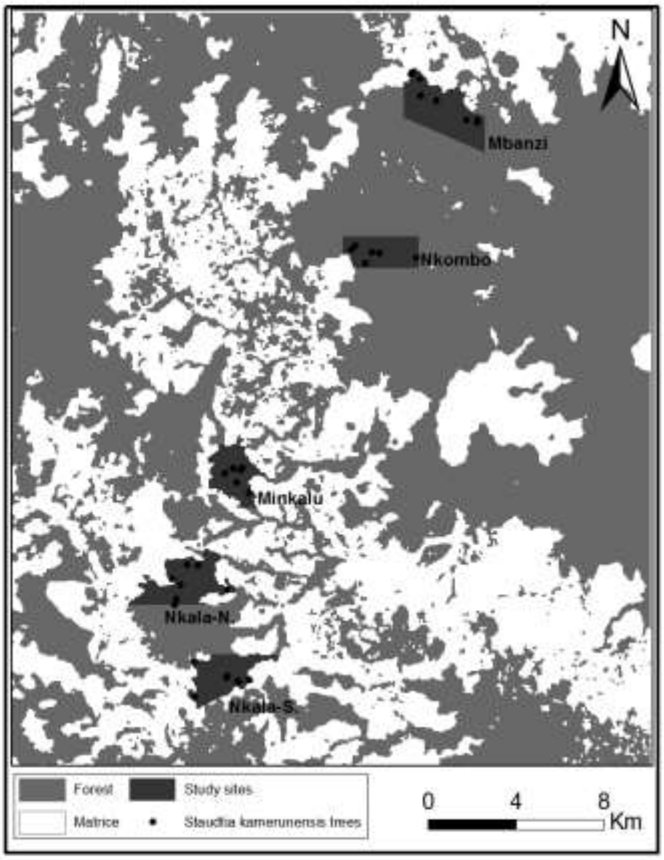


Fig. 5 Study area in the forest-savanna mosaic of Western D.R.Congo, with the five sites (Mbanzi, Nkombo, Nkala-N. and Nkala-S.) and the 34 *Staudtia kamerunensis* trees.

Hunting pressure and abundances of frugivores

We quantified the diversity and abundance of the main frugivores species susceptible to disperse seeds of *S. kamerunensis* (i.e. hornbills and primates), as well as hunting activity, by conducting a surveys on a system of line-transects and REConnaissanCE (RECCE) transects (Vanthomme et al 2010) for a total of 131 km across the five sites. We recorded all direct and indirect traces of frugivores presence (feces, footprints, calls, nests...) and hunting activity (rifle cartridges, gunshots, traps, fires). As a mean of quantification, we summed up all observations found for each category (hornbills, primates and hunting activity) and calculated Kilometric Abundance Indexes (KAI, observations/km), a method allowing efficient inter-sites comparisons (Mathot and Doucet 2006).

Forest fragmentation

To quantify forest fragmentation we used a Landsat 7 satellite image of the study area with the software ArcGis (version 9.3). We firstly conducted an unsupervised classification of the vegetation to obtain a simplified image with two classes accounting for forest and savanna. We then defined ring buffer zone of 3 km radius around each of the 34 *S. kamerunensis* trees. Within each of those ring buffer, we quantified the number of forest pixels and savanna pixels using the Thematic Raster Summary function in Hawth's analysis Tools extension. We could finally compute a percentage of forest cover around each single tree as a way to quantify forest fragmentation. Due to the complexity of habitat structure in the mosaic (i.e forest patches are not clearly delimited but connected with a system of forest corridors and surrounded by isolated forest islands, and savanna inclusions are found within forest patches), we believe this method to be really efficient at characterizing levels of forest fragmentation around each tree.

Staudtia kamerunensis' fruit availability

To quantify fruit availability at the forest scale we recorded and measured the diameter at breast height (DBH) of all *S. kamerunensis* fruiting tree on the line transect system. We calculated an index of fruit availability for each site by summing up the basal area of all fruiting trees. The index is therefore a function of both *S. kamerunensis* fruiting tree density and trunk size (DBH). DBH is known as the most accurate way to estimate fruit abundance of tropical trees (Chapman et al., 1992).

Fruits-frugivores interactions

To define the diurnal frugivore assemblage feeding on *S. kamerunensis* fruits we conducted a total of 121.5 h of focal observation at fruiting trees between 2012 and 2013 across the 5 sites. Due to dense foliage, the visibility was low and we could not systematically observed each feeding events. To determine the contribution of each frugivore species on seed removal rate we recorded the time spent in the tree by each individual. We used 10x42 Nikon Monarch binocular to perform observation during sessions between 6 am-10 am and 3 pm-6 pm and regularly changed focal tree to scan a maximum of fruiting trees during each session. Observation at each tree lasted from 5 to 40 minutes depending on the distance to the next focal tree.

Estimates of seed production and seed dispersal failure

To measure seed production and removal at fruiting trees we followed the method of Howe & Vande Kerckhove (1981). We set up from one to four fruit collectors (2,25m² each) made of plastic mesh below fruiting trees to cover at least 5 % of the canopy projection area on the floor. We hanged them up to the surrounding vegetation at 1.5 m above ground level to prevent animal to get in. We installed fruit collectors below the canopy of 34 trees in the five sites in 2013. From the beginning to the end of the 2013's fruiting season, we weekly collected all fruits and seeds found in the collectors and classified them into four categories following Boissier et al., (2014): (1) intact open fruit (naturally dehisced fruit with two valves and a seed), (2) empty fruit (two valves without seed), (3) single fruit valve and (4) seed. We calculated the fruit production as the sum of the number of whole fruits, empty fruits, and single fruit valves divided by 2 during the whole fruiting season. To obtain the tree crop size we extrapolated this estimate to the whole crown area *Ca* which was calculated as:

$$Ca = \frac{\pi r_n r_e}{4} + \frac{\pi r_e r_s}{4} + \frac{\pi r_s r_o}{4} + \frac{\pi r_o r_n}{4}$$

Where r_i are the projection of the radius from the trunk to the terminal branch in the four cardinal directions. We derived from this count the proportion of seed dispersal failure SDF, i.e. the proportion of seeds which failed to be dispersed away from parent tree. It is calculated as:

$$SDF = \left(\frac{S_T}{F_T}\right) \times 100 \ = \left(\frac{S_g + F_i}{F_i + F_e + F_b}\right) \times 100$$

where S_T is the number of undispersed seeds (S_g being the number of loose seeds found on the ground and F_i the number of intact open fruits) and F_T the number of fruits produced (F_e being the number of empty fruits and F_b the number of broken fruits (half the number of single valves)), given that each fruit contain a single seed.

Statistical analysis

We used R software. We firstly tested whether SDF could be considered normally distributed using the Kolmogorov-Smirnov test (fitdistrplus package of Delignette-Muller & Dutang 2015). To determine which variables influenced SDF, we firstly proceeded to univariate analysis using linear mixed models to screen out variables with statistically non-significant effect with the function lme of the nlme package (Pinheiro et al. 2015). Determination coefficients were computed using lmmR2 function of the lmmfit package (Maj 2011). We included a random effect of the dependent variable with an exponential spatial correlation structure, according to Dormann et al. (2007). This first step allowed us to lighten the following multivariate analysis in which we considered quadratic effects and two by two interactions. Due to the very high number of candidate models, we used the glmulti package, which allows for model selection among all possible candidate models by fixing a maximum number of effects to include. We fixed this number to five. The model selection was based on AIC but we added the condition that the factor t-test of the included effects must have a p-value ≤ 0.05.

Results

Study sites characteristics

The five selected sites were highly contrasted in terms of mean percentage of forest cover (50-88.6%), fruit availability (0-5266 cm^2/km), hunting pressure (0.9-1.66 obs./km), and abundance of frugivores (hornbills: 1.76-4.36 obs./km; primates: 0.47-4.96 obs./km) (Table 8)

Fruit-frugivore interactions

During the focal observation sessions at fruiting trees, we observed the white-thighed hornbill, *Bycanistes albotibialis* (Bucerotideae), for more than 95.5% of the time with a frugivore present in a tree (when considering observations made at all sites together and at each site separately), visiting fruiting trees at a rate of 1 visit/hr. This result confirmed the observation made by Clark et al. (2005) in Cameroon where hornbills accounted for 95% of visits and *B. albotibialis* was the main visitor at *S. kamerunensis* fruiting trees. Another species, the black-casqued hornbill, *Ceratogymna atrata* (Bucerotideae), was observed to enter fruiting trees at five occasions, and a red-tailed monkey, *Cercopithecus ascanius* (Cercopithecideae), was only observed to enter a tree once.

Seed dispersal failure

SDF had a mean of 72.4% (± 38.9), but show great variations across the mosaic with value as low as 17.6% (Mbanzi) and reaching particularly high values, above 100% and up to 177.9% (Nkala-N.). Those particularly high percentages indicated a higher number of seeds found relative to fruits (i.e estimate of the number of seeds produced). Overall, five trees had values of seed dispersal failure above 100%. Four of those trees are in Nkala-N. and one in Nkala-S. Those two sites were characterized by the lowest mean forest cover around the study trees (51.5% ± 4.8 and 50.0% ± 2.5, respectively) and the highest *S. kamerunensis'* fruit availalibity (5266 and 2456 cm^2/km). Inversely, the two lowest mean value of seed dispersal failure were found in Mbanzi (48.7% ±22.5) and Nkombo (51.1% ±10.1), the two sites in the continuous forest bloc, having therefore the highest mean value of forest cover around trees (Mbanzi: 71.2% ± 9.5; Nkombo: 88.6% ± 5.8). Those two sites were also characterized by the two lowest values of *S. kamerunensis'* fruit availability (683 and 0 cm^2/km, respectively). In Nkombo, the value of 0 cm^2/km indicated that no fruiting *S. kamerunensis* tree was found on the transect system

Table 8 Characteristics of five sites in the forest-savanna mosaic in Western D.R. Congo

Site	**Forest patch area (km^2)**	**Mean % of forest cover* ± SD**	**Fruit availability index (cm^2/km)**	**Kilometric Abundance Index (KAI, observations/km)**				
					Frugivore abundance			
				Hunting pressure	***Bycanistes albotibialis***	**All hornbills**	***Pan paniscus***	**All primates**
Mbanzi	>500	71.2 ± 9.5	683	1.19	3.13	3.82	0	0.94
Nkombo	>500	88.6 ± 5.8	0[a]	0.46	4.36	5.85	0	0.47
Minkalu	4.6	54.2 ± 4.7	239	1.28	2.24	2.62	1.1	1.35
Nkala-N.	17.6	51.5 ± 4.8	5266	1.66	1.76	1.85	4.11	4.56
Nkala-S.	17.6	50.0 ± 2.5	2456	0.9	2.23	3.08	4.28	4.96

* Forest cover calculated within a 3km radius around each tree

[a] Index calculated on the basis of fruiting *S. kamerunensis* trees found on the transects

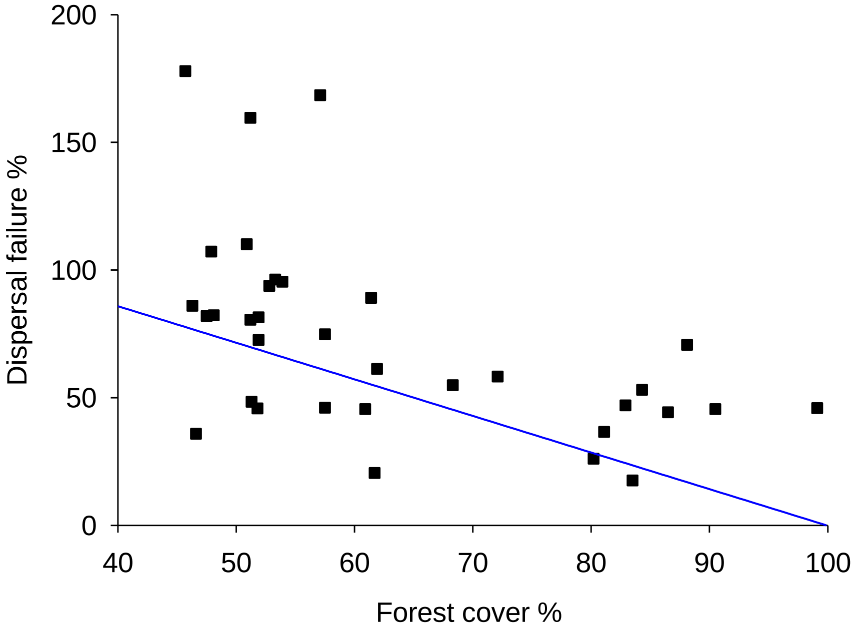


Fig. 6 Scatter plot of percentage of forest cover against percentage of seed dispersal failure. Each square indicates a tree. The line indicates the model simulation. Lower forest covers were associated with higher proportions of seeds failing to disperse and trees with higher forest cover around knew lower proportion of dispersal failure (i.e. highest proportions of seed dispersal).

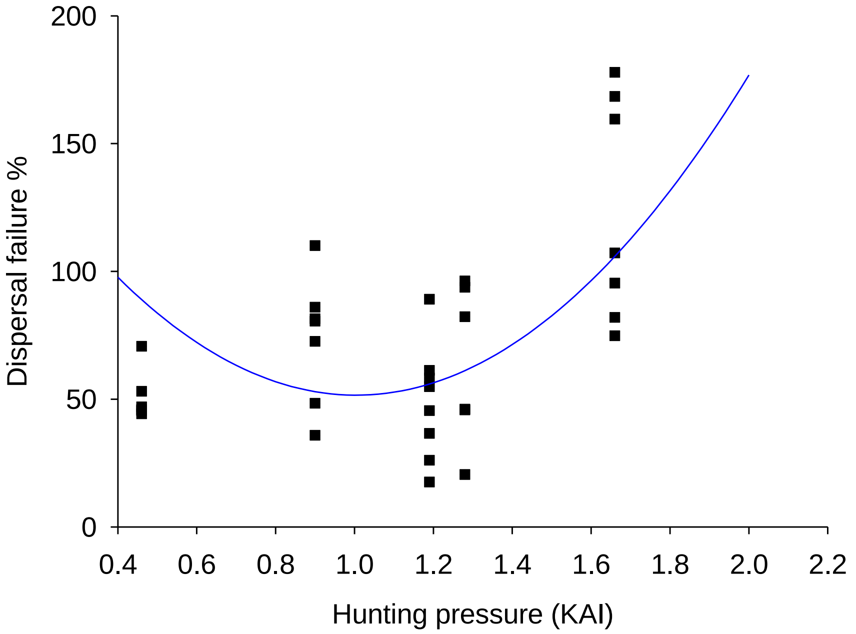


Fig. 7 Scatter plot level of hunting pressure against percentage of seed dispersal failure. Each square indicates a tree. The line indicates the model simulation. Sites with high hunting pressure were associated with higher proportions of seed dispersal failure and sites with lower hunting pressure knew lower proportion of dispersal failure.

Table 9 Diameter at Breast Height (DBH), mean crop size and percentages of seed dispersal failure for the *Staudtia kamerunensis* trees selected in the five sites in the forest-savanna mosaic in Western D.R.Congo

Site	**Nb of trees**	**Mean DBH ± SD**	**Mean crop size ± SD**	**% seed dispersal failure**	
				Mean ± SD	**Min- Max**
Mbanzi	8	54.6 ± 11.8	4747 ± 5264	48.7 ± 22.5	17.6- 89.1
Nkombo	6	45.1 ± 11.3	6219 ± 7299	51.1 ± 10.1	44.3- 70.7
Minkalu	6	50.8 ± 15.5	3629 ± 3156	64.1 ± 31	20.5- 96.3
Nkala-N.	7	60.1 ± 19.6	2965 ± 3607	123.6 ± 43.6	74.8- 177.9
Nkala-S.	7	49.2 ± 14.6	1286 ± 1109	73.6 ± 24.7	35.9- 110.1
TOTAL	34	52.3 ± 14.8	3730 ± 4563	72.4 ± 38.9	17.6- 177.9

Model selection

Through the first univariate analysis, tree crop size was statistically not significant ($p=0.2703$) and therefore not retained for the multivariate analysis, for which we considered percentage of forest cover ($p=0.006$), *B. albotibialis* abundance ($p=0.041$), primates abundance ($p=0.001$), hunting pressure ($p=0.008$) and fruit availability ($p<0.000$). Through the exhaustive model selection, the model with the best AIC and with all of its terms statistically significant only included forest cover and hunting pressure ($r^2 = 0.7641$). The model also contained a quadratic effect of hunting pressure. Forest cover had a negative effect on seed dispersal failure (Fig. 6, partial $r^2 = 0.3749$). Trees surrounded by relatively lower forest cover were associated with higher proportions of seeds failing to disperse, inversely, trees surrounded by more forest knew lower proportion of dispersal failure (i.e. highest proportions of seed dispersed). Hunting pressure had a positive effect on seed dispersal failure (Fig. 7, partial $r^2 = 0.6774$ for the model containing "hunting pressure" and its quadratic effect). Sites subject to higher hunting pressure were associated with higher percentages of dispersal failure.

Discussion

The present study was the first to investigate the effect of human disturbances on the seed dispersal of the pan-tropical and well known family Myristicaceae in Africa. More particularly, we asked ourselves whether and how the seed dispersal capacity of the zoochorous species *Staudtia kamerunensis* could be affected by forest fragmentation, bushmeat hunting, the abundance of large frugivores, and by the availability of fruits at the local and habitat scale.

Seed dispersal system

According to the focal observation conducted across the forest-savanna mosaic, seed dispersal of *S. kamerunensis* depended almost exclusively on the hornbill species *Bycanistes albotibialis* (Bucerotideae), and to a lesser extent on *Ceratogymna atrata* (Bucerotideae). This large-seeded species has therefore a highly specialized dispersal strategy, which confirms the observations made in Cameroon (Clark et al. 2005), and in Asia (Kitamura and Poonswad 2013) and South-America (Howe, 1981; Sabatier, 1997) for other Myristicaceae species. Plants with such restricted frugivores assemblages responsible for their dispersal are known to be particularly sensitive to human disturbances (Ratiarison and Forget 2013), and especially when they have large seeds that only larger vertebrates can ingest and disseminate (Vanthomme et al., 2010; Markl et al., 2012).

Effect of hunting and forest fragmentation

Here, we brought evidence of the negative effect of both hunting pressure and forest fragmentation on the seed dispersal capacity of *S. kamerunensis*. While several studies reported on the effect of those two threats on a range of tree species (e.g. Kirika et al., 2008; Holbrook & Loiselle, 2009; Neuschulz et al., 2011; Boissier et al., 2014), the present study was one the few to consider and proved the effect of both variables together on zoochorous seed dispersal (but see Galetti et al., 2006). The white-thighed hornbill, *B. albotibialis,* has been reported to move across anthropogenic barriers (roads, villages) and heterogeneous habitats and to use disturbed secondary and fragmented forests (Stauffer & Smith, 2004; Chasar et al., 2014). In the forest-savanna mosaic, we also regularly observed this species to fly above the savanna over several hundred meters to travel between forest patches. *B. albobilialis* does not seem to be a strict forest specialist and is therefore likely to offer great seed dispersal services across heterogeneous and anthropized habitats by providing long distance seed dispersal and moving seeds from primary forest plant species to early successional forests and to the vicinity of human activities. Other hornbills (*Ceratogyma atrata*) and especially large frugivorous mammals such as primates and elephants are less likely to travel in this way (Laurance et al., 2006; Buij et al., 2007; Chasar et al. 2014). However, our results provided evidence that the extent of forest cover has a strong effect on white-thighed hornbill's frugivore activity. This finding allowed us to define a threshold of about 2,800 ha of forest (the surface area corresponding to the 3 km-radius ring used) below which a diminution of forest cover will influences *B. albotibialis* frugivorous activity. Interestingly, this area corresponds to the mean home range size's estimation for that species (2,716 ha: Holbrook & Smith, 2000). We saw that hunting pressure had a strong effect on the seed dispersal capacity. This finding confirms the growing threats to african hornbills (Trail 2007).

The value of hornbills, and especially *B. albotibialis*, as seed disperser is believed to increase in the future compared to large frugivorous mammals whose populations are rapidly declining. Primates and elephants are indeed particularly sensitive to forest fragmentation and primarily targeted by bushmeat hunting. However, the present study recalled that when larger vertebrates have been extirpated, the remaining smaller mammals and birds become increasingly hunted (Fa et al. 2000). The long-term ecological role of hornbills as seed disperser should therefore be considered cautiously.

Particularly high values of seed dispersal failure, exceeding hundred percent, indicated a higher number of seeds relative to fruits below tree crown. Interestingly, such values have only been found in the two sites Nkala-N. and Nkala-S. We propose two hypotheses to explain such values. Firstly, it could be the consequence of a methodological artifact: seeds could drop from dehiscent fruits while those would remain attached in the crown, leading us to count un-dispersed fallen seeds in the collectors but to omit the valves remaining in the crown (in which the seeds were initially contained). In this perspective, we would finally overestimate the proportion of un-dispersed seeds relative to fruit (i.e. seed) production. While we were not certain dehisced fruits without their seed can remain in crowns for long periods of time (i.e. long enough as not to fall within the duration of the sampling period), we did observed dried un-dehisced (closed valves) fruits in crowns up to 6 months after the fruiting season. Then, why would so many fruits remained in tree crowns only in Nkala-N. and Nkala-S.? This could be influenced by the low abundances of *B. albotibialis* in those two sites and consequently to a low level of fruit-frugivore interactions likely to induce fruit fall compared to the other sites were hornbills are at higher abundances (apart from Minkalu). Additionally, mean crop size was lower in the two Nkala sites than in the three other sites (Table 9). Fruits remaining attached in crowns (i.e. not quantified here) could explain the lower crop size values estimated for those sites. However, given that neither abundance of *B. albotibialis*, nor crop size has been retained as explanatory variables, we should be cautious with this interpretation. Secondly, we highly suspected the high number of seeds relative to fruits to result from inter-conspecific (contagious) seed dispersal. Such contagious seed dispersal have been reported to be particularly strong in bird-dispersed tree species and especially for *Staudtia kamerunensis* (Clark et al. 2004). Also, Wang et al. (2007) showed that up to 42% of the seeds retrieved below crowns of the zoochorous species *Antrocaryon klaineanum* belonged to conspecific neighboring trees. Interestingly, the two lowest mean forest cover characterizes the two Nkala sites where we suspected high level of inter-conspecific dispersal across the five sites. Such small forest fragments could tend to confine hornbill's movements within a limited area and induce repeated travels between *S. kamerunensis* trees. Additionally, the two Nkala sites have the highest *S. kamerunensis'* fruit availabity index (i.e highest fruiting tree densities) which would also be very likely to motivate repeated travels between neighboring fruiting trees and finally would induce frequent seed dispersal events between them.

Evaluation of anthropogenic pressures on the establishement capacity of the zoochorous plant communit (Task 2.2)

Authors: F. Trolliet, M.-C. Huynen, P.-M. Forget, A. Hambuckers (ULG-ENV)

Introduction

It is assumed that on the long run, deposit of endozoochorous seeds is more substantial below fruiting trees (Nuñez-Iturri & Howe, 2007) because frugivores spend lots of time in some trees. Therefore, heterospecific regeneration (the establishement of seeds deposited by frugivores during their visits at fruiting trees) below those tree's crown is more susceptible to be affected by shift in the frugivore community than in randomly selected area.

According to the predictions of the Janzen-Connell model (Janzen, 1970), our hypothesis are that an increase in hunting pressure and a decrease in hornbills and primates abundances should be associated with a decrease in diversity and abundance of zoochorous species and an increase in the abundance of abiotically dispersed plant species.

Material and methods

We followed the method of Vanthomme et al., (2010) which consist at describing the community of seedlings below the crown of zoochorous species. This method allows to standardize the conditions between sites and to estimate heterospecific regeneration. We selected two focal tree species to conduct our survey. We firstly selected Staudtia kamerunensis to be able to complete our study on seed dispersal process. This species will allow us to consider bird-dispersed species and therefore to investigate the impact of anthropogenic pressures affecting hornbill populations on the capacity of plant establishement. We then chose a tree species known to be dispersed by another important frugivorous taxa, primates: *Dialium spp*. (Fabaceae). Those two species will thus allow us to focus on the activity of specific frugivorous taxa and to drive inter-sites comparisons according to the frugivores abundances.

According to the tree's crown size, we set up one or two 50 m² plots below the crown. For each sampled tree, we also set up one or two 50 m² control plots at 50 meters away from the tree. In every plot we systematically identified all seedling from 50 cm to 2 m. high. To consider the potential effect of abiotic factors, we also took an hemispheric photography of the canopy to estimate the quantity of light reaching the ground, and a sample of dirt to estimate the relative abundance of important minerals.

We surveyed a total of 5 trees for the two species, corresponding to a total of 4900 m² across the five sites.

Results

This study being part of a PhD project (Franck Trolliet), the dataset is currently being analyzed and the results and conclusions will be available in the near future.

Table 10. Distribution of effort sampling across the two tree species (*Staudtia kamerunensis* and *Dialium spp.*) and the five sites for the survey of seedling community

	Staudtia kamerunensis		***Dialium spp.***		***Total***	
Site	Nb trees	Total surface area (m², with control plots)	Nb trees	Total surface area (m², with control plots)	Nb trees	Total surface area (m², with control plots)
Mbanzi	7	500	6	550	13	1050
Nkombo	7	500	5	450	12	950
Mbominzoli	7	500	6	500	13	1000
Minkalu	6	600	3	300	9	900
Nkala	5	500	6	500	11	1000
Total	32	2600	26	2300	58	4900

Upgrading DVM for studying local forest production and regeneration (Task 2.3, Task 3.3, 3.4, 3.5 and 3.6)

Authors: M. Dury and L. François (ULg-UMCCB)

Introduction

We refined the tropical vegetation representation from plant functional types (PFTs) to individual species. As far as we know, it is the first time that a DVM simulates vegetation at the species levels for tropical Africa. Indeed, there are currently very few studies available for African plant species (Chambers *et al.*, 2013). A list of plant species representative of the studied area and a list of ES-related plant species were provided respectively by the ULg-ENV partner and the FUNDP and UGent partners. We defined the climatic requirements of 78 species confronting their present-day distribution with Worldclim high-resolution climatic data (see **Annex** of this section). The species occurrences were provided by Adeline Fayolle (Fayolle *et al.*, submitted) and completed by GBIF database for some species (http://www.gbif.org/). The collection for some of these species of parameters such as the specific leaf area or the leaf C/N also helped the refinement of the species modelling. For the project, we finally decided not to produce a classification of the vegetation in bioclimatic affinity groups (BAGs) and to rather remain at the level of species. It allows to directly follow the future evolution of individual species which are sometimes directly related to some ecosystem services (WP4).

Material and methods

Owing to difficulties linked to data collection, we studied the full dynamics (i.e., including seed dispersal and regeneration processes, which allows modelling not only the temporal, but also the spatial dynamics of tree species) of only one species: *Staudtia kamerunensis*. However, future potential (climate-driven, no dispersal limitation) distributions of the other species were simulated in WP5. To evaluate the *S. kamerunensis* dispersal and regeneration in forest-savannah mosaic, we introduced a dispersal module in the CARAIB dynamic vegetation model. The dispersion module firstly developed off-line (Coos, 2013) has then been introduced in the CARAIB model. The module has been developed using data collected for the project and completed by literature data.

S. kamerunensis seed production and dispersal were evaluated by the collection of diaspores at some fruiting trees using traps. Based on these data, different classes of number of dispersed seeds were created to represent different levels of productivity.

According to field observations, the main disperser of *S. kamerunensis* seeds is a species of hornbill, *Bycanistes albotibialis* (> 95 % of observation time). The species dispersal kernel (which gives the probability that a seed is dispersed at a certain distance) used here is the one constructed by Lenz *et al.* (2011) that takes seed retention time and hornbill displacement in fragmented landscapes into account. Since the spatial resolution of the off-line simulation is 100 m, we focused only on "long-distance" flights with a preferred distance of about 512 m and a maximum distance of 8914 m (Fig. 8). For each seed, the module calculates random direction and distance. The direction is however influenced by the habitat type (hornbills preferring to fly over the forests) and the distance by the normal distribution of the kernel.

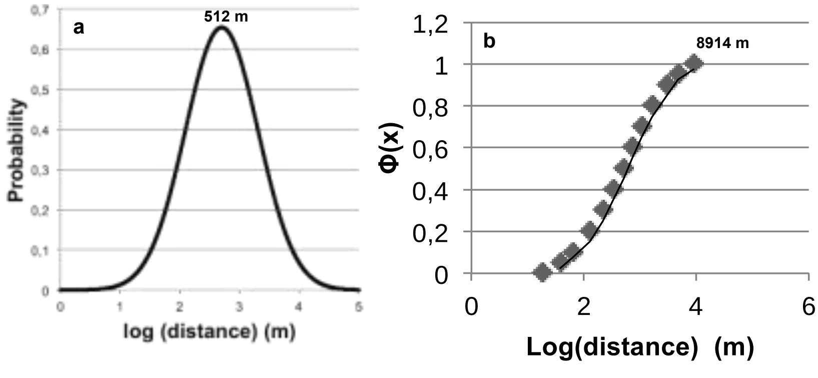


Fig. 8 Probability density function (a) and cumulative distribution function (b) of hornbill dispersal kernel (normal distribution).

A land cover map of the Congo Basin (Fig. 9) at a 300 m resolution derived from ENVISAT MERIS (300 m) and SPOT VEGETATION (1 km) sensors (Verhegghen *et al.*, 2012) was used to create a virtual landscape at 100 m resolution. The different cover classes were aggregated in four main habitat classes (Table 11 and Fig. 10): primary forest, secondary forest, savannah and water. This landscape was carried out in order to study the *S. kamerunensis* recolonization of disturbed habitat from primary forest.

Results

An off-line simulation was driven over 10 years to assess the *S. kamerunensis* re-colonization of the landscape from primary forests (Fig. 11). A *S. kamerunensis* density of maximum 2 trees per ha was assumed in accordance with field observations. A decrease in the amount of seed dispersed is observed from the edges of the primary forests to the center of the savannahs. Gaps in primary forests receiving a large amount of seeds are faster recolonized. Fig. 11b shows the effective recruitment (seed number) after having applied a seed survival rate derived from Clark *et al.* (2013). Then the module has been implemented into the CARAIB model and Fig. 12 shows the species re-colonization from primary forests after 10 years (above-ground biomass).

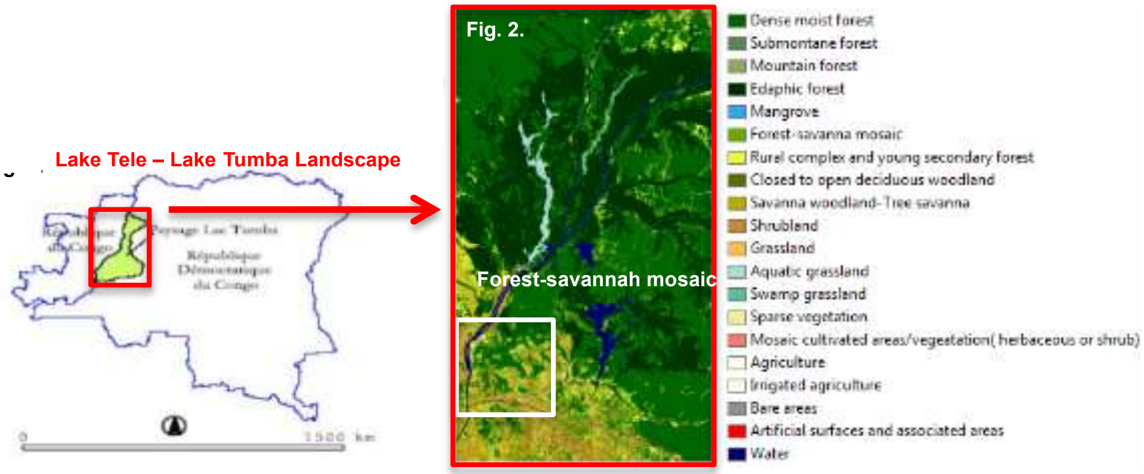


Fig. 9 Land cover over the WWF Lake Tele – Lake Tumba Landscape Landscape (Verhegghen *et al.*, 2012) and area of forest-savannah mosaic where forest regeneration is studied (white square).

Table 11 Vegetation classes and types constraining re-colonization in off-line and on-line simulations

HABITAT CLASSES	VEGETATION TYPES	SURVIVAL RATES
Class1 Primary forests	Dense moist forest, edaphic forest	0 % (tree-saturated habitat, no establishment)
Class 2 Secondary forests	Forest-savannah mosaic, rural complex, young secondary forests, closed to open deciduous woodlands, savannah woodland – tree-savannahs	6 % (shaded habitat, establishment)
Class 3 Savannahs	Shrublands, grasslands, sparse vegetation, mosaic cultivated areas / vegetation (herbaceous or shrub)	0 % (sunny habitat, no establishment)
Class 4 Water	No simulation	-

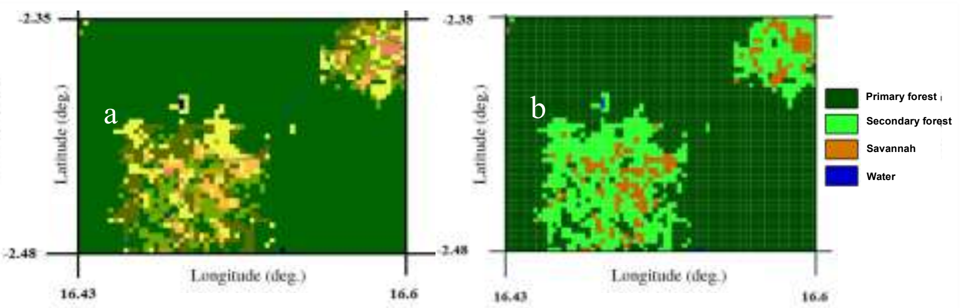


Fig. 10 Land cover over an area of forest-savannah mosaic (a; see Fig. 9 for details) and habitat classes (b).

Re-colonization percentages of 43% and 47 % were respectively obtained with the off-line and online module (Fig. 12). These results were compared to two field studies in order to achieve a pre-validation of the module. The study of Lévesque *et al.* (2011) provides 80 % of colonization, a value significantly higher than our result. However, this study was conducted in a tropical dry forest. The second study (Rondon *et al.*, 2008), conducted in tropical rainforests presents a percentage between 58-73 % after 15 years. Our module would probably give a similar percentage if the simulation were run over 5 more years.

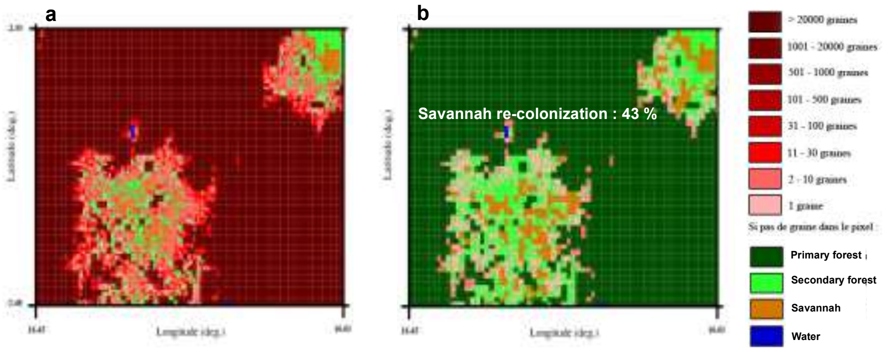


Fig. 11 Off-line simulation at 300 m spatial resolution. (a) Re-colonization of « disturbed » habitat by *S. kamerunensis* after 10 years and (b) effective re-colonization taking seed survival rate into account (Table 11). In the absence of seed in the grid cell, the underlying virtual landscape appears.

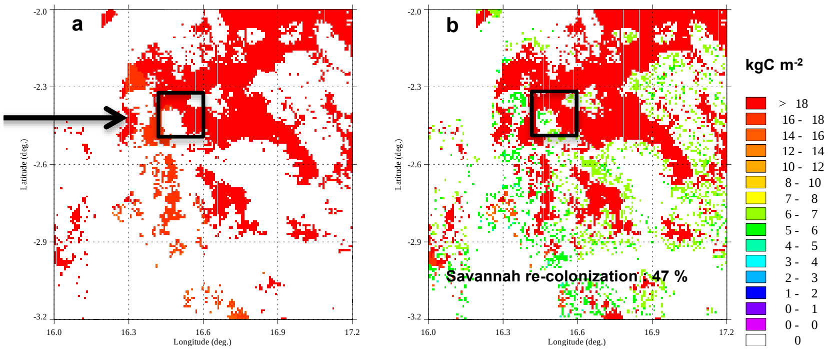


Fig. 12 Online CARAIB simulation at 1 km resolution. Re-colonization of « disturbed » habitat by *S. kamerunensis* after 10 years. Above-ground biomass per grid-cell. (a) Initial conditions, *S. kamerunensis* only present in primary forests. (b) Re-colonization after 10 years.

Annex

Species-dependent parameters controlling plant stress and germination. The species type is shrub (S) or tree (T). Soil water thresholds SW_{mins} and SW_{maxg} refer to available soil water in relative units, *i.e.*, in terms of the variable (W-WP)/(FC-WC) where W, WP and FC are respectively the soil water content, the wilting point and the field capacity in mm. Species observed by partner 1 in the southern area (S) and by partners 2 and 5 in the northern area (N) of the Lake Tumba Landscape. Species studied by Tosso (2013) in his master thesis (AFR).

	Species name	**Species type**	**T_{mins} (°C)**	**Sw_{mins}**	**$GDD5_{ming}$ (°C day)**	**Sw_{maxg}**	**Area of observations**
1	*Hymenocardia acida*	S	14.9	0.063	5460.	0.504	S
2	*Sarcocephalus latifolius*	S	19.6	0.031	7194.	-	S
3	*Alchornea cordifolia*	S	14.1	0.021	4769.	-	N
4	*Alchornea floribunda*	S	14.9	0.029	5493.	-	N
5	*Vitex welwitschii*	S	19.5	0.151	7313.	-	N
6	*Acacia senegal (Africa)*	T	9.4	0.000	4545.	0.159	AFR
7	*Annickia chlorantha*	T	15.3	0.122	5256.	-	S
8	*Anonidium mannii*	T	16.7	0.144	5574.	-	S /N
9	*Antiaris toxicaria*	T	14.3	0.018	5273.	0.748	S
10	*Coelocaryon preussii*	T	14.7	0.151	5191.	-	S
11	*Cola ballayi*	T	19.0	0.159	7037.	-	S
12	*Dacryodes edulis*	T	16.6	0.145	5539.	-	S
13	*Ganophyllum giganteum*	T	18.5	0.157	6907.	-	S
14	*Garcinia kola*	T	17.8	0.053	6598.	-	S
15	*Garcinia punctata*	T	17.5	0.159	5914.	-	S
16	*Guarea cedrata*	T	18.1	0.055	6129.	-	S/N
17	*Irvingia gabonensis*	T	16.5	0.096	5576.	0.753	S
18	*Macaranga monandra*	T	13.7	0.122	4822.	-	S/N
19	*Maranthes glabra*	T	17.8	0.122	5983.	-	S
20	*Millettia laurentii*	T	19.5	0.219	6967.	-	S
21	*Pancovia laurentii*	T	19.7	0.192	7076.	-	S
22	*Parinari excelsa*	T	10.9	0.019	4240.	-	S
23	*Pentaclethra eetveldeana*	T	18.5	0.158	6680.	-	S/N
24	*Plagiostyles africana*	T	17.6	0.128	6181.	-	S
25	*Polyalthia suaveolens*	T	16.9	0.134	5653.	0.950	S/N
26	*Quassia silvestris*	T	11.8	0.101	4644.	-	S
27	*Scorodophloeus zenkeri*	T	18.5	0.157	6649.	0.970	S
28	*Staudtia kamerunensis*	T	15.6	0.113	5325.	-	S
29	*Strombosia grandifolia*	T	16.2	0.092	5391.	-	S/N
30	*Tabernaemontana crassa*	T	14.0	0.131	4966.	-	S
31	*Afzelia africana*	T	18.2	0.005	6943.	-	AFR
32	*Khaya senegalensis*	T	17.7	0.003	6942.	-	AFR
33	*Milicia excelsa*	T	11.3	0.018	4729.	0.656	AFR
34	*Pterocarpus erinaceus*	T	17.6	0.004	6547.	0.294	AFR
35	*Alstonia boonei*	T	16.4	0.046	5535.	-	N
36	*Amphimas pterocarpoides*	T	19.9	0.062	7037.	0.957	N
37	*Anthonotha_macrophylla*	T	16.8	0.064	5605.	-	N

38	*Blighia welwitschii*	T	16.8	0.055	5663.	-	N
39	*Carapa procera*	T	12.4	0.037	4618.	-	N
40	*Ceiba pentandra*	T	14.8	0.044	5221.	0.573	N
41	*Cleistopholis glauca*	T	18.6	0.160	6776.	-	N
42	*Cola acuminata*	T	15.7	0.112	5480.	-	N
43	*Cynometra hankei*	T	19.5	0.158	6817.	-	N
44	*Cynometra sessiliflora*	T	21.4	0.690	7323.	-	N
45	*Dialium corbisieri*	T	19.3	0.158	7084.	-	N
46	*Dialium pachyphyllum*	T	18.5	0.117	6487.	-	N
47	*Elaeis guineensis*	T	14.4	0.014	5268.	-	N
48	*Fillaeopsis discophora*	T	18.5	0.155	6718.	-	N
49	*Garcinia epunctata*	T	18.3	0.157	6923.	-	N
50	*Guibourtia demeusei*	T	19.3	0.163	6968.	-	N
51	*Harungana madagascariensis*	T	12.8	0.037	4758.	-	N
52	*Hymenocardia ulmoides*	T	18.4	0.042	6958.	-	N
53	*Lannea welwitschii*	T	16.8	0.106	5657.	0.848	N
54	*Lophira alata*	T	14.3	0.104	5295.	0.612	N
55	*Macaranga spinosa*	T	12.5	0.087	4305.	-	N
56	*Maesopsis eminii*	T	13.8	0.059	5160.	-	N
57	*Mammea africana*	T	16.8	0.081	5653.	-	N
58	*Musanga cecropioides*	T	13.8	0.115	5262.	-	N
59	*Nauclea diderrichii*	T	16.8	0.068	5635.	-	N
60	*Ongokea gore*	T	18.7	0.131	6920.	-	N
61	*Oubanguia africana*	T	18.5	0.158	6532.	-	N
62	*Panda oleosa*	T	18.6	0.090	6700.	-	N
63	*Paramacrolobium coeruleum*	T	18.7	0.104	6411.	-	N
64	*Pentaclethra macrophylla*	T	17.3	0.098	5817.	-	N
65	*Pericopsis elata*	T	19.6	0.120	6955.	0.761	N
66	*Pseudospondias microcarpa*	T	13.3	0.041	5109.	-	N
67	*Pterocarpus soyauxii*	T	18.8	0.097	6917.	-	N
68	*Pycnanthus angolensis*	T	14.5	0.054	5221.	-	N
69	*Sterculia tragacantha*	T	17.8	0.047	6069.	0.581	N
70	*Strombosiopsis tetrandra*	T	16.8	0.100	5787.	-	N
71	*Symphonia globulifera*	T	11.9	0.090	3980.	-	N
72	*Synsepalum stipulatum*	T	18.6	0.157	6445.	-	N
73	*Terminalia superba*	T	18.7	0.086	6807.	0.525	N
74	*Tetrapleura tetraptera*	T	14.4	0.042	5552.	0.746	N
75	*Treculia africana*	T	12.0	0.048	5380.	-	N
76	*Uapaca guineensis*	T	16.8	0.057	5578.	-	N
77	*Uapaca heudelotii*	T	19.5	0.151	7057.	-	N
78	*Xylopia phloiodora*	T	19.5	0.189	6691.	-	N

Validating the DVM for the present situation using remote sensing and field data (Task 2.4)

Authors: M. Dury and L. François (ULg-UMCCB)

Introduction

In the lack of abundant and long-term field measurements, we compared the model results with time series of remote sensing products (e.g. vegetation leaf area index (Zhu *et al.*, 2013, Fig. 13 and 14), gross and net primary productivities (Zhao *et al.*, 2005, Fig. 15, 16 and 17). The vegetation biomass calculated by the DVM was compared to collected biomass data (*e.g.* Lewis *et al.*, 2009) (Dury *et al.*, 2014).

If the spatial variations of carbon stocks and fluxes are quite well simulated by the model, the temporal variations are not very well reproduced. Representing the vegetation at the species levels tends to improve the results compared to PFT simulations but, since the species set includes nearly only tropical species, it is tricky to generalize to the whole Africa. Unfortunatly, over the studied area and the Congo basin, the comparison with satellite products is delicate due to their frequent contamination by cloud cover.

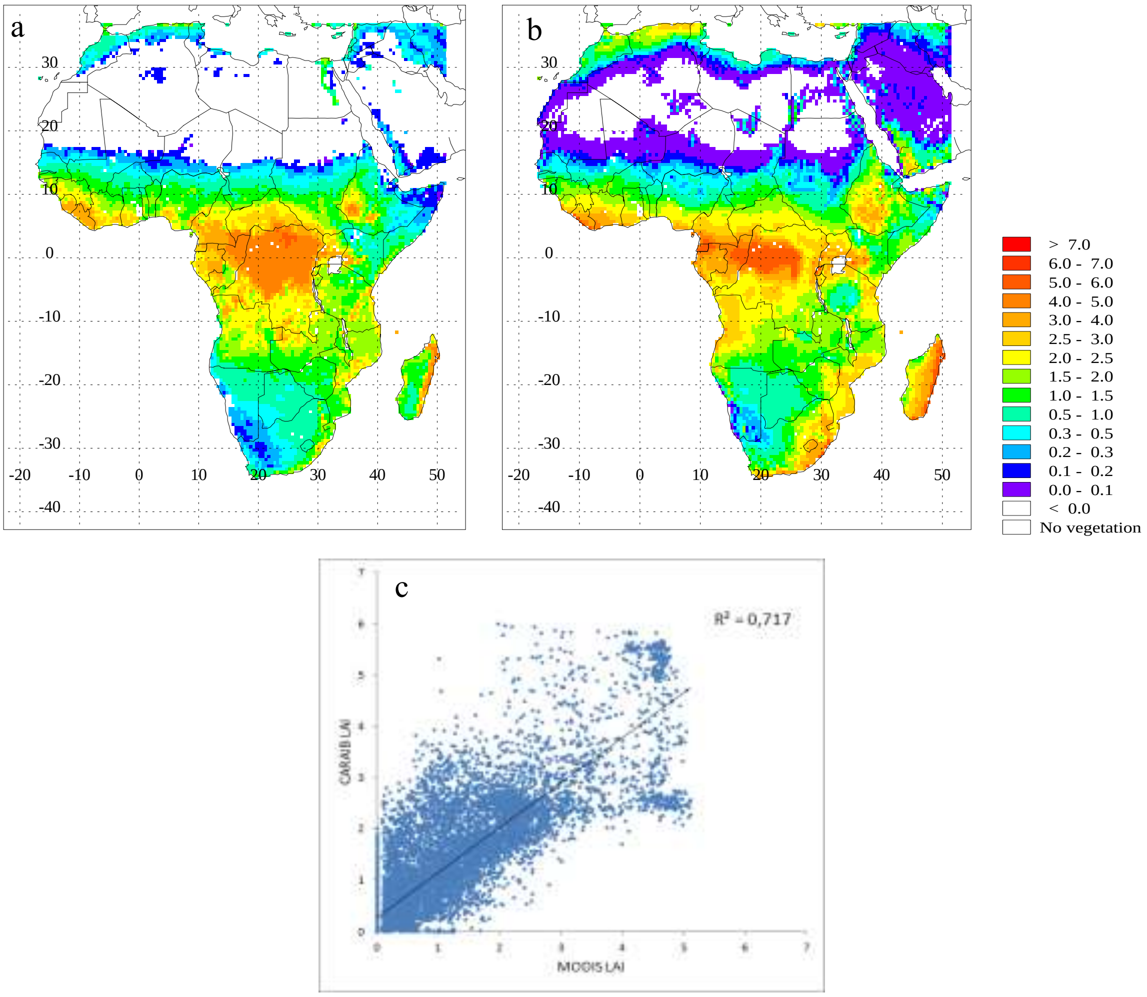


Fig.13 Leaf area index spatial variation (m^2 m^{-2}). Mean 1982-2011 annual LAI from (a) remote sensing (LAI3g, Zhu *et al.*, 2013) and (b) simulated by CARAIB with a vegetation represented by a set of species. (c) Relationships between CARAIB LAI computed values and LAI from remote sensing.

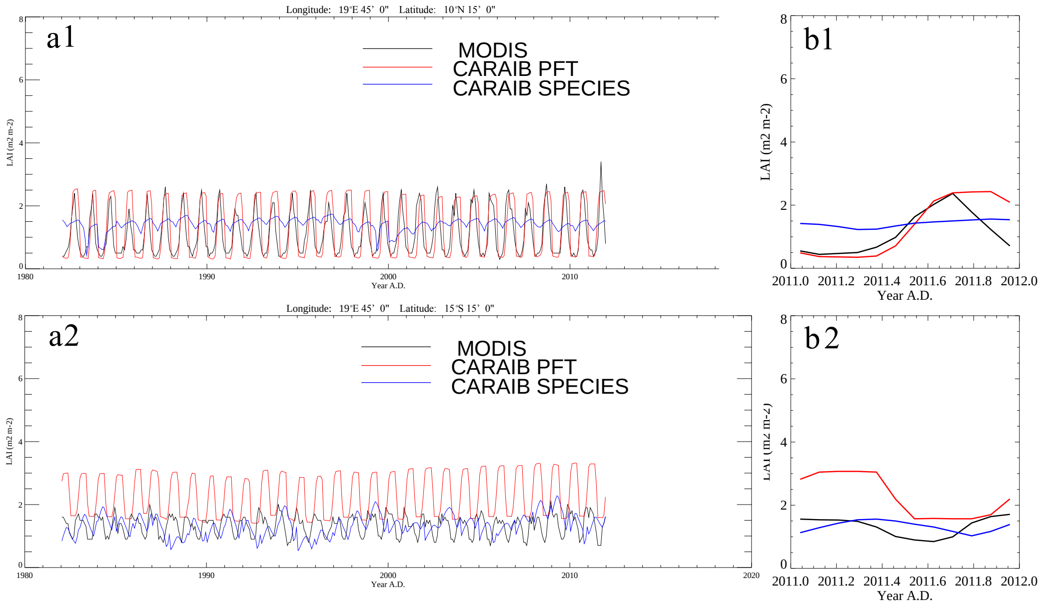


Fig. 14 Leaf area index temporal variation (m^2 m^{-2}). (a) Monthly LAI over the period 1982-2011 and (b) mean 1982-2011 monthly LAI for two grid cells located at (1) 19.75° E and 10.25° N and (2) 19.75° E and 15.25° S.

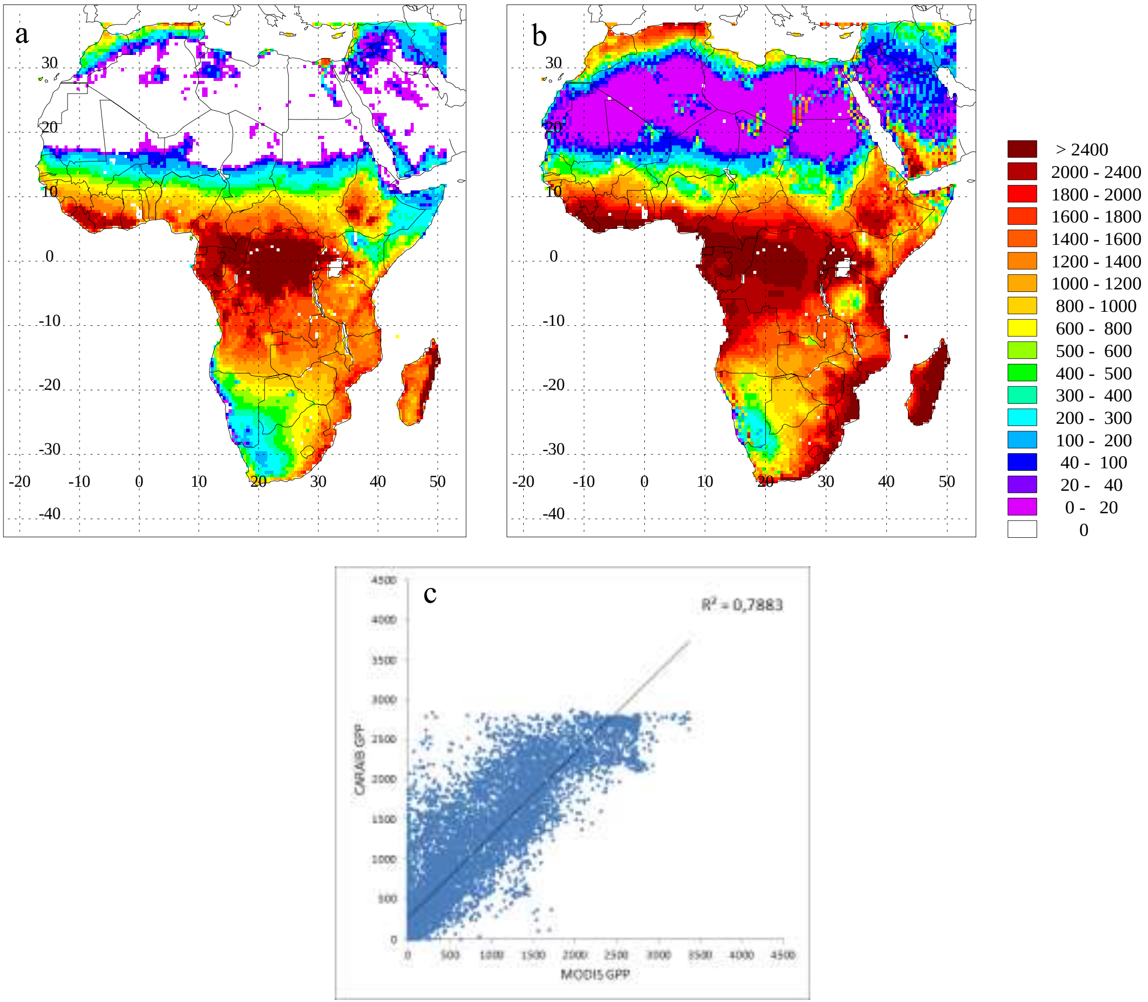


Fig. 15 Gross primary productivity spatial variation (g C m^{-2}). Mean 2000-2012 annual GPP from (a) remote sensing (Zhao *et al.*, 2005) and (b) simulated by CARAIB with a vegetation represented by a set of species. (c) Relationships between CARAIB GPP computed values and GPP from remote sensing.

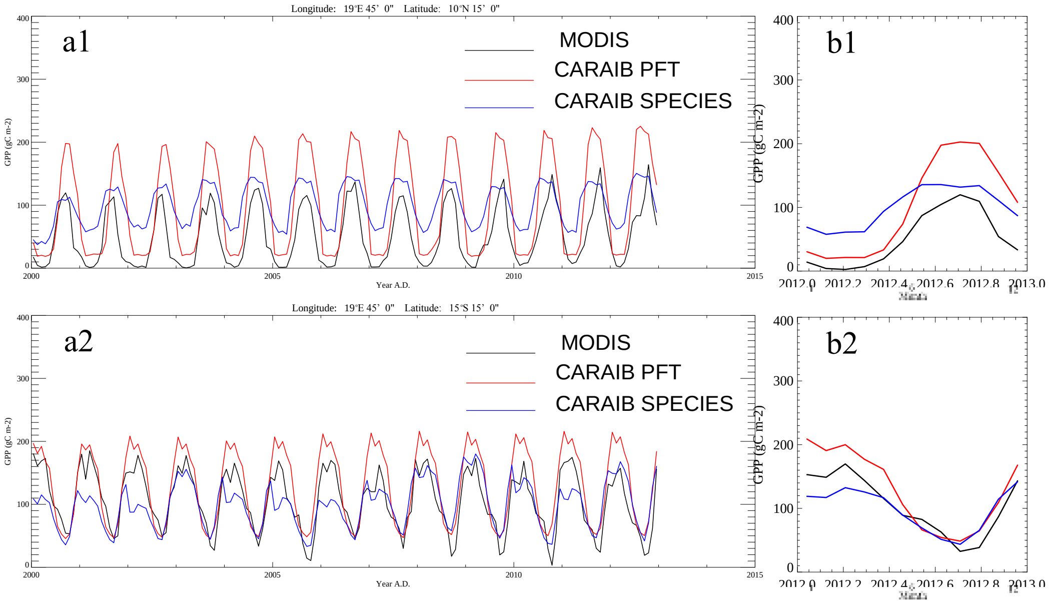


Fig. 16 Gross primary productivity temporal variation (gC m-2). (a) Monthly GPP over the period 2000-2012 and (b) mean 2000-2012 monthly GPP for two grid cells located at (1) 19,75° E and 10,25° N and (2) 19,75° E and 15,25° S.

At the Equator (Fig. 17), the monthly GPP is around 200 gC m^2 and then 2,500 gC m^2 annually. This annual value is in agreement with the value usually presented for equatorial regions (Beer *et al.*, 2010).

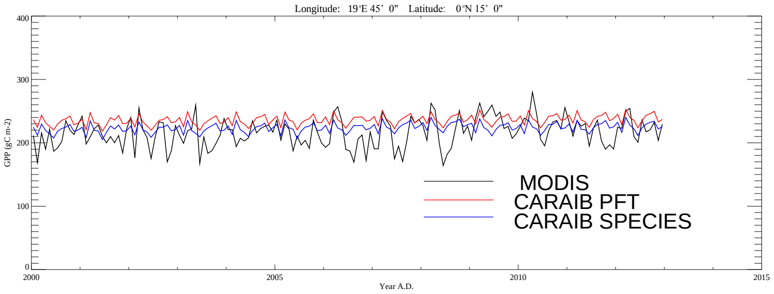


Fig. 17 Gross primary productivity temporal variation (g C m^{-2}). Monthly GPP over the period 2000-2012 for a grid cell located at 19.75° E and 0.25° N.

The simulated species current ranges were evaluated comparing them with species occurrences from CJB (Conservatoire et Jardin botaniques de la Ville de Genève, http://www.ville-ge.ch/musinfo/bd/cjb/africa/recherche.php?langue=fr)), distinct from the one used to define species climatic thresholds (Fayolle *et al.*, 2014). The species presented here provide important services to populations of the Lake Tumba Landscape: food and medicinal uses (oil, sauces, etc.) (Fig. 18), food (fruit) (Fig. 19), construction-materials (Fig. 20) and materials and fuelwood (Fig. 21).

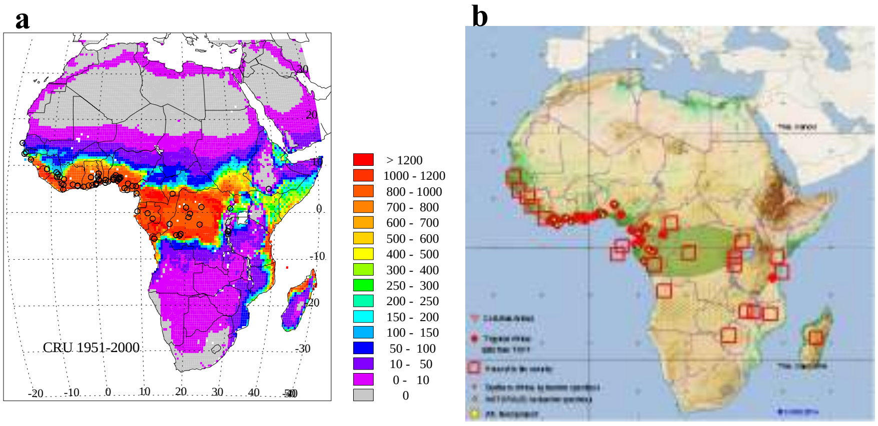


Fig. 18 *Elaeis guineensis*. (a) Species net primary productivity (gC m^{-2}) simulated by CARAIB (black circles are species observed presences from Fayolle et al. 2014). (b)Observed species distribution (CJB)

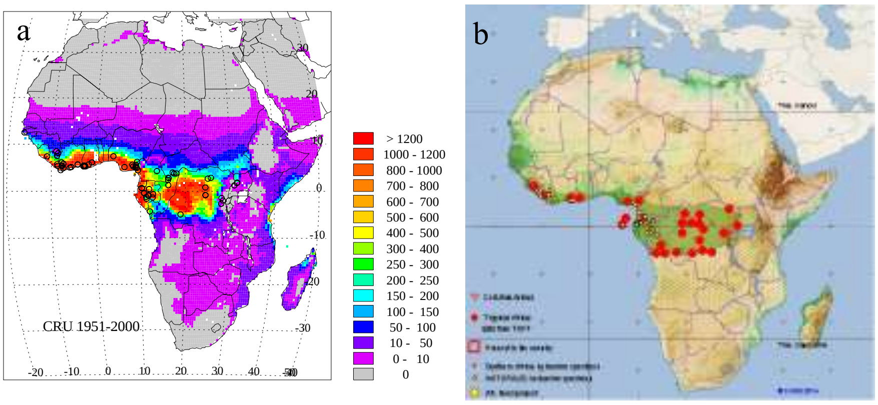


Fig. 19 *Mammea africana* (see Fig. 18 for details).

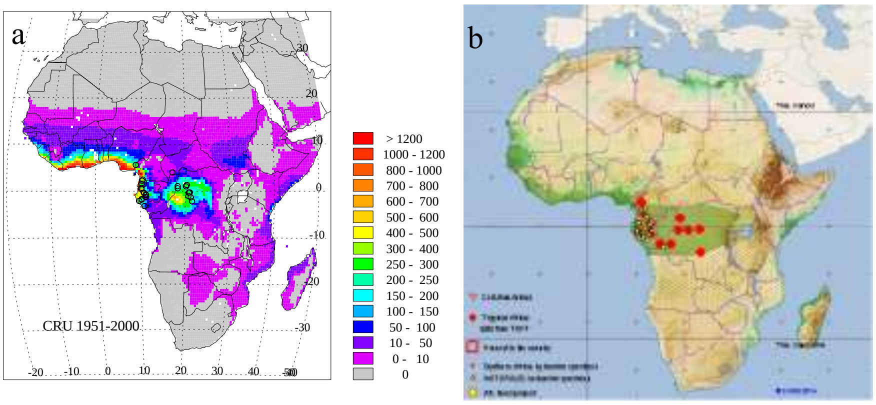


Fig. 20 *Oubanguia africana* (see Fig. 18 for details).

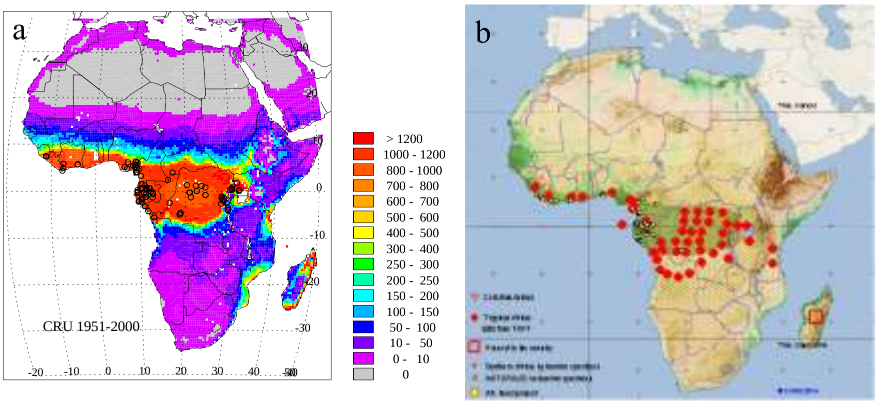


Fig. 1. *Symphonia globulifera* (see Fig. 18 for details).

WP3 FAUNA ANALYSIS

Introduction

This section is constituted of three subsections. The first one reports systematic observations on fauna and hunting conducted in the framework of the *S. kamerunensis* seed dispersal (Task 3.1). The objective was to characterize animal presence and hunting activity in the forest fragments containing the focal trees. Those data have been included in the study presented in WP2. The second subsection exposes a study on the contribution of the bonobo to the forest regeneration through the service of seed dispersal (Task 3.2). For this study, we benefited of the close collaboration of P.-M. Forget (Muséum d'Histoire Naturelle de Paris). It is presented in the form of a paper, which will be soon submitted. The third subsection reports the animal surveys conducted in three contrasted part of the Lac Tumba landscape (Task 3.2 and 3.6).

Seed dispersal of Staudtia kamerunensis: fruits-frugivores interactions and the quantification of frugivores abundance and hunting activity (Task 3.1)

Authors: F. Trolliet, M.-C. Huynen, P.-M. Forget, A. Hambuckers (ULg-ENV)

Methods

Fruits-frugivores interactions

To define the diurnal frugivore assemblage feeding on *Staudtia kamerunensis* fruits we conducted a total of 121.5 h of focal observation at fruiting trees between 2012 and 2013 across the 5 sites in the Malebo study region. Due to dense foliage, the visibility was low and we could not systematically observed each feeding event. To determine the contribution of each frugivore species on seed removal rate we recorded the time spent in the tree by each individual. We used 10x42 Nikon Monarch binocular to perform observation during sessions between 6 am and10 am and between 3 pm and 6 pm, regularly moving from one focal tree to another in order to scan a maximum of fruiting trees during each session. Observation at each tree lasted from 5 to 40 minutes depending on distance to the next focal tree. As direct observations are not efficient at detecting nocturnal and/or terrestrial species, we set up camera traps (8 Reconyx HC500 and 2 Bushnell Trophy Cam) to ensure a permanent monitoring of diurnal and nocturnal activity below 18 fruiting trees for a total of 815 traps/days across the 5 sites during the 2012 and 2013's fruiting seasons. Given the difficulty to define whether animals feed on fallen fruits or not, we only described the species assemblage entering the fruit fall area and their respective visit frequencies. While direct observations allowed defining the species responsible for primary seed removal (from the crown), camera-traps gave us an indication of the species responsible for secondary seed removal. Those activities completed those presented in WP2 regarding the estimation of seed removal rate.

Quantifying frugivores abundance and hunting actitivty

Our second objective was to investigate the effect of local animal abundances as well as hunting activity, on seed removal rates. To do so, we quantified the diversity and abundance of the main frugivores species susceptible to interact with the fruits of *S. kamerunensis* (i.e. hornbills and primates) by conducting a surveys on a system of line RECCE (Vanthomme et al. 2010) for a total of 131 km. We recorded all direct and indirect traces of frugivores presence (faeces, footprints, calls, nests...) and hunting activity (rifle cartridges, gunshots, traps, fireplaces). As a mean of quantification, we summed up all traces found for each taxa and hunting activity and calculated Kilometric Abundance Indexes (KAI), a method allowing efficient inter-sites comparisons (Mathot & Doucet 2006). We attributed one KAI value for each category and for each of the 5 study site in order to investigate the role played by the frugivores found in the vicinity of the focal trees.

Results

Fruits-frugivores interactions

During the focal observation sessions at fruiting trees, we observed the hornbill species *Bycanistes albotibialis* for more than 96 % of total time with visiting frugivores. This species visited fruiting trees at a rate of 1 visit/hr. The other hornbill species *Ceratogymna atrata* was observed to enter fruiting trees at five occasions, and *Cercopithecus ascanius* was only observed to enter a tree once. The camera-trapping sampling allowed us to detect six different nocturnal species potentially feeding on *S. kamerunensis* fruits (the giant pouched rat (*Crycetomis emini*), the Bay duiker (*Cephalophus dorsalis*), the servaline genet (*Genetta servalina*), the African brush-tailed porcupine (*Atherurus africanus*), the African civet (*Civettictis civetta*)) and the Red river hog (*Potamocherus porcus*). The visit frequency at fruiting trees of all those species reaches a much lower rate of 0.008 visit/hr than the hornbills. Among the nocturnal terrestrial vertebrates, the giant pouched rat has been recorded more frequently than all the other species.

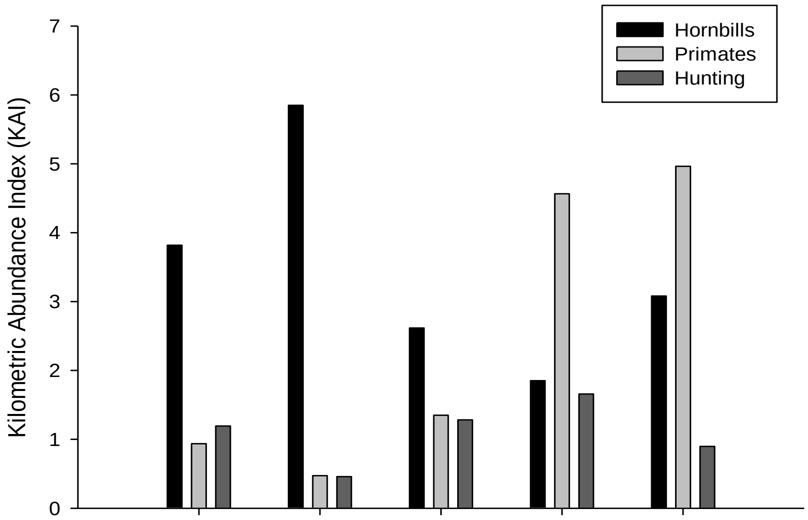


Fig. 22 Relative abundances, expressed as Kilometric Abundance Index (KAI), of hornbills, primates and signs of hunting activity in the five selected study sites. Due to the different nature of the three categories of interest (i.e hornbills, primates and hunting signs have different detection probability), abundances of each category have to be compared between sites but not within site.

Quantifying frugivores abundance and hunting activity

The results obtained (Fig. 22) show large differences in abundance of hornbills, primates and hunting activity between the five different sites. More specifically, Mbanzi and Nkombo, the two sites selected within a large patch of continuous forest (>500 km²) house larger abundances of hornbills than in the three sites situated within forest fragments. Inversely, primates are more abundant in smaller fragments, especially in the Nkala Nord and Nkala Sud sites, where the WWF conservation activities take place.

Influence of bonobo seed dispersal services in the dynamics of forest (re)colonization in a forest-savanna mosaic (Task 3.2)

Authors: F. Trolliet, M.-C. Huynen, A. Serckx, P.-M. Forget, A. Hambuckers (ULg-ENV)

We investigated the ecological role of the bonobo (*Pan paniscus*) in the regeneration of the forest in the forest-savanna mosaic in the Malebo study region in the South of the Landscape. A large part of the data used in the following study were collected in the frame of Dr. Adeline Serckx's PhD project on bonobo's behavioral ecology (Serckx 2014). We benefited also of the collaboration of P.-M. Forget (Muséum d'Histoire Naturelle de Paris).

Methods

Study site and bonobo population

Field work has been conducted close to the Malebo study site previously described (see WP2). More precisely, data have been collected in a section of 170 km² housing a bonobo population probably made up of two communities in the vicinity of the Nkala and Mpelu villages.

Frugivory and seed dispersal

As part of the WWF bonobos habituation program, trackers regularly geolocated fresh nesting sites and collected fresh bonobo's feces between May 2011 and June 2013. We collected a total of 2,252 faecal samples during the course of the study. Faeces were gathered together in Marantaceae leaves for transport to the field camp. The faecal material was washed through a 1-mm mesh sieve to retrieve contained seeds and proceeded to identification. We defined important fruits as those present in more than 50 % of samples for at least 1 month (Rogers et al. 2004). We also defined preferred food species as those ones consumed disproportionately relative to their abundance in the habitat (Marshall & Wrangham 2007). We systematically kept a seed sample for each species to perform the germination trials.

Germination trial

To test the effect of bonobos seed ingestion on germination, we conducted trials to compare the temporal pattern of germination between dispersed and control seeds. To collect control seeds, we searched the forest for the same species as those found in bonobos' faeces. When reachable, we collected fruits from the crown. If not reachable, we picked up ripe fruits without signs of rot on the ground. A total of 2,074 seeds (929 control; 1145 dispersed) of 16 plant species were sown in sterile cotton compress in individually labelled Petri dishes. All dishes were placed in a wooden closed shelf to prevent consumption by rodent and in a shaded environment to prevent direct sun ray and seed desiccation. We controlled every dish twice a week to record and remove any germinated seeds (germination is defined as the emergence of the radicle) and add water.

Habitat use and seed rain

At time of the study the bonobos were not habituated enough as to allow us to perform direct observations and record all defecation sites. As a surrogate we used indirect traces of bonobos activities to describe habitat use as to infer defecation pattern. Knowing that the interval between two consecutive defecation for bonobos is on average 95 min. (Beaune et al. 2013), we could thus consider that any defecation is done randomly in respect to (i.e correlated with) habitat use. We surveyed a total of 179.1 km on a system of linear transect to search for any trace of bonobos activity (nest, food remain, footstep, vocalization, direct encounter, feces). We also considered all nesting sites geolocated during the WWF habituation program. For any trace of bonobo activity, we described the habitat in terms of vegetation type. To compare the frequencies of bonobos presence in different habitat types with the relative availability of those habitat type in the forest patches we systematically described habitat types with the same methodology every 25m on the transect.

Light guild of plant species

We categorized each plant species to one of the following light guild (i.e. shade tolerance class): Shade-Bearer (SB), Non-Pioneer Light Demanding (NPLD), Pioneer (P) or to a general description of the habitat in which they are found according to the literature (Hawthorne 1995; Detchuvi 1996). We use this information as a proxy to evaluate potential seed-site ecological match. Even though we acknowledge the point made by Schupp (1993; 2010) in that sites are not simply suitable or unsuitable, our goal here is to highlight main variations in plants species' ecological requirements.

Statistical analysis

Germination trials of the dispersed and control seeds were compared with a time-to-event analysis, the Cox'F test with the software Statistica (Statsoft). Time-to-event analysis allow stronger analysis than most used germination indexes by focusing on individual seeds rather than groups of seeds and consider different properties of the temporal pattern of germination (i.e. delay, extend, average speed and variation in speed of germination) (McNair 2012). We computed Kaplan-Meier curves to visually compare the temporal patterns of germination and highlight which properties differ between the two treatments.

Regarding the data on habitat use, we analyzed data from nesting behaviour and other indices (feeding and travelling) separately because they did not reflect the same kind of behaviour. Indeed, we can hypothesize that bonobos would use safer parts of the forests for sleeping than for feeding and travelling. We converted the percentage of habitat type where indices were observed, into percentage of expected habitat type for a uniform distribution of indices within the different habitats types. For each of the two categories ('Nests' and 'Other indices') we then compared the percentage of observed with the percentage of expected habitat type with Fisher test.

Results

Frugivory and seed dispersal

Overall, bonobos were found to be highly frugivorous with more than 95 % of faeces volume containing fruits, and a total of 78 seed species being dispersed (Serckx et al. 2015). More specifically, sixteen species were considered as important, among which five were considered as preferred (Table 12). In terms of seed dispersal, important species can be considered as species which are frequently dispersed relatively to other species, and preferred food species as species which are, in addition to their frequent dispersal, particularly well dispersed relatively to the density of fruiting parent plants.

Table 12. List of the 16 most important and 5 preferred fruit species in bonobos' diet. From top to bottom, species appear by order of preference in the diet.

Species	**Family**	**Preferred food**
Musanga cecropioides	Urticaceae	No
Aframomum sp	Zingiberaceae	-
Marantochloa leucantha	Marantaceae	-
Uapaca sp.	Euphorbiaceae	No
Cissus dinklagei	Vitaceae	-
Landolphia sp3	Apocynaceae	-
Piptostigma fasciculatum	Annonaceae	Yes
Dialium sp.	Fabaceae	Yes
Landolphia sp2	Apocynaceae	-
Landolphia sp1	Apocynaceae	-
Polyalthia suaveolens	Annonaceae	Yes
Inc. Local name: Lenkala	NA	-
Pycnanthus angolensis	Myristicaceae	No
Cordia platythyrsa	Boraginaceae	Yes
Pancovia laurentii	Sapindaceae	Yes
Annona senegalensis	Annonaceae	-

Germination trial

The Cox'F tests gave us information on the statistical difference in the general temporal pattern of germination between the dispersed and control seeds. Of 16 species tested, we found that seed ingestion by bonobos had a statistically significant effect for 12 species, including 10 species gaining benefits and 2 knowing a deficit in terms of germination potential. We can describe temporal patterns of germination with three main components: the initial delay (the time needed for a first seed to germinate), the speed of germination (the average speed of germination following onset) and the total percentage of germination (the proportion of seeds that ultimately germinate). When visually analyzing the temporal patterns of germination with the Kaplan-Meier curves (Fig. 23 for examples) we found that 5 species clearly benefited from transit in bonobo's gut compared to the control seeds, either in terms of initial delay, speed of germination or total percentage of germination. Finally, we found that seed ingestion had a neutral effect (no germination for both treatments) for 3 species and a statistically insignificant difference for one species. More interestingly, we found that percentage of germination and germination speed of the most important species in the diet *(Marantochloa leucantha, Aframomum* sp., *Musanga cecropioides)* are enhanced when ingested.

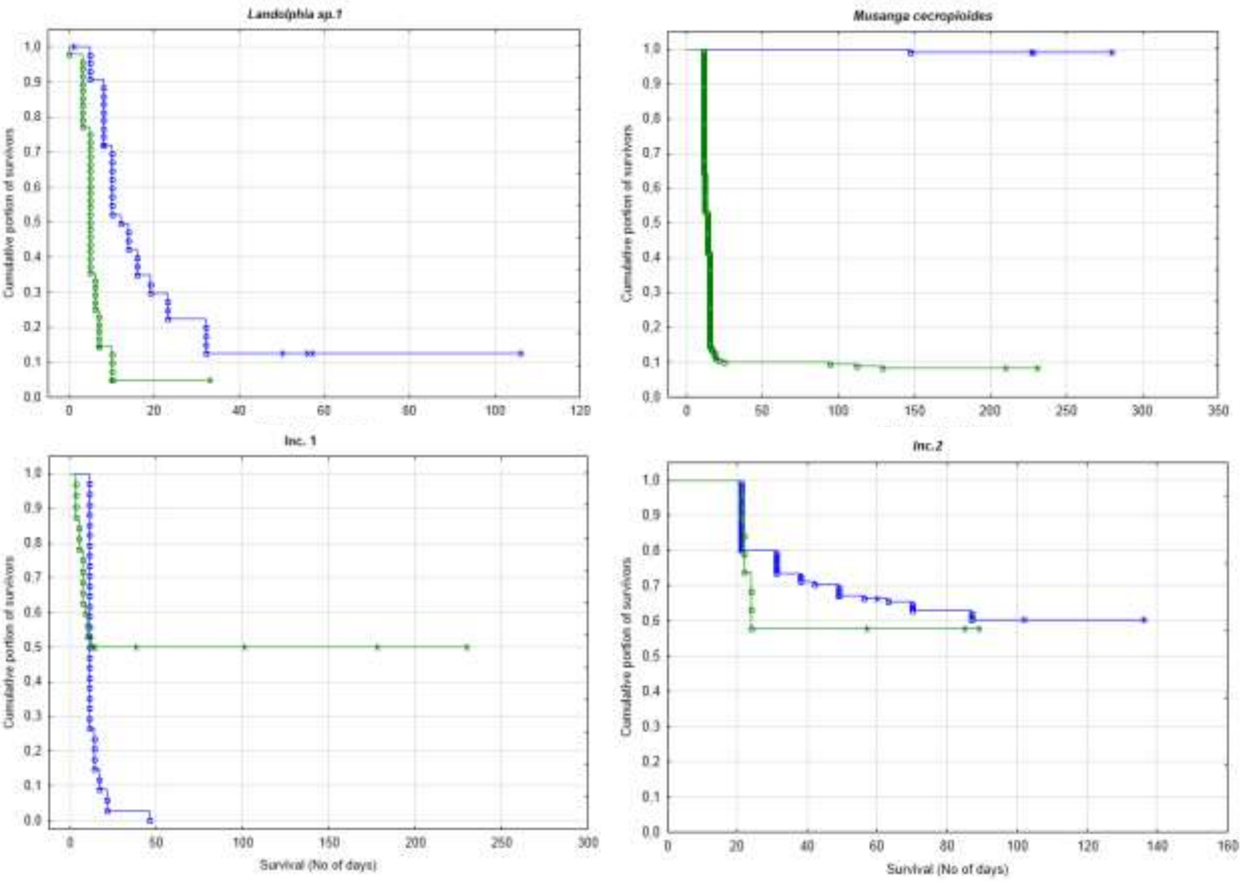


Fig. 23 Examples of Kaplan-Meier curves illustrating the temportal patterns of seed germination. Circles represent germination events. The blue curves represents the control seeds and the green curve the defecated seeds. The four graphs show the different major patterns occuring: statistically significant but little difference (up left), statistically significant and drastically different (with benefits of ingestion: up right; with deficit of ingestion: down left), and statistically unsignificant difference (down right).

Habitat use

According to the distribution of habitat types in the forest, we found that bonobos do not build nest sites at random but instead choose specific habitat to build their nests. Indeed, by comparing the number of nests observed and expected in the different habitats, it appears that bonobo build nests more often in forest with an understorey composed of the plant *Haumania sp*. (Marantaceae), terra firma soil condition and a canopy cover between 25 and 75 % (Fisher test $p<0.05$). However, for other activities (travelling and feeding), we found that bonobos do not select a particular habitat and use all kinds of habitat types available at random (Fisher test $p>0.05$), including forest edges and savannah matrix.

Light guild of plant species

Among all the fruit species dispersed, we could gather information of light guild for 36 species. We found that they belong to the variety of light guilds representative of the different successional stages of the forest. More specifically, 15 species are classified as shade bearer, seven as non-pioneer light demanding, nine as pioneer and one found exclusively in the savannah. Finally four species of terrestrial herbaceous vegetation (hereafter THV) were classified as 'tolerant' as they are found in closed canopy forests with low levels of light available, and also in more open area, gaps and along forest edges. Interestingly, the three most consumed species in the diet (*Musanga* *cecropioides, Aframomum sp, Marantochloa leucantha*) are representative of more open habitats: *M. cecropioides* is a pioneer species found in secondary forests, at forest edges and in recent clearing. *Aframomum* is a genus composed of species with varying light requirements but some of the species found in the study area are typical of forest edges. *Marantochloa leucantha* is a species needing much light and is more often found in greater gaps than any of the other THV species.

Discussion

Our goal was to investigate the ecological role of the bonobo (*Pan paniscus*), on the regeneration of tropical forest in a particular ecological context: a forest-savannah mosaic. By considering several successional steps in seed dispersal and establishment processes, we could highlight the characteristics of bonobos' endozoochorous services in the mosaic. Firstly, we found that they disperse a large number of seeds from several species. Those species belong to different functional forms such as trees, lianas and THV. The large majority of the seeds retrieved in the feces were intact, thus potential candidates for the following steps in the regeneration process (germination and establishment). Then, we found that the majority of the species tested received an enhancement in germination potential after their transit in bonobos gut. This enhancement concerns the general speed of germination (initial delay and average speed) and/or the final percentage of seeds germinating. Those enhancements are susceptible to decrease seed mortality and to increase the probability of seedling recruitment. More importantly, the germination potential of the three most consumed species by bonobos, the one benefiting from high rates of dispersal, are enhanced when ingested. Then, due to their generalist use of the mosaic (forests and savannas), and of the forest ecosystem (different forest types), we found that bonobos are likely to dispersed seeds in all kinds of habitats, including forests at different successional stages (primary and secondary), with varying understory conditions (lianas, Marantaceae, woody), at the interface between forest and savannas (forest edges), and further from forest patches within the savanna matrix. Finally, we found that the species dispersed are characterized by a diversity of ecological guilds in terms of light requirements. Those species are therefore able to establish and grow in a set of specific conditions which are otherwise found in the habitats used by bonobos.

Through the enhancement of germination and the deposition of a large number and diversity of seeds to diverse habitats types, bonobos are likely to favor forest regeneration at early and late successional stages. This finding is of primordial relevance given the increasing anthropogenic pressures (i.e deforestation and forest degradation) threatening the resilience of old primary forests. Here, we showed that bonobos enhance plant recruitment and the evolution of forest successional stages.

Faunal surveys (Task 3.2 and 3.6)

Authors : R.C. Beudels-Jamar, R.-M. Lafontaine, H. Robert (RBINS)

Introduction

All activities carried out in the context of BIOSERF project in RDC have been prepared and performed in close collaboration with WWF-RDC. The "Institut Congolais pour la Conservation de la Nature" (ICCN) has also been a close partner during these missions for access to the reserves, protection of the staff, technical support and training regarding the different methodologies applied (see methods section) .

The main objective of these inventories are on the one hand, to contribute to a better knowledge on the biodiversity (birds and mammals essentially) and ecosystem services of the selected areas, and on the other hand, to estimate the status of the physical and biological processes that rule the forest ecosystem regeneration. These processes are essentially dependant on seed dispersal by large birds and mammals but they are more than ever impacted by the decrease of their population size (because of over hunting or habitat degradation or loss). The encountered animals were classified into functional groups in order to obtain estimates of their quantitative contribution to the dispersal of tree species in the Lac Tumba Landscape. Those data could be ultimately used to derive seed dispersal kernels for the CARAIB vegetation model in WP2.

Material and methods

Areas of interest

During year 2013 and 2014, three different mission of wildlife inventory have been carried on within the "Lac Tumba Landscape" in the tropical rain forest of the Congo basin (RDC, Fig. 24). The first one took place in the Natural Reserve of the Ngiri Triangle (RNTN; from 21/10 to 10/11/2013, Fig. 25); the second one in the northern part of the Natural Reserve of Tumba-Lediima (RNTL; from 17/03 to 25/04/2014) and the third one has been split geographically to cover two different areas: first in the unprotected forests located between the River Bambou (near the WWF Malebo station) and the southern edge of the RNTL and the second in the southern part of the Natural Reserve of Tumba-Lediima (from 19/08 to 19/09/2014, Fig. 26). These areas have been chosen among others of the landscape essentially because of their high biodiversity potential. Their natural reserve status may indeed imply that the environment and the biodiversity of these reserves could be closer to their pristine state in comparison to the vastness of the degraded (with intensive logging and agriculture) and largely populated areas around them.

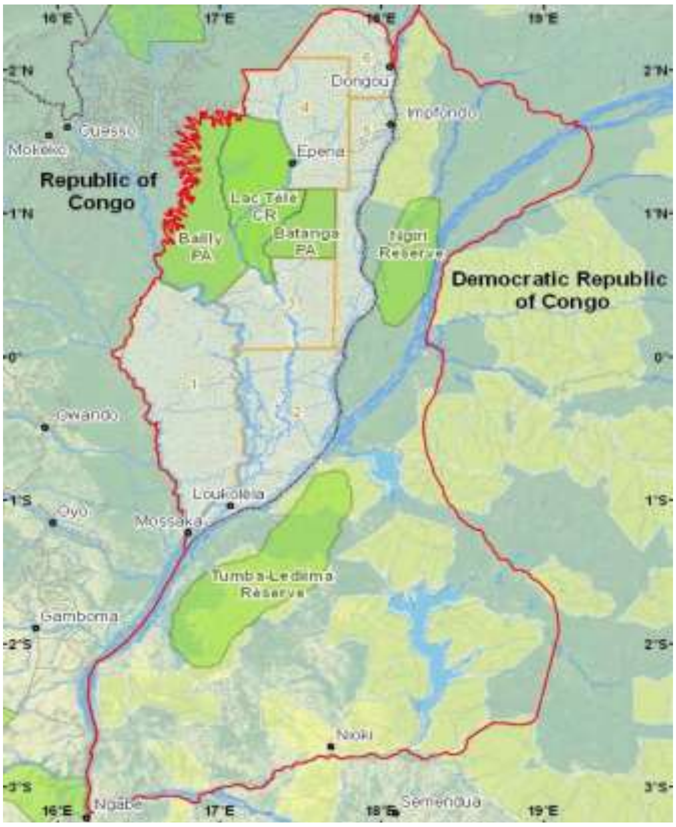


Fig. 24 Localisation of the RNTL and RNTN in the « Lac Télé-Lac Tumba » landscape (RDC et ROC)

Fig. 25 RNTN between the Congo River and the Ubangi River. The blue lane represents the track followed by our team during the 21 days of the field work. The blue ellipse represents the prospected areas reached with the secondary river network (by pirogue or on foot). The white and yellow dots represent different camp sites and prospection zones. Source : Google Earth

Fig. 26 Localization of the Nature Reserve of Tumba-Lediima and the WWF base of Malebo within the « Lac Télé-Lac Tumba » landscape (RDC). The blue ellipse represents the different research areas of prospection. Source : Google Earth

The RNTN is a recently protected area of 420.000 hectares under the "arête ministérielle" N°001/CAB/MIN/ECM-T/27/JEB/10 of the Environment Ministry, Conservation and Tourism since January 8th 2011. Located in the province of "Equateur" (RDC) it is confined between the Congo River to the east and the Ubangi River to the west, it is also included in the RAMSAR site "Ngiri-TUMBA-Mai-Ndombe" classified by the Congolese government in July 8th 2008. RNTN is composed of swamp forest in which flows southward several rivers, the most important ones being the Ngiri River in the North and the Mpoka River in the southern part of the reserve. The triangular shape of the reserve stretches over a distance of 300 kilometers (between 02°00'N and 0°30'S) with a mean width of about 50 kilometers.

The hydrography and physionomy of the reserve is mainly influenced by the Ngiri River which flows into the Oubangi River along several large swamp savannas ("ésobé") and long stretches of forest partially or periodically inundated. The most common tree species in these swamp forest are *Parinaria* spp., *Uapaca heudelotii*, *Gibourtia demeusei*, *Oubanguia Africana*, *Entandrophragma palustre* and *Coelocaryon botryoides*. During the rise of the water level, most savannas are inundated and should have been (up to recently) an excellent habitat for large mammals such as hippopotamus and buffaloes. During dry season the savannas are often burned as a hunting practice.

Human density into the reserve is high. More than 70 villages have been recently listed along the edges of the Reserve. From different ethnical origin and established following several successive invasions, the inhabitants of these villages are not able to perform large scale agriculture since more than 80% of the reserve is covered by swampy forest or forest regularly inundated. Their principal source of subsistence is therefore concentrated on the product of intensive fisheries and hunting/poaching.

The RNTL stretches on the left bank of the Congo River from Lake Tumba in the north (province of Equateur) to the town of Yumbi in the south (province of Bandundu) on a surface of 7500 km². Created on December 7th 2006, under the "arête ministériel"

N°053/CAB/MIN/ECM-EF/2006, it is mostly composed of swamp forest with an important hydrographic network of rivers flowing either into Lake Tumba to the North, Lake Mai-Ndombe to the east and into the Congo River to the west. The southern part of the reserve displays of a mosaic of swamp forest alternating with small savannas seasonally or partially inundated.

Important pressure on the environment is particularly obvious because of the activity of several logging companies active in the region (e.g. SODEFOR, SOFORMA) and because of the large and growing human population which depends entirely on the forest for their subsistence. Most of the villages are located along the north-south route of wood exploitation in the south-central part of the reserve. Agriculture is the main source of income for most families living in the RNTL. Monoculture of Manioc is largely dominant over any other crop although it is often associated to corn and bananas. Agriculture is typically performed on slashed and burned plots of primary forest for a couple of years before the soil qualities are depleted and the next plots are made available for agriculture. With the growing population, huge areas of primary forest are devastated each year for this endless process of inadequate and unsustainable type of agriculture. Fishing is the second source of subsistence and income of the populations into the RNTL. Fishing is performed on all rivers of the reserve and if villages are distant from the rivers, fishing camps are installed along the water banks for constant access to the resource. Here again, constant and unsustainable pressure on the fish stock is generally associated with the use of illegal gear (e.g. small mesh nets or mosquito nets).

Hunting, although in total violation of the regulations applicable (e.g. hunting season, protection of threatened species etc.) is widely performed over the entire reserve and become more important where fish stocks are declining. The hunt with dogs, trapping and shooting are the most common means for bush meat production and/or trade.

Birds data collection

Data collection was accomplished on a continuous basis by the team while on the field (at base camp, at mist-net stations, with camera trap and during time of site shift or transportation to the study area).

Birds were searched and recorded following direct observation, at mist net stations, base camps, along “recces”, and secondarily with camera trap. By “recce” we hear circuits of prospection targeted between two defined points of interest or in a loop in which probability of wildlife observation is highest. The length of each “recce” is not defined prior to the inventory but represents usually several kilometers of progression into the environment or as long as topographic, hydrographic or meteorological condition allows it. During these “recce” all direct observations of bird species are recorded. The gear used for bird identification consist of 2x Swarovski EL 10x42 binoculars and 1x Leica Ultravid 10x32 binoculars. Photographic documentation was taken for further identification with a Nikon D200 camera equipped with a 70-300mm NIKKOR zoom, a Canon EOS camera equipped with 70-300 Canon zoom and a Canon IXUS 80 of 16 megapixels pocket camera. The capture of birds with mist nets allows an efficient and complementary way to detect cryptic species very often difficult to observe in their habitat such as dense forest understorey or savannas. It is moreover well adapted to this kind of inventory because it is the safest way to capture birds and it does not disturb the habitat. During the three mission of inventory 10 mist nets (of 6, 9 and 12 meter long and 2 meter high) were used at several stations (in primary forest, marsh, savanna or along streams). In RNTN, six different mist net stations were operational for a total duration of 96 hours and a total mist net length of 90 meter. In the north part of RNTL, 90 meter of mist net was set for a duration of 120 hours. Finally, in the Forest of Mukulungu and Nsélé (south of RNTL, along the Bambou river), 120 meter of mist net was set for a duration of 120 hour. Once captured, the birds were kept securely in special bags for species, age and, if possible, sex identification at the base camp. Immediately after, they were released into the habitat in which they have been captured.

For particular bird captured at the edge/beyond their known distribution range or species for which taxonomical ambiguity persist, a DNA sample was taken (few feathers of the bird's flanks or belly) in order to asses similarity with DNA sequences of the COI gene of the same species or for species taxonomically close. These gene sequences are publicly available online on GenBank (http://www.ncbi.nlm.nih.gov/genbank/).

Mammal data collection

Data on mammal presence were collected either by direct observation, detection of presence evidence (feces, tracks, burrows) during recces, at camp sites, during transfers and by interviewing local villagers, trackers and hunters.

Along with the field data a total of 6 camera traps were installed for 6 days at 3 different locations in RNTN; 11 camera traps were installed for 11 days along two transects in the North part of RNTL and 30 camera traps were set in three different zones of the southern part of RNTL, Nsélé and Mbanzi area. Camera traps were installed in target sites as a complementary mean of mammal presence detection in RNTL. Different brands of Camera traps were used: Acorn, Reckonyx, Bushnell, and Moultrie. The image resolution was set to 12 mega pixels and all devices are equipped with infrared/movement sensors. Distance of detection in the primary forest fluctuates between 5 to 10 meters (depending on the local vegetation) within an angle of 100°. Depending on the settings, each detection triggers either a picture, a video or a picture followed by a video depending on the physiognomy of the place where the camera was set (e.g. a picture for a camera pointing at a track, a video on front of a pond or a picture and video where animals are likely to wonder about on front of the camera). When Picture and/or video are taken in optimal light condition the image is in color; in the dark, only black and white (infrared) images are taken. Camera traps are set on tree trunk at a height of 50 to 200 cm depending on the point of view desired, facing apparent animal tracks, burrows or feeding grounds.

Results

Birds

A total of 343 bird species (Table 13 and 14) were observed during the three missions of faunal inventories in the "Lac Télé-Lac Tumba" Landscape (see **Annex 1**). This number represents 75 % of the potential list of species present in the landscape. Among these 343 species, a very similar number of species (respectively 188 for RNTN, 183 of RNTL north and 181 for RNTL south) were observed at the three different locations. A large disparity in species distribution has been observed and over the total, only 80 species were considered as widespread and observed within each area prospected (see **Annex 2a**).

Among the 263 species that are not widely spread (or absent from one or two of the sites prospected), 130 species have only been observed in one of the three sites. This means that half of these species are only present in only one site prospected. Among this fraction we count 53 species that were only observed in the RNTN (with a majority of aquatic species; see **Annex 2b** 35 species were only observed in the northern part of RNTL (including several long distance migratory species found temporarily there at the time of prospection; see **Annex 2c**) and 42 species were only observed in the southern part of RNTL (see **Annex 2d**). Among this last group we encountered many species associated with open savannahs which reflect the characteristic of the area. The southern limit of the RNTL is indeed located in a transitional zone between large primary forest and savannahs and these two habitats can be found there in a mosaic pattern.

Finally, the combination of several techniques of inventory (by sound detection, by sight and mist net trapping) and the continuous presence of several observers on the field allowed to gather an important data set. A total of 181 bird species were observed in twenty days spent only in the Malebo-Mbanzi-Nsélé area (see **Annex 1**). In addition to this, 43 species (thus a total of 224 bird species) were observed in the southern part of the "Lac Télé-Lac Tumba" Landscape. A series of species has indeed only been observed along the Congo River (near Bolobo) or during our journey to the study sites, between Bandundu, Bolobo and Malebo; a region where savannas represent the dominant habitat. This number correspond exactly to nearly two thirds (224/343) of the total number of species observed by our team within the landscape during our three missions of inventories in the field. This highlight the fact that the different avifauna detected in the three regions are complementary.

Table 13 Capture results for the Natural Reserve of the Ngiri Triangle

Locality	**Camp « Tout Jeune »**	**Nord Mpoka**	**Bobangi**	**Camp Bamba**	**Konge 1**	**Bondillo**
Dates	26/10/13 27/10/13	29/10/13	01/11/13	03/11/13 05/11/13	09/11/13 (5 nets/6 h)	10/11/13
Species number	10	5	3	12	2	8
Number of individuals	23	6	6	35	2	10
Average number of birds captured per day	11.5	6	6	15	2	10

Besides the species found only in the vicinity of the Congo River or in degraded or urbanized habitats, between 180 and 190 bird species were observed in pristine or semi-pristine habitats during each of our mission. The intensive search for additional species has moreover allowed detecting between 50 and 60 exclusive species per site.

Regarding the bird trapping with the mist nets: 389 bird were captured, processed (species identified, individual age and sex determined when possible) and released in their habitat. These birds belonged to 45 different species (see ANNEX 4). The presence of several of these species was only detected thanks to this mist net trapping which represent thus an effective and complementary mean of inventory.

Table 14 Capture results for the Natural Reserve of Tumba-Lédiima North et South

Locality	**Camp de base 1**	**Camp de base 2**	**Mbanzi**	**Nsélé**
Dates	01/05/14 04/04/14	09/04/14 15/04/14	05/09/14 09/09/14	10/09/14 15/09/14
Species number	16	20	13	26
Number of individuals	39	92	45	131
Average number of birds captured per day	9.75	15.33	11.25	26.2

Mammals (and reptiles)

The following species were detected :

- **Chimpanzee** (*Pan troglodytes*) : Several evidence of presence (at least 3 nests) have been detected in the heart of the RNTL. Because of the heavy poaching pressure, individuals of this small population seem to have found shelter in the zone of full protection of the reserve in an area densely covered by raphia (Arecaceae). The testimony of two local fisher/poachers confirmed the presence of at least two adults in the area about two days before our visit to the site.

Fig. 27 Screenshots of a video attesting the presence of bonobos in the Mukulungu forest (located between the RNTL and the Bambou river).

a **b**

- **Bonobo** (*Pan paniscus*) : Although some groups of bonobo are likely to be present in the RNTL, none of our recce nor the use of the camera traps allowed us to detect individuals or signs of presence in the reserve. We have however evidence of presence of bonobos in the forests of Mukulungu (south-east of Mbanzi) where one group of at least five individual has been filmed thanks to one of our camera trap (see screenshots of the video on Fig. 27).

- **Black mangabey** (*Lophocebus aterrimus*) : Small groups have been observed in the protected forest of Mabali (along the north shore of lake Tumba) in 2013 and 2014.
- **Allen Swamp Monkey** (*Allenopithecus nigroviridis*) : The species is known to inhabit the swampy forests of the Natural reserve of Mabali. Several individuals were heard in 2013 in the swamps near the pygmy village of Mabali and 2 individuals were observed in 2014 in the palm trees above the official buildings of the reserve (north shore of lake Tumba).
- **Wolf's Monkey** (*Cercopithecus wolfi*) : The species was detected among other monkeys at three locations in the forest of Mabali and above the official buildings of the reserve in 2014.
- **Red tailed Monkey** (*Cercopithecus ascanius*) : Probably the most widespread Cercopithecus in the studied area. Although observed in very small numbers in the RNTL, RNTL and in the forests south of RNTL, the species has been detected in all area visited. The natural reserve of Mabali is the place where the highest abundance has been detected.
- **Small monkey sp.** (*Cercopithecus* spp. + *Colobus* sp.) : In a general, small monkeys are experiencing a strong hunting pressure (most likely for local human consumption) and in the landscape, most populations are declining drastically. Except in the particular protected forest of Mabali (where small monkey populations seem to not fear humans and do not suffer from poaching) most observation of groups of monkeys were very difficult as they immediately escaped from great distance at the sight of humans. Only 2 mixed groups of small monkeys have been observed in three weeks of search in RNTN (probably composed of *Cercopithecus nictitans*, *C. wolfi* and *Colobus* sp.). In the RNTL as well small groups were observed on few occasions displaying a shy and cryptic behavior indicating that they are constantly hunted, even in the core or the reserve.
- **Forest Elephant** (*Loxodonta africana*): Only four tracks of elephant were detected in the RNTN during our mammal inventories in the field. Although these evidence of presence in the site seems quite poor, it is however important to highlight this data particularly since it is known that elephant spend most of the wet season (time of our passage in RNTN) on the east side of the reserve; an area that we could not prospect during our limited time there. Further inventories are therefore needed for this species in particular.

  In the northern part of RNTL, our work in the field and information from local hunters leads us to conclude that elephant population have been depleted for at least 10 years. Camera trapping, observation of many tracks and the testimony of many villagers have, on the other hand, confirm the presence of small group (size unknown) in the southern part of the RNTL and several groups (total estimated population of 20-30 individuals) in the forest around Mbanzi (south of the RNTL;

see Fig. 28). During the months of October, November and December 2014, forest elephant have been photographed and filmed (88 detections in total) by 5 of the 10 cameras set in the Mukulungu forest (south-east of Mbanzi).

- **Hyppopotamus** (*Hippopotamus amphibius*) : A single individual isolated in the upper Mpoka river (RNTN) was observed several times by members of our team. This individual is most likely the ultimate member of a relictual population once widely present in most of the hydrographic network and the numerous savannas of the region. Rumors still arise concerning the existence of few other individuals remaining at the southern tip of the reserve but no evidence of presence or possibility of connection between elements of this fragmented population allow us to fear local extinction in the near future.

Fig. 28 Group of five forest elephant (including juveniles) attesting the presence of the species in the forest of Mukulungu (south-east of Mbanzi).

Although, no evidence of hyppopotamus presence was detected within RNTL during our missions in the field, one case of poaching has been brought to light by ICCN staff and a foot of the animal was brought back to Mbandaka as a proof. Apparently the individual would have been shot along the Congo River not far from the river mouth of lake Tumba indicating some presence of the species between RNTL and RNTN.

- **Red River Hog** (*Potamochoerus larvatus*) : The species has been detected either by direct observation, detection of footprints and with the camera trap in all three region prospected. It is a species with a high reproductive success and it is a primary target for hunters and trappers. During the months of April, October, November and December 2014, the species has been photographed and filmed by 7 of the cameras set in the northern and southern part of RNTL and the Nsélé/Bbanzi forests. A total of 90 detections has been recorded.
- **Bongo** (*Tragelaphus eurycerops*) : Tracks of this heavy animal have been detected during recces in the central part of RNTN. These signs of presence and the

testimony of villagers/hunters attest the presence of this species that was so far not known to inhabit this area.

- **Sitatunga** (*Tragelaphus spekei*) : Signs of presence of this species were observed regularly in all area prospected during our inventories. Not less than 10 camera traps captured evidence of presence of this species (43 pictures and videos). Among the Bovinae, the sitatunga is probably one of the most common species in the landscape. It represents also a major target for hunters and it is not rare to find corpse in local markets.
- **Duikers spp**. (*Cephalophus spp.*) : At least four species are present and commonly detected in the prospected area (*Cephalophus monticola*, *C. callipygus, C. dorsalis* and *C. sylvicultor*). *C. spp*. has been detected by 13 camera traps (at RNTN, RNTL north and south, forest of Mbanzi and Nsélé) and 103 photo/videos were taken. Duikers can therefore be considered as the most common game still present in the forests taken into consideration during our inventories.
- **Sciuridae spp**. (*Funisciurus spp.*) : Several undetermined species belonging to the genus Funisciurus were sporadically observed in dense forest. 6 camera trap captured 9 photo/videos in all area inventoried.
- **Giant pangolin** (*Smutsia gigantea*) : Often detected by their burrows or the damage done to termites mounts, the cryptic pangolin are present in all area visited. No images were taken by the camera traps. It is however an animal increasingly targeted by poachers for Asian black market.
- **Gambian Giant Pouched Rat** (*Cricettomys gambianus*) : Several individual were detected by camera traps in the RNTN (3 photo/video). The species is commonly hunted for local consumption.
- **Hammer Bat** (*Hypsignathus monstruosus*) : Many individuals (sometimes several dozen) were observed regularly at dusk all along the Congo River and the Ubangi River.
- **Guano Bat** (*Tadardia* spp.) : The species is observed regularly at the vicinity of villages. It forms dense colonies of several hundereds individuals (as it is the case in the Scientific center of Mabali).
- **Nile crocodile** (*Crocodylus niloticus*) : Several specimens were found alive in captivity for sale on local markets. This attests the presence of the species in the landscape and its commercial value.

Each of the three missions of inventory in the “Lac Tumba” landscape was performed in a relative limited period of time (18 to 25 days in the field at most). Therefore, the data collected during these missions cannot be considered as exhaustive. Several trans-saharian or intra-African migratory species or other that are only present temporally during the year (e.g. when water level is low) can still be detected if more time is spent for inventory or at complementary periods of the year.

Nonetheless, we estimate that the number of species that we encountered in the field represents at least 75 % of the total amount of species potentially present in the landscape (about 250 species possible for each site prospected). Table 15 details the number of bird species detected and the number of days spent in the field for each location.

Table 15 Number of bird species detected in the field in regard of the location and the days spent at each site

Area	Number of days of inventory	Number of species of bird detected
RNTN	21	188
Northern part of RNTL	25	183
Southern part of RNTL and Malebo/Mbanzi/Nsélé area	18	181

In addition to the 181 species observed in the Southern part of RNTL and Malebo/Mbanzi/Nsélé area, 43 species encountered during our last mission (Aug-Sept. 2014) in the vicinity of Bolobo, along the Congo River, during journeys between Bandundu, Bolobo, Malebo and across the stretches of large savannas present in the province of Bandundu. This brings to 242 the total number of bird species observed in the southern part of the landscape during our most recent inventories. This number represent nearly two thirds (224/336) of the total number of species encountered by our team during the three missions performed for this project. This highlights the complementarity of the different avifaunas present in the landscape. With the species often found along rivers and degraded habitats, we encountered between 180 and 190 bird species at each of the most pristine area prospected intensively.

Among all the species observed, 130 of them are considered as exclusive because they were only found at one particular site visited. Sites like the RNTN, forests of the northern part RNTL and the mosaic of forest-savannas of the Malebo/Mbanzi area all have their own original value and at the scale of the landscape, the values is even greater than each of its parts. The number of exclusive species per site varies between 35 and 53 species; meaning a relatively constant and high number. This last information tells us that the biodiversity of the landscape will only be sustainably conserved if a network of various habitats is protected at the scale of the entire landscape.

Discussion

Among all **bird taxa** encountered during our three missions of inventory (in the RNTN, RNTL and surroundings), some families were particularly abundant. We can highlight in particular the accipiteridae (diurnal raptors) with 20 species, bulbuls with 18 species, sunbirds with 17 species, ploceidaes (weavers and malimbe) with 14 species, cuckoos and muscicapidae with 12 species, turdidae, swallows and barbets with 11 species encountered. Many species of kingfishers were also detected (9 in total), 8 species of ralllidae, 7 species of owls, and also 7 species of ardeidae (herons and allies).

The great number of bird of prey encountered (27 species of diurnal raptors and owls in total) reflects the wide diversity of food resource available in the landscape. On the comparable point of view, the fact that at least 9 species of kingfisher inhabit the area visited attests that the halieutic resources are (were) diverse and abundant.

Globally, in primary forest, specific diversity is often relatively high as opposed to the abundance of individuals of each species being relatively low. This particular feature of primary forest has been observed in each area visited.

On the other hand we have also noticed that some groups or families of birds were particularly poorly represented (e.g. the grey parrot *Psittacus erithacus,* and large hornbills *Tropicranus*, *Bycanistes* and *Ceratogymna*). The presence in low numbers of such species who plays a crucial ecological role in the forest dynamic (as seed dispersers) is due to increasing trapping and hunting activities (for food or captured alive and sold as pets worldwide). In other environments such as open woodlands, dry or humid savannas and swamps we also noticed a severe deficit in bird species abundances (e.g ardeidae, anatidae and even small passerines). Unfortunately this deficit can so far only be explained by human pressure on their habitat and extensive hunting. This growing trend is detectable on the field where bird escapes or hides at great distance. These behaviors are correlated with hunt pressure everywhere in the world and are clearly obvious in the areas visited. Birds do fear humans that hunt either with gun, catapult or just with stones as we observed it during passage through villages.

The IUCN Red List of Threatened Species (International Union for Nature Conservation; http://www.iucnredlist.org/) ranks all species on the planet according to their status of conservation. Among 184-188 species encountered during our inventories only one is listed as can be considered as vulnerable. This species is the Grey Parrot (*Psittacus erithacus*) for which continuous capture in the wild has lead IUCN to attributed this status worldwide. Other species such as the maned owl (*Jubula letti* – DD), the African river martin (*Pseudochelidon eurystomina* – DD), African anhiga (*Anhiga rufa* -NT), the African crowned eagle (*Stephanoaetus coronatus*- NT) and the Shelley's eagle owl (*Bubo shelleyi* – NT) are either considered as near threatened or for which insufficient data exist to estimate the degree of threat on the species.

Several species detected in the field and for which no previous record has ever been made previously are here considered as "new" species (but not new to Science). Our list of species was indeed compared to the Bird Checklist of the Democratic Republic of Congo (Tommy Pedersen 2010) to highlight important distribution extension (sometimes several hundreds of kilometers) so far never recorded. Among these species we can highlight the presence in the "Lac Tumba" landscape of the *Sarothrura lugens lugens, Chlidonias hybridus, Jubula letti, Bubo shelleyi, Cossypha niveicapilla, Saxicola rubicola, Terpsiphone rufocinerea, Illadopsis fulvescens ugandae, Cinnyris johannae johannae* and *Paludipasser locustella uelensis*. In some other case species encountered in RDC were only known to be present on the western side of the Ubangi/Congo River (e.g. *Stiphrornis (erythrothorax) xanthogaster*, *Bleda (eximia) ugandae*, *Delornis (fraseri) axillaris*, *Euplectes hartlaubi humeralis*, *Spermophaga haematina pustulata*).

Among all species encountered during our inventories in the landscape, some are particularly interesting for ornithologist and represent a potential asset for eco-tourism. Some of these species have an extremely restricted area of distribution. Many of them are riparian forest species quite easily observed along the Congo or the Ubangui River and may very well attract birdwatchers from across the globe just to see them. These are for example: the African River martin (*Pseudochelidon eurystomina*), the Congo River swallow (*Riparia congensis*), the Gosling's apalis (*Apalis goslingi*), the Weyn's weaver (*Ploceus weynsi*) or even the Congo River sunbird (*Cinnyris congensis*). We can also enumerate *Jubula letti*, *Bubo shelleyi*, *Scotopelia peli*, *Scotopelia bouvieri,* for species of nocturnal raptors typical of the swamp forest. The Hartlaub duck (*Pteronetta hartlaubi*), the African pygmy goose (*Nettapus auritus*) and the spot breasted ibis (*Bostrychia rara*) are also species that may very well attract foreign birdwatchers. More generally, the presence of several ardeidae, kingfishers, colorful birds such as bee-eater and large gatherings of swallows are always source of wonderment for all tourists-naturalists.

As already mentioned many species present in the landscape play a crucial role in the dynamic and the ecological equilibrium of the forests. These species seed dispersal and regeneration of the forest after the death and fall of large trees or areas devastated by fire or other natural disaster. The size of the seed transported is proportional to the bird size. Large species such as hornbills (*Tropicranus*, *Bycanistes* and *Ceratogymna spp.)* are indeed able to carry large fruits whereas smaller species such as bulbuls (*Pycnonotidae*), barbets (*Pogoniulus sp*.), the African thrush (*Turdus pelios*), the African oriole (*Oriolus brachyrhynchus*) or starlings (*Lamprotornis sp.)* are more "specialized" in the dispersion of very small seeds. Most of these species being still quite common, the dispersion of small seed is assured. Medium size seed are usually dispersed by species like the black-billed turaco (*Tauraco schuetti*) or the grey parrot (*Psittacus erithacus*) which are experiencing a drastic decline in their local population. On the other hand, medium size hornbills (e.g. *Tockus sp*. and *Bycanistes sp*.) and the great blue turaco (*Corythaolea cristata*) are still well represented sustainably along river courses and even degraded habitats or secondary forests. The dispersal of medium size seed is therefore probably not performed homogenously at the scale of the forest and trees of open or degraded area may find an advantage against plants of the pristine primary forest. The black-casqued wattled hornbill (*Ceratogymna atrata)* and the palm vulture (*Gypohierax angolensis*) are the only species able to disperse large size seeds. *Ceratogymna atrata* may however start to experience a severe hunting pressure with the rarefaction of similar size game such as small monkeys. The shortfall of bird species able to disperse large and medium size seed in the heart of the primary forest could trigger a series of disturbances in the regeneration of the forest. This phenomenon could even be amplified with the fact that similar size seed dispersers such as monkeys are being extensively hunted and that their population is drastically declining.

From our observations, it appears that large hornbills (e.g. *Tropicranus*, *Bycanistes*, *Tockus* and *Ceratogymna*) were much rarer in the forests around Mbanzi, Nsélé and Malebo compared to the RNTN or the north part of RNTL. At the same time we often found feathers on the ground and gun shells in the forest. These are indications that in this area, large bird are becoming target for hunter following small monkey's population decline. As explained above, the increasing scarcity of these ultimate seed dispersers due to extensive hunting is alarming.

Conclusion

As a general observation for the area in which our inventories have been performed during the three mission (2013-2014), we can say that, at this stage of exploitation and human population, the diversity of natural habitats as well as large vertebrates remains quite high (at least in the protected areas which often serves as the last refuges for the fauna). On the other hand, we noticed that the densities of large mammals and large birds were surprisingly low.

The impact of human presence and activities were obvious even at (great) distance from human settlements and into the heart of each protected area. Human population is growing at a high rate in the areas prospected. The number of human settlements is growing along communication routes (often build by logging companies) but also deep into the forest, along streams and savannahs. This imply that more and more people need resources for living and thus, the pressure from hunting, fishing and deforesting for agriculture is reaching an alarming level.

We have also detected an important heterogeneity in the biodiversity across the "Lac Tumba" landscape and the presence of many exclusives species (present only in specific habitat) justifies the need to preserve (elaborate and conserve) an overall network of protected areas throughout the landscape. At least the two existing Protected Areas need to be efficiently managed. The southern of Tumba- Lediima a certain level of protection is needed to the Mbanzi - Mambou river area. Another place we have visited should be highlighted. The very particular protected area of Mabali, located on the north shore of Lake Tumba and besides the patrimonial value of the remaining infrastructure, is a little pearl of biodiversity where wildlife in general seem to sustain as in a local Noah's ark. This only shows how simple protection by local guards, the absence of logging activities and a very limited hunting pressure can allow survival of most patrimonial species.

Annex 1. Bird species observed in RNTN, RNTL north and south and the forests around Mbanzi, Nsélé and Malebo during three mission of inventory in 2013 and 2014

English species name	*Latin name*	Ngiri octobre-novembre 2013	Nord Tumba-Lédima mars-avril 2014	Sud Tumba-Lédima (Malebo-Mbanzi-Nzélé) août-septembre 2014	Mabali novembre 2013-avril 2014	Fleuve Congo	Sud Landscape Tumba , août-septembre 2014	Statut de conservation - IUCN Red List	Type d'alimentation carnivore/frugivore/granivore/herbivore/insectivore/omnivore/piscivore	Habitats occupés forêts / lacs / marais / rivières / savannes / aérien / dégradé	Fréquence Ngiri oct-nov 2013	Fréquence Tumba-Lediima mars-avril 2014	Fréquence Sud Tumba Lediima aout-sept 2014	Disperseur de graines	Taille / poids: 1, 2, 3, 4, 5	Utilisation ES: chasse pour nourriture, capture pour commerce, tourisme (potentiel)
LONG-TAILED CORMORANT	*Phalacrocorax africanus africanus*	x			x	x	x	LC	p	l,r	r			n	4	
AFRICAN DARTER	*Anhinga rufa rufa*	x				x	x	NT	p	l,r	r			n	4	t
LITTLE BITTERN	*Ixobrychus minutus payesii*	x								m	r			n	3	
WHITE-CRESTED TIGER HERON	*Tigriornis leucolophus*		x					LC	p	r,f		tr		n	4	t
SQUACCO HERON	*Ardeola ralloides*	x				x	x	LC	p	l,m,r	r			n	3	
CATTLE EGRET -	*Bubulcus ibis ibis*	x			x		x	LC	p	l,m,r				n	4	
LITTLE EGRET	*Egretta garzetta*					x	x	LC	p	l,m,r	r			n	4	
GREAT WHITE EGRET	*Egretta alba melanorhyncha*	x				x	x	LC	p	l,m,r	r			n	4	t
PURPLE HERON	*Ardea purpurea purpurea*	x	x			x	x	LC	p	l,m,r	ac	ac		n	4	t
HAMERKOP	*Scopus umbretta umbretta*	x	x			x	x	LC	o	l,m,r	ac	ac		n	3	t
AFRICAN OPENBILL STORK	*Anastomus lamelligerus lamelligerus*		x					LC	o	l,m,r		r		n	5	
ABDIM'S STORK	*Ciconia abdimii*							LC	o	l,m,r	tr			n	5	
WOOLLY-NECKED STORK	*Ciconia episcopus microscelis*	x	x					LC	o	l,m,r	r	r		n	5	t
HADADA IBIS	*Bostrychia hagedash brevirostris*	x	x					LC	o	l,m,r	r	r		n	5	
SPOT-BREASTED IBIS	*Bostrychia rara*	x						LC	o	f,l,m,r	r			n	3	t
WHITE-FACED WHISTLING DUCK	*Dendrocygna viduata*				x		x	LC	h	l,m,r				oui, plantes aquati	4	
SPUR-WINGED GOOSE	*Plectropterus gambensis gambensis*	x						LC	h	l,m,r	r			oui, plantes aquati	5	
HARTLAUB'S DUCK	*Pteronetta hartlaubii*	x	x					LC	h	r,f	ac	ac		oui, plantes aquati	4	t
AFRICAN PYGMY GOOSE	*Nettapus auritus*	x						LC	h	l,m,r	r			oui, plantes aquati	3	t
AFRICAN CUCKOO HAWK	*Aviceda cuculoides cuculoides*							LC	c	f				n	3	
AFRICAN CUCKOO HAWK	*Aviceda cuculoides batesi*	x							c	f	tr			n	3	
EUROPEAN HONEY BUZZARD	*Pernis apivorus apivorus*	x	x				x	LC	i	f	tr	tr		n	4	
BLACK KITE	*Milvus migrans migrans*			x				LC	o	s,r,m,d			r	n	4	
YELLOW-BILLED KITE	*Milvus (migrans) tenebrosus*	x	x	x	x	x	x	LC	o	s,r,m,d	c	c	ac	n	4	
AFRICAN FISH EAGLE	*Haliaeetus vocifer*	x						LC	p	r,m,l	r			n	5	t
PALM-NUT VULTURE	*Gypohierax angolensis*	x	x	x	x	x	x	LC	o	r,f	c	c	ac	n	5	t
BLACK-CHESTED SNAKE EAGLE	*Circaetus pectoralis*		x					LC	c	s		tr		n	5	
CONGO SERPENT EAGLE	*Dryotriorchis spectabilis batesi*	?			x			LC	c	f	tr?			n	4	t
AFRICAN HARRIER HAWK	*Polyboroides typus typus*							LC	c,i	f,s,d				n	4	
AFRICAN HARRIER HAWK	*Polyboroides typus pectoralis*	x	x	x		x	x		c,i	f,s,d	ac	ac	ac	n	4	
WESTERN MARSH HARRIER	*Circus aeruginosus*	x				x		LC	c	l,m,r	r			n	4	
DARK CHANTING GOSHAWK	*Melierax metabates mechowi*			x			x						tr			
BLACK SPARROWHAWK	*Accipiter melanoleucus melanoleucus*	x	x	x			x	LC	c	f	tr	r	r	n	4	
RED-THIGHED SPARROWHAWK	*Accipiter erythropus zenkeri*		x					LC	c	f		tr		n	3	
CHESTNUT-FLANKED SPARROWHAWK	*Accipiter castanilius castanilius*	x	x					LC	c	f	tr	r		n	3	
RED-CHESTED GOSHAWK	*Accipiter toussenelii toussenelii*		x					LC	c	f		r		n	3	
LONG-TAILED HAWK	*Urotriorchis macrourus*			x			x	LC	c	f			tr	n	4	t
LIZARD BUZZARD	*Kaupifalco monogrammicus monogrammicus*	x					x	LC	c,i	s,d	r			n	4	
CASSIN'S HAWK EAGLE	*Spizaetus africanus*			x			x	LC	c	f			tr	n	5	
LONG-CRESTED EAGLE	*Lophaetus occipitalis*			x			x	LC	c	s			tr	n	4	t
CROWNED EAGLE	*Stephanoaetus coronatus*	x		x			x	NT	c	f	tr		r	n	5	t

GREY KESTREL	*Falco ardosiaceus*						x									
PEREGRINE FALCON	*Falco peregrinus minor*	x				x		LC	c	d,s	r			n	4	
PEREGRINE FALCON	*Falco peregrinus calidus*								c	d,s				n	4	
SCALY FRANCOLIN	*Francolinus squamatus*		x					LC	g	f		tr		n	4	
RED-NECKED SPURFOWL	*Francolinus afer cranchii*		?	x			x	LC	g	s		r?	ac	n	4	
HARLEQUIN QUAIL	*Coturnix delegorguei delegorguei*		x					LC	g	s		r		n	2	
CRESTED GUINEAFOWL	*Guttera pucherani verreauxi*		x					LC	g	f		r		n	5	
HELMETED GUINEAFOWL	*Numida meleagris galeata*						x									
NKULENGU RAIL	*Himantornis haematopus*	x	x	x				LC	o	f,m	r	r	r	n	3	t
WHITE-SPOTTED FLUFFTAIL	*Sarothrura pulchra centralis*	x	x				x	LC	i	f,m	r	r		n	1	
()	*Sarothrura rufa elizabethae*								i	f,m				n	1	
CHESTNUT-HEADED FLUFFTAIL	*Sarothrura lugens lugens*	x						LC	i	f,m				n	1	t
()	*Sarothrura lugens lynesi*								i	f,m				n	1	
AFRICAN CRAKE	*Crecopsis egregia*		x					LC	i	s,m		r		n	2	
BLACK CRAKE	*Amaurornis flavirostris*	x	x					LC	i	m,r	r	r		n	3	
STRIPED CRAKE	*Aenigmatolimnas marginalis*		x					LC	i	m,r		tr/e		n	3	t
ALLEN'S GALLINULE	*Porphyrio alleni*	x						LC	h,i	m,r	r			oui, plantes aquati	3	
LESSER MOORHEN	*Gallinula angulata*	x						LC	h,i	m,r	r			oui, plantes aquati	3	
()	*Podica senegalensis camerunensis*								i	m,r				n	3	
BLACK-BELLIED BUSTARD	*Eupodotis melanogaster melanogaster*			x			x	LC	i	s			r	n	5	t
AFRICAN JACANA	*Actophilornis africanus*	x				x	x	LC	i	m,r	ac			n	2	
EGYPTIAN PLOVER	*Pluvianus aegyptius*					x		LC	i	r				n	1	t
COLLARED PRATINCOLE	*Glareola pratincola*						x	LC	i	s,m,a				n	3	
ROCK PRATINCOLE	*Glareola nuchalis nuchalis*					x		LC	i	r				n	3	
GREY PRATINCOLE	*Glareola cinerea*					x		LC	i	r				n	2	t
COMMON RINGED PLOVER	*Charadrius hiaticula hiaticula*					x		LC	i	r,m				n	1	
Tundra Ringed Plover	*Charadrius hiaticula tundrae*								i	r,m				n	1	
WHITE-FRONTED PLOVER	*Charadrius marginatus mechowi*					x		LC	i	r,m	r			n	1	
WHITE-HEADED LAPWING	*Vanellus albiceps*	x				x		LC	i	r,m	tr			n	2	
SENEGAL LAPWING	*Vanellus lugubris*			x			x	LC	i	r,m			r	n	2	
GREAT SNIPE	*Gallinago media*							LC	i	m,r	tr			n	2	
COMMON GREENSHANK	*Tringa nebularia*					x		LC	i	r,m				n	2	
WOOD SANDPIPER	*Tringa glareola*					X		LC	i	r,m	tr			n	2	
COMMON SANDPIPER	*Actitis hypoleucos*	x			x	x		LC	i	r,m	r			n	1	
LITTLE STINT	*Calidris minuta*					x		LC	i	r,m				n	1	
LESSER BLACK-BACKED GULL	*Larus fuscus fuscus*				x			LC	o	r	e			n	4	
WHITE-WINGED TERN	*Chlidonias leucopterus*	x				x		LC	i	r,m	r			n	1	
WHISKERED TERN	*Chlidonias hybridus*	x				x		LC	i	r,m	e			n	2	
AFRICAN SKIMMER	*Rynchops flavirostris*					x		LC	i	r				n	2	t
AFEP PIGEON	*Columba unicincta*	x	x	x	x		x	LC	f	f	ac	ac	ac	oui, petits fruit	3	n
WESTERN BRONZE-NAPED PIGEON	*Columba iriditorques*		x	x	?		x	LC	f	f		r	ac	oui, petits fruit	2	n
RED-EYED DOVE	*Streptopelia semitorquata*	x	x				x	LC	f,g	f,s,d	ac			oui, petits fruit	2	n
RING-NECKED DOVE	*Streptopelia capicola tropica*						x									
BLUE-SPOTTED WOOD DOVE	*Turtur afer*	x	x	x		x	x	LC	f,g	f,s,d	r	r	ac	oui, petits fruit	1	
TAMBOURINE DOVE	*Turtur tympanistria*						x	LC	f,g	f,s,d				oui, petits fruit	1	
BLUE-HEADED WOOD DOVE	*Turtur brehmeri brehmeri*	x		x			x	LC	f,g	f,s,d	tr		r	oui, petits fruit	1	
AFRICAN GREEN PIGEON	*Treron calva calva*	x	x	x			x	LC	f	f	c	ac	ac	oui, petits fruit	2	n
GREY PARROT	*Psittacus erithacus erithacus*	x	x	x	x	x	x	VU	f	f	r	ac	ac	i, taille moyen	3	t,c
GREAT BLUE TURACO	*Corythaeola cristata*	x	x	x	x		x	LC	f	f,r	ac	ac	ac	i, taille moyen	4	t
BLACK-BILLED TURACO	*Tauraco schuettii schuettii*	x	x	x			x	LC	f	f	tr	r	r	i, taille moyen	3	t
WESTERN GREY PLANTAIN-EATER	*Crinifer piscator*						x	LC	f	s				oui, taille moyen	3	t
LEVAILLANT'S CUCKOO	*Clamator levaillantii*		x					LC	i	s		tr		n	2	
RED-CHESTED CUCKOO	*Cuculus solitarius solitarius*	x	x	x			x	LC	i	f	r	r	ac	n	2	
BLACK CUCKOO	*Cuculus clamosus clamosus*	x	x	x			x	LC	i	f	r	r	ac	n	2	
DUSKY LONG-TAILED CUCKOO	*Cercococcyx mechowi*	x		x			x	LC	i	f	tr		r	n	2	
OLIVE LONG-TAILED CUCKOO	*Cercococcyx olivinus*	x		x			x	LC	i	f	ac		ac	n	2	
AFRICAN EMERALD CUCKOO	*Chrysococcyx cupreus cupreus*	x	x	x			x	LC	i	f	ac	ac	ac	n	1	
YELLOW-THROATED CUCKOO	*Chrysococcyx flavigularis*	x						LC	i	f	tr			n	1	t

KLAAS'S CUCKOO	*Chrysococcyx klaas*		?	x		x	x	LC	i	s		tr?	r	n	1	
DIDRIC CUCKOO	*Chrysococcyx caprius*	x	x				x	LC	i	s	r	r	r	n	1	
YELLOWBILL	*Ceuthmochares aereus aereus*	x	x	x			x	LC	i	f	ac	ac	ac	n	1	
BLACK COUCAL	*Centropus grillii*		x				x	LC	i	m,r		tr		n	3	
GABON COUCAL	*Centropus anselli*					x		LC	i	m,r				n	3	
SENEGAL COUCAL	*Centropus senegalensis senegalensis*	x	x	x		x	x	LC	i	m,r	ac	ac	ac	n	3	
BARN OWL	*Tyto alba*						x	LC	c	s				n	3	
MANED OWL	*Jubula lettii*	x						DD	c	f,r	tr			n	2	t
SPOTTED EAGLE OWL	*Bubo africanus africanus*	x	x					LC	c	f	r	r		n	4	t
SHELLEY'S EAGLE-OWL	*Bubo shelleyi*	x						NT	c	f	tr			n	5	t
PEL'S FISHING-OWL	*Scotopelia peli*	x						LC	p,c	r,f	tr			n	5	t
VERMICULATED FISHING-OWL	*Scotopelia bouvieri*	x	x					LC	p,c	r,f	r	r		n	4	t
RED-CHESTED OWLET	*Glaucidium tephronotum medje*	x	x	x			x	LC	i	f	r	r	tr	n	1	t
AFRICAN WOOD OWL	*Strix woodfordii nuchalis*	x	x	x	x		x	LC	c	f	r	ac	ac	n	3	
RUFOUS-CHEEKED NIGHTJAR	*Caprimulgus rufigena rufigena / damarensis*		x					LC	i	s		r		n	1	
BATES'S NIGHTJAR	*Caprimulgus batesi*	x	x	x			x	LC	i	f	tr	tr	ac	n	1	t
SWAMP NIGHTJAR	*Caprimulgus natalensis*	x						LC	i	s,m	r			n	1	
SQUARE-TAILED NIGHTJAR	*Caprimulgus fossii welwitschii*		x	x			x	LC	i	s		r	r	n	1	
LONG-TAILED NIGHTJAR	*Caprimulgus climacurus sclateri*			x			x	LC	i	s			r	n	1	
PENNANT-WINGED NIGHTJAR	*Macrodipteryx vexillarius*		x					LC	i	s		tr		n	2	
MOTTLED SPINETAIL	*Telacanthura ussheri sharpei*	x						LC	i	a	tr			n	1	
SABINE'S SPINETAIL	*Rhaphidura sabini*		x	x			x	LC	i	a		r	r	n	1	
CASSIN'S SPINETAIL	*Neafrapus cassini*	x	x	x			x	LC	i	a	tr	tr	r	n	1	
AFRICAN PALM SWIFT	*Cypsiurus parvus brachypterus*	x	x	x	x		x	LC	i	a	ac	r	ac	n	1	
COMMON SWIFT	*Apus apus apus / pekinensis*	x	x	x			x	LC	i	a	r		ac	n	1	
LITTLE SWIFT	*Apus affinis aerobates*			x			x	LC	i	a			r	n	1	
SPECKLED MOUSEBIRD	*Colius striatus congicus*			x			x	LC	f,o	d			r	ui, petits fruit	1	
MALACHITE KINGFISHER	*Alcedo cristata cristata*	x	x		x		x	LC	p	r,m,f	ac	ac		n	1	
WHITE-BELLIED KINGFISHER	*Alcedo leucogaster leopoldi*	x	x	x			x	LC	p	r,m	r	r	r	n	1	
AFRICAN DWARF KINGFISHER	*Ceyx lecontei*			x			x	LC	p	r,f,s	tr		r	n	1	t
AFRICAN PYGMY KINGFISHER	*Ceyx picta ferrugina*	x		x			x	LC	p	r,f,s	r	ac	ac	n	1	t
()	*Ceyx picta natalensis*								p	r,f,s		r	ac	n	1	
CHOCOLATE-BACKED KINGFISHER	*Halcyon badia*		x	x			x	LC	c,l,p	f				n	1	t
()	*Halcyon leucocephala pallidiventris*								c,l,p	s				n	1	
BLUE-BREASTED KINGFISHER	*Halcyon malimbica malimbica*	x	x	x			x	LC	c,l,p	f	ac	ac	ac	n	1	
WOODLAND KINGFISHER	*Halcyon senegalensis fuscopilea*	x	x	x	x	x	x	LC	c,l,p	d,r,s	ac	ac	ac	n	2	
()	*Halcyon senegalensis cyanoleuca*								c,l,p	d,r,s				n	2	
GIANT KINGFISHER	*Megaceryle maxima maxima*	x						LC	p	r,m,l	tr			n	3	t
PIED KINGFISHER	*Ceryle rudis*	x	x		x	x	x	LC	p	r,m,l	ac	r		n	2	t
BLUE-HEADED BEE-EATER	*Merops muelleri muelleri*		x					LC	i	r,s		tr		n	1	t
BLACK BEE-EATER	*Merops gularis australis*		x	x			x	LC	i	r,s		tr	r	n	1	t
LITTLE BEE-EATER	*Merops pusillus meridionalis*	x						LC	i	s,m	r			n	1	
BLUE-BREASTED BEE-EATER	*Merops variegatus loringi*	x	x	x			x	LC	i	s,m	ac	ac	ac	n	1	t
()	*Merops variegatus variegatus*							LC	i	s,m				n	1	t
BLUE-CHEEKED BEE-EATER	*Merops persicus persicus*					x		LC	i	s,r				n	1	
EUROPEAN BEE-EATER	*Merops apiaster*		x					LC	i	s,f,d		r		n	1	
ROSY BEE-EATER	*Merops malimbicus*	x		x			x	LC	i	s,r	r		ac	n	1	t
BROAD-BILLED ROLLER	*Eurystomus glaucurus glaucurus*						x	LC	i	s,d				n	2	
()	*Eurystomus glaucurus afer*								i	s,d				n	2	
BLUE-THROATED ROLLER	*Eurystomus gularis neglectus*	x	x	x			x	LC	i	f,d	tr	r	r	n	2	t
FOREST WOOD-HOOPOE	*Phoeniculus castaneiceps*		x	x			x					tr	r			
()	*Phoeniculus aterrimus anchietae*								i	s				n	1	
Central African Hoopoe	*Upupa (epops) africana waibeli*								i	s				n	1	
WHITE-CRESTED HORNBILL	*Tropicranus albocristatus cassini*	x	x	x	x		x	LC	f	f	r	ac	r	i, taille moyen	3	t,n
RED-BILLED DWARF HORNBILL	*Tockus camurus*	x	x	x	x		x	LC	f	f	ac	ac	ac	i, taille moyen	3	t
AFRICAN PIED HORNBILL	*Tockus fasciatus fasciatus*	x	x	x	x	x	x	LC	f	f,r,d	c	c	ac	i, taille moyen	3	t,n
PIPING HORNBILL	*Bycanistes fistulator duboisi*	x	x	x	x		x	LC	f	f,r	c	c	c	i, taille moyen	4	t,n

WHITE-THIGHED HORNBILL	*Bycanistes (cylindricus) albotibialis*	x	x	x	x	x	x	LC	f	f,r	ac	ac	ac	i, taille moyen	4	t,n
BLACK-CASQUED HORNBILL	*Ceratogymna atrata*	x	x	x	x		x	LC	f	f,r	r	r	tr	oui, gros fruits	5	t,n
SLADEN'S BARBET	*Gymnobucco sladeni*	x	x					LC	f,i	f,d	r	tr		oui, petits fruit	1	
GREY-THROATED BARBET	*Gymnobucco bonapartei bonapartei*	x	x	x	x		x	LC	f,i	f,d	ac	ac	ac	oui, petits fruit	1	
YELLOW-SPOTTED BARBET	*Buccanodon duchaillui*	x	x	x			x	LC	f,i	f,d	ac	r	ac	oui, petits fruit	1	
SPECKLED TINKERBIRD	*Pogoniulus scolopaceus flavisquamatus*	x	x	x	x		x	LC	f,i	f,d	ac	c	c	oui, petits fruit	1	
YELLOW-FRONTED TINKERBIRD	*Pogoniulus chrysoconus extoni*			x			x									
LEMON-RUMPED TINKERBIRD	*Pogoniulus bilineatus leucolaima*	x	x	x			x	LC	f,i	f,d	ac	ac	c	oui, petits fruit	1	
YELLOW-THROATED TINKERBIRD	*Pogoniulus subsulphureus flavimentum*	x	x	x			x	LC	f,i	f,d	ac	ac	ac	oui, petits fruit	1	
RED-RUMPED TINKERBIRD	*Pogoniulus atroflavus*	x	x	x	x		x	LC	f,i	f,d	ac	ac	ac	oui, petits fruit	1	
HAIRY-BREASTED BARBET	*Tricholaema (hirsuta) = flavipunctata ansorgii*	x			x			LC	f,i	f	r			oui, petits fruit	1	
BLACK-BACKED BARBET	*Lybius minor macclounii*	x	x					LC	f,i	f	tr	tr		oui, petits fruit	1	
YELLOW-BILLED BARBET	*Trachyphonus purpuratus purpuratus*		x	x			x	LC	f,i	s,d		r	ac	oui, petits fruit	1	t
SPOTTED HONEYGUIDE	*Indicator maculatus stictothorax*		x					LC	f,i	f		r		n	1	
GREATER HONEYGUIDE	*Indicator indicator*						x									
THICK-BILLED HONEYGUIDE	*Indicator conirostris conirostris*			x			x	LC	f,i	f			r	n	1	
LEAST HONEYGUIDE	*Indicator exilis exilis*		x					LC	f,i	f		tr		n	1	
LYRE-TAILED HONEYGUIDE	*Melichneutes robustus*		x					LC	f,i	f		tr		n	1	t
AFRICAN PICULET	*Sasia africana*		x					LC	i	f		r		n	1	
BUFF-SPOTTED WOODPECKER	*Campethera nivosa nivosa*		x	x			x	LC	i	f		r	r	n	1	
BROWN-EARED WOODPECKER	*Campethera caroli caroli*	x	x	x			x	LC	i	f	r	r	r	n	1	
GABON WOODPECKER	*Dendropicos gabonensis gabonensis*						x	LC	i	f				n	1	
YELLOW-CRESTED WOODPECKER	*Dendropicos xantholophus*	x	x	x	x		x	LC	i	f	r	ac	ac	n	1	
RUFOUS-SIDED BROADBILL	*Smithornis rufolateralis rufolateralis*		x	x			x	LC	i	f		r	r	n	1	
MALBRANT'S LARK	*Mirafra (africana) malbranti*			x			x						r			
	Mirafra rufocinnamomea schoutedeni		x	x			x	LC	g,i	s		ac	ac	n	1	
AFRICAN RIVER MARTIN	*Pseudochelidon eurystomina*	x						DD	i	a,r	r			n		
Shari Black Saw-wing	*Psalidoprocne pristoptera chalybea*							LC	i	a,s,f				n	1	
Petit's Black Saw-wing	*Psalidoprocne pristoptera petiti*							LC	i	a,s,f				n	1	
Eastern Black Saw-wing	*Psalidoprocne pristoptera reichenowi*			x			x	LC	i	a,s,f			r	n	1	
BRAZZA'S MARTIN	*Phedinopsis brazzae*		x					LC	i	a,r		r		n	1	t
CONGO SAND MARTIN	*Riparia congica*	x	x			x		LC	i	a,r	r	r		n	1	
BANDED MARTIN	*Riparia cincta parvula*	x		x			x	LC	i	a,r,m	r	r	ac	n	1	
GREY-RUMPED SWALLOW	*Pseudhirundo griseopyga griseopyga*	x	x			x		LC	i	a,r,m	ac	r		n	1	t
RED-BREASTED SWALLOW	*Hirundo semirufa gordoni*					x	x	LC	i	a	r			n	1	
MOSQUE SWALLOW	*Hirundo senegalensis saturatior*			x			x	LC	i	a			r	n	1	
LESSER STRIPED SWALLOW	*Hirundo abyssinica unitatis*					x	x	LC	i	a				n	1	
SOUTH AFRICAN CLIFF SWALLOW	*Hirundo spilodera*		x	x			x	LC	i	a		r	ac	n	1	
WHITE-THROATED BLUE SWALLOW	*Hirundo nigrita*	x						LC	i	a	r			n	1	
BARN SWALLOW	*Hirundo rustica rustica*	x	x	x	x	x	x	LC	i	a	ac	r	ac	n	1	
COMMON HOUSE MARTIN	*Delichon urbica urbica*		x					LC	i	a		r		n	1	
YELLOW (BLUE-HEADED) WAGTAIL	*Motacilla flava flava*					x		LC	i	m,s				n	1	
Grey-headed Wagtail	*Motacilla flava thunbergi*								i	m,s				n	1	
Spanish Yellow Wagtail	*Motacilla flava iberiae*								i	m,s				n	1	
AFRICAN PIED WAGTAIL	*Motacilla aguimp vidua*					x		LC	i	r,m				n	1	
WOODLAND PIPIT	*Anthus (nyassae) schoutedeni*			x			x	LC	i	s			ac	n	1	
LONG-LEGGED PIPIT	*Anthus pallidiventris esobe*		x	x			x	LC	i	s	r	r	r	n	1	
SHORT-TAILED PIPIT	*Anthus brachyurus leggei*			x			x	LC	i	s			r	n	1	

YELLOW-THROATED LONGCLAW	*Macronyx croceus*		x	x			x	LC	i	m,s		r	r	n	1	
BLUE CUCKOOSHRIKE	*Coracina azurea*	x	x	x			x	LC	f,i	f	ac	r	r	ui, petits fruit	1	
LITTLE GREENBUL	*Andropadus virens virens*	x	x	x			x	LC	f,i	f	ac	ac	ac	, tout petits fr	1	
GREY GREENBUL	*Andropadus gracilis gracilis*	x	x	x			x	LC	f,i	f	r	r	r	, tout petits fr	1	
ANSORGE'S GREENBUL	*Andropadus ansorgei ansorgei*	x	x	x			x	LC	f,i	f	r	r	r	, tout petits fr	1	
PLAIN GREENBUL	*Andropadus curvirostris curvirostris*		x					LC	f,i	f		r		oui, tout petits fr	1	
SLENDER-BILLED GREENBUL	*Andropadus gracilirostris gracilirostris*		x					LC	f,i	f		r		oui, tout petits fr	1	
YELLOW-WHISKERED GREENBUL	*Andropadus latirostris latirostris*	x	x	x			x	LC	f,i	f	ac	ac	ac	, tout petits fr	1	
HONEYGUIDE GREENBUL	*Baeopogon indicator indicator*		x	x			x	LC	f,i	f		r	r	, tout petits fr	1	
SPOTTED GREENBUL	*Ixonotus guttatus*	x	x	x	x		x	LC	f,i	f,r	c	ac	ac	, tout petits fr	1	
SIMPLE GREENBUL	*Chlorocichla simplex*		x	x		x	x	LC	f,i	f		r	ac	, tout petits fr	1	
YELLOW-THROATED (White-throated) LEAF-LOVE	*Chlorocichla flavicollis soror*	x		x		x	x	LC	f,i	f	ac		r	, tout petits fr	1	
SWAMP GREENBUL	*Thescelocichla leucopleura*		x	x			x	LC	f,i	f,m		r	r	, tout petits fr	2	
LEAF-LOVE	*Pyrrhurus scandens orientalis*		x		x		x	LC	f,i	f		r		oui, tout petits fr	2	
ICTERINE GREENBUL	*Phyllastrephus icterinus*	x	x	x			x	LC	f,i	f	ac	ac	ac	, tout petits fr	1	
WHITE-THROATED GREENBUL	*Phyllastrephus albigularis albigularis*		x					LC	f,i	f		r		oui, tout petits fr	1	
RED-TAILED BRISTLEBILL	*Bleda syndactyla syndactyla*		x	x			x	LC	f,i	f		r	r	n	2	
GREEN-TAILED BRISTLEBILL	*Bleda (eximia) ugandae*	x	x	x			x	LC	f,i	f	r	ac	r	n	2	t
RED-TAILED GREENBUL	*Criniger calurus emini*	x	x	x			x	LC	f,i	f	r	r	r	n	2	
DARK-CAPPED BULBUL	*Pycnonotus (barbatus) tricolor*	x	x	x		x	x	LC	f,i	s	r	r	r	, tout petits fr	1	
RED-TAILED ANT-THRUSH	*Neocossyphus rufus gabunensis*	?		x			x	LC	i	f	tr?		r	n	1	
WHITE-TAILED ANT-THRUSH	*Neocossyphus poensis praepectoralis*		?	x			x	LC	i	f		tr?	tr	n	1	
RUFOUS FLYCATCHER-THRUSH	*Stizorhina fraseri vulpina*	x	x	x	x		x	LC	i	f	ac	ac	r	n	1	
()	Stizorhina fraseri rubicunda								i	f				n	1	
AFRICAN THRUSH	*Turdus pelios centralis*	x				x		LC	f,i	d,f	r			oui, tout petits fr	1	
()	Turdus pelios saturatus								f,i	d,f				oui, tout petits fr	1	
FIRE-CRESTED ALETHE	*Alethe (diademata) castanea woosnami*	x	x	x	x		x	LC	i	f	r	r	ac	n	1	
FOREST ROBIN	*Stiphrornis (erythrothorax) xanthogaster*	x	x	x			x	LC	i	f	ac	r	r	n	1	
SNOWY-CROWNED ROBIN-CHAT	*Cosypha niveicapilla*	x						LC	i	f,s	r			n	1	
RUFOUS-TAILED PALM-THRUSH	*Cichladusa ruficauda*			x		x	x	LC	f,i	d	c		r	n	1	
WHITE-BROWED SCRUB-ROBIN	*Erythropygia leucophrys munda*			x			x	LC	i	s			r	n	1	
AFRICAN STONECHAT	Saxicola (torquata) rubicula salax	x						LC	i	s,m				n	1	
SOOTY CHAT	*Myrmecocichla nigra*			x			x	LC	i	s			ac	n	1	
FAN-TAILED GRASSBIRD	*Schoenicola brevirostris alexinae*	x		x			x	LC	i	m,s	r		r	n	1	
GREEN-CAPPED EREMOMELA	*Eremomela scotops pulchra*			x			x	LC	i	s			tr	n	1	
RUFOUS-CROWNED EREMOMELA	*Eremomela badiceps badiceps*			x			x	LC	i	s			tr	n	1	
SALVADORI'S EREMOMELA	*Eremomela salvadorii*	x		x			x	LC	i	f	tr		r	n	1	
GREEN CROMBEC	*Sylvietta virens virens*	x	x	x			x	LC	i	f	r	r	r	n	1	
	Sylvietta virens baraka							LC	i	f				n	1	
RED-CAPPED CROMBEC	*Sylvietta ruficapilla rufigenis*			x			x	LC	i	s			tr	n	1	t
GREY LONGBILL	*Macrosphenus concolor*	x		x			x	LC	i	s	r		r	n	1	
WILLOW WARBLER	*Phylloscopus trochilus acredula*	x				x		LC	i	s,d	r			n	1	
Willow Warbler	*Phylloscopus trochilus yakutensis*								i	s,d				n	1	
GREEN HYLIA	*Hylia prasina prasina*	x	x	x	x		x	LC	i	f	ac	ac	ac	n	1	
GARDEN WARBLER	*Sylvia borin borin*		x					LC	f,i	s				oui, tout petits fr	1	

CHATTERING CISTICOLA	*Cisticola anonymus*	x	x			x		LC	i	m,s	r	r		n	1	
CROAKING CISTICOLA	*Cisticola natalensis strangei*		x	x			x	LC	i	m,s		r	ac	n	1	
RATTLING CISTICOLA	*Cisticola chiniana fortis*		x	x			x	LC	i	m,s		r	ac	n	1	
SIFFLING CISTICOLA	*Cisticola brachypterus brachypterus*	x	x	x			x	LC	i	m,s	ac	ac	r	n	1	
()	*Cisticola (brachypterus) loanda*			x			x		i	m,s				n	1	
WHISTLING CISTICOLA	*Cisticola lateralis modesta*	x		x			x	LC	i	m,s	ac		r	n	1	
PALE-CROWNED CISTICOLA	*Cisticola cinnamomeus midcongo*		x	x			x					r	r			
WINDING CISTICOLA	*Cisticola galactotes amphilectus = C. marginatus*	x	x				x	LC	i	m,s	ac	ac		n	1	
TAWNY-FLANKED PRINIA	*Prinia subflava graueri*	x	x	x		x	x	LC	i	s,d,m	ac	ac	ac	n	1	
WHITE-CHINNED PRINIA	*Prinia leucopogon leucopogon*			x			x	LC	i	s			r	n	1	
()	*Prinia leucopogon reichenowi*								i	s				n	1	
BUFF-THROATED APALIS	*Apalis rufogularis nigrescens*	x						LC	i	r,m	r			n	1	
GOSLING'S APALIS	*Apalis goslingi*	x						LC	i	r,f	r			n	1	t
GREY-BACKED CAMAROPTERA	*Camaroptera brachyura tincta*	x	x	x		x	x	LC	i	d,s	r	ac	ac	n	1	
YELLOW-BROWED CAMAROPTERA	*Camaroptera superciliaris*		x	x			x	LC	i	r,f		tr	r	n	1	
OLIVE-GREEN CAMAROPTERA	*Camaroptera chloronota chloronota*		?	x			x	LC	i			tr?	r	n	1	
PALE FLYCATCHER	*Bradornis pallidus murinus*	x		x			x	LC	i		tr		r	n	1	
FRASER'S FOREST-FLYCATCHER	*Fraseria ocreata ocreata*		x	x			x	LC	i	f		r	r	n	1	
WHITE-BROWED FOREST-FLYCATCHER	*Fraseria cinerascens ruthae*	x						LC	i	f	ac			n	1	
COLLARED FLYCATCHER	*Ficedula albicollis*			x			x						r			
SPOTTED FLYCATCHER	*Muscicapa striata striata*	x	x					LC	i	s	r	r		n	1	
CASSIN'S FLYCATCHER	*Muscicapa cassini*	x	x	x?			x?	LC	i	r,f	ac	r	tr?	n	1	
ASHY FLYCATCHER	*Muscicapa caerulescens brevicauda*	x						LC	i	f	tr			n	1	
SOOTY FLYCATCHER	*Muscicapa infuscata minuscula*		x	x			x	LC	i	f		tr	r	n	1	
GREY TIT-FLYCATCHER	*Myioparus plumbeus plumbeus*		x	x			x	LC	i	f		r	tr	n	1	
GREY-THROATED TIT-FLYCATCHER	*Myioparus griseigularis griseigularis*		x					LC	i	f		tr		n	1	
SHRIKE-FLYCATCHER	*Megabyas flammulatus aequatorialis*		x					LC	i	s		r		n	1	
BLACK-AND-WHITE FLYCATCHER	*Bias musicus musicus*		x	x			x	LC	i	s		r	r	n	1	t
BLACK-HEADED BATIS	*Batis (minor) erlangeri*						x									
CHESTNUT WATTLE-EYE	*Dyaphorophyia castanea castanea*	x	x	x			x	LC	i	f	r	r	r	n	1	t
BROWN-THROATED WATTLE-EYE	*Platysteira cyanea nyansae*			x		x	x	LC	i	f			r	n	1	
BLUE-HEADED CRESTED FLYCATCHER	*Trochocercus nitens nitens*		x	x			x	LC	i	f		r	ac	n	1	
AFRICAN PARADISE-FLYCATCHER	*Terpsiphone viridis speciosa*		x	x	x	x	x	LC	i	d,s		r	r	n	1	t
()	*Terpsiphone viridis plumbeiceps*							LC	i	d,s				n	1	
RUFOUS-VENTED PARADISE-FLYCATCHE	*Terpsiphone rufocinerea*	x						LC	i	f	r			n	1	t
BATES'S PARADISE-FLYCATCHER	*Terpsiphone batesi batesi*		x		x			LC	i	f		tr		n	1	t
()	*Terpsiphone rufiventer schubotzi*							LC	i	f				n	1	
RED-BELLIED PARADISE-FLYCATCHER	*Terpsiphone rufiventer mayombe*	x	x	x	x		x	LC	i	f	r	r	ac	n	1	
BROWN ILLADOPSIS	*Illadopsis fulvescens ugandae*	x						LC	i	f	r			n	1	
PALE-BREASTED ILLADOPSIS	*Illadopsis rufipennis rufipennis*		x	x			x	LC	i	f		r	r	n	1	
SCALY-BREASTED ILLADOPSIS	*Illadopsis albipectus*			x			x	LC	i	f			tr	n	1	
WHITE-WINGED BLACK TIT	*Parus leucomelas insignis*			x			x	LC	i	s			tr	n	1	
TIT-HYLIA	*Pholidornis rushiae denti*		x					LC	i	f		r		n	1	
VIOLET-TAILED SUNBIRD	*Anthreptes aurantium*	x						LC	I,f	d,s	ac			n	1	t
GREY-CHINNED SUNBIRD	*Anthreptes rectirostris tephrolaema*			x			x	LC	I,f	s			r	n	1	
LITTLE GREEN SUNBIRD	*Anthreptes seimundi traylori*		x	x			x	LC	I,f	s		r	r	n	1	
GREY-HEADED SUNBIRD	*Deleornis (fraser)i axillaris*	x	x	x			x	LC	I,f	f	ac	r	r	n	1	
REICHENBACH'S SUNBIRD	*Anabathmis reichenbachii*	x			x			LC	I,f	m,s	r			n	1	
GREEN-HEADED SUNBIRD	*Cyanomitra verticalis bohndorffi*	x	x		x	x		LC	I,f	d,s	r	r		n	1	
BLUE-THROATED BROWN SUNBIRD	*Cyanomitra cyanolaema octaviae*		x	x			x	LC	I,f	f,d,s		r	r	n	1	

WESTERN OLIVE SUNBIRD	*Cyanomitra obscura cephaelis*	x	x	x	x		x	LC	I,f	f	r	c	c	n	1	
GREEN-THROATED SUNBIRD	*Chalcomitra rubescens rubescens*	x	x	x			x	LC	I,f	f,s	r	r	r	n	1	
COLLARED SUNBIRD	*Hedydipna collaris somereni*	x	x	x			x	LC	I,f	d,s	c	ac	ac	n	1	
OLIVE-BELLIED SUNBIRD	*Cinnyris chloropygia chloropygia*	x		x		x	x	LC	I,f	d,s	ac		ac	n	1	
TINY SUNBIRD	*Cinnyris minullus*		x					LC	I,f	f,s		r		n	1	
CONGO SUNBIRD	*Cinnyris congensis*	x		x		x	x	LC	I,f	r,m	ac		r	n	1	t
JOHANNA'S SUNBIRD	*Cinnyris johannae johannae*	x						LC	I,f	f,s	r			n	1	
SUPERB SUNBIRD	*Cinnyris superba superba*	x	x	x			x	LC	I,f	d,s	r	r	r	n	1	
COPPER SUNBIRD	*Cinnyris cuprea cuprea*	x		x			x	LC	I,f	d,s	r		ac	n	1	
WESTERN BLACK-HEADED ORIOLE	*Oriolus brachyrhynchus laetior*	x	x					LC	f,i	f	r	r		oui, tout petits fr	1	
RED-BACKED SHRIKE	*Lanius collurio*	x						LC	i	s,m	tr/e			n	1	
COMMON FISCAL	*Lanius collaris capelli*			x			x	LC	i	s			r	n	1	
SABINE'S PUFFBACK	*Dryoscopus sabini melanoleucus*		x					LC	i	f		tr		n	1	
MARSH TCHAGRA	*Tchagra minuta minuta*			x			x	LC	i	m,s			tr	n	1	
BROWN-CROWNED TCHAGRA	*Tchagra australis emini*						x	LC	i	s,m				n	1	
BLACK-CROWNED TCHAGRA	*Tchagra senegala camerunensis*						x	LC	i	s				n	1	
()	*Tchagra senegala rufofusca*							LC	i	s				n	1	
SOOTY BOUBOU	*Laniarius leucorhynchus*	?					x	LC	i	f,m,r	tr?			n	1	
WESTERN NICATOR	*Nicator chloris*	x	x	x			x	LC	i	f	r	ac	c	n	1	
YELLOW-THROATED NICATOR	*Nicator vireo*			x			x	LC	i	f			r	n	1	t
SHINING DRONGO	*Dicrurus atripennis*	x		x			x	LC	I,f	f	r		tr	n	1	
FORK-TAILED DRONGO	*Dicrurus adsimilis apivorus*						x									
VELVET-MANTLED DRONGO	*Dicrurus (modestus) coracinus*	x		x	x		x	LC	I,f	f	r		r	n	1	
PIED CROW	*Corvus albus*		x	x	x	x	x	LC	o	d	c	ac	ac	n	4	
CHESTNUT-WINGED STARLING	*Onychognathus (fulgidus) hartlaubi*		x					LC	f,i	d,f	r	r		oui, tout petits fr	2	
PURPLE-HEADED GLOSSY STARLING	*Lamprotornis purpureiceps*	x	x	x	x		x	LC	f,i	f	r	r	r	, tout petits fr	1	
SPLENDID GLOSSY STARLING	*Lamprotornis splendidus splendidus*	x	x	x			x	LC	f,i	f	r	ac	r	, tout petits fr	2	
VIOLET-BACKED STARLING	*Cinnyricinclus leucogaster verreauxi*			x			x	LC	f,i	d,s				oui, tout petits fr	1	
NORTHERN GREY-HEADED SPARROW	*Passer griseus ugandae*	x	x	x		x	x	LC	g	d	r	r	ac	n	1	
SLENDER-BILLED WEAVER	*Ploceus pelzelni monachus*	x					x	LC	g,i	d,r	r			n	1	
BLACK-NECKED WEAVER	*Ploceus nigricollis nigricollis*	x	x				x	LC	g,i	d	r	r		n	1	
ORANGE WEAVER	*Ploceus aurantius aurantius*	x				x		LC	f,g	r,f	ac			n	1	
VIEILLOT'S BLACK WEAVER	*Ploceus nigerrimus nigerrimus*	x	x		x	x	x	LC	f,g	d,s	r	r		n	1	
VILLAGE WEAVER	*Ploceus cucullatus bohndorffi*	x	x	x		x	x	LC	f,g	d	c	ac	ac	n	1	
WEYNS'S WEAVER	*Ploceus weynsi*	x	x	x	x		x	LC	f,g	f,r	s en grand nc	ac	ac	n	1	t
BLACK-HEADED WEAVER	*Ploceus melanocephalus duboisi*	x						LC	f,g	d	ac			n	1	
YELLOW-MANTLED WEAVER	*Ploceus tricolor interscapularis*	x						LC	f,g	f	r			n	1	
COMPACT WEAVER	*Pachyphantes superciliosus*			x			x	LC	f,g	f			r	n	1	
BLUE-BILLED MALIMBE	*Malimbus nitens microrhynchus*		x	x			x	LC	f,i	f		r	r	n	1	
CRESTED MALIMBE	*Malimbus malimbicus malimbicus*	x	x					LC	f,i	f	r	r		n	1	
CASSIN'S MALIMBE	*Malimbus cassini*	x	x	x	x		x	LC	f,i	f	ac	r	r	n	1	
RED-HEADED MALIMBE	*Malimbus rubricollis rubricollis*	x	x		x			LC	f,i	f	r	r		n	1	
RED-CROWNED MALIMBE	*Malimbus coronatus*	x		x			x	LC	f,i	f	r		r	n	1	
RED-HEADED QUELEA	*Quelea erythrops*	x						LC	g	s,m	mais abondant			n	1	
BOB-TAILED WEAVER	*Brachycope anomala*					x	x	LC	g	d				n	1	
YELLOW-CROWNED BISHOP	*Euplectes afer afer*	x						LC	g	m,s	ac			n	1	
BLACK-WINGED BISHOP	*Euplectes hordeaceus hordeaceus*			x			x	LC	g	s,m			r	n	1	
YELLOW-MANTLED WIDOWBIRD	*Euplectes macrourus macrourus*						x	LC	g	s,m				n	1	
MARSH WIDOWBIRD	*Euplectes hartlaubi humeralis*	x	x				x	LC	g	m,s	ac	r	r	n	1	
WOODHOUSE'S ANTPECKER	*Parmoptila woodhousei ansorgei*		x	x			x	LC	i	f		r	r	n	1	

JAMESON'S ANTPECKER	*Parmoptila jamesoni*		x					LC	i	f		r		n	1	
GREY-CROWNED NEGROFINCH	*Nigrita canicapilla canicapilla*							LC	f,g	f				n	1	
GREY-CROWNED NEGROFINCH	*Nigrita canicapilla schistacea*	x		x			x	LC	f,g	f	r		r	n	1	
PALE-FRONTED NEGROFINCH	*Nigrita luteifrons luteifrons*		x	x			x	LC	f,g	f		r	r	n	1	
CHESTNUT-BREASTED NEGROFINCH	*Nigrita bicolor brunnescens*	x	x	x			x	LC	f,g	f	r	ac	ac	n	1	
WHITE-BREASTED NEGROFINCH	*Nigrita fusconota fusconota*	x						LC	f,g	f	r			n	1	
BLACK-BELLIED SEEDCRACKER	*Pyrenestes ostrinus ostrinus*	x	x					LC	g	f	r	r		n	1	
Large billed Seedcracker	*Pyrenestes ostrinus frommi*								g	f				n	1	
Rothschild's Seedcracker	*Pyrenestes ostrinus rothschildi*								g	f				n	1	
WESTERN BLUEBILL	*Spermophaga haematina pustulata*	x	x	x			x	LC	g	f	r	r	ac	n	1	
AFRICAN FIREFINCH	*Lagnosticta rubricata congica*	x		x			x	LC	g	s,m	r		r	n	1	
FAWN-BREASTED WAXBILL	*Estrilda paludicola ruthae*	x	x	x			x	LC	g	m,s	r	r	r	n	1	
ORANGE-CHEEKED WAXBILL	*Estrilda melpoda melpoda*	x	x	x			x	LC	g	s,d	ac	r	ac	n	1	
COMMON WAXBILL	*Estrilda astrild occidentalis*	x	x			x		LC	g	s,d	r	r		n	1	
BLUE-BREASTED CORDON-BLEU	*Uraeginthus angolensis angolensis*							LC	g	s	r			n	1	
Orange-breasted (Zebra) Waxbill	*Sporaeginthus subflavus clarkei*							LC	g	s				n	1	
LOCUST-FINCH	*Paludipasser locustella uelensis*	x	x	x			x	LC	g	s	r	r	ac	n	1	
BLACK-CHINNED QUAILFINCH	*Ortygospiza gabonensis gabonensis*		x	x			x	LC	g	s		r	ac	n	1	
BRONZE MANNIKIN	*Spermestes cucullatus cucullatus*	x	x	x			x	LC	g	s,d	r	r	r	n	1	
BLACK-AND-WHITE MANNIKIN	*Spermestes bicolor poensis*							LC	g	s,d	c			n	1	
MAGPIE MANNIKIN	*Spermestes fringilloides fringilloides*							LC	g	s,d	ac			n	1	
PARASITIC WEAVER	*Anomalospiza imberbis imberbis*			x			x	LC	g	s			r	n	1	
PIN-TAILED WHYDAH	*Vidua macroura*	x	x	x	x		x	LC	g	s,d	r	ac	ac	n	1	
()	*Serinus atrogularis lwenarum*								g	d				n	1	
YELLOW-FRONTED CANARY	*Serinus mozambicus barbatus*			x			x	LC	g	d			r	n	1	
()	*Serinus mozambicus tando*								g	d				n	1	
()	*Emberiza cabanisi cognominata*								g	s,d				n	1	
		188	183	181	47	64	224									

LC = Least Concern
DD = data deficient
NT = Near threatened
VU = Vulnerable
EN = Endangered

C = commun, observé > 1j/2j dans son habitat
AC = assez commun, observé > 1j/4J dans son habitat
R = rare, observé < 1j/10j
TR = observé une seule fois en 20 jours
Exc = exceptionnel,

1 :< 100g
2: 100g-< 250g
3: 250g- <500g
4: 500g - < 1kg
5: > 1kg

t = potentiel touristique
n = source de nourriture
c = commerce animaux sauvages
= aucun usage (actuel)

Annex 2a

80 species observed in all three area prospected: *Gypohierax angolensis, Polyboroides typus pectoralis, Accipiter melanoleucus melanoleucus, Columba unicincta, Turtur afer, Treron calva calva, Psittacus erithacus erithacus , Corythaeola cristata, Tauraco schuettii schuettii , Cuculus solitarius solitarius, Cuculus clamosus clamosus, Chrysococcyx cupreus cupreus, Ceuthmochares aereus aereus, Centropus senegalensis senegalensis, Glaucidium tephronotum medje, Strix woodfordii woodfordii, Caprimulgus batesi , Neafrapus cassini, Cypsiurus parvus brachypterus, Apus apus apus / pekinensis , Alcedo leucogaster leopoldi, Halcyon malimbica malimbica, Halcyon senegalensis fuscopilea, Merops variegatus loringi , Eurystomus gularis neglectus, Tropicranus albocristatus cassini, Tockus camurus, Tockus fasciatus fasciatus, Bycanistes fistulator duboisi, Bycanistes (cylindricus) albotibialis, Ceratogymna atrata, Gymnobucco bonapartei bonapartei, Buccanodon duchaillui, Pogoniulus scolopaceus flavisquamatus, Pogoniulus bilineatus leucolaima, Pogoniulus subsulphureus flavimentum, Pogoniulus atroflavus, Campethera caroli caroli, Dendropicos xantholophus, Hirundo rustica rustica, Coracina azurea, Andropadus virens virens, Andropadus gracilis gracilis, Andropadus ansorgei ansorgei, Andropadus latirostris latirostris, Ixonotus guttatus, Phyllastrephus icterinus, Bleda (eximia) ugandae, Criniger calurus emini, Pycnonotus (barbatus) tricolor, Stizorhina fraseri vulpina, Alethe (diademata) castanea woosnami , Stiphrornis (erythrothorax) xanthogaster, Sylvietta virens baraka, Hylia prasina prasina, Cisticola brachypterus brachypterus, Prinia subflava graueri, Camaroptera brachyura tincta, Muscicapa cassini, Dyaphorophyia castanea castanea, Terpsiphone rufiventer mayombe, Deleornis (fraseri) axillaris,Cyanomitra obscura cephaelis,Chalcomitra rubescens rubescens, Hedydipna collaris somereni, Cinnyris superba superba, Nicator chloris, Lamprotornis purpureiceps, Lamprotornis splendidus splendidus,Passer griseus ugandae, Ploceus cucullatus bohndorffi, Ploceus weynsi , Malimbus cassini, Nigrita bicolor brunnescens, Spermophaga haematina pustulata, Estrilda paludicola ruthae, Estrilda melpoda melpoda, Paludipasser locustella uelensis, Spermestes cucullatus cucullatus, Vidua macroura).*

Annex 2b

53 species observed only in RNTN : *Phalacrocorax africanus africanus, Anhinga rufa rufa, Ixobrychus minutus payesii, Ardeola ralloides, Bubulcus ibis ibis, Egretta alba melanorhyncha, Bostrychia rara, Plectropterus gambensis gambensis, Nettapus auritus, Aviceda cuculoides batesi, Haliaeetus vocifer, Circus aeruginosus, Kaupifalco monogrammicus monogrammicus, Falco peregrinus minor, Sarothrura lugens lugens, Porphyrio alleni, Gallinula angulata, Actophilornis africanus, Vanellus albiceps, Actitis hypoleucos, Chlidonias leucopterus, Chlidonias hybridus, Chrysococcyx flavigularis, Jubula lettii, Bubo shelleyi, Scotopelia peli, Caprimulgus natalensis, Telacanthura ussheri sharpei, Megaceryle maxima maxima, Merops pusillus meridionalis, Tricholaema (hirsuta) = flavipunctata ansorgii, Pseudochelidon eurystomina, Hirundo nigrita, Turdus pelios centralis, Cosypha niveicapilla, Saxicola (torquata) rubicula salax, Phylloscopus trochilus acredula, Apalis rufogularis nigrescens, Apalis goslingi, Muscicapa caerulescens brevicauda, Terpsiphone rufocinerea rufocinerea, Illadopsis fulvescens ugandae, Anthreptes aurantium, Anabathmis reichenbachii, Cinnyris johannae johannae, Lanius collurio, Ploceus pelzelni monachus, Ploceus aurantius aurantius, Ploceus melanocephalus duboisi, Ploceus tricolor interscapularis, Quelea erythrops, Euplectes afer afer, Nigrita fusconota fusconota*.

Annex 2c

35 species were only observed in the northern part of RNTL: *Tigriornis leucolophus, Anastomus lamelligerus lamelligerus, Circaetus pectoralis, Accipiter erythropus zenkeri, Accipiter toussenelii toussenelii, Francolinus squamatus (ou afer cranchii et alors pas), Coturnix delegorguei delegorguei, Guttera pucherani verreauxi, Crecopsis egregia, Aenigmatolimnas marginalis, Clamator levaillantii, Centropus grillii, Caprimulgus rufigena rufigena / damarensis, Macrodipteryx vexillarius, Merops muelleri muelleri, Merops apiaster, Indicator maculatus stictothorax, Indicator exilis exilis, Melichneutes robustus, Sasia africana, Phedinopsis brazzae, Delichon urbica urbica, Andropadus curvirostris curvirostris, Andropadus gracilirostris gracilirostris, Pyrrhurus scandens orientalis, Phyllastrephus albigularis albigularis, Sylvia borin borin, Myioparus griseigularis griseigularis, Megabyas flammulatus aequatorialis, Terpsiphone batesi batesi, Pholidornis rushiae denti, Cinnyris minullus, Dryoscopus sabini melanoleucus, Onychognathus (fulgidus) hartlaubi, Parmoptila woodhousei (ansorgei?)*

+ Possibly *: Macheiramphus alcinus andersoni, Ptilopsis granti, Dendropicos elliotii elliotii*

Annex 2d

42 species only observed in the southern part of RNTL : *Melierax metabates mechowi, Urotriorchis macrourus, Spizaetus africanus, Lophaetus occipitalis, Francolinus afer cranchii (ou pas car partagé avec TLN), Eupodotis melanogaster melanogaster, Vanellus lugubris, Chrysococcyx klaas (ou partagé avec TLN), Caprimulgus climacurus sclateri, Apus affinis aerobates, Colius striatus congicus, Ceyx lecontei, Pogoniulus chrysoconus extoni, Indicator conirostris conirostris, Mirafra (africana) malbranti, Psalidoprocne pristoptera reichenowi, Hirundo senegalensis saturatior, Anthus (nyassae) schoutedeni, Anthus brachyurus leggei, Neocossyphus rufus gabunensis, Neocossyphus poensis praepectoralis (or not because shared with TLN), Cichladusa ruficauda, Erythropygia leucophrys munda, Myrmecocichla nigra, Eremomela scotops pulchra, Eremomela badiceps badiceps, Sylvietta ruficapilla rufigenis, Prinia leucopogon leucopogon, Camaroptera chloronota chloronota (ou pas car partagé ? avec TLN), Ficedula albicollis, Platysteira cyanea nyansae, Illadopsis albipectus, Parus leucomelas insignis, Anthreptes rectirostris tephrolaema, Lanius collaris capelli, Tchagra minuta minuta, Nicator vireo, Cinnyricinclus leucogaster verreauxi, Pachyphantes superciliosus, Euplectes hordeaceus hordeaceus, Anomalospiza imberbis imberbis, Serinus mozambicus barbatus*

+ Possibly *: Milvus migrans migrans*

Annex 3

Species names and numbers of individuals captured with mist net during each of the three missions of inventory in the « Lac télé » landscape.

Bird species: vernacular name	**Species: latin name**	**Ngiri** October-November 2013	**Tumba-Lédima** March-April 2014	**Sud Tumba-Lédima (Malebo-Mbanzi-Nzélé)** August-September 2014
WHITE-BELLIED KINGFISHER	*Alcedo leucogaster leopoldi*	2	4	2
AFRICAN DWARF KINGFISHER	*Ceyx lecontei*			5
AFRICAN PYGMY KINGFISHER	*Ceyx picta ferrugina*	x		1
RED-RUMPED TINKERBIRD	*Pogoniulus atroflavus*	x	x	1
SPOTTED HONEYGUIDE	*Indicator maculatus stictothorax*		2	
AFRICAN PICULET	*Sasia africana*		2	
BROWN-EARED WOODPECKER	*Campethera caroli caroli*	2	1	x
LITTLE GREENBUL	*Andropadus virens virens*	20	10	3
PLAIN GREENBUL	*Andropadus curvirostris curvirostris*		1	
YELLOW-WHISKERED GREENBUL	*Andropadus latirostris latirostris*	8	15	8
ICTERINE GREENBUL	*Phyllastrephus icterinus*	7	4	16
WHITE-THROATED GREENBUL	*Phyllastrephus albigularis albigularis*		5	
RED-TAILED BRISTLEBILL	*Bleda syndactyla syndactyla*		3	2
YELLOW-EYED (Green-tailed) BRISTLEBILL	*Bleda (eximia) ugandae*	3	6	10
RED-TAILED GREENBUL	*Criniger calurus emini*	x	4	1
RED-TAILED ANT-THRUSH	*Neocossyphus rufus gabunensis*	?		3
WHITE-TAILED ANT-THRUSH	*Neocossyphus poensis praepectoralis*		?	1
RUFOUS FLYCATCHER-THRUSH	*Stizorhina fraseri vulpina*	3	x	3
FIRE-CRESTED ALETHE	*Alethe (diademata) castanea woosnami*	3	9	10
FOREST ROBIN	*Stiphrornis (erythrothorax) xanthogaster*	1	1	4
SNOWY-CROWNED ROBIN-CHAT	*Cosypha niveicapilla*	1		
GREEN HYLIA	*Hylia prasina prasina*	2	2	2
OLIVE-GREEN CAMAROPTERA	*Camaroptera chloronota chloronota*		?	1
WHITE-BROWED FOREST-FLYCATCHER	*Fraseria cinerascens ruthae*	1		
CASSIN'S FLYCATCHER	*Muscicapa cassini*	x	x	1
CHESTNUT WATTLE-EYE	*Dyaphorophyia castanea castanea*	3	2	x
BLUE-HEADED CRESTED FLYCATCHER	*Trochocercus nitens nitens*		1	4
RUFOUS-VENTED PARADISE-FLYCATCHER	*Terpsiphone rufocinerea rufocinerea*	1		
RED-BELLIED PARADISE-	*Terpsiphone rufiventer*	4	5	7

FLYCATCHER	*mayombe*			
BROWN ILLADOPSIS	*Illadopsis fulvescens ugandae*		1	
PALE-BREASTED ILLADOPSIS	*Illadopsis rufipennis rufipennis*	2	2	5
SCALY-BREASTED ILLADOPSIS	*Illadopsis albipectus*			1
VIOLET-TAILED SUNBIRD	*Anthreptes aurantium*	2		
LITTLE GREEN SUNBIRD	*Anthreptes seimundi traylori*		x	1
GREY-HEADED SUNBIRD	*Deleornis (fraser)i axillaris*	5	1	x
REICHENBACH'S SUNBIRD	*Anabathmis reichenbachii*	1		
WESTERN OLIVE SUNBIRD	*Cyanomitra obscura cephaelis*	6	41	73
WESTERN NICATOR	*Nicator chloris*	x	x	1
CRESTED MALIMBE	*Malimbus malimbicus malimbicus*	1	x	
YELLOW-CROWNED BISHOP	*Euplectes afer afer*	1		
MARSH WIDOWBIRD	*Euplectes hartlaubi humeralis*	1	x	
JAMESON'S ANTPECKER	*Parmoptila jamesoni*		1	1
CHESTNUT-BREASTED NEGROFINCH	*Nigrita bicolor brunnescens*	x	x	2
BLACK-BELLIED SEEDCRACKER	*Pyrenestes ostrinus ostrinus*	1	x	
WESTERN BLUEBILL	*Spermophaga haematina pustulata*	x	2	6
	TOTAL :	**24sp**	**24sp**	**28sp**

WP4 VALUATION OF ECOSYSTEM SERVICES

FUNDP contribution (Tasks 4.1, 4.2, 4.3)

Authors: C. M. Fontaine & .Dendoncker (FUNDP)

Work context

The difficult reality of the field of study counteracted the initial plans for the valuation exercise in three ways: much more resources were dedicated to infield socio-economic data collection than planned; the shutdown of the local office of the NGO partner froze most infield activities and indirect data acquisition; the disappearance of an onsite researcher's data and analysis in Congo jeopardized the spatio-dynamic analysis.

The selection of the subarea to study, in the northern part of the Lake Tumba-Lake Tele landscape (the Ngiri subarea), was suggested by a local NGO partner: WWF-Congo. The local partner was very much interested in knowing better the Ngiri socio-cultural context. They argued having already performed socioeconomic survey in the southern part of the general case study area. Information they were willing to share, although we never got it since the sudden shutdown of the WWF offices in the Lake Tumba-Lake Tele landscape.

As the Ngiri subarea is a quite secluded hardly accessible part of the Lake Tumba-Lake Tele landscape, much more resources than expected were required to conduct the surveys. As a consequence, a second round of survey originally planned could not be conducted. Therefore, the longitudinal analysis, which was supposed to reveal the change in consumption over a couple of years, could not be done either.

Besides, the consumption data collected cannot be properly measured with the project resources. Indeed, local people are using ballpark estimates when trading (e.g. a bag, a cup, a bundle of sticks, etc.) without consistency from a village to another, from a household to another. An attempt was made to convert these estimates in metrics, but without success. As a result, the quantification was limited to listing abundancies and perceived threats of species with respect to revealed consumptions and habits.

Without such crucial information, the SES modelling cannot be built in practice, even if a conceptual model was designed (Fig. 29 **ABM CONCEPTUAL DESIGN**). Indeed, the core of a spatial Agent-Based Model (ABM) is the behavior of the households with respect to expected returns from certain ecosystem services consumption (e.g. grow crop for subsistence vs hunt monkey for sell on illegal market). Generally speaking, household H collects annually amount A of species S for direct or indirect subsistence of its people. Without the link between amount A and biomass productivity, calculated with the Dynamic Vegetation Model CARAIB, the integration between the two models cannot be made operationally.

Most importantly, the infield work provided some evidence of really marginal spatial impact of agriculture practices. Hence, the picking activities, for survival, are the one with the greatest impact on ecosystem services. In other words, the degradation of ecosystem services provided by evergreen forest are most probably to be related directly to population change rather than farming activities. Considering the remoteness of the subarea investigated, only partial and revealed population estimates are available. Projections are possible but must be considered with great care.

Finally, scenarios of future infrastructure development could have been drawn in order to project future plausible change in population, deforestation and over use of ecosystem services locally. Nonetheless, information on the Equator Province Development Plans collected are suggesting that no infrastructure are to be put in the Ngiri subarea anytime soon. In consequence, with such poor information on the political context and on the socio-economic situation, with no help of a local partner, there was no opening for developing plausible scenarios smartly but for conjectures.

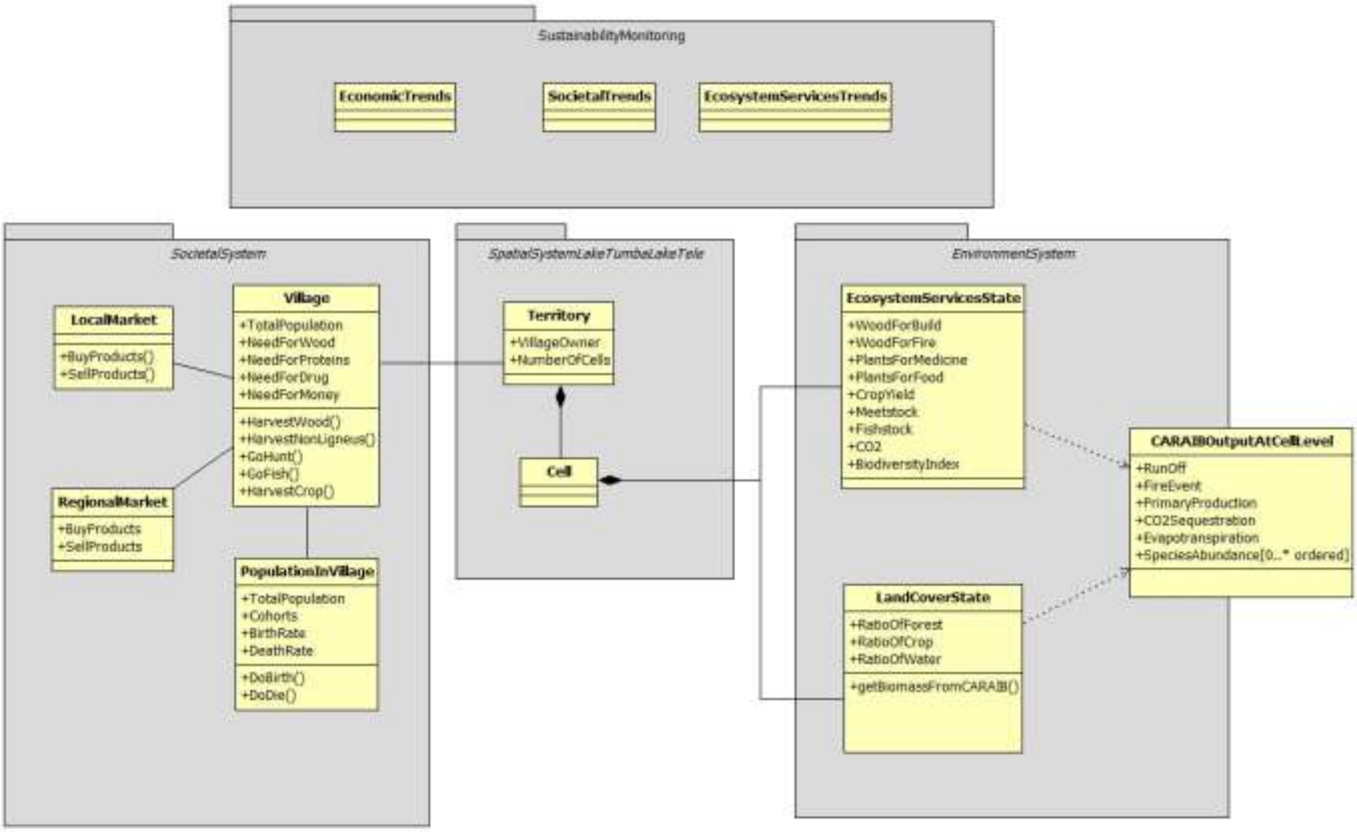


Fig. 29 ABM conceptual design

Qualitative estimates of prevalent ecosystem services

Amongst the ca. one hundred species encountered in the Ngiri subarea, around 40 were considered as vital and/or strategic by local com

Table 6 and Table), of which half was estimated to have less than 15 individuals per hectare in a 2006 inventory (column, "rareness" with level 4 or 5). In terms of ecosystem services, production services are prevalent. The wood of these species is largely used for a variety of craft productions, whilst the others parts are dedicated to medicinal products.munities (see

Table 16 Most important species for local people

#	Species	Family	Vernacular name	Commercial name
4	*Anonidium mannii*	Annonaceae	Mopombi	Ebom
27	*Daniella pynaertii*	Caesalpiniaceae	Bolengu	Faro
30	*Diospyros laurentii*	Ebenaceae	Ilo	Ebène
32	*Elaeis guineensis*	Arecaceae	Mbila	Palmier à huile

39	*Guibourtia demeusei*	Caesalpiniaceae	Waka, Mobaka	Bubinga
47	*Lophira alata*	Ochnaceae	Mokole	Azobe
79	*Raphia gilletii*	Arecaceae	Ndele	
80	*Raphia laurentii*	Arecaceae	Ndele	
81	*Raphia sese*	Arecaceae	Ndele ou Nsesse ???	
85	*Staudtia stipitata*	Myristicaceae	Nkonya	Niové
92	*Terminalia superba*	Combretaceae	Mangota, Mandoto ?	Limba
96	*Uapaca heudelotii*	Euphorbiaceae	Mosenge	Rikio rouge
98	*Xylopia aethopica*	Annonaceae	Nsange	Bosange
99	*Xylopia phloiodora*	Annonaceae	Ebili	Bolonda
19	*Ceiba pentandra*	Bombacaceae	Buma	Fromager / Fuma
20	*Chlorophora excelsa*	Moraceae	Molondo	Kambala Iroko
22	*Cleistopholis glauca*	Annonaceae	Bontole	Sobu na mokili
25	*Cynometra sessiliflora*	Caesalpiniaceae	Monkese	Botuna
44	*Irvingia wombolu*	Irvingiaceae	Bombo	
45	*Klainedoxa gabonesis*	Irvingiaceae	Bolobolo	Eveuss petites feuilles
49	*Macaranga saccifera*	Euphorbiaceae	Bwenge	Macaranga sacci
52	*Maesopsis eminii*	Rhamnaceae	Lofandje la ndjoku	Musisi
55	*Musanga cecropioides*	Moraceae	Mombambo	
60	*Ongokea gore*	Olacaceae	Boleko	Angueuk
61	*Oubanguia africana*	Scytopetalaceae	Mbondjo	
73	*Polyalthia suaveolens*	Annonaceae	Bolinda	Otunga (ou Molinda)
76	*Pterocarpus soyauxii*	Fabaceae	Mosulu, Bosulu	Padouk vrai
88	*Strombosia grandifolia*	Olacaceae	Botubu	Booko
89	*Strombosiopsis tetrandra*	Olacaceae	Botaka	Botaka
90	*Symphonia globulifera*	Clusiaceae	Molaka	Ossol (ou Namil)
95	*Uapaca guineensis*	Euphorbiaceae	Mosenge	Bosenge/Rikio
2	*Alstonia boonei*	Apocynaceae	Mokuka	Emien
3	*Amphimas pterocarpoides*	Fabaceae	Bokanga	Bokanga
16	*Canarium schweinfurtii*	Burseraceae	Boele	Aiele
69	*Pentaclethra macrophylla*	Mimosaceae	Bobala	Mubala
71	*Piptadeniastum africanum*	Mimosaceae	Mokungu, Bokungu	Dabema
77	*Pycnanthus angolensis*	Myristicaceae	Mokuka, Bosenga	Ilomba na mokili (ou Llombe)
70	*Pericopsis elata*	Fabaceae	Honi	Afrormosia

Relating this importance of service with species considered at risk of overexploitation ("rareness" = 5) gives some evidence of over exploitation, especially for wood products and medicinal plants. Nonetheless, that information should be crossed with the total consumption of each species per year (or average consumption per person per year), in order to adequately estimate the total biomass reduction due to human exploitation. At this time, we do not have such information.

Table 17 Species vs usage revealed: qualitative estimates of ecosystem services

Resources	**Estimated as**	**Usages**

#	**Species**	**Vital**	**Stratégiq**	**Representative**	**Rareness**	**Wood product**	**Log**	**Building**	**House**	**Paddle**	**Pirogue**	**Artcraft**	**Medicinal**	**Oil**	**Wine**	**Caterpilar**	**Fishing**
61	*Oubanguia africana*		1	1	1				1				1				
95	*Uapaca guineensis*	1	1	1	1	1							1			1	
39	*Guibourtia demeusei*	1	1	1	2								1			1	
47	*Lophira alata*	1	1	1	2		1										
79	*Raphia gilletii*	1	1	1	2				1								
80	*Raphia laurentii*	1	1	1	2				1								
81	*Raphia sese*	1	1	1	2										1		
92	*Terminalia superba*		1		2		1										
96	*Uapaca heudelotii*	1	1	1	2	1							1			1	
4	*Anonidium mannii*	1			3	1											
27	*Daniella pynaertii*	1	1		3		1										
30	*Diospyros laurentii*	1		1	3	1											
32	*Elaeis guineensis*	1	1		3									1			
85	*Staudtia stipitata*	1			3	1				1							
98	*Xylopia aethopica*	1			3	1											
99	*Xylopia phloiodora*	1			4	1											
19	*Ceiba pentandra*		1		4	1					1		1				
20	*Chlorophora excelsa*		1		4	1					1						
22	*Cleistopholis glauca*	1			4	1											
25	*Cynometra sessiliflora*	1	1		4							1					
44	*Irvingia wombolu*	1			4	1							1				
45	*Klainedoxa gabonesis*	1			4	1							1				
49	*Macaranga saccifera*			1	4	1											
52	*Maesopsis eminii*	1			4	1											
55	*Musanga cecropioides*	1		1	4			1					1				1
60	*Ongokea gore*			1	4	1											
73	*Polyalthia suaveolens*	1			4	1											
76	*Pterocarpus soyauxii*			1	4	1											
88	*Strombosia grandifolia*			1	4	1							1				
89	*Strombosiopsis tetrandra*	1			4	1							1				
90	*Symphonia globulifera*			1	4	1	1										
2	*Alstonia boonei*			1	5	1											
3	*Amphimas pterocarpoides*	1		1	5											1	
16	*Canarium schweinfurtii*	1		1	5		1				1	1					
69	*Pentaclethra macrophylla*	1		1	5								1				
71	*Piptadeniastum africanum*	1		1	5								1				
77	*Pycnanthus angolensis*			1	5	1							1				
70	*Pericopsis elata*			1	5			1									

Population estimates

During the socioeconomic survey, people were asked to describe the demographic situation of their household and in their villages. The challenge was to adequately adapt words of mouth with respect to other indirect evidence, such as the number of houses seen within the settlement boundaries. In consequence, population estimates are to be taken with caution, also since some village chiefs argued that a larger number of people were staying within the deeper forest, but still with an "administrative" link to their own village.

1,771 head of households were interviewed, gathering information on 9,335 people over all 72 villages. Overall, the pyramid of age reveals a young demographic structure, consistent with what is expected in most southern countries (Fig. 30).

The age pyramid for adults (Fig 31) only reveals possible small bias in the survey. First, women birthdates are only rough estimates. The cohorts of age multiple of 5 are significantly larger than the one in-between. In other words, heads of household presumably don't know their wife's age accurately. Second, men tends to exaggerate their age: the pyramid shows a surprisingly larger number of men aged 70 or higher, compared to women, although most demographic analysis worldwide reveals that there is a tendency for women to live older than men. Third, marital habits follow a traditional behavior as about 30 wives were declared under 18 at survey time.

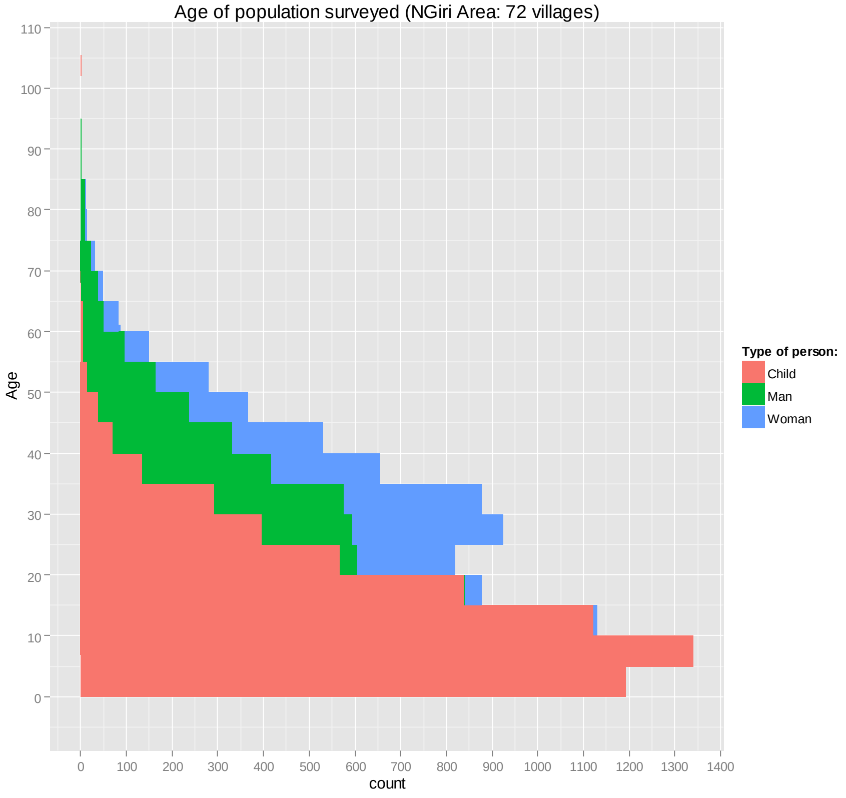


Fig. 30 Age pyramid from survey for all villages and all people

As the survey did not account for the sex of children, it is not possible to build a gender-accurate pyramid of age for the surveyed population. Staking children cohorts to men and women (Fig. 30, see also Fig. 31 Age pyramid of surveyed adults) reveals that the head of household gave birthdates of all children, whether the child was part of the household or not. In consequence, we have no mean to crosscheck that the older children are or are not other surveyed household chiefs. Besides, another evidence that data collected needs to be taken with caution: one of the children was given the age of 105, older than any surveyed man, which cannot be possible.

The share of people per cohort, plotted per village (Fig. 32) indicates that a majority of villages has a similar demographic structure: the largest cohorts are the youngest; but for the village of Ngiri that reveals a median age about 25 years older than the others. Three other villages are in-between: the largest cohorts are for young adults, but not to the extent of Ngiri.

Without much information about these villages' environment, no strong demographic or socio-economic hypothesis could be written for interpretation, and possible forecast.

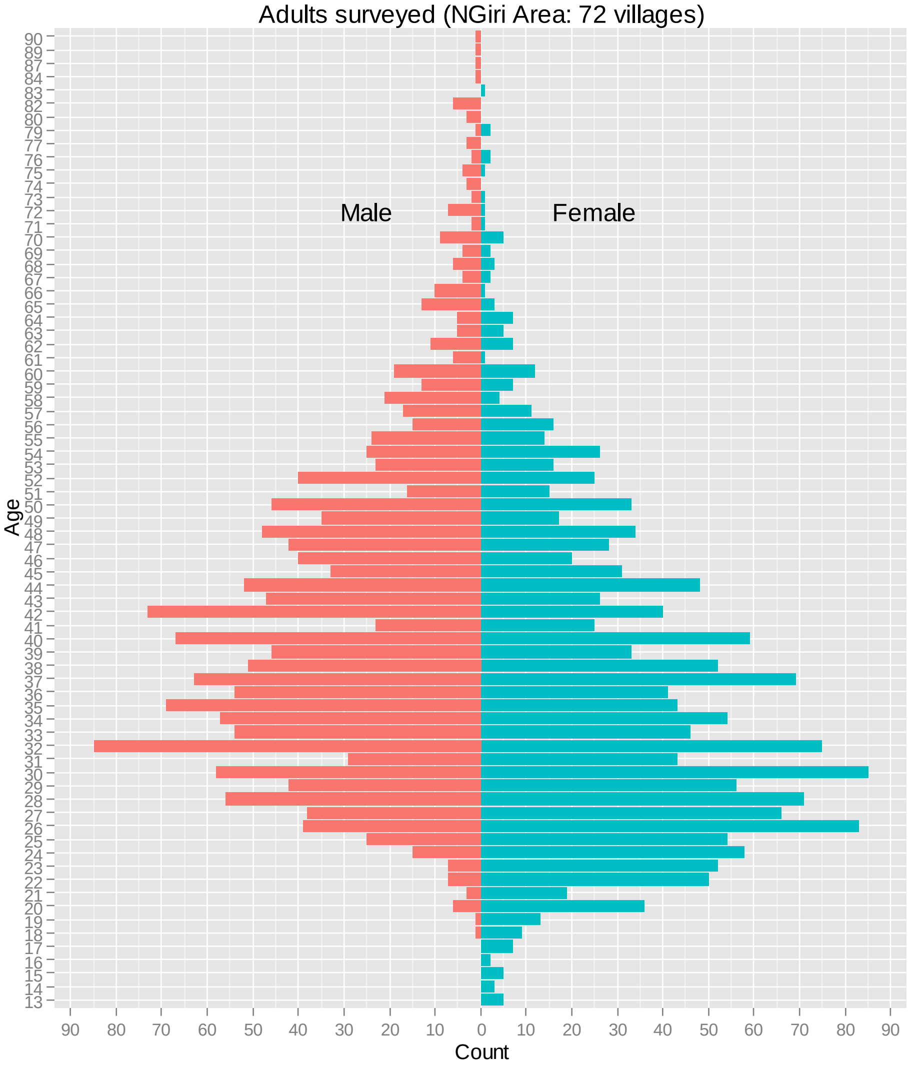


Fig. 31 Age pyramid of surveyed adults

Trajectories and plausible change in ES consumption

Following the UN median projections for Congo and the Ecuador Province, some trajectories in the population change can be drawn (Fig. 33). Essentially, the main message is that the plausible evolution of the surveyed population is to slowly increase overall: +6% from 2020 to 2050. Everything else being equal, ES consumption should then not much change. Notwithstanding, the structure of the pyramid evolves quite clearly: newborn are reducing and people live older. Clearly, UN projections assume a demographic transition for the country for this century, starting around 2025.

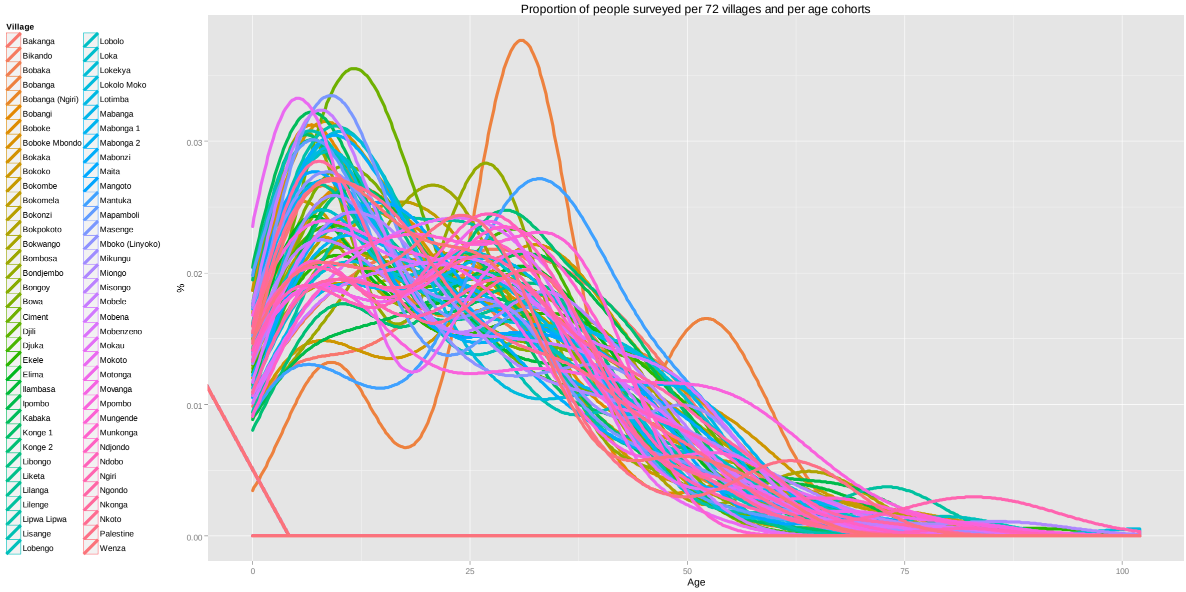


Fig. 32 Share of people per cohort per village

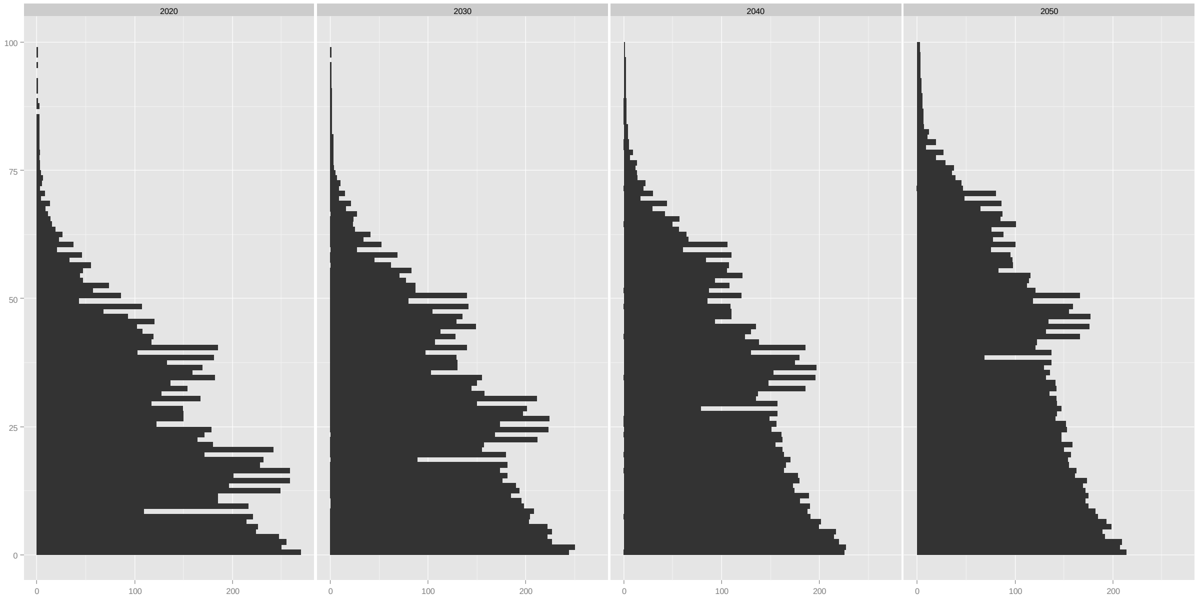


Fig. 33 Projected population evolution (UN median trends)

Observations in other parts of the world indicate then that ES consumption will change with that transition. Indeed, a population that is more fit and supposedly healthier will adapt consumption and production behaviours. Magnitude and location cannot be estimated at this stage.

In addition, external demand for Forest products is more than likely to increase, with globalization, hence overall ES usage in the area. However, the correlation to be drawn between local products consumption outside the study area and world population or wealth change goes beyond the resources of this project.

Finally, when the Province of Ecuador plans for increasing mobility on the river will be realized (confidential documents have been seen on that matter, but with no evidence of concrete realisation), ES consumption will be completed skewed towards the more accessible villages.

Mapping ES for the present over the studied zone (Task 4.4)

Authors: M. Dury, L. François & A. –J. Henrot (ULg-UMCCB)

The dynamic vegetation model was run over the historic period 1951-2012 for its evaluation and calibration (WP2) but also to assess current availability and distribution of ecosystem services. As already described in WP2, simulations of the vegetation model were performed with a set of species identified in WP 1 and 2. The model ability to reproduce their observed distribution was evaluated in WP2. Fig. 34 shows the current distribution of all the species simulated for this project. We classified these species according the ecosystem services they provide.

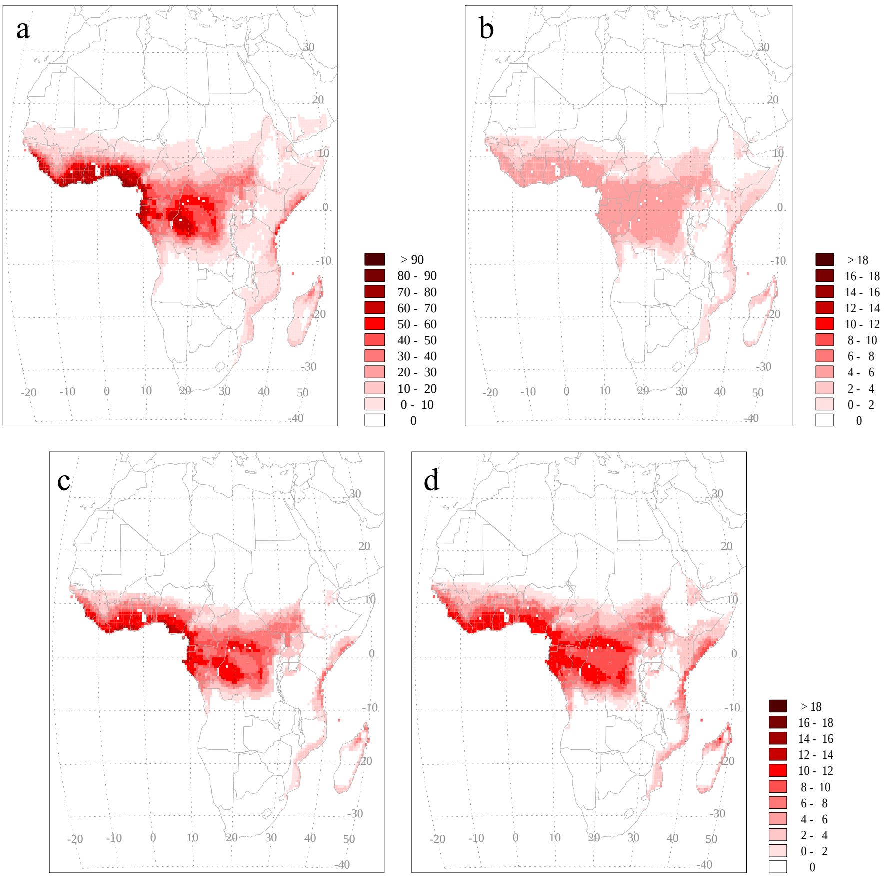


Fig. 34 Modelled species distributions (number of species per grid cell): (a) all the simulated species, species related to (b) food, (c) material and (d) medicinal services.

Some models outputs were also used to characterize other ecosystem services. The runoff is directly associated to different type of ES like provisioning ES (water availability, navigation) or regulating ES (flood, erosion prevention). Water plays an important role in the studied area, especially in the northern swamped area. Fig. 35

compares the runoff simulated by the model with the data from the UNESCO atlas (Cogley, 1998). The model tends to overestimate runoff.

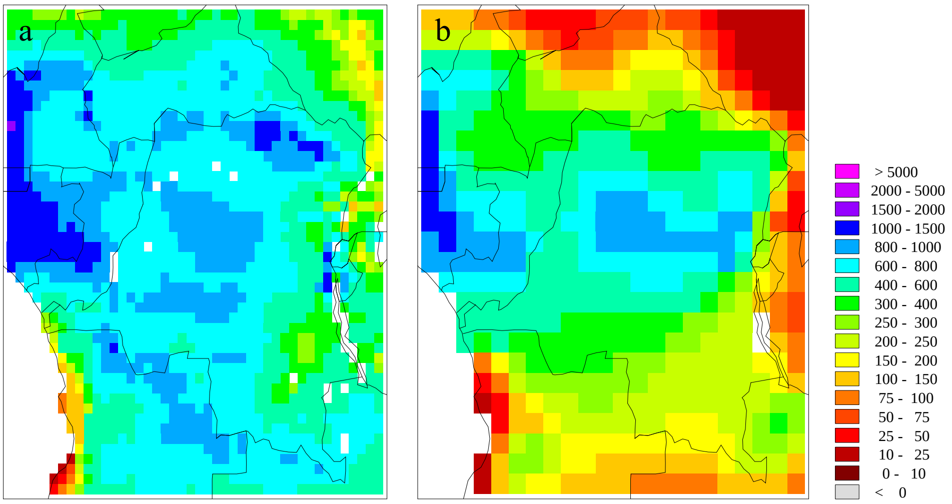


Fig. 35 Annual runoff (mm yr^{-1}) from (a) CARAIB and (b) UNESCO (Cogley, 1998) for the period 1961-1990.

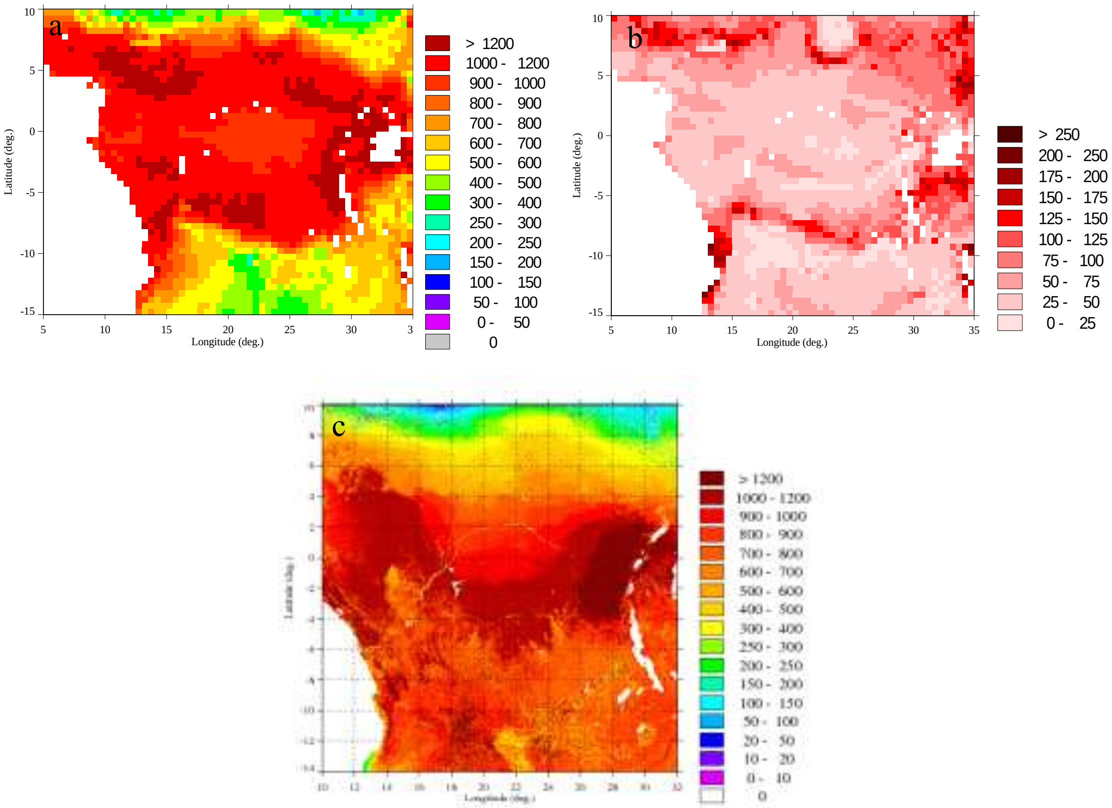
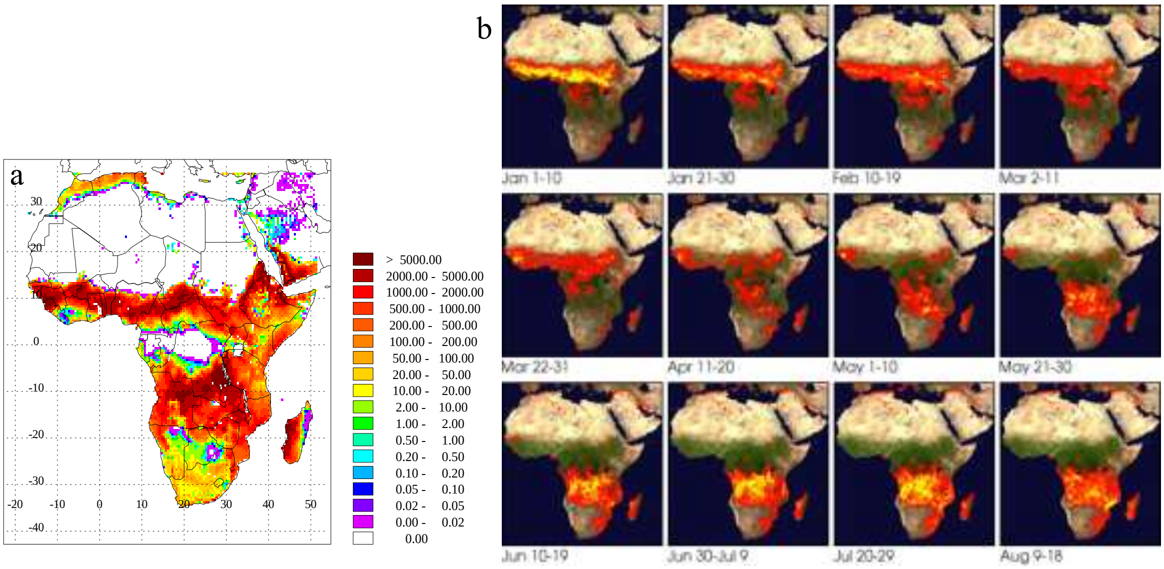


Fig. 36 Grid cell net primary productivity (gC m^2) over the period 2000-2006: (a) simulated annual mean cell NPP, (b) simulated interannual variability and (c) MODIS annual mean cell NPP (Zhao et al., 2005).

Besides individual species distributions, the mean net primary productivity indicates the mean timber production of each grid cell (Fig. 36). The interannual variability of NPP is nowadays relatively low in the studied area (Fig. 36b). The comparison with MODIS NPP shows that the CARAIB NPP in the equatorial area is quite good. Since the simulations were performed with almost exclusively evergreen tropical species, the model possibly underestimates NPP in regions where other species can establish.

Fig. 37a displays the annual burned area simulated by the vegetation model. The fact that the model only simulates natural fires may explain the discrepancies with fire distribution recorded by remote sensing (figure 37b). Indeed, this latter dataset also includes anthropic fires that are important in these regions of slash and burn agriculture. All these model outputs were used and combined in WP5 to assess ES sustainability in the future and risk of severe climate change impacts on ecosystems ('ecosystem disruption').



(http://earthobservatory.nasa.gov/IOTD/view.php?id=5800)

Fig. 37 Present burned area. (a) Mean area burned annually per pixel by natural fires (ignition through lightning only) in CARAIB runs covering the period 1982-2011 and (b) african fires detected by MODIS on NASA's Terra and Aqua satellites between January and August 2005.

WP5 SUSTAINABILITY ASSESSMENT

Authors: M. Dury, L. François & A. –J. Henrot (ULg-UMCCB)

Developing scenarios for the future over the studied zone (Task 5.1)

For future projections, we have acquired the monthly outputs of about thirty GCMs contributing to the IPCC CMIP5 (Coupled Model Intercomparison Project Phase 5, Taylor et al. 2012). We used these climatic scenarios (historical (1950-2005), RCP4.5 (≈ 550 ppm in 2100) and RCP8.5 (≈ 950 ppm in 2100) (2006-2100)) rather than, as written in the proposal, the old AR4 scenarios (A1B and A2) from the 2007 fourth IPCC report. During the project, regional climatic projections (CORDEX Africa) were not available yet.

The ability of these GCMs to reproduce the present-day climate of the Congo Basin was evaluated. The monthly outputs of mean temperature and precipitation were compared to CRU data over the 1980-1999 period (mean, variability and trend). Simulations were performed with the five best-ranked models (CMCC-CM, CNRM-CM5, HadGEM2-CC, MIP-ESM-MR and MPI-ESM-LR) at the 0.5° spatial resolution over Africa with the set of 78 species, under RCP4.5 and RCP8.5 scenarios with/without CO_2 fertilization effect on vegetation (see WP5.2 and 5.3). For the Lake Tumba Landscape, all these five climatic models project under the RCP8.5 scenario an increase of more than 3.5°C of annual mean temperature and an increase (slight decrease with the MPI-ESM-MR model) of annual precipitation for the end of the century (Fig. 38).

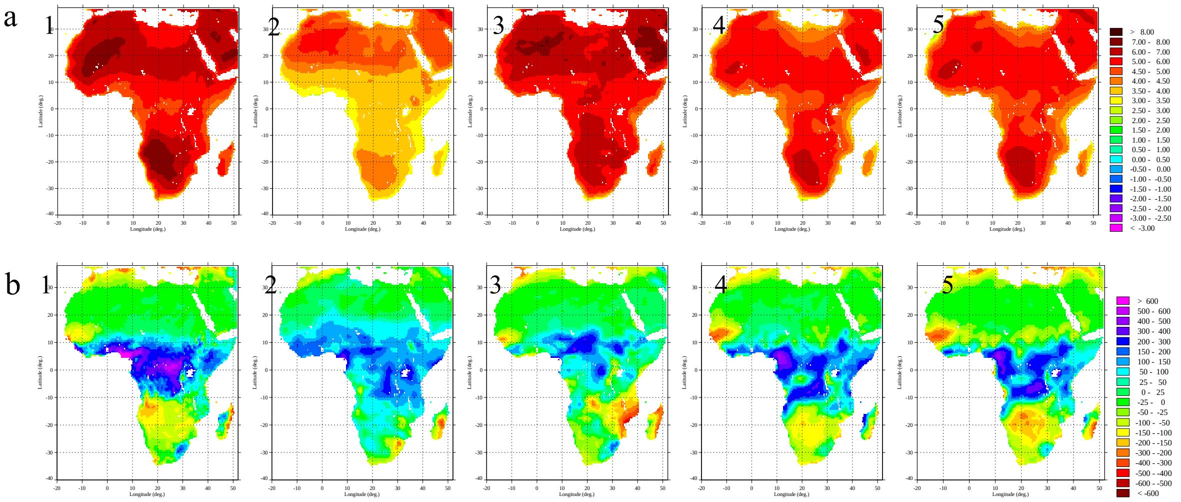


Fig. 38 Temperature (a) and precipitation (b) anomalies projected by the 5 selected climatic models under the RCP 8.5 scenario between the 2080-2099 and 1980-1999 periods: (1) CMCC-CM, (2) CNRM-CM5, (3) HadGEM2-CC, (4) MPI-ESM-MR and (5) MPI-ESM-LR.

The DVM was also forced with all the climatic scenarios to assess the uncertainties on the projections (Fig. 39). These simulations have been performed at the 0.5° spatial resolution over the Congo basin with plant functional traits (not species) and only under the RCP8.5 scenario (≈ 950 ppm in 2100). An increase of the annual mean temperature of 4-5°C is projected (average of the 30 GCMs) (Fig. 39a). All the climate models project a temperature increase of at least 2°C (and yet a 2°C increase of the global mean temperature is considered as a critical threshold to avoid the triggering of positive feedbacks). For the precipitations, two-thirds of the models project no change or an increase (Fig. 39b). With most of these climate scenarios, CARAIB projects decrease of the soil water content while net primary productivity is not impacted and tends to increase (Fig. 39c). These results are however obtained assuming CO_2 fertilization effects. When CO_2 concentration is kept constant (no fertilization effects), the forest growth is more severely affected by climate change (see WP5.2 and 5.3).

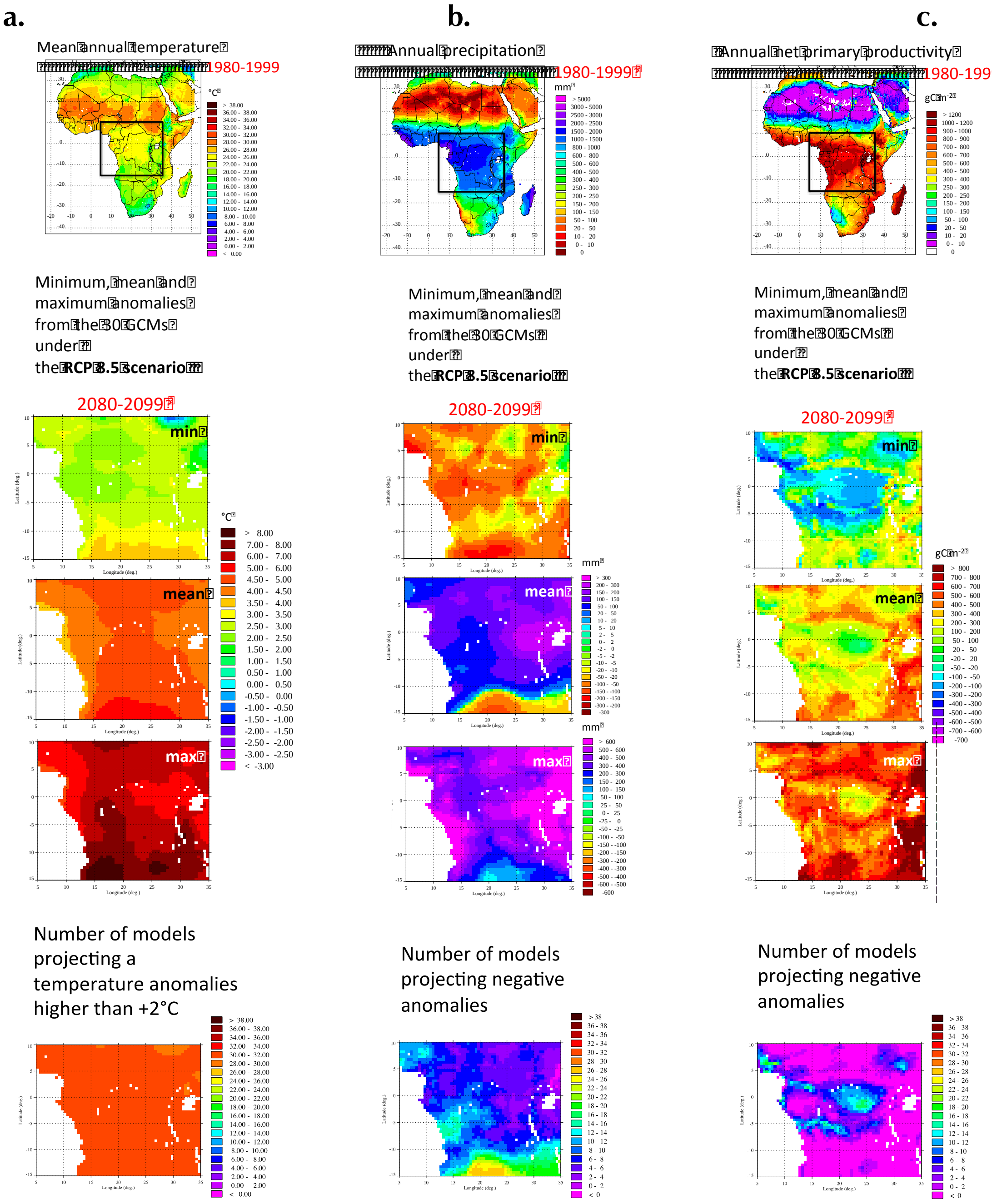


Fig. 39 1980-1999 mean annual temperature (a), annual precipitations (b) from the Climatic Research Unit and annual net primary productivity (c) simulated by the DVM. Grid cell minimum, mean and maximum anomalies projected from a set of 30 CMIP5 GCMs under the RCP 8.5 scenario between the 2080-2099 and 1980-1999 periods.

Projecting and mapping ES for the future over the studied zone (Task 5.2)

We studied the future range and productivity of our set of tree species. We decided to show almost exclusively in this report the results of the vegetation model obtained with the best ranked climatic model CMCC-CM. We also present only the scenario assuming no vegetation fertilization by CO_2.

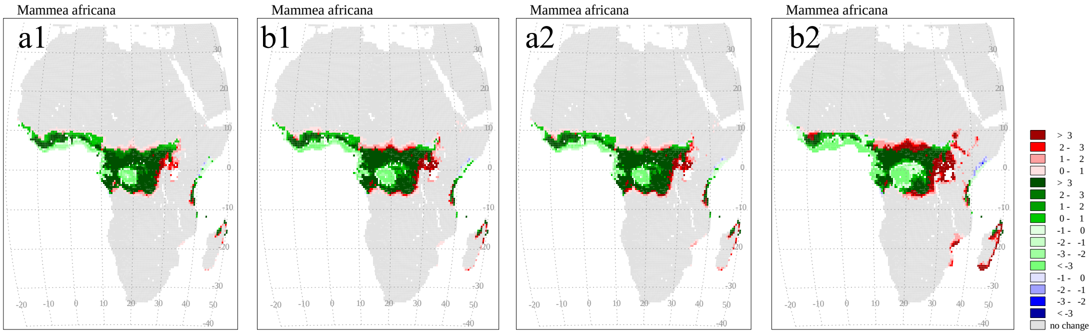


Fig. 40 *Mammea africana* modelled future distribution. Changes in NPP between (a) the period 2041-2060 as well as (b) the period 2081-2100 and the reference period 1951-2000 calculated with the CMCC-CM climatic projection under (1) the RCP4.5 and (2) RCP8.5 scenarios (assuming no CO_2 fertilization effect). Magnitude of changes is expressed in standard deviations of grid cell species NPP variability over the reference period. Species range retraction in blue, extension in red and preserved range in green.

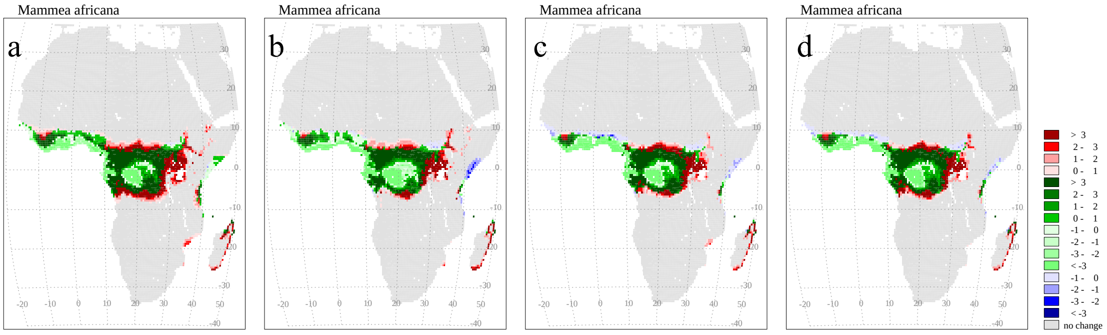


Fig. 41 *Mammea africana* modelled future distribution. Changes in NPP between the period 2081-2100 and the reference period 1951-2000 calculated with (a) CNRM-CM5, (b) HadGEM2-CC, (c) MPI-ESM-MR and (d) MPI-ESM-LR climatic projection under the RCP8.5 scenarios (assuming no CO_2 fertilization effect). Magnitude of changes is expressed in standard deviations of grid cell NPP variability over the reference period. Species range retraction in blue, extension in red and preserved range in green.

The Fig. 40 to 44 show the future distributions of some important species related to provisioning services. *Mammea Africana* is used for food and medicine. *Elaeis guineensis*, notably used for oil or alcohol, is considered as a vital species by local population (see Table 17 in WP4). *Oubanguia africana*, used for construction or as firewood, is a representative species of the vegetation of studied landscape. *Symphonia globulifera*, employed for construction and for its resin, is nowadays a rare species and yet a strategic species. They are potential distributions assuming unlimited dispersal. When the CO_2 is kept constant in the vegetation model, the geographic range of most of the species remains unchanged (even if some species, e.g. *Oubanguia Africana*, expand their range). Species disappearance occurs only at some distribution edges but productivities might be strongly reduced in the preserved part of the present-day range.

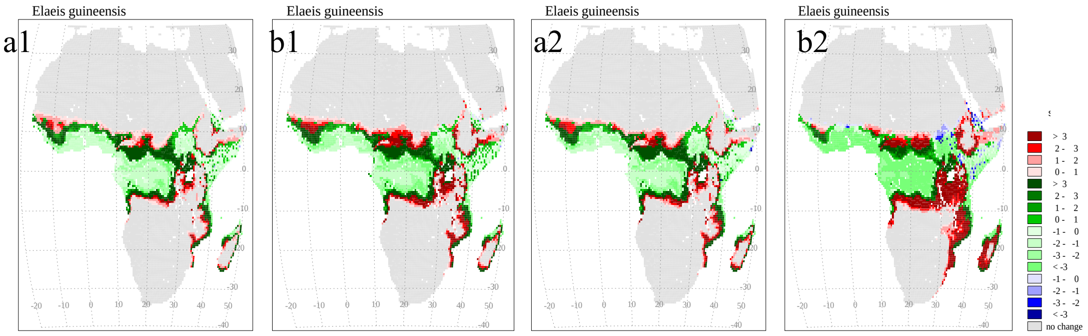


Figure 42 *Elaeis guineensis* modelled future distribution (see Fig. 40 for details).

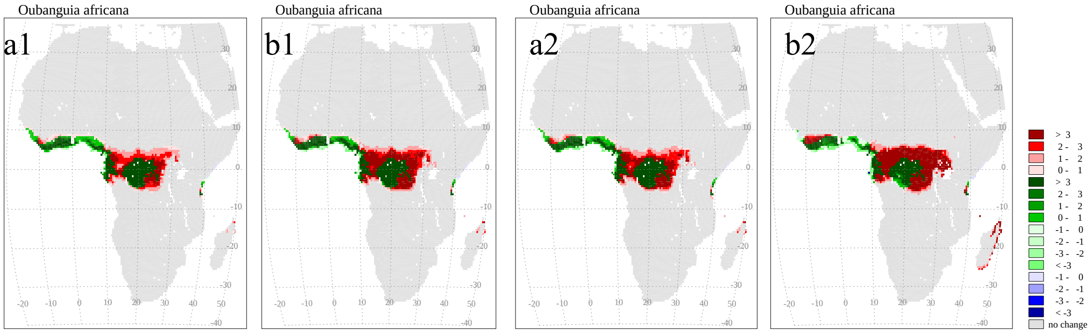


Fig. 43 *Oubanguia africana* modelled future distribution (see Fig. 40 for details).

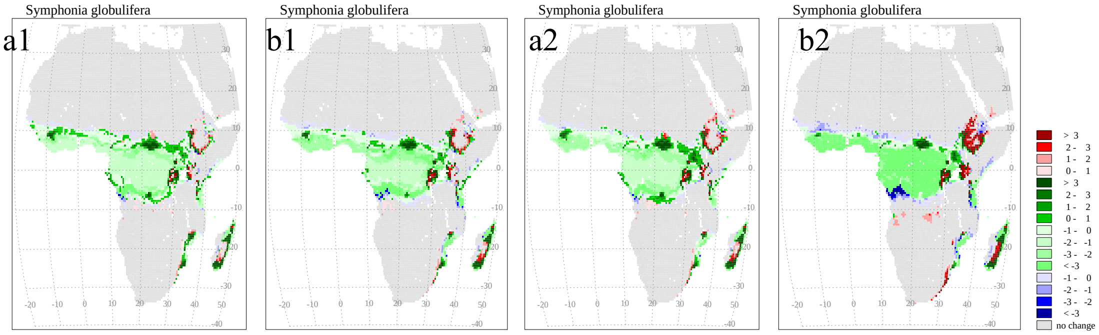


Fig. 44. *Symphonia globulifera* modelled future distribution (see Fig. 40 for details).

Fig. 45 to 48 display the future distribution and abundance of species classified by the ecosystem services they provided. We considered that a species is present in the historic 1951-2000 period if its simulated net primary productivity is higher than 100 gC m^2 yr^{-1} (Fig. 45a, 46a, 47a, 48a). For the future, we combined the species NPP and its cover fraction. Indeed, if the species distribution area may not be impacted, new climatic conditions may alter the species abundance and the source-sink dynamics. For the ecosystem services for which we simulated some representative species, figures b and c present respectively the number of species for which the future product of NPP by the cover fraction is 10 % lower and 10 % higher than the present-day one.

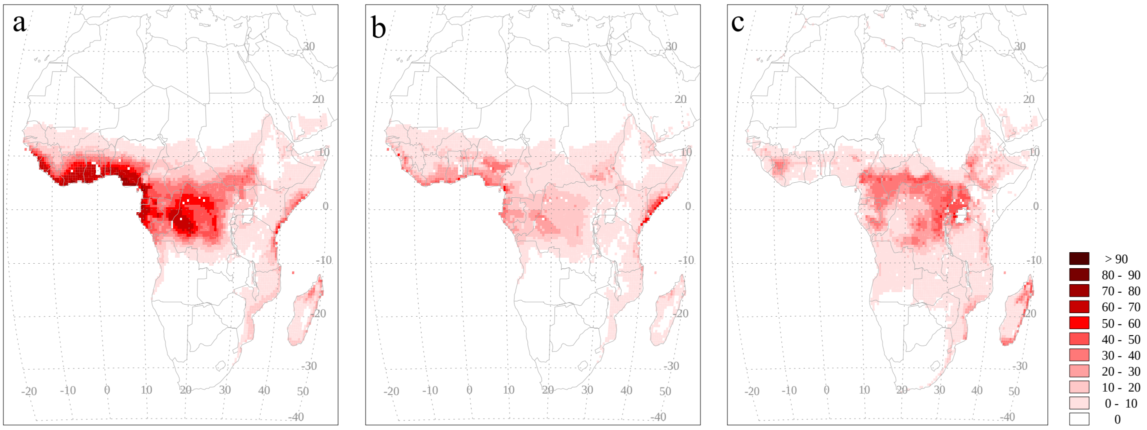


Fig. 45 Modelled species distribution: (a) number of species per grid cell for the period 1951-2000, (b) number of species whose the product of productivity (NPP) by cover fraction (frac) decrease and (c) increase of more than 10 % between the periods 1951-2000 and 2081-2100 under the CMCC-CM climatic projection (RCP8.5 scenario and no CO_2 fertilization).

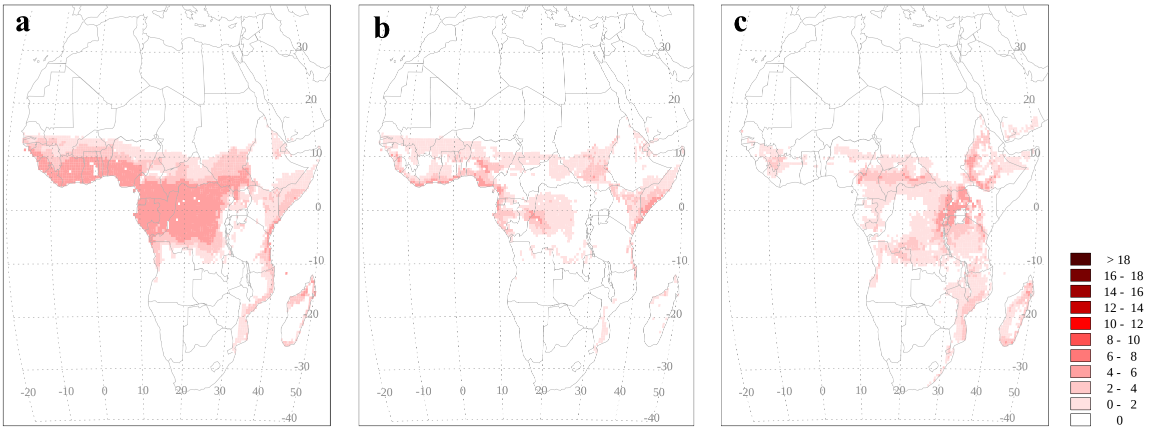


Fig. 46 Future distribution of species related to food services (see Fig. 45 for details).

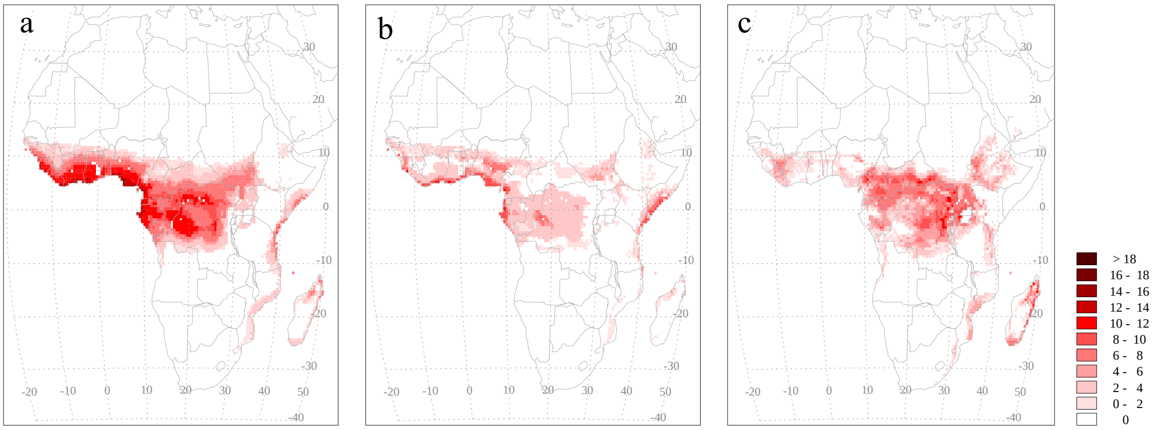


Fig. 47 Future distribution of species related to material services (see Fig. 45 for details).

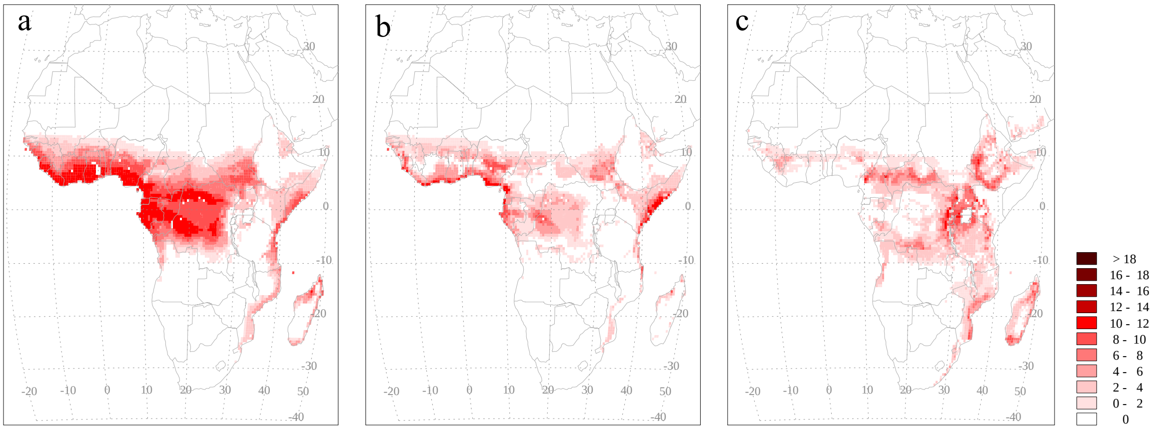


Fig. 48 Future distribution of species related to medicinal services (see Fig. 45for details).

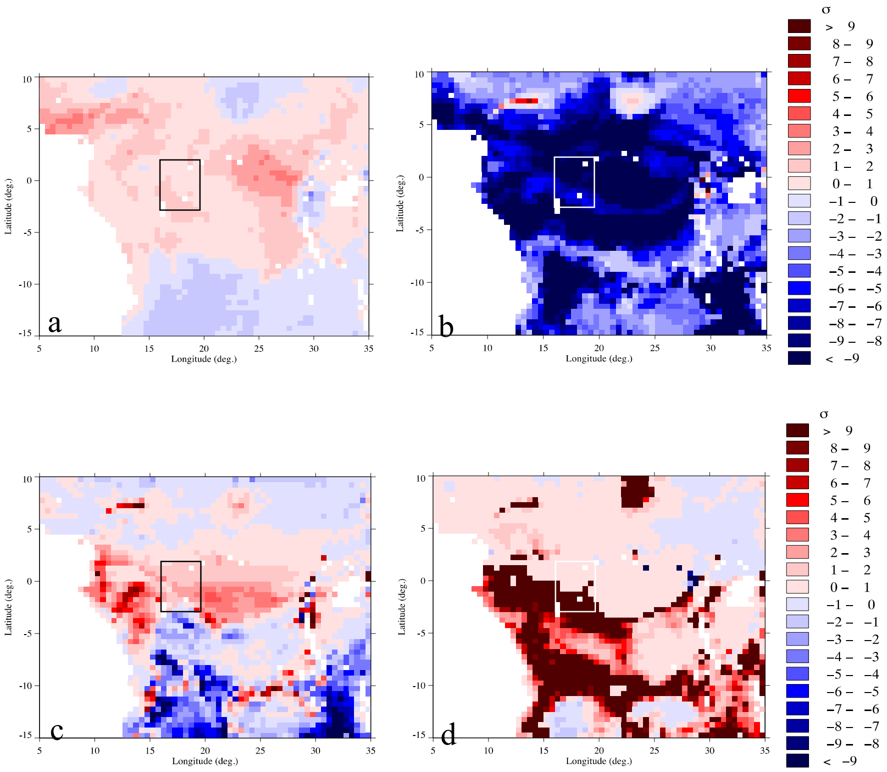


Fig. 49 Changes between the period 2081-2100 and the reference period 1951-2000 under the CMCC-CM climatic projection (RCP8.5 and no CO_2 fertilization) of variables featuring the ecosystem state: (a) annual runoff, (b) annual mean net primary productivity, (c) soil turnover and (d) annual burned area. Rectangle: Lake Tumba Landscape.

Beside the species composition, we simulated future behaviour of some outputs of the vegetation model direct related to ES (see WP4.4 for their present day state): annual runoff, annual mean NPP, soil turnover and annual burned area. For each grid cell, we evaluated the severity of change projected for these variables in the light of their current variability (Fig. 49 and 50 respectively for CMCC-CM and CNRM-CM5 climatic scenarios). Mean changes are considered severe if they exceed observed variability. Like for primary productivity in Fig. 40 to 44, we calculated variability (standard deviation, σ) of the variables in each grid cell for the period 1951-2000. We expressed change projected for the period 2081-2100 in term of standard deviation (σ) calculated within the reference period.

In the Lake Tumba Landscape, the annual runoff slightly increases or decreases depending on the climatic projection (Fig. 49a and 50a). This results from a concomitant increase of temperature and precipitation. With the two climatic scenarios, the grid cell mean net primary productivity decreased in the landscape (Fig. 49b and 50b). The anomalies expressed in term of present-day variability are very important since the NPP interannual variability simulated by the vegetation model for the present is very low (see WP4.4). The soil turnover is simulated to increase (Fig. 49c and 50c) while the burned area increases in the southern part of the landscape (Fig. 49d and 50d). Similarly to NPP, the anomalies are significant since currently the risk of natural fire in the studied area is very low.

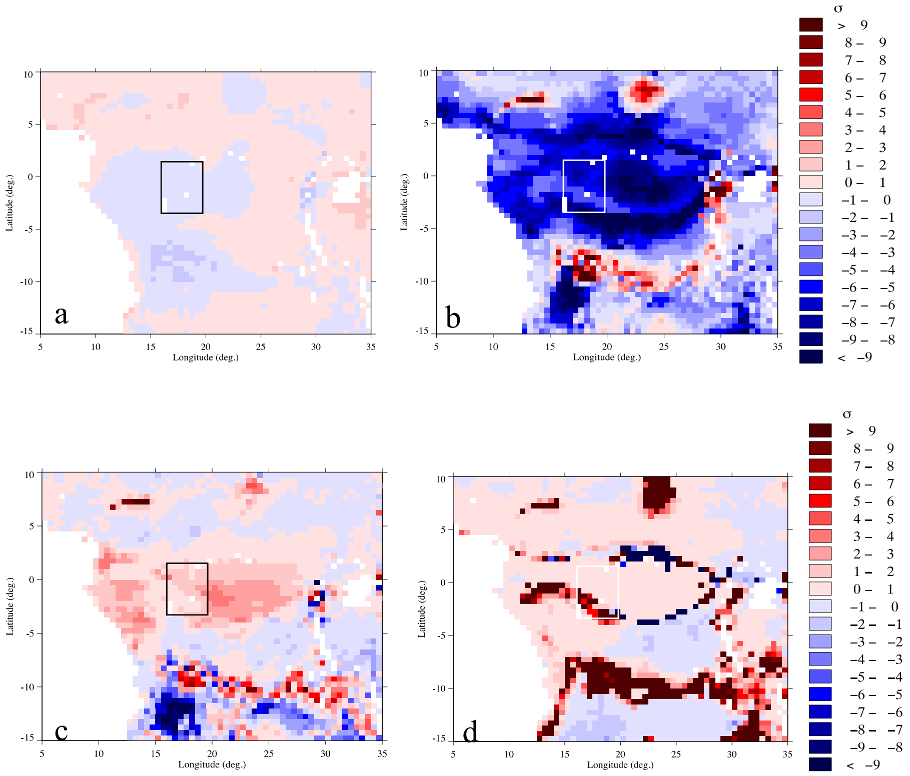


Fig. 50 Changes between the period 2081-2100 and the reference period 1951-2000 under the CNRM-CM5 climatic projection (RCP8.5 and no CO_2 fertilization) of variables featuring the ecosystem state: (a) annual runoff, (b) annual mean net primary productivity, (c) soil turnover and (d) annual burned area. Rectangle: Lake Tumba Landscape.

Assessing sustainability of ecosystem and ES (Task 5.3)

In WP5.2, we showed that different components of Lake Tumba Landscape ecosystems (soil water, NPP, fires, *etc.*) might be strongly affected by change in climatic conditions projected for the future. At the end of the 21st century (2081-2100), many components might be in a state far from one in the reference period (1951-2000). Ecosystems could not be able to adapt to these new conditions and might be disrupted. To assess the risk of ecosystem disruption and to identify the vulnerable areas in the Congo Basin, we created an index combining several CARAIB outputs: runoff, mean NPP, soil turnover, burned area, species composition. Relatively independent, these variables represent the main ecosystem features. We assumed that ecosystems are vulnerable to variability, but that the risk of ecosystem disruption only starts when some components go beyond their historic variability range to which the ecosystem is used to be exposed. The risk probability is zero for change with amplitude $<1\ \sigma$ and 1 for change with amplitude $>3\ \sigma$. The index is calculated summing the individual probabilities and renormalizing between 0 and 1 (Fig. 51). If the Lake Tumba Landscape is not the area the most endangered of the Congo Basin, its southern part undergoes a very significant risk of severe ecosystem modifications linked to climate change.

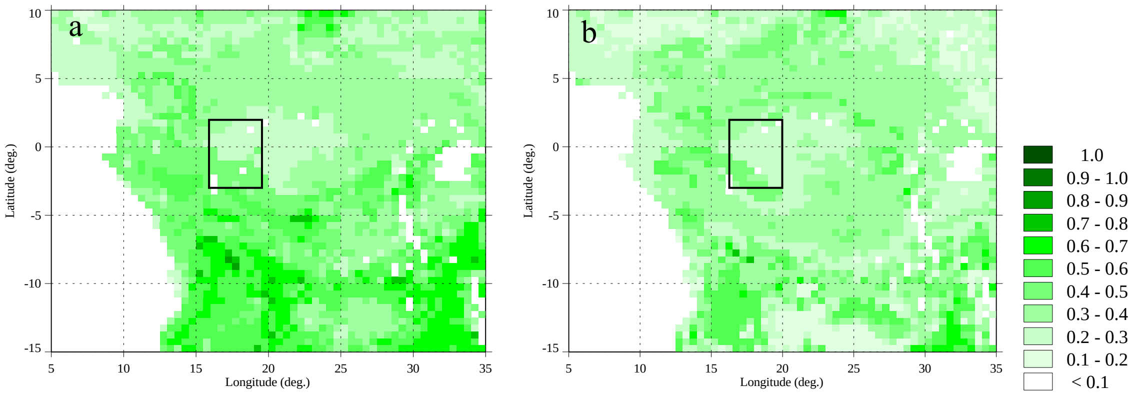


Fig. 51. Ecosystem disruption index under (a) CMCC-CM and (b) CNRM-CM5 climatic projections. Rectangle: Lake Tumba Landscape.

3. POLICY SUPPORT

The project has allowed on the one hand the collection of quantitative field data on sociology, on the use of nature by man, on terrestrial ecosystem biodiversity and on functional ecology, and on the other hand, the simulation of ecosystems processes for the present and for the future under the most common hypothesis of climate change (IPCC Fifth Assessment Report).

For the short term (years to decade), we can conclude, from collected observations, that the studied ecosystems in DR Congo are currently under heavy pressure and that the risk of collapse is high. For instance, slash-and-burn agriculture is no longer sustainable because fallow lengths are far too short, fields are now too distant from the villages, large animal densities are very low (while diversity, particularly of small birds, remained exceptionally high), the community of seed disperser (large mammals and large birds in particular) is greatly impoverished, seed dispersal failure is more common, etc. Such trends will certainly get worse if the way people acquire their basic resources remains unchanged and the urban centres continue to consume forest products.

Local communities extract their daily livelihood from nature, but natural resources are increasingly part of the commercial circuits directed at the large urban centres, and overexploitation is now obvious: i there is little hope without a shift in production methods and a drastic strengthening of governance. Sustainable agricultural practices must be absolutely implemented in the area. Fertilizer use, conservation agriculture, agroforestry, livestock farming should be supported while at the same time, governance should be reinforced; protected areas must be managed for the conservation of nature and biodiversity survival, not only in the studied area, but also elsewhere in Congo.

For the long term (several decades), another threat comes from climate change even though most IPCC climate models projected an increase of precipitations in the area. Possible scenarios of forest growth in the future have been drawn from simulations with a dynamic vegetation model. The results were contrasted owing to the hypothesis of CO_2 fertilization. If CO_2 fertilization is efficient, then productivity of most of the studied species can be expected to increase (+ 20 to 30 %) and with them the associated ecosystem goods and services, despite a significant reduction of soil water. Such an increase in productivity would require the availability of nutrients, and for this reason, the scenario is not likely to occur since tropical soils are usually very poor. Otherwise, if CO_2 fertilization is not taken into account, some tree species may increase their productivity while the productivity of others could decline. Consequently, some reduction of the services provided by the declining tree species can be expected. Moreover, many of the studied species could spread outside their present range. However, this would depend on seed dispersal efficiency, which normally relies mainly on animals (zoochory), when the animals are not being overexploited.

As stated before, there is an urgency of short terms actions to adapt agricultural practices and strongly improve governance, and these actions are of the highest priority. However, it is also important to develop plans to face the effects of climate change on a longer term because the risk of severe perturbations of the forest ecosystem (disruption), by climate change only, is quite significant. Thus, the important species for provisioning ecosystem services should be favoured through forestry management; care should be taken in particular to the regeneration processes including the important step of seed dispersal by animals. This of course implies the establishment of strong conservation measures for the protection of wildlife.

An important issue is the uncertainties of the predicted impacts of climate change on tropical forest. First, additional financial means for field data collection should be made available in order to attempt to capture the variations of ecosystem traits and functions, and the range of people practices in the studied area. This would allow the necessary adaptations of the agent-based model and the functional development of the dynamic vegetation model. Secondly, data collection on plant physiology (acclimation of plant to temperature, species-specific response of growth/mortality to climate, fertility, predators, etc.) remains also essential in order to achieve more reliable simulations with the dynamic vegetation model.

4. DISSEMINATION AND VALORISATION

A web-based platform has been established, to ensure effective dissemination of information within the network of partners, but also beyond. Much of the platform is available to the public.

The partners combine an education and training function. Project results have been disseminated to young scientists through teaching and individual project/thesis work.

RBINS has draw from the Institute, links with the WWF Lake Tele- Lake Tumba Landscape programme, as well as from previous and current contacts with the DRC administration and policy makers.

The project was presented in several symposia held in Africa to disseminate the ideas and the concepts within its scientific community. No meeting was organized with the local communities because the results were not operational this level. Otherwise, results were communicated in the form of oral presentations or posters during international scientific conferences. Several manuscripts are in preparation for submission to international peer-reviewed scientific journals.

Finally, the experience with the new emerging questions made the matter of new research projects with the same partners and with new ones.

5. PUBLICATIONS

Coos, W., Dury, M., Trolliet, F., Hambuckers, A., Huynen, M.C., François, L., 2014. Modelling seed dispersal and tropical forest regeneration: application to *Staudtia kamerunensis* in the WWF Lake Tele-Tumba Landscape in DR Congo. First International Conference on Biodiversity in the Congo Basin. Consortium Congo 2010, Kisangani, p. 123.

Dury, M., Hambuckers, A., Trolliet, F., Huynen, M.C., Haineaux, D., Fontaine, C., Fayolle, A., François, L., 2014. Modelling the Congo basin ecosystems with a dynamic vegetation model. EGU, Vienna.

Halleux, C., Dendoncker, N., Huynen, M.-C., Trolliet, F., Van Damme, P., Baert, A., Fontaine, C., François, L., Hambuckers, A., Lafontaine, R.-M., Beudels, R., Isumbisho Mwapu, P., Balagizi Karhagomba, I., Bukobero, L., 2012. Une approche participative des interactions entre les hommes, femmes et la biodiversité de la forêt tropicale dans la région du lac Tumba, RDC. In: Isumbisho Mwapu, P., Balagizi Karhagomba, I., Bukobero, L. (Eds.), International Conference on Governance of Collective Natural Resources. ADISCO, DIOBASS & IDRS, Bukavu, RD Congo.

Hambuckers, A., Dury, M., Tosso, F., Trolliet, F., Huynen, M.C., Haineaux, D., Fayolle, A., François, L., 2014. Modelling the future range and productivity of African tree species. Perspectives and limits., First International Conference on Biodiversity in the Congo Basin. Consortium Congo 2010, Kisangani, pp. 121-122.

Huynen, M.-C., Beudels, R., Baert, A., Culot, L., Dendoncker, N., Fontaine, C., Francois, L., Hambuckers, A., Lafontaine, R.-M., Trolliet, F., Van Damme, P., 2011. Sustainability of tropical forest biodiversity and services under climate and human pressure (BIOSERF): tracking the regeneration of human-used plants through dispersal by the animal community. In: Cordeiro, N., Mwampamba, T.H., Ismail, F., Dovie, D. (Eds.), Adaptability to Climate Change and Attaining the Millennium Development Goals for Tropical Ecosystems. Association for Tropical Biology and Conservation & The Society for Conservation Biology, Arusha, Tanzania.

Robert, H., Beudels, R., Lafontaine, R.-M., Bankanza, M., Fumutoto, R., Kabongo, M., Botefa, C., 2014. Premiers inventaires de biodiversité dans la réserve de Ngiri (Equateur). First International Conference on Biodiversity in the Congo Basin. Consortium Congo 2010, Kisangani, p. 116.

Serckx, A., Huynen, M.-C., Bastin, J.-F., Hambuckers, A., Beudels-Jamar, R., Vimond, M., Raynaud, E., Kühl, H., 2014. Nest grouping patterns of bonobos (*Pan paniscus*) in relation to fruit availability in a forest-savannah mosaic. *Plos One* **9**, e93742.

Trolliet, F., 2011. Regeneration capacity of socio-economically important tree species in terra-firma forest in Western DR Congo: role of primates. Primate Tidings Brussels, pp. 11-12.

Trolliet, F., Huynen, M.-C., Hambuckers, A., 2012. Dispersal and regeneration capacity of large-seeded tree species in a forest-savanna mosaic in Western DR Congo (poster). In: Niekisch, M., Bräuning, A., Thorsten, P., Richter, M. (Eds.), Islands in land- and seascape: the challenges of fragmentation. Association for Tropical Biology and Conservation, Erlangen, Germany.

Trolliet, F., Serckx, A., Huynen, M.C., Beudels-Jamar, R., Hambuckers, A., 2013. Could bonobos, *Pan paniscus*, influence forest re(colonization) in a forest-savana mosaic? In: D'Août, K., Stevens, J. (Eds.), European Federation for Primatology, Antwerpen, p. 333.

Trolliet, F., Serckx, A., Huynen, M.C., Hambuckers, A., 2013. Dynamic of seed dispersal by large frugivores in a forest-savanna mosaic subject to anthropic pressure in Western D.R. Congo. Annual Conference of the Society for Tropical Ecology - Tropical organisms and ecosystems in a changing world. Hochschule Karlsruhe, Vienna, Austria.

Trolliet, F., Forget, P.-M., Huynen, M.-C., Hambuckers, A., 2014. Influence of hunting and forest fragmentation on animal-mediated seed dispersal in a forest-savanna mosaic. In: Turton, S., Laurance, S.G. (Eds.), ATBC Annual Meeting - The future of tropical biology and conservation, Cairns.

Trolliet, F., Vermeulen, C., Huynen, M.-C., Hambuckers, A., 2014. Use of camera traps for wildlife studies: a review. *BASE* **18** : 446-454.

Trolliet, F., Forget, P.-M., Huynen, M.-C., Hambuckers, A., Forest cover and hunting pressure control seed dispersal in a forest-savanna mosaic in 3 the Congo Basin (submitted).

Trolliet, F., A. Serckx A., Beudels-Jamar, F., Forget, P.-M., Huynen, M.-C., Hambuckers, A., Could bonobos, *Pan paniscus*, seed dispersal services influence the dynamic of forest 1 (re)colonization in a mosaic landscape? (in preparation).

6. ACKNOWLEDGMENTS

R. Beudels-Jamar and colleagues would like to thank BELSPO for providing the funds necessary and making this project alive. Thank you to Alain Hambuckers for the coordination of the project. We would also like to express our sincere gratitude to the WWF/RDC (project CAFEC) and the ICCN for their support, protection, priceless time spent in the field, friendship and the logistic that allowed us to perform successfully these 3 missions of inventories in the Congo basin. Sincere reconnaissance as well to the MONUSCO for providing us the transport to the study sites.

A. Hambuckers and colleagues are sincerely grateful to the WWF-Congo (World Wide Funds for Nature) for logistical help and more particularly to the Malebo field team. Particularly, Franck Trolliet thanks the chef-de-terres and the trackers from the Nkala, Mpelu and Mbanzi community that allowed us to work in their forest and helped us in data collection. This research was funded by BESLPO and FNRS-FRIA PhD scholarship. We thank the Mbou-Mon-Tour NGO for providing logistical support from Kinshasa to the field and in the field.

7. REFERENCES

Abernethy, K., & L. Coad. 2013. Extent and ecological consequences of hunting in Central African rainforests in the twenty-first century. *Philosophical Transaction of the Royal Society B* 368.

Adesokan, A. A., Yakubu, M. T., Owoyele, B. V., Akanji, M. A., Soladoye, A. O. & Lawal, O. K. 2008. Effect of administration of aqueous and ethanolic extracts of *Enantia chlorantha* stem bark on brewer's yeast-induced pyresis in rats. *African Journal of Biochemistry Research* 2: 165-169

Aga Alo, C., & Wang, G. 2010. Role of dynamic vegetation in regional climate predictions over western Africa. *Climate Dynamic*s 35: 907-922..

Albuquerque, U.P., Lucena, R.F.P., Monteiro, J.M., Florentino, A.T.N. & Almedia, C.B.R. 2006. Evaluating two quantitative ethnobotanical techniques. *Ethnobotany Research and Applications* 4: 51-60.

Aliyu, B., H. Adamu, E. Moltchanova, P.-M. Forget, & H. Chapman. 2014. The Interplay of Habitat and Seed Type on Scatterhoarding Behavior in a Fragmented. *Biotropica* 46:1–4.

Arora, V.K., & Boer, G.J. 2005. Fire as an interactive component of dynamic vegetation models. *Journal of Geophysical Research-Biogeosciences* 110.

Babweteera, F. 2009. *Cordia millenii*: on the risk of local extinction? *African Journal of Ecology* 47: 367 - 373.

Babweteera, F., & N. Brown. 2009. Can remnant frugivore species effectively disperse tree seeds in secondary tropical rain forests? *Biodiversity and Conservation* 18: 1611-1627.

Beer, C., Reichstein, M., Tomelleri, E., Ciais, P., Jung, M., Carvalhais, N., Rödenbeck, C., Arain, M.A., Baldocchi, D., Bonan, G.B., Bondeau, A., Cescatti, A., Lasslop, G., Lindroth, A., Lomas, M., Luyssaert, S., Margolis, H., Oleson, K.W., Roupsard, O., Veenendaal, E., Viovy, N., Williams, C., Woodward, F.I., Papale, D., 2010. Terrestrial gross carbon dioxide uptake: Global distribution and covariation with climate, *Science* 329: 834-838.

Beaune, D., F. Bretagnolle, & L. Bollache. 2013. Ecological services performed by the bonobo (*Pan paniscus*): seed dispersal effectiveness in tropical forest. *Journal of Tropical Ecology* 29: 367-380.

Beaune, D., Bretagnolle, F., Bollache, L., Bourson, C., Hohmann, G., & Fruth, B. 2013. Ecological services performed by the bonobo (*Pan paniscus*): seed dispersal effectiveness in tropical forest. *Journal of Tropical Ecology* 29: 367-380.

Beckman, N. G., & H. C. Muller-landau. 2007. Differential effects of hunting on pre-dispersal seed predation and primary and secondary seed removal of two neotropical tree species. *Evolution* 39: 328-339.

Bharwani, S., Bithell, M., Downing, T.E., New, M., Washington, R., & Ziervogel, G. 2005. Multi-agent modelling of climate outlooks and food security on a community garden scheme in Limpopo, South Africa. *Philosophical Transactions of the Royal Society B-Biological Sciences* 360: 2183-2194.

Biapa, P. C.-N., N. B.,Agbor, G. A., Oben, J. E., Ngogang, J. E. 2007. Phytochemical studies and antioxidant properties of four medicinal plants used in Cameroon. African Journal of Traditional and Complementary Medecines 4: 495–500.

Betti, J.L. 2004. An ethnobotanical study of medicinal plants among the Baka pygmies, in the Dja biosphere Reserve, Cameroon. African Study Monographs 25: 1-27.

Blendinger, P., B. Loiselle, & J. Blake. 2008. Crop size, plant aggregation, and microhabitat type affect fruit removal by birds from individual melastome plants in the Upper Amazon. *Oecologia* 158: 273-283.

Boissier, O., A. Bouiges, I. Mendoza, F. Feer, & P.-M. Forget. 2014. Rapid assessment of seed removal and frugivore activity as a tool for monitoring the health status of tropical forests. *Biotropica* 46:633–641.

Bond, W.J., Woodward, & F.I., Midgley, G.F. 2005. The global distribution of ecosystems in a world without fire. *New Phytologist* 165: 525-537.

Buij, R., W. J. McShea, P. Campbell, M. E. Lee, F. Dallmeier, S. Guimondou, L. Mackaga, N. Guisseougou, S. Mboumba, J. E. Hines, J. D. Nichols, & A. Alonso. 2007. Patch-occupancy models indicate human activity as major determinant of forest elephant Loxodonta cyclotis seasonal distribution in an industrial corridor in Gabon. *Biological Conservation* 135:189–201.

Byg, A. & Baslev, H. 2001. Diversity and use of palm in Zahamena, eastern Madagascar. *Biodiversity and Conservation* 10: 951-970.

Cao, M.K., Zhang, Q.F., & Shugart, H.H. 2001. Dynamic responses of African ecosystem carbon cycling to climate change. *Climate Research* 17: 183-193.

Carretero, A.L.M. 2005. Useful plants and traditional knowledge in the Tucumano-Boliviano forest. Denmark: Aarhus University.

Chapman, C., L. Chapman, & R. Wrangham. 1992. Estimators of fruit abundance of tropical trees. *Biotropica* 4: 527-531.

Chasar, A., R. J. Harrigan, K. M. Holbrook, T. V Dietsch, T. L. Fuller, & M. Wikelski. 2014. Spatial and temporal patterns of frugivorous Hornbill movements in Central Africa and their implications for rain corest conservation. *Biotropica* 46:763–770.

Clark, C. J., J. R. Poulsen, B. M. Bolker, E. F. Connor, & V. T. Parker. 2005. Comparative seed shadows of bird- , monkey- , and wind-dispersed trees. *Ecology* 86:2684–2694.

Clark, C. J., J. R. Poulsen, E. F. Connor, & V. T. Parker. 2004. Fruiting trees as dispersal foci in a semi-deciduous tropical forest. *Oecologia* 139: 66–75.

Clark, C. J., J. R. Poulsen, D. J. Levey, 2013. Roles of seed and establishment limitation in determining patterns of afrotropical tree recruitment. PloS One 8 (5) article e 63330.

Clark, C. J., J. R. Poulsen, & V. T. Parker. 2001. The role of arboreal seed dispersal groups on the seed rain of a lowland tropical forest. *Biotropica* 33:606–620.

Cogley, J., 1998. GGHYDRORGlobal hydrographic data, release 2.2, *Trent Clim*. Note 98R1, Dept. of Geog., Trent Univ., Peterborough, Ontario, Canada.

Coos, W.. 2013. Elaboration d'un module de dispersion des diaspores pour le modèle dynamique de végétation CARAIB. Mémoire - Master en Biologie des Organismes et Ecologie. Université de Liège.

Cordeiro, N., & H. Howe. 2003. Forest fragmentation severs mutualism between seed dispersers and an endemic African tree. *Proceedings of the National Academy of Sciences of the United States of America* 24: 14052-14056.

Cramer, W., & Bondeau, A., Woodward, F.I. 2001. Global response of terrestrial ecosystem structure and function to CO2 and climate change: results from six dynamic global vegetation models. *Global Change Biology* 7: 357-373.

Danquah, E. and Oppong, S. K. 2007 Phenology of forest trees favoured by elephants in the Kakum Conservation Area, Ghana. *Pachyderm* 42: 43-51.

DeFries, R.S., Foley, J.A. & Asner, G.P. 2004. Land-use choices: balancing human needs and ecosystem function. *Front Ecol Environment* 2:249-257.

Delignette-Muller, & M.-L., Dutang, C. 2015. Fitdistrplus: An R package for fitting distributions. *Journal of Statistic Software* 64:1-34.

de Melo, F.P.L., Martinez-Salas, E., Benitez-Malvido, J., & Ceballos, G. 2010. Forest fragmentation reduces recruitment of large-seeded tree species in a semi-deciduous tropical forest of southern Mexico. *Journal of Tropical Ecology* 26: 35-43.

Demey, R. & Louette, M. 2001. Democratic Republic of Congo, pp 199 - 218 in Fishpool, L.D.C. and Evans M.I. (eds) Important Bird Areas in Africa and Associated Islands: Priority sites for conservation. Newbury and Cambridge, UK. Pisces Publications and BirdLife International (BirdLife Conservation Series No.11).

Dhetchuvi JB. 1996. Taxonomie et phytogéographie des Marantaceae et des Zingiberaceae de l´Afrique Centrale (Gabon, Congo, Zaire, Rwanda et Brundi). PhD Thesis, Université Libre de Bruxelles, Belgique.

Dormann, F. C., J. M. McPherson, M. B. Araújo, R. Bivand, J. Bolliger, G. Carl, R. G. Davies, A. Hirzel, W. Jetz, W. Daniel Kissling, I. Kühn, R. Ohlemüller, P. R. Peres-Neto, B. Reineking, B. Schröder, F. M. Schurr, & R. Wilson. 2007. Methods to account for spatial autocorrelation in the analysis of species distributional data: A review. *Ecography* 30: 609–628.

Dury M., Hambuckers A., Trolliet F., Huynen M.-C., Haineaux D., Fontaine C.M., Fayolle A., François L., 2014. Modelling the Congo basin ecosystems with a dynamic vegetation model. *Geophysical Research Abstracts* 16, EGU2014-9033-1.

Fa, J., C. Peres, & J. Meeuwig. 2002. Bushmeat Exploitation in Tropical Forests: an Intercontinental Comparison. *Conservation Biology* 16: 232–237.

Fa, J., S. Ryan, & D. Bell. 2005. Hunting vulnerability, ecological characteristics and harvest rates of bushmeat species in afrotropical forests. *Biological Conservation* 121:167–176.

Fa, J., J. Yuste, & R. Castelo. 2000. Bushmeat markets on Bioko Island as a measure of hunting pressure. Conservation Biology.

Fayolle, A., M. D. Swaine, J.-F. Bastin, N. Bourland, J. A. Comiskey, G. Dauby, J.-L. Doucet, J.-F. Gillet, S. Gourlet-Fleury, O. J. Hardy, B. Kirunda, F. N. Kouame & A. J. Plumptre. 2014. Patterns of tree species composition across tropical African forests. *Journal of Biogeography*. 41: 2320–2331.

Farwig, N., K. Böhning-Gaese, & B. Bleher. 2006. Enhanced seed dispersal of Prunus africana in fragmented and disturbed forests? *Oecologia* 147: 238–252.

Fischer, E., & Hinkel, H. 1992. Natur Ruandas. Einfuhrung in die Flora und Faune Ruandas - La nature du Rwanda. Aperçu sur la flore et la faune rwandaises. Rhein Main Druck, Mainz.

Forget, P. 1991. Comparative recruitment patterns of two non-pioneer canopy tree species in French Guiana. *Oecologia* 85: 434-439.

Forget, P.-M., A. J. Dennis, S. J. Mazer, P. A. Jansen, S. Kitamura, J. E. Lambert, & D. A. Westcott. 2007. Seed allometry and disperser assemblages in tropical rain forests: A comparison of four floras on different continents. In Dennis A.J. et al. Seed dispersal: theory and its application in a changing world. CABI 5–36.

Fujisaka, S., Escobar, & G., Veneklaas, E. 1998. Plant community diversity relative to human land uses in an Amazon forest colony. *Biological Conservation* 7: 41-57.

Galetti, M., C. P. Alves-costa, & E. Cazetta. 2003. Effects of forest fragmentation , anthropogenic edges and fruit colour on the consumption of ornithocoric fruits. *Biological Conservation* 111: 269–273.

Galetti, M., C. I. Donatti, A. S. Pires, P. R. G. Jr, & P. Jordano. 2006. Seed survival and dispersal of an endemic Atlantic forest palm : the combined effects of defaunation and forest fragmentation. *Botanical Journal of the Linnean Society* 151: 141–149.

Geist, H.J. & Lambin, E. 2001. What drives tropical deforestation? A meta-analysis of proximate and underlying causes of deforestation based on subnational case study evidence. *LUCC Report Series* 4. LUCC International Project Office, University of Louvain, Belgium.

Gautier-Hion, A., J. Duplantier, & R. Quris. 1985. Fruit characters as a basis of fruit choice and seed dispersal in a tropical forest vertebrate community. *Oecologia* 65: 324–337.

Grace, J., San Jose, J., Meir, P., Miranda, H.S., Montes, R.A.J.o.B., 2006. Productivity and carbon fluxes of tropical savannas. *Journal of Biogeography* 33: 387-400.

Head, J. S., C. Boesch, L. Makaga, & M. M. Robbins. 2011. Sympatric chimpanzees (*Pan troglodytes troglodytes*) and Gorillas (*Gorilla gorilla gorilla*) in Loango National Park, Gabon: dietary composition, seasonality, and intersite comparisons. *International Journal of Primatology* 32:755–775.

Hély, C., Bremond, L., Alleaume, S., Smith, B., Sykes, M.T., & Guiot, J. 2006. Sensitivity of African biomes to changes in the precipitation regime. *Global Ecology and Biogeography* 15: 258-270.

Hladika, A. & Hladika, C.M. 1969. Rapports trophiques entre végétation et primates dans la forêt de Barro Colorado (Panama). *Terre et Vie* 23 : 25-117.

Holbrook, K., & B. Loiselle. 2009. Dispersal in a Neotropical tree, *Virola flexuosa* (Myristicaceae): Does hunting of large vertebrates limit seed removal? *Ecology* 90: 1449-1455

Holbrook, K., & T. B. Smith. 2000. Seed dispersal and movement patterns in two species of *Ceratogymna* hornbills in a West African tropical lowland forest. *Oecologia* 125: 249–257.

House, J.I., Archer, S., Breshears, D.D., & Scholes, R.J. 2003. Conundrums in mixed woody-herbaceous plant systems. *Journal of Biogeography* 30: 1763-1777.

Howe, H. 1981. Dispersal of a neotropical nutmeg (*Virola sebifera*) by birds. *The Auk* 98: 88-98.

Howe, H., & V. Kerckhove. 1981. Removal of Wild Nutemg(*Virola surinamensis*) Crops by Birds. *Ecology* 62: 1093-1106.

Howe, H., & J. Smallwood. 1982. Ecology of seed dispersal. *Annual review of ecology and systematics* 13: 201-228.

Idani, G., S. Kuroda, T. Kano, & R. Asato. 1994. Flora and Vegetation of Wamba Forest , Centrd Zaire, with reference to Bonobo (*Pan paniscus*) foods. *Tropics* 3: 309–332.

Janzen D.H., 1970. Herbivores and the number of tree species in tropical forests. *American Naturalist*, 104: 501–528.

Jesus, F. M., V. R. Pivello, S. T. Meirelles, G. a. D. C. Franco, & J. P. Metzger. 2012. The importance of landscape structure for seed dispersal in rain forest fragments. *Journal of Vegetation Science* 23: 1126–1136.

Kennedy, W.G., Hailegiorgis, A.B., Rouleau, M., Bassett, J.K., Coletti, M., Balan, G.C., & Gulden, T. 2010. An Agent-Based Model of Conflict in East Africa And the Effect of Watering Holes. 19th Conference on Behavior Representation in Modeling and

Simulation, 21 - 24 March, Charleston.

Kirika, J. M., B. Bleher, & K. Böhning-Gaese. 2008a. Fragmentation and local disturbance of forests reduce frugivore diversity and fruit removal in *Ficus thonningii* trees. *Basic and Applied Ecology* 6: 663-672....

Kirika, J. M., N. Farwig, & K. Böhning-Gaese. 2008b. Effects of local disturbance of tropical forests on frugivores and seed removal of a small-seeded Afrotropical tree. *Conservation Biology* 22: 318–328.

Kitamura, S., & P. Poonswad. 2013. Nutmeg-vertebrate interactions in the Asia-Pacific region: importance of frugivores for seed dispersal in Myristicaceae. *Tropical Conservation Science*. 6: 608-636

Kurten, E. 2013. Cascading effects of contemporaneous defaunation on tropical forest communities. *Biological Conservation* 163: 22-32.

Lambin, E.F., Turner, B.L., Geist, H.J., Agbola, S.B., Angelsen, A., Bruce, J.W. Coomes, O.T., Dirzo, R., Fisher, G., Folke, C., George, P.S., Homewood, K., Imbernon, J., Leemans, R., LI, X., Moran, E.F., Mortimore, M., Ramakrishnan, P.S., Richards, J.F., Skåne, H., Steffen, W., Stone, G.D., Svedin, U., Veldkamp, T.A., Vogel. C,. & Xu, J. 2001. The causes of land-use and land-cover change: moving beyond the myths. *Global Environmental Change* 11: 261-269.

Laurance, W. F., B. M. Croes, L. Tchignoumba, S. Lahm, A. Alonso, M. E. Lee, P. Campbell, & C. Ondzeano. 2006. Impacts of roads and hunting on central African rainforest mammals. *Conservation Biology* 20:1251–1261.

Lenz, J., W. Fiedler, T. Caprano, W. Friedrichs, B. H. Gaese, M. Wikelski, K. Böhning-Gaese, 2011. Seed-dispersal distributions by trumpeter hornbills in fragmented landscapes. *Proceedings. Biological sciences / The Royal Society* 278: 2257–2264.

Lévesque, M., K. P. McLaren, M. A. McDonald, 2011. Recovery and dynamics of a primary tropical dry forest in Jamaica, 10 years after human disturbance. *Forest Ecology and Management* 262: 817–826.

Lewis, S.L., Lopez-Gonzalez, G., Sonké, B., Affum-Baffoe, K., Baker, T.R., Ojo, L.O., Phillips, O.L., Reitsma, J.M., White, L., Comiskey, J.A., Djuikouo K, M.-N., Ewango, C.E.N., Feldpausch, T.R., Hamilton, A.C., Gloor, M., Hart, T., Hladik, A., Lloyd, J., Lovett, J.C., Makana, J.-R., Malhi, Y., Mbago, F.M., Ndangalasi, H.J., Peacock, J., Peh, K.S.-H., Sheil, D., Sunderland, T., Swaine, M.D., Taplin, J., Taylor, D., Thomas, S.C., Votere, R., Wöll, H. Increasing carbon storage in intact African tropical forests (2009) *Nature*, 457: 1003-1006.

Maj, A. 2011. Goodness-of-fit-measures for linear mixed models with one-level-grouping. http://cran.r-project.org/web/packages/lmmfit/index.html.

Mangan, S.A., Schnitzer, S.A., Herre, E.A., Mack, K.M.L., Valencia, M.C., Sanchez, E.I., & Bever, J.D. 2010. Negative plant-soil feedback predicts tree-species relative abundance in a tropical forest. *Nature* 466: 752-755.

Markl, J., M. Schleuning, P. Forget, P. Jordano, J. E. Lambert, A. Traveset, S. J. Wright, & K. Böhning-gaese. 2012. Meta-analysis of the effects of human disturbance on seed. dispersal by animals. *Conservation Biology* 26: 1072-1081.

Marshall, A. J., & Wrangham, R. W. 2007. Evolutionary consequences of fallback foods. *International Journal of Primatology* 28: 1219-1235.

Mathot, L., & J. Doucet. 2006. Méthode d'inventaire faunique pour le zonage des concessions en forêt tropicale. *Bois et Forêt des Tropiques* 287: 59-70.

Mazoyer, M., & Roudart, L. 1997. Histoire des agricultures du monde. Du néolithique à la crise contemporaine. Editions du Seuil, Paris.

McNair, J. N., Sunkara, A., & Frobish, D. 2012. How to analyse seed germination data using statistical time-to-event analysis: non-parametric and semi-parametric methods. *Seed Science Research* 22: 77-95.

Millenium Ecosystem Assessment. 2005. Ecosystems and Human Well-being: Synthesis. Island Press, Washington, DC., USA.

Moss, R.H., Edmonds, J.A., Hibbard, K.A., Manning, M.R., Rose, S.K., Van Vuuren, D.P., Carter, T.R., Emori, S., Kainuma, M., Kram, T., Meehl, G.A., Mitchell, J.F.B., Nakicenovic, N., Riahi, K., Smith, S.J., Stouffer, R.J., Thomson, A.M., Weyant, J.P., Wilbanks, T.J. 2010. The next generation of scenarios for climate change research and assessment. Nature, 463 (7282):747-756.

Murray-Rust, D., Brown, C., van Vliet, J., Alam, S.J., Robinson, D.T., Verburg, P.H., & Rounsevell, M. 2014. Combining agent functional types, capitals and services to model land use dynamics. *Environmental Modelling and Software* 59: 187-201.

Ndoye, O. & Awono, A. 2005. The Markets Of Non Timber Forest Products In The Provinces Of Equateur And Bandundu, Democratic Republic Of Congo. Congo Livelihood Improvement And Food Security Project, CIFOR. Central African regional office, Yaoundé, Cameroon.

Neuschulz, E., A. Botzat, & N. Farwig. 2011. Effects of forest modification on bird community composition and seed removal in a heterogeneous landscape in South Africa. *Oikos* 120: 1371-1379.

Nuñez-Iturri G., & Howe H.F. 2007. Bushmeat and the fate of trees with seeds dispersed by large primates in a lowland rain forest in western Amazonia. *Biotropica,* 39:348–354.

Paniagua, N.Y.Z. 2005. Factors determining the knowledge and use of palms in the western Amazon. Denmark: University of Aarhus.

Pedersen T. 2010. The systematic follows mainly “Checklist of African Birds” published by the African Bird Club 2004 - http://www.africanbirdclub.org/resources/checklist.html.

Pendje G. 1994. La frugivorie de *Civettictis civetta* (Schreiber) et son rôle dans la dispersion des graines au Mayombe. *Revue d'écologie* 49: 107-116.

Phillips, O. & Gentry A.H. 1993a. The useful plants of Tambopata, Peru: I Statistical hypotheses tests with a new quantitative technique. *Economic Botany* 47: 15–32.

Phillips, O. & Gentry A.H. 1993b. The useful plants of Tambopata, Peru: II Statistical hypotheses tests with a new quantitative technique. *Economic Botany* 47: 33–43.

Pinheiro J, Bates D, DebRoy S, Sarkar D & R Core Team (2015). *nlme: Linear and Nonlinear Mixed Effects Models*. R package version 3.1-120, http://CRAN.R-project.org/package=nlme.

Poulsen, J. R., C. J. Clark, E. F. Connor, & T. B. Smith. 2002. Differential resource use by primates and hornbills: implications for seed dispersal. *Ecology* 83:228–240.

Poulsen, J. R., C. J. Clark, & T. B. Smith. 2001. Seed dispersal by a diurnal primate community in the Dja Reserve , Cameroon. *Journal of Tropical Ecology* 17: 787–808.

Queenborough, S. 2013. Adding spice to life: A special issue on the Myristicaceae. *Tropical Conservation Science* 6: 592-594.

Ratiarison, S., & P.-M. Forget. 2013. The role of frugivores in determining seed removal and dispersal in the Neotropical nutmeg. *Tropical Conservation Science* 6: 690-704.

Rogers, M. E., Abernethy, K., Bermejo, M., Cipolletta, C., Doran, D., Mcfarland, K., & Tutin, C. E. 2004. Western gorilla diet: a synthesis from six sites. *American Journal of Primatology* 64: 173-192.

Rondon, X.J., D. L. Gorchov, F. Cornejo, 2008. Tree species richness and composition 15 years after strip clear-cutting in the Peruvian Amazon. Plant Ecology 201, 23–37.

Russo, S. 2005. Linking seed fate to natural dispersal patterns: factors affecting predation and scatter-hoarding of *Virola calophylla* seeds in Peru. *Journal of Tropical Ecology* 21.

Ruthenberg, H. 1977. Farming system in the tropics. Clarendon Press, Oxford.

Scheiter, S., Higgins, S.I., 2009. Impacts of climate change on the vegetation of Africa: an adaptive dynamic vegetation modelling approach. *Global Change Biology* 15: 2224-2246.

Sabatier, D. 1997. Description et biologie d'une nouvelle espèce de *Virola* (Myristicaceae) de Guyane. *Adansonia* 19: 273–278.

Schupp, E. W. 1993. Quantity, quality and the effectiveness of seed dispersal by animals. In Frugivory and seed dispersal: ecological and evolutionary aspects (pp. 15-29). Springer Netherlands.

Schupp, E. W., Jordano, P. & Gómez, J. M. 2010. Seed dispersal effectiveness revisited: a conceptual review. *New Phytologist* 188: 333–353.

Serckx, A., Huynen, M. C., Bastin, J. F., Hambuckers, A., Beudels-Jamar, R. C., Vimond, M., & Kühl, H. S. 2014. Nest Grouping Patterns of Bonobos (*Pan paniscus*) in relation to fruit availability in a forest-savannah mosaic. *PloS one* 9.

Serckx, A., Kühl, H. S., Beudels - Jamar, R. C., Poncin, P., Bastin, J. F., & Huynen, M. C. 2015. Feeding ecology of bonobos living in forest - savannah mosaics: Diet seasonal variation and importance of fallback foods. *American Journal of Primatology* (in press).

Stauffer, D. J., & T. B. Smith. 2004. Breeding and nest site characteristics of the Black-casqued Hornbill *Ceratogymna atrata* and White-thighed Hornbill *Ceratogymna cylindricus* in south-central Cameroon. *Ostrich-Journal of African Ornithology* 75: 79–88.

Taylor, K. E., R. J. Stouffer, & G. A. Meekl. 2012. An overview of CMIP5 and the experiment design. *Bulletin of the American Meteorological Society* 93: 485-498.

Termote, C., Van Damme, P. and Dhed'a Djailo B. 2011. Eating from the wild: Turumbu, Mbole and Bali traditional knowledge on non-cultivated edible plants, District Tshopo, DRCongo. *Genetic Resources and Crop Evolution* 58: 585-618.

Theuerkauf, J., W.E. Waitkuwait, Y. Guiro, H. Ellenberg & S. Porembski. 2000. Diet of forest elephants and their role in seed dispersal in the Bossematié Forest Reserve, Ivory Coast. *Mammalia* 64: 447-459.

Tosso, F., 2013. Modélisation de la distribution de six espèces d'arbres multi-usages en Afrique et évaluation de l'effet des changements climatiques. University of Liège, p. 61.

Trail, P. W. 2007. African hornbills : keystone species threatened by habitat loss , hunting and international trade. *Main* 78:609–613.

Vanthomme, H., Bellé, B. & Forget, P.-M. 2010. Bushmeat hunting alters recruitment of large-seeded plant species in Central Africa. *Biotropica*, 42: 672–679.

Verhegghen, A., P. Mayaux, C. de Wasseige, P. Defourny, 2012. Mapping Congo Basin vegetation types from 300 m and 1 km multi-sensor time series for carbon stocks and forest areas estimation, *Biogeosciences* 9: 5061-5079.

Wang, B. C., & T. B. Smith. 2002. Closing the seed dispersal loop. *Trends in Ecology & Evolution* 8: 379-386

Wang, B. C., V. Sork, M. Leong, & T. B. Smith. 2007. Hunting of Mammals Reduces Seed Removal and Dispersal of the Afrotropical Tree *Antrocaryon klaineanum* (Anacardiaceae). *Biotropica* 39: 340-347.

Whitney, K. D., M. K. Fogiel, A. M, K. M. Holbrook, D. J. Stauffer, B. D. Hardesty, V. T. Parker, and T. B. 1998. Seed dispersal by *Ceratogymna* hornbills in the Dja Reserve, Cameroon. *Journal of Tropical Ecology* 14: 351–371.

Whitney, K. D., and T. B. Smith. 1998. Habitat use and resource tracking by African *Ceratogymna hornbills*: implications for seed dispersal and forest conservation. *Animal Conservation* 1: 107–117.

Williams, C.A., Hanan, N.P., Neff, J.C., Scholes, R.J., Berry, J.A., Denning, A.S., & Baker, D.F. 2007. Africa and the global carbon cycle. *Carbon Balance and Management* 2: 3.

Woodward, F.I., & Lomas, M.R. 2004. Vegetation dynamics - simulating responses to climatic change. *Biological Reviews* 79: 643-670.

Wunderle Jr., J. 1997. The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. *Forest Ecology and Management* 99: 223-235.

Zhao, M., F. A. Heinsch, R. R. Nemani, S. W. Running, 2005. Improvements of the MODIS terrestrial gross and net primary production global data set. *Remote Sensing of Environment* 95: 164-176.

Ziervogel, G., Bithell, M., Washington, R., & Downing, T. 2005. Agent-based social simulation: a method for assessing the impact of seasonal climate forecast applications among smallholder farmers. *Agricultural Systems* 83: 1-26.

Zhu, Z., J. Bi, Y. Pan, S. Ganguly, A. Anav, L. Xu, A. Samanta, S. Piao, R. R. Nemani, R. B. Myneni, 2013. Global data sets of vegetation leaf area index (LAI)3g and fraction of photosynthetically active radiation (FPAR)3g derived from global inventory modeling and mapping studies (GIMMS) normalized difference vegetation index (NDVI3G) for the period 1981 to 2011. *Remote Sensing* 5: 927-948.

ANNEX 1: COPY OF THE PUBLICATIONS

ANNEX 2: MINUTES OF THE FOLLOW-UP COMMITTEE MEETINGS

The annexes are available on our website:

http://www.belspo.be/belspo/SSD/science/pr_terrestrial_fr.stm#BIOSERF