Pre-harvest forestry and botanical inventories in ENRA logging concession in the Ituri Forest Landscape, northeastern Congo Basin Rainforest (Democratic Republic of Congo)

A Report Submitted to CARPE by the Center for Tropical Forest Science and the Wildlife Conservation Society

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Executive Summary

This report concerns a study that assessed timber abundance and distribution in natural unlogged forests, as well as floristic composition and tree diversity in a 500-ha plot in ENRA concession in northeastern Congo basin, Democratic Republic of Congo. The four main objectives pursued in the study were 1) to provide training to ENRA's forestry inventory team, 2) to estimate the standing volume of major timber tree species, 3) to determine forest structure and composition, and tree specie diversity, and 4) to evaluate the impacts of timber harvesting on forest structure, tree diversity and timber regeneration with the goal of identifying species for which current logging practices are not compatible with sustainable forest management. For the first phase of the study, only objectives 1-3 were accomplished. To achieve these objectives, we completed forestry and botanical surveys in a 500-ha (2000m x 2500m) plot in undisturbed forest in ENRA concession. All trees ≥ 30 cm dbh belonging to class I timber species and all other timber trees above the minimum cutting diameter were counted, measured for diameter, mapped, tagged and identifies to species in the entire plot area. Botanical surveys were completed in 50 0.1-ha (20m x 50m) subplots evenly dispersed across the 500-ha plot. All trees ≥ 10 cm dbh were measured for diameter and identified to species. Forestry inventories were done on 50m x 2000m transects. Each transect was divided into 40 50m x 50m quadrats. Forest types and soil texture were determined for each quadrat. Monodominant and mixed forests were the dominant forest types in the plot, representing ~ 79% of total plot area. Low canopy forest, resulting from past natural or anthropogenic disturbance events, represented about 13% of the plot area, while the rest of the plot vegetation was made of farmlands. Timber volume was estimated using allometric equations based on tree diameter alone. Fifteen timber species were recorded in the plot, among which *Gilbertiodendron dewevrei* and *Julbernardia seretii* were extremely abundant. Major timber species currently harvested by ENRA showed relatively low abundances. Overall standing volume was 19.5 m^3 per ha, but the top species currently harvested represented only for ~ 3.5 m^3 per ha. Botanical surveys revealed that forests in the plot are very diverse. A total of 170 species was recorded for trees ≥ 10 cm dbh. Monodominant stands were less diverse than mixed forest stands even after accounting for tree density.

Results from timber inventories showed that timber abundance varies widely within the ENRA concession. Inventories conducted in the eastern part of the concession yielded much higher abundance of timber trees than that observed in this study. This can be partly explained by the prevalence of monodominant forest stands in the western part of the concession. Monodominant forests have lower density of major timber trees as compared to mixed or low canopy stands. This latter forest type exhibited the highest density of light demanding timber species, suggesting that this forest type probably results from past large-scale disturbance events such as wild fire or shifting cultivation.

The low abundance of major timber species calls for an urgent diversification of timber harvesting to include less-known but abundant timber species such as *G. dewevrei* and *J. seretii* in order to promote sustainable management of forest for timber production in the Ituri Forest region.

Acknowledgements

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Introduction

The Democratic Republic of Congo (DRC) is one of the most important countries in Africa for biodiversity conservation. In terms of species diversity, DRC has the highest number of mammal and bird species in Africa (415 and 1,094 respectively), and plant diversity is also very high (>11,000 species). The country harbors a number of spectacular endemic species and subspecies like the okapi (*Okapia johnstoni*), northern white rhinoceros (*Ceratotherium simum*), Grauer's gorilla (*Gorilla gorilla graueri*), bonobo (*Pan paniscus*), and the Congo peacock (*Afropavo congensis*). In addition to their role as a reservoir of biodiversity, the forests of DRC support the lives of millions of people who use them for the construction of shelter, harvesting food and commercial products, and as a source of spirituality.

Given that DRC possesses at least 50% of Africa's tropical moist forest, it has an enormous potential for timber production. Over the next decade, the government intends to increase timber production from its current level of < 500,000 m^3 / yr to around 10,000,000 m^3 /yr (Wolfire et al. 1998), which it considers a sustainable harvest level. In 2002, the DRC government published a new Forest Code that lays the legal framework for sustainable forest management. However, a marked lack of expertise may make it difficult for many logging operators to apply sustainable timber management techniques provided by the new forest code and its application measures.

Commercial logging involves activities that put the forest at high risk. In addition to the direct negative impacts of timber harvesting on forest structure and tree diversity, road construction provides farmers and hunters with easy access into otherwise inaccessible forest interior areas (Laurance 2001; Wilkie et al. 2000), leading to large-scale forest degradation and loss of biodiversity. In order to reach CARPE's Strategic Objective of "reducing the rate of forest degradation and loss of biodiversity in Central Africa", it is crucial to clearly understand the effects of timber harvesting and associated human activities on forest structure, species composition and diversity, and forest regeneration.

Under a SI/MBG subcontract, WCS initiated forest inventories in the northeastern region of DRC (Ituri Forest landscape) to assess timber resources in one logging concession, Enzyme Refiners Association (ENRA). The eastern part of the Congo moist forest, bordering the Albertine Rift, is one of the richest areas in Africa in terms of biodiversity and endemism (Pomeroy 1991) and the forests of the region are rich in many of the most valuable tropical timber species such as African mahoganies (Makana 2004). This region is thus of special importance for the conservation of biodiversity, as well as for forest management for timber production. The forests of eastern Congo are a major source of timber for neighboring countries (Uganda, Rwanda and Kenya), a fact that is fuelling illegal logging and timber trade in the region (WCS 2005; Hart & Ducarme 2005). Therefore, it is critical that CARPE partners begin to work towards sound forest management in the region. This project represents the first effort to truly begin to work towards sustainable forestry in eastern DRC.

ENRA is the only legitimate timber company presently operating in eastern DRC and the company has shown a good faith in working towards sound forestry for many years, in spite of difficult conditions. ENRA's concession (52.000 ha) is located south of the Ituri Landscape. This project in the Ituri Landscape revolved around improving forest inventories and inventory techniques. An emphasis was placed on training technicians capable of undertaking forestry inventories that will allow for both an assessment of the standing timber volume as well as assessing the impacts of logging on forest structure, floristic diversity and on forest productivity. Further, it is expected that the project will substantially contribute to build the capacity of local organizations (ENRA) that will continue to monitor forest resources in the future. The skills gained by technicians during these forest inventories will permit WCS to begin work on assessing forests that may be appropriate – from a timber point of view – as future logging concessions in this part of DRC. This information is essential and must feed into the zoning work to be undertaken by WCS in collaboration with the USDA Forest Service in the Ituri Forest Landscape.

1. Objectives

The overall goal of this project was to improve forest inventories and inventory techniques in eastern DRC and beyond by training technicians capable of undertaking timber resources assessment in managed or unmanaged forests and evaluation of the effects of timber harvesting on forest conservation. An accurate assessment of timber resources is the first step towards sustainable management of forest for timber production as it allows for effective planning of harvesting schedule and the development of appropriate silvicultural prescriptions for the species involved in timber harvesting. In order to accomplish the project's goal, four specific objectives were defined as follows:

- To provide training in forest inventory techniques to ENRA's field staff in order to improve the evaluation of timber resources in the concession and beyond;
- To assess the abundance (standing volume) and the regeneration of current and potential timber species in the concession's forests;
- To determine forest structure and tree species diversity in the concession;
- To evaluate the effects of timber harvesting on forest structure, tree diversity and timber regeneration. This would also permit the identification of species for which current logging practices are not sustainable.

During this initial stage of the study, only the first three objectives will be accomplished. The evaluation of the impacts of logging on forest structure, tree diversity and timber regeneration will be carried out during later studies after the area surveyed has been logged over.

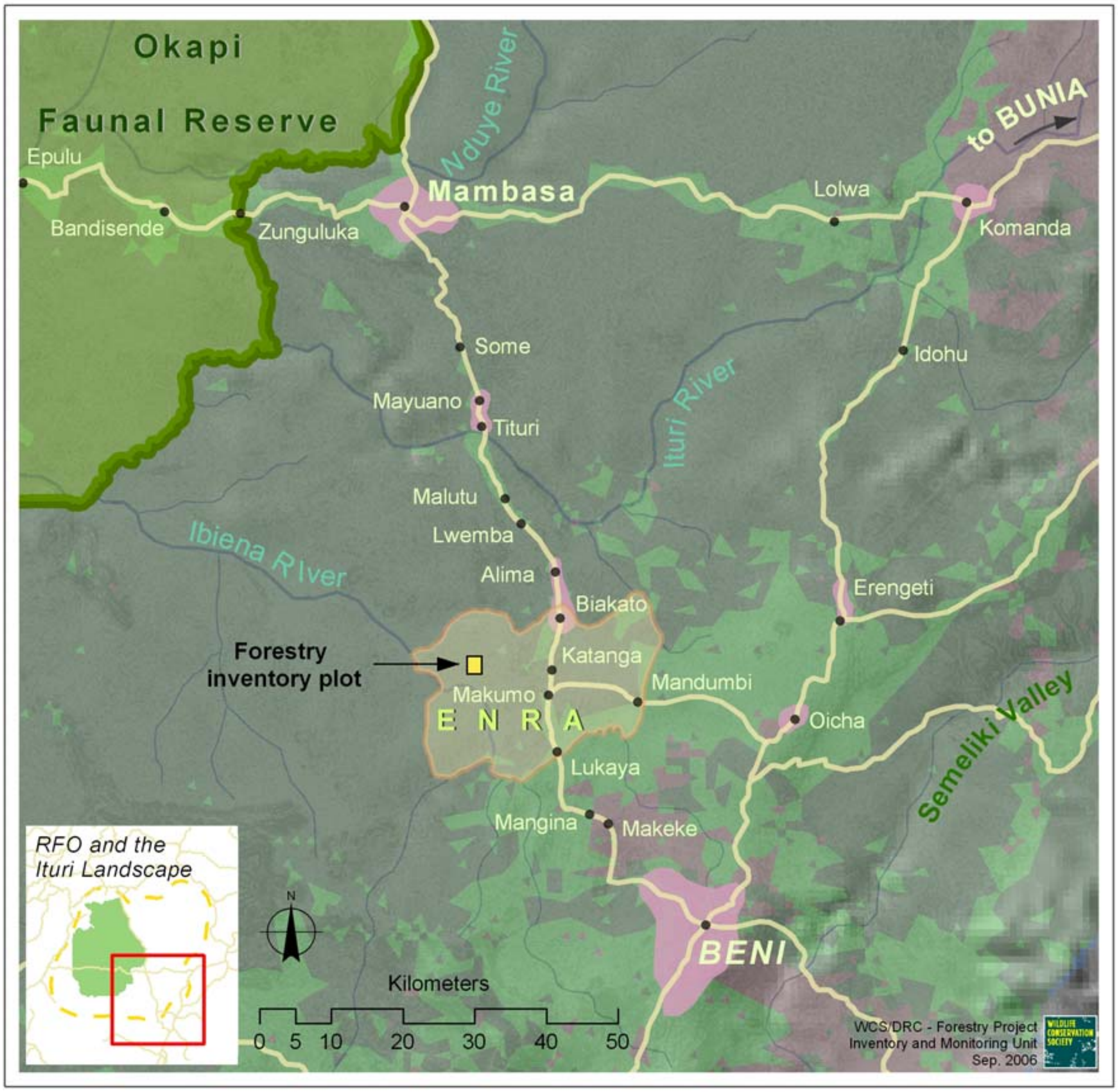

Figure 1. Location of ENRA logging concession in eastern Ituri Forest, Democratic Republic of Congo. Inventory plot is indicated with the yellow rectangle toward the northwest corner of the concession.

2. Study Site

2. 1. Geographic location and physical characteristics

The Ituri Forest is located in the northeastern part of the Congo basin rainforest block (DRC) and it lays between the equator and 3° N latitude, and between ~ 27° E and 30° E longitude. Elevation in the Ituri Forest ranges from ~ 600m asl in the west to over 1000m in the east where the lowland forest borders the savanna and transition montane forest. The topography of the Ituri region is gentle, with occasional rolling hills containing exposed patches of shallow rocky soils (Hart et al. 1996). The soils in the region are derived from granitic pre-Cambrien shield rock (Laveau 1982) and fall under the order oxisols that dominates most of the Congo basin forest block (Brady 1990). They are generally very deep, uniform in texture, and lacking distinct horizons from ~ 3 cm to 150 cm depth. Their texture ranges from loamy sand to sandy clay. The soils are acidic and low in nutrients, particularly available phosphorus and nitrogen (Hart 1985).

The study was conducted in ENRA logging concession located ~ 25 km northwest of the town of Beni. The study site was a 500-ha rectangular (2000m x 2500m) plot located in the northwestern corner of the concession (0°48" N latitude and 29°09" E longitude, Fig. 1). The elevation in the area is ~ 900m asl. Mean annual rainfall is 1673 mm in Beni (location of the nearest weather station), with a dry season (monthly rainfall below 100 mm) occurring from December to February. May and October are the wettest months of the year, with average precipitation of 187 mm and 206 mm, respectively (Fig. 2A). In the last 28 years, minimum rainfall was 934 mm (1979) and maximum rainfall was 2096 mm in 1985 (Fig. 2B). Annual average daily temperature is 23.5° C and varies little from year to year (Makana & Thomas 2006).

2. 2. Vegetation and fauna

The vegetation in the region is a mixture of evergreen forest, including extensive areas of "mbau forest" dominated by *Gilbertiodendron dewevrei* (De Wild.) Léonard, and "mixed forests" in which no species is predominant, but other Caesalpinoid legumes, such as *Julbernardia seretii* (De Wild.) Troupin and *Cynometra alexandri* C. H. Wright, are abundant (Hart et al. 1989; Richards, 1996; Makana et al. 1998, 2004a). To the north and east of the main forest block, and on drier slopes of hills, evergreen forests grade into a semi-deciduous forest whose canopy contains higher representation of light-demanding tree species that include *Entandrophragma* spp., *Khaya anthotheca, Albizia* spp., etc. At the eastern and northern limits of the landscape, the closed canopy forest gives way to a mosaic that includes evergreen galleries and patches of wooded savanna ecotone.

Swamp forests occur locally along streams and rivers and in areas of impeded drainage at the headwater of smaller streams. Characteristic canopy species include *Hallea stipulosa* with *Raphia* palms occasionally dominating and lianas becoming more abundant. At a smaller spatial scale, specialized and highly localized xerophyllous vegetation adapted to shallow and dry rocky soils occurs in isolated patches on the bare granitic inselbergs. This vegetation type comprises a significant number of plant species with very narrow ranges, making it an ecosystem of global conservation importance (Ewango 2006).

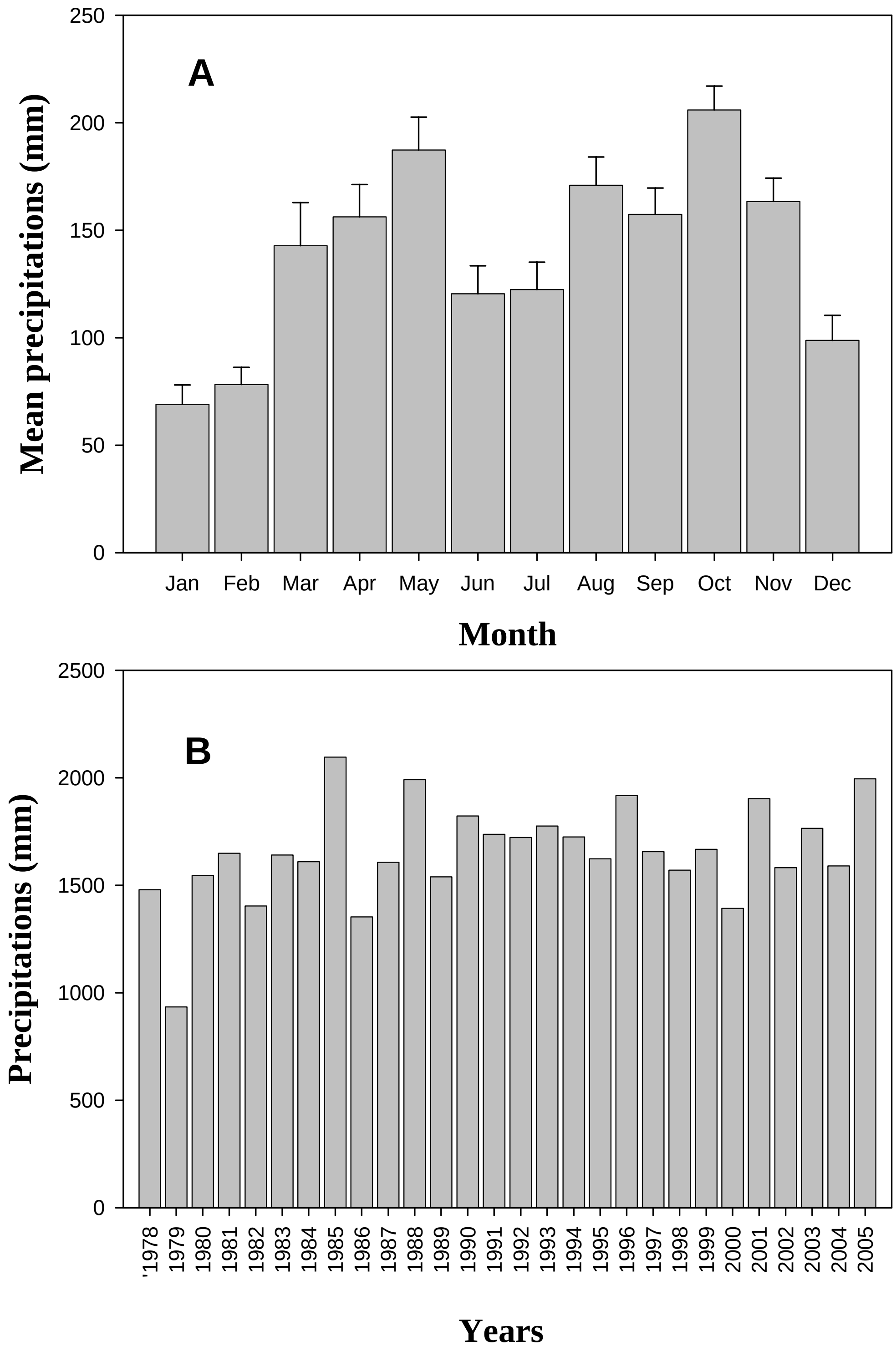

Figure 2. Climatic data for eastern Ituri Forest. Data came from a weather station in the town of Beni, 25 km southeast of ENRA concession. Mean annual rainfall for the 28 years is 1,673 mm.

Secondary forests of varying age cover significant portions of the Ituri Forest. These originate from both natural and anthropogenic causes. Significant areas of secondary vegetation within the Ituri Forest are the direct results of shifting agriculture and to a limited but increasing extent artisanal logging. These regenerating forests and agricultural clearings are primarily restricted to a broken strip (up to 6 km in width) along the two main roads that cross the Ituri Forest (Wilkie & Finn 1988; Wilkie et al. 1998). In the southeastern part of the Ituri Forest, forest degradation has accelerated over the past two decades leading to the conversion of large areas of closed forest into a mosaic of logged forest and farmed bushes. Secondary forests in this region are generally young, less than 10 years old, and are dominated by the early pioneer tree *Musanga cecropioides* R. Br. (Makana 2004).

The Ituri Forest is floristically very diverse. Botanical inventories conducted in the Epulu areas (central sector of the Ituri Forest) from 1994 to present yielded ~ 700 woody plant species in four 10-ha plots, including 460 tree species above 1 cm dbh and 243 liana species above 2 cm dbh (Makana et al. 2004a). Based on these data and additional collections or surveys in other areas (Ewango 2006), it has been estimated that at least 1500 plant species can be found in the Ituri Forest Landscape.

Biogeographical evidence suggests that the Ituri forest was an important Pleistocene forest refuge and a center of dispersal for many current east and central African vertebrate taxa (Thomas 1991; Hart et al. 1996). Presently, the Ituri forest is thought to be Africa's most species-rich area in mammalian fauna (Grubb 1982). In addition to endemic species of mammals such as the okapi (a forest giraffe, *Okapia johnstoni*), the aquatic genet (*Osbornictis piscivora*), and the owl-faced monkey (*Cercopithecus hamlyni*), the forest is home to nine antelope species – including bongo (*Tragelaphus eryceros*), sitatunga (*Tragelaphus spekei*), Bates pygmy antelope (*Neotragus batesi*), and six species of duiker (*Cephalophus* spp.) – forest elephant (*Loxodonta cyclotis*), forest buffalo (*Syncerus caffer nanus*), water chevrotain (*Hyemoschus aquaticus*), African golden cat (*Profelis aurata*), leopard (*Panthera pardus*), giant ground pangolin (*Manis gigantea*), two species of tree pangolin (*Manis* spp.), giant forest genet (*Genetta victoriae*), bush pig (*Potamochoerus porcus*), giant forest hog (*Hylochoerus meinertzhageni*), tree hyrax (*Dendrohyrax arboreus*), at least four tree squirrels, and two species of flying squirrels. There are many primate species in the Ituri forest, 13 of which are anthropoid primates, including chimpanzee (*Pan troglodytes*), baboons (*Papio anubis*), six species of *Cercopithecus* monkeys (*C. ascanius, C. hamlyni, C. l'hoesti, C. mitis, C. neglectus,* and *C. pogonius*), two species of mangabeys (*Cercocebus* spp.), and three species of *Colobus* monkeys. At least 333 bird species are known to occur within the central sector of the Ituri Forest (Hart 1986; Thomas 1991; Plumptre 1996; Makana et al. 2004b).

Most of the species enumerated above were present in ENRA concession prior to commencement of timber harvesting operations and subsequent invasion of logged forests by squatters. Informal interviews with Mbuti pygmies dwelling in the concession indicated that most large mammals have gone locally extinct, particularly those who require large tracks of natural forest such as forest elephant, okapi, leopard, forest buffalo, Sitatunga, Bongo, etc. The disappearance of those species in the concession can be largely attributed to the conversion of mature forest areas into farmlands.

3. Logging in northeastern Congo Basin

Logging activities in the Ituri region are concentrated in the relatively drier semi-deciduous forests near the transition between closed canopy forest and eastern savanna woodlands, likely due to the proximity of export routes to the Indian Ocean through Uganda and Rwanda. The forests at the savanna margin are richer in high-value timber trees such *Khaya anthotheca*, *Entandrophragma* spp and *Milicia excelsa* than moist evergreen forests found in central and western Ituri (Makana 2000). Both artisanal (small-scale) and industrial operators harvest timber in eastern DRC. Small-scale loggers produce the majority of the wood for the domestic market. Their main products are boards, planks, beams and rafters, used for construction or furniture. They also export wood and wood-based products to neighboring countries, particularly Kenya, Rwanda and Uganda (WCS 2005).

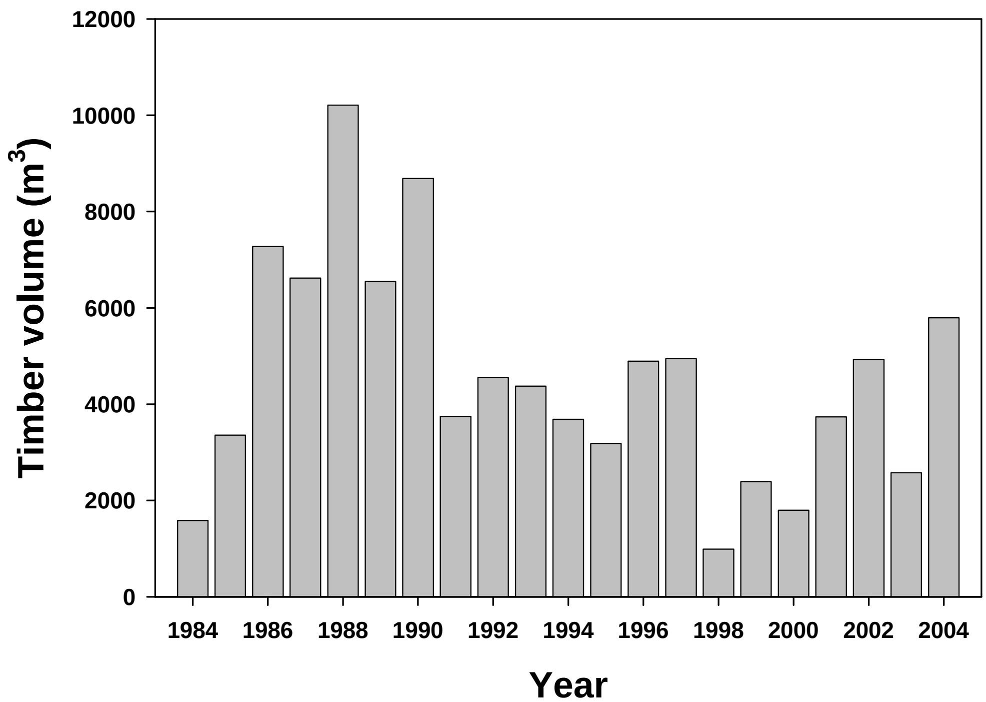

Figure 3. Timber volume harvested over the last 21 years in ENRA concession. ENRA is a relatively small company and its logging activities are very selective likely due to low demand on the local market and high costs of transportation.

Mechanized timber harvesting in the region dates back to the early 1980s, when a 52,000-ha logging concession was awarded to ENRA in 1983. Actual logging operations commenced in 1984 and have since continued without major interruption until now (Hart & Ducarme 2005). ENRA is a relatively small company harvesting on average less than 10,000 m^3 of logs a year (Fig. 3). The most commonly extracted species include Iroko (*M. excelsa),* African mahoganies *(K. anthotheca* (Fig. 4)*, E. cylindricum, E. candollei, E. angolensis, and E. utile),* Limbali *(G. dewevrei),* Mukulungu *(Autranella congolana),* Olovongo *(Zanthoxylum gillettii),* and Cordia (*Cordia abyssinica,* ENRA 2005).

Fig. 4. *Khaya anthotheca* (true African mahogany) is one of the major timber trees harvested in eastern Ituri Forest. This large timber tree was left in an area cleared for agricultural purposes.

Timber extraction uses heavy machinery for road construction, skidding and transporting logs from the forest to the mills (Fig. 5). All the logs are processed locally and the wood is turned into high quality parquet flooring, crafted doors and windows, and carved furniture. However, most of the final products are only destined to a small wealthy elite or exported abroad.

Fig. 5. Loading bay and logs being loaded on a truck in ENRA concession. Log landings, along with logging roads, are the most severely disturbed areas by logging operations.

Currently, logging is very selective with only large trees of highly valuable species being extracted (Fig. 6). *M. excelsa*, which is the most valuable timber tree in the region, and five species of African mahogany account for over 85% of the total volume harvested in recent years. This “high-grading” of the forest requires large areas of forest to obtain sufficient supply of logs. High population density in the neighboring eastern savanna regions leads to continual immigration of landless farmers, who take advantage of the roads constructed for logging operations, into the lowland forest frontier where land is plentiful and cheap (Witte 1992). The agricultural frontiers created by the invasion of logged forests pose the most serious threats to forest management and biodiversity conservation in the Ituri Forest.

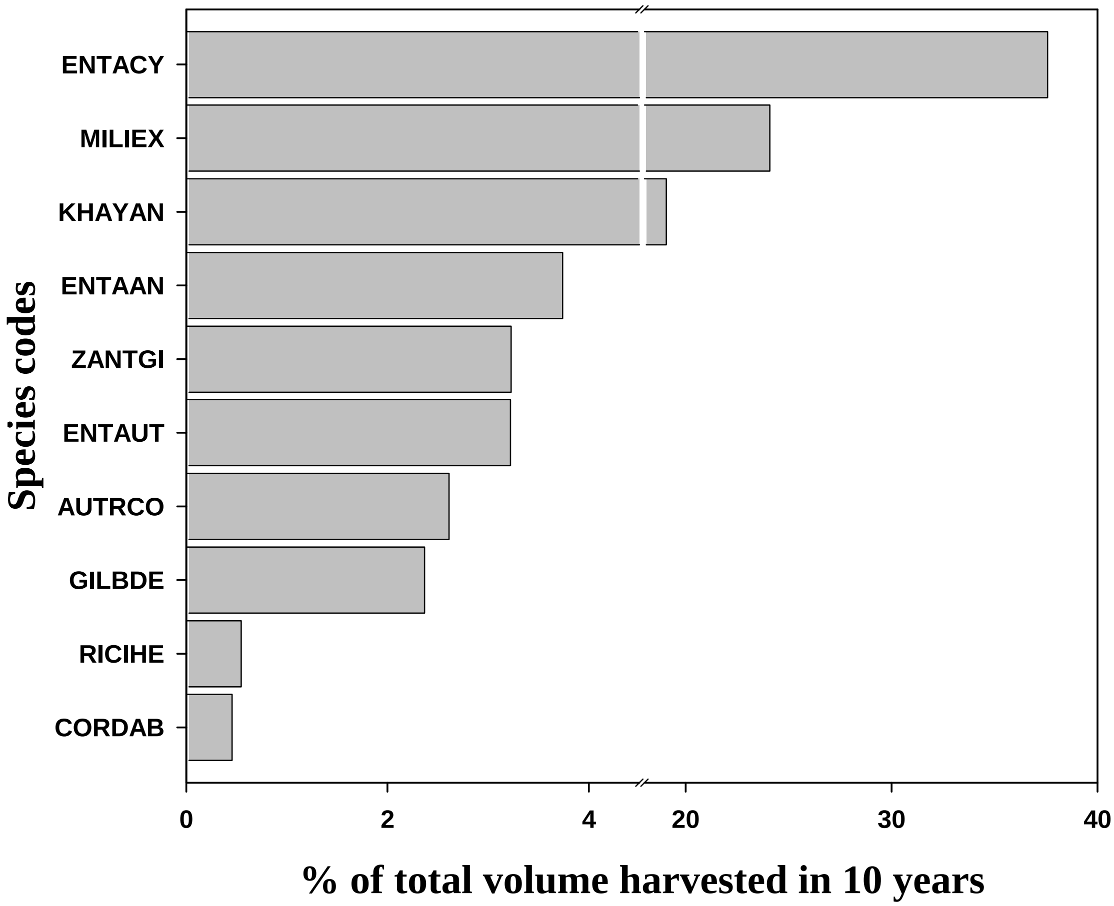

Figure 6. Log volume contributed by each of the top ten species during the last 10 years in ENRA concession. These ten species accounted for 97% of total volume harvested during this period. Species codes as follows: ENTACY = *Entandrophragma cylindricum*, MILIEX = *Milicia excelsa*, KHAYAN = *Khaya anthotheca*, ENTAAN = *E. angolense*, ZANTGI = *Zanthoxylum gillettii*, ENTAUT = *E. utile*, AUTRCO = *Autranella congolana*, GILBDE = *Gilbertiodendron dewevrei*, RICIHE = *Ricinodendron heudelotii*, CORDAB = *Cordia abyssinica*.

4. Survey methods

4. 1. Vegetation sampling

ENRA concession is heavily invaded by farmers migrating from the densely populated Kivu region. It has been estimated that at least 50% of the forest area in the concession is under cultivation (R. Ducarme, pers. comm.). The goal of the survey team was to locate an area that was largely free of human disturbance. A vegetation map produced from 2003 satellite images was used to locate areas that seemed undisturbed. A survey team was then sent to the field to ground truth the vegetation map information and to delineate an area to be used for vegetation sampling, forestry and botanical surveys.

A 10-km long base transect was laid out in an east-west direction and three 2,000 km long perpendicular transects, 1 km apart, were cut in the forest area that had fewer anthropogenic disturbance events (agricultural fields or settlements). A 500-ha rectangular (2000 m x 2500 m) plot was then delineated in a lightly disturbed forest area. To allow a detailed assessment of forest type distribution and survey of timber resources, fifty transects, 50 m apart and 2000 m long, were cut throughout the plot.

Along each transect, dominant vegetation type and soil texture were determined every 50 m. Four main vegetation types were distinguished:

Monodominant forest: dominated by *Gilbertiodendron dewevrei* that accounted for more than 50% of large trees. The understory is open with little herbaceous vegetation on the ground floor and few lianas. A thick layer of non-decomposed leaf litter covers the forest floor (Boubli et al. 2004; Richard 1996).

Mixed forest: no canopy species is exclusively dominant but *Julbernardia seretii* is very abundant. The understory is denser than that of monodominant and lianas are also more abundant. The leaf litter layer is generally thin.

Low canopy forest: characterized by dense tangles of thorny lianas and smaller trees. Large trees are rare or absent. This vegetation type likely resulted from past anthropogenic or natural disturbance events such as large-scale blowdowns, forest fire, agricultural clearing, etc. A large-scale forest fire event occurred in the area in the early 1980s during the 1983-1984 El Niño southern oscillation drought.

Farming areas: active agricultural fields were the dominant vegetation in this category. There were also farm bushes growing after abandonment of agricultural fields. Farm bushes were dominated by either dense thicket of herbaceous plants and treelets or by the early pioneer trees *Musanga cecropioides* and *Trema guineensis* that colonize abandoned farmlands and constitute the first stage of forest recolonization.

4. 2. Timber inventories

Timber inventories were carried out in the whole 500-ha plot along each transect. Transects were divided in 50 m x 50 m (0.25 ha) subplots, each extending 25 m in both sides of each transect. The first and last transects were therefore placed 25 m away from the plot northern and southern borders. A total of 2000 subplots were surveyed and systematically searched for major timber trees currently harvested by ENRA. For class I timber species (*M. excelsa, Entandrophragma* spp. and *K. anthotheca*) and *Zanthoxylum gillettii*, all trees ≥ 30 cm were mapped, measured for diameter at breast height, tagged and identified to species. Individuals belonging to secondary timber species were only measured if they reached the minimum harvestable diameter. For two very abundant but rarely exploited species (*G. dewevrei* and *J. seretii*), only large trunks of exceptionally good form were counted and measured. The form of the trunk was evaluated as “good”, “crooked” or “hollow”. Indications on the phenological status of the trees were also noted. Tree indicators working for the logging company and Mbuti (pygmy) technicians with a good knowledge of local trees were used to identify timber trees.

4. 3. Botanical surveys

Botanical surveys were conducted in nested plots systematically placed along transects. One plot was located on each transect such that half of the plots were in monodominant forest and the other half in mixed forest. In addition, plots were placed in a way to separate those situated on adjacent transects as far away from each other as possible. All trees ≥ 10 cm dbh were counted, measured and identified in fifty 50 m x 20 m (0.1 ha) plots. In most cases the diameter of each tree was measured at breast height, 1.3 m above ground. However, stems with irregular trunks were measured at the nearest lower point where the trunk was cylindrical (CTFT 1989; Makana 1999).Trees with buttresses rising near or beyond 1.3 m were measured at least 0.5 m above buttresses. Diameter was measured by diameter tapes and recorded to the nearest 0.1 cm. Trees with multiple stems were counted as single individuals, but the diameter of each stem was measured and recorded separately.

The census team included an experienced botanist whose primary objective was tree identification. For the most common tree species, identification was made directly in the field. When definitive field identification was not possible, pygmy technicians collected leaf samples from large trees and lianas. Plant samples were pressed and dried, and then compared to voucher specimens at CEFRECOF herbarium in Epulu.

In addition to botanical data, environmental information was collected at the center of each plot, including soil texture, slope and canopy cover. Soil texture was determined according to the finger assessment of the Ontario Institute of Pedology (1985). For the purpose of this study, soil texture was classified in five major categories: clay, loamy, sandy, rocky and inundated soils. The only topographic feature evaluated here was the slope of the terrain, which was separated in three classes: 0 – flat terrain, 1 – slope of less than 45°, and 2 – ≥ 45° slope. Canopy cover was visually assessed at ~ 20 m above ground and grouped in four categories: 0 – less than 25% canopy cover; 1 – 25-50%, 2 – 50-75% , and 3 – > 75% canopy cover.

5. Data analysis

Forestry inventories: To assess the total contribution of each forest type to the total sample, each 50 m x 50 m quadrat was classified according to its dominant forest type (monodominant, mixed, low canopy forest or farming area). Each quadrat was given spatial coordinates (x, y) to produce a vegetation map for the entire surveyed area.

For each timber tree species, the total number of individuals, basal area and standing volume were tallied. Standing volume was estimated based on equations developed from ENRA's timber harvesting data (trunk diameter and bole length). First, log volume was calculated based on diameter at the middle of the bole and the length of the harvested trunk or log. Using the calculated volume and initial diameter at breast height, we fitted a regression equation to estimate standing volume from diameter at breast height alone. The relationship between tree diameter and standing volume was linear and explained 71.5% of the variation in standing volume. Although there were significant differences among species in this relationship (ANCOVA F-tests for differences in intercepts and slopes with $P < 0.05$), these differences accounted only for 3.5% of the variation in standing volume. Therefore, we used a single equation to calculate standing volume for all species: $V = -12.61 + 18.35D$, where V is the standing volume and D is diameter at breast height.

Morisita's index of dispersion was used to evaluate the spatial patterns of timber trees in the plot. This index is based on counts within quadrats. It is given by

$$I_d = q(\sum n(n-1)/(N(N-1)),$$

(Brower and Zar 1984) where q is the number of quadrats, n the number of trees in each quadrat and N is the total number of trees in all quadrats. An I_d value of 1 indicates random distribution, with values less than 1 indicating regular spacing and values greater than 1 suggesting clumping. Significance of departure from randomness was evaluated by computing the following statistic:

$$I_d(N-1)+q-N$$

The test statistic is then compared to a chi-square with $q-1$ degrees of freedom.

Logistic regression was used to compare the abundance of major timber species between forest types. The number of trees per quadrat was transformed into three categories: 0 for no tree recorded, 1 for 1-2 trees, and 2 for ≥ 2 trees. Association between timber tree species and forest types was evaluated for all species pulled and for individual species or group of species (African mahoganies) that had at least 25 individuals in the plot.

Data for botanical surveys were analyzed separately from forestry data. For each plot, the total number of individuals, the number of species, the level of dominance and Shannon-Wiener diversity index were calculated for all trees ≥ 10 cm dbh. ANOVA was used to assess the effects of forest type on tree density, basal area and tree diversity. Linear regression was utilized to assessed the relationships between tree density and species richness, and between dominance by a single species and tree diversity.

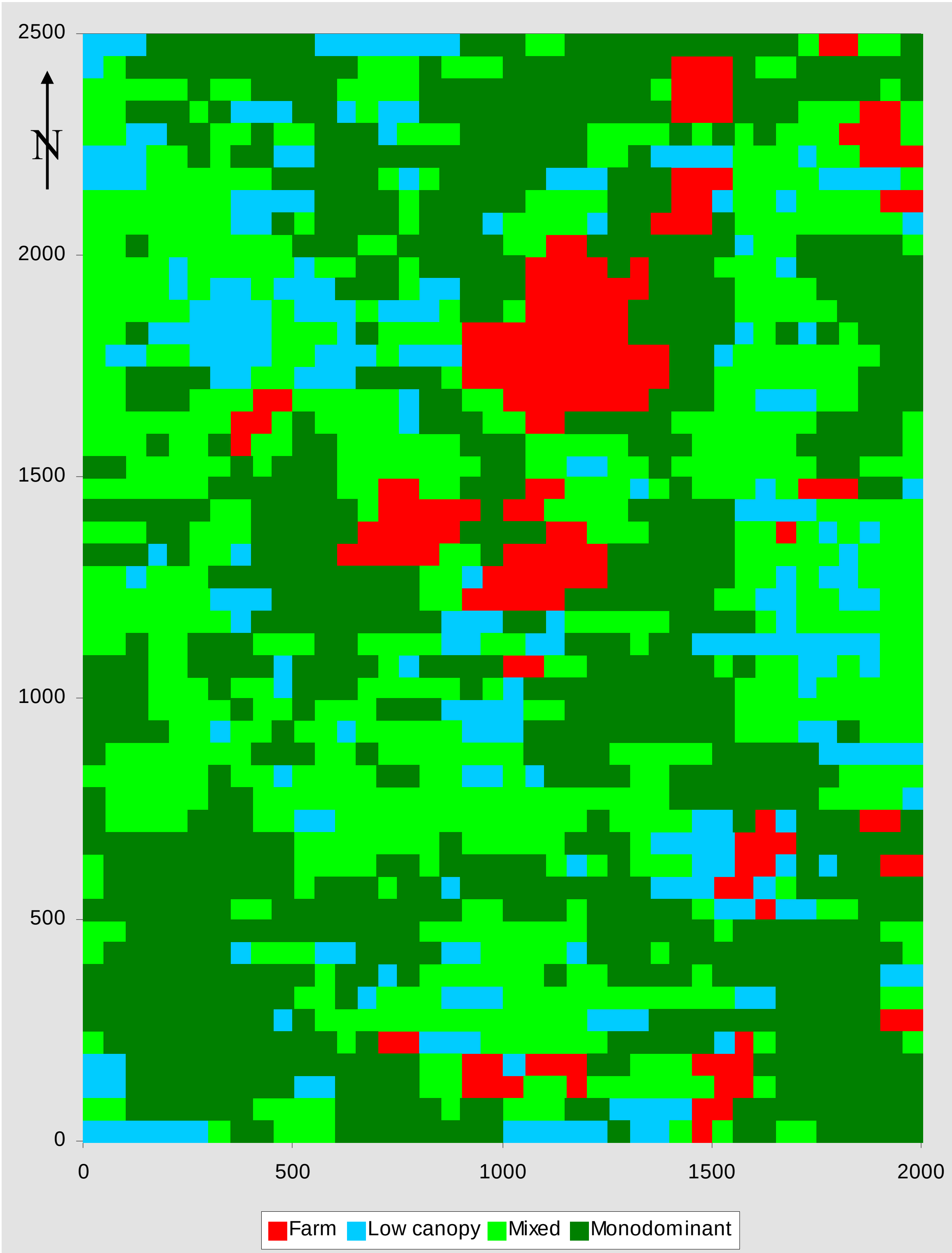

Figure 7. Distribution of forest types in a 500-ha plot in ENRA concession, eastern Ituri Forest in northeastern Congo Basin. Mapping was based on 50 m x 50 m quadrats. Each quadrat was attributed to one forest type

6. Results

6. 1. Plot description

Topography and soils: the area surveyed for this study was relatively level. More than half of plot area was under flat terrains, and only less than five percent of the plot area had a 50% slope or more. Sandy soils were the dominant soil type and they accounted for about three-quarters of plot area. Loamy soils were also well represented (~22%), followed by clay soils (~4%). Rocky and inundated soils accounted for less than 1% of the total surveyed area (Table 1).

Table 1. Soil types in the 500-ha plot. Soil type was determined at the center of each 50 m x 50 m quadrat and area covered by each soil type was obtained by multiplying quadrat area (0.25 ha) by the number of quadrat occupied by each soil type.

Soil type	Area (ha)	% of total area
Clay	19.25	3.85
Loamy	111.25	22.25
Sandy	365.25	73.05
Rocky	2.75	0.55
Swampy	1.50	0.30
Total	**500**	**100**

Vegetation types: the four main vegetation types distinguished in the 500-ha plot were not equally represented in the plot (Fig. 7). Monodominant and mixed forests were the dominant vegetation types, covering 395.25 ha or ~ 80% of total area (Table 2). Monodominant forest was dominated by *Gilbertiodendron dewevrei*, whereas *Julbernardia seretii* was the most abundant canopy tree in mixed forests. Low canopy was the third most important vegetation type and farming areas covered the lowest portion of the surveyed forest (Fig. 7). Farming areas were represented by active farms, farm bushes and young secondary forests dominated by *Musanga cecropioides*.

Table 2. Vegetation types in a 500-ha forest plot in ENRA concession. Forest types were determined based on species composition and vegetation structure (canopy height, liana abundance, etc.).

Forest type	Area (ha)	% of total area
Monodominant	215.25	43.1
Mixed	180.00	36.0
Low canopy	62.50	12.5
Farming area	42.25	8.4
Total	**500**	**100**

6. 2. Forestry inventory

Abundance and standing volume of timber trees: Fifteen timber species were recorded during forestry inventories in the 500-ha plot (Table 3). Of the 15 species, two species Limbali (*Gilbertiodendron dewevrei*) and Mubangu (*Julbernardia seretii*) were extremely abundant, accounting for ~ 78% of tree density and 80% of standing volume. Limbali was mostly restricted to monodominant forest stands, whereas Alumbi was present in all forest types. Currently, ENRA only rarely harvests the two species. Although Limbali is class 2 species, it is not well known neither on the local nor on the international markets. Mubangu is a class 3 species and it has been harvested by ENRA only in the last two years to make parquet floors. Both species have some drying problems, likely due to their high wood densities.

Table 3. Abundance of common timber species in a 500-ha forestry plot in ENRA concession

Trade name	**Scientific name**	**Species codes**	**Timber class**	**Density (trees/ha)**	**Standing volume (m^3 ha^{-1})**
Sapeli	*Entandrophragma cylindricum*	ENTACY	1	0.184	0.88
Iroko	*Milicia excelsa*	MILIEX	1	0.090	0.32
African mahogany	*Khaya anthotheca*	KHAYAN	1	0.032	0.19
Kosipo	*Entandrophragma candollei*	ENTACA	1	0.028	0.20
Sipo	*Entandrophragma utile*	ENTAUT	1	0.012	0.09
Tiama	*Entandrophragma angolense*	ENTAAN	1	0.008	0.07
Ebony	*Diospyros crassiflora*	DIOSCR	1	0.006	0.01
Guarea	*Guarea cedrata*	GUARCE	1	0.024	0.01
Limbali	*Gilbertiodendron dewevrei*	GILBDE	2	2.340	5.51
Olovongo	*Zanthoxylum gillettii*	ZANTGI	2	0.832	1.72
Lati	*Amphimas pterocarpoides*	AMPHPT	2	0.004	0.02
Mukulungu	*Autranella congolensis*	AUTRCO	2	0.004	0.02
Longhi	*Gambeya lacourtiana*	GAMBLA	2	0.002	0.00
Mubangu	*Julbernardia seretii*	JULBSE	3	2.220	9.84
Sougue	*Parinaria excelsa*	PARIEX	3	0.410	0.27
	Total			**6.196**	**19.15**

The five species of African mahogany (*Entandrophragma* spp. and *Khaya anthotheca*), Iroko (*Milicia excelsa*), Olovongo (*Zanthoxylum gillettii*) and Mukulungu (*Autranella congolana*) are the most commonly exploited species in ENRA concession. All the above species belong to the top two classes (class 1 and class 2) of to the Congolese timber quality classification. These eight species make up over 90% of the timber harvested by ENRA, but they only represented ~ 20% of the total standing volume in the 500-ha plot surveyed for this study (Table 3). *Zanthoxylum gillettii* (1.72 m^3 ha^{-1}), *Entandrophragma cylindricum* (0.88 m^3 ha^{-1}) and *Milicia excelsa* (0.32 m^3 ha^{-1}) were the most common species among the major timber species harvested by ENRA during the last ten years (Fig. 8).

Sougue (*Parinari excelsa*), a class 3 species, was also well represented in the plot and it accounted for 1.72% of total standing volume. Four other species, Ebony (*Diospyros crassiflora*), Guarea (*Guarea cedrata*), Lati (*Amphimas pterocarpoides*) and Longhi (*Gambeya lacourtiana*), were represented only by one or two individuals in the plot.

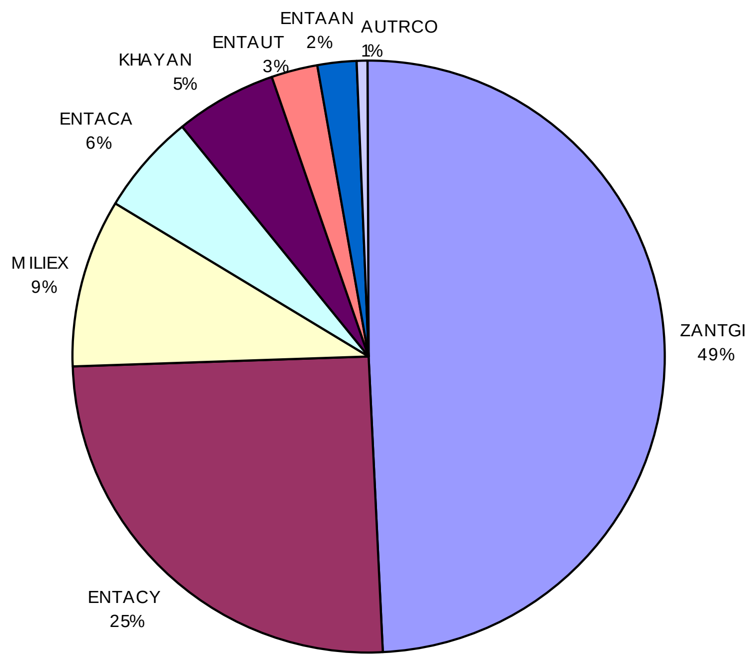

Figure 8. Standing volume contributed by each of the most commonly harvested timber species in a 500-ha plot in ENRA concession. Species codes as in Table 3.

<u>Diameter class distribution of major timber species</u>: diameter distribution of individual species or group of species can provide a good idea about their regeneration status. Two types of diameter distribution were observed among the timber species measured in the plot. Two species, *Gilbertiodendron dewevrei* and *Julbernardia seretii*, exhibited an inverse J-shaped distribution for 10 cm diameter class intervals with many more trees in the smaller diameter classes than in the larger ones (Fig. 9A&B). These species were the most abundant ones and they generally show abundant regeneration in undisturbed forest.

African mahoganies and other timber species had a humped diameter class distribution with medium diameter classes having more trees than either smaller or larger classes. Typical examples of this type were *Entandrophragma cylindricum* (Fig. 9C) and *Parinaria excelsa*. These two species were relatively common and they were also well distributed across the plot area. African mahoganies as a group also exhibited a humped diameter class distribution (Fig. 9D). A third group of species showed irregular diameter class distribution (Fig. 9E&F). The species in this group were light demanding species that regenerate in large canopy gaps such as *Zanthoxylum gillettii* and *Milicia excelsa*.

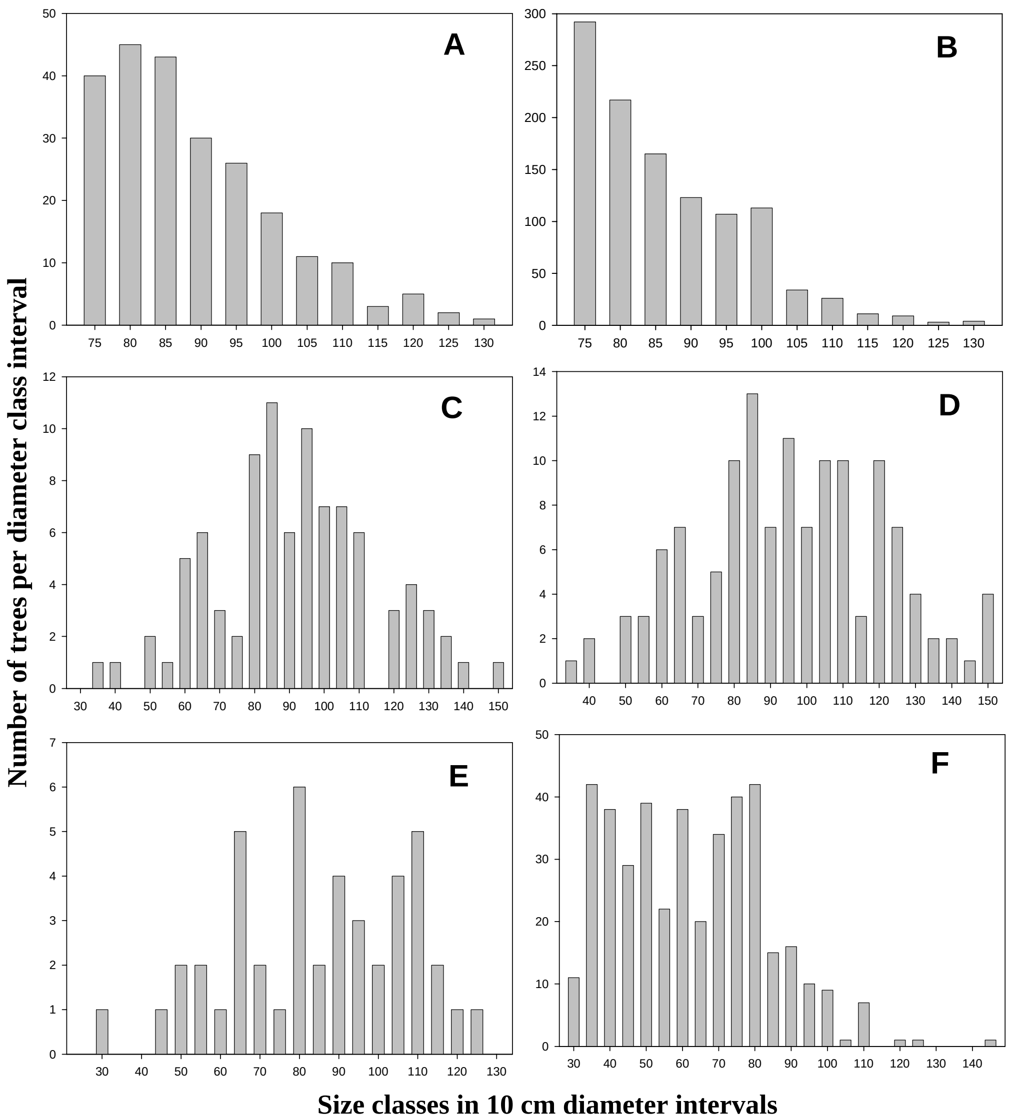

Figure 10. Diameter class distribution of selected timber tree species in eastern Ituri Forest. A: *Gilbertiodendron dewevrei*, B: *Julbernardia seretii*, C: *Entandrophragma cylindricum*, D: African mahoganies as a group, E: *Milicia excelsa*, F: *Zanthoxylum gillettii*.

<u>Spatial distribution of timber tree species</u>: spatial patterns were assessed for a few common species or group of species including *Julbernardia seretii, Gilbertiodendron dewevrei, Entandrophragma cylindricum, Zanthoxylum gillettii, Milicia excelsa, Parinari excelsa* and African mahoganies pulled as a single group (Table 4).

Table 4. Morisita's index of dispersion (I_d) and chi-square values (χ^2) for test of departure from complete randomness in a 500-ha plot in eastern Ituri Forest.

Species name	Abundance (trees ha^{-1})	100 m x 100 m quadrats		500 m x 500 m quadrats	
		(I_d)	χ^2	(I_d)	χ^2
Julbernardia seretii	2.22	1.353	**581.15**[1]	1.043	**66.18**
Gilbertiodendron dewevrei[2]	2.34	2.175	**372.84**	1.189	**46.99**
Entandrophragma cylindricum	0.18	1.911	**581.91**	1.147	**33.10**
Zanthoxylum gillettii	0.83	3.447	**1517.05**	1.172	**63.54**
Milicia excelsa	0.09	1.515	521.67	1.785	**38.62**
Parinari excelsa[2]	0.41	1.951	**137.05**	1.195	**10.80**
African mahogany	0.26	1.905	**612.10**	1.246	**48.82**

[1] The critical value of χ^2 was 552.1 and 30.14 for 100 m and 500 m quadrats respectively. Numbers in bold indicate significant departure from random patterns at α-level of 0.05.
[2] *G. dewevrei* and *P. excelsa* were only measured in 100 ha. Thus, the critical χ^2 value for the two species was 123.23 and 7.82 for 100 m and 500 m quadrats, respectively.

All the species and group of species for which spatial patterns were assessed showed significant clumping at both 1-ha (100 m quadrat) and 25-ha (500 m quadrat) scales (Fig. 11), with the exception of *M. excelsa* whose dispersion patterns could not be distinguished from complete randomness at the 1-ha scale. At the scale of 1-ha quadrat, *Z. gillettii* had the highest χ^2 value of all species, indicating strongly clumped patterns of dispersion. African mahogany as a group and *G. dewevrei* had the second highest level of aggregation. Although *M. excelsa* had a χ^2 value greater than 1, its dispersion pattern could not be distinguished from randomness at the 1-ha scale likely due to the very low density of the species. Of 500 individual hectares, *M. excelsa* was present in only 42, and no single hectare had more than two individuals of this species.

Clumped patterns of dispersion in major timber species were likely due to the association of these species with different types of vegetation. For example, forest type had significant effects on the densities of African mahoganies ($\chi^2 = 7.45$, df = 2, p = 0.024), with tree densities in low canopy forest averaging 2.3 times those in monodominant forest and 1.2 times those in mixed forest.

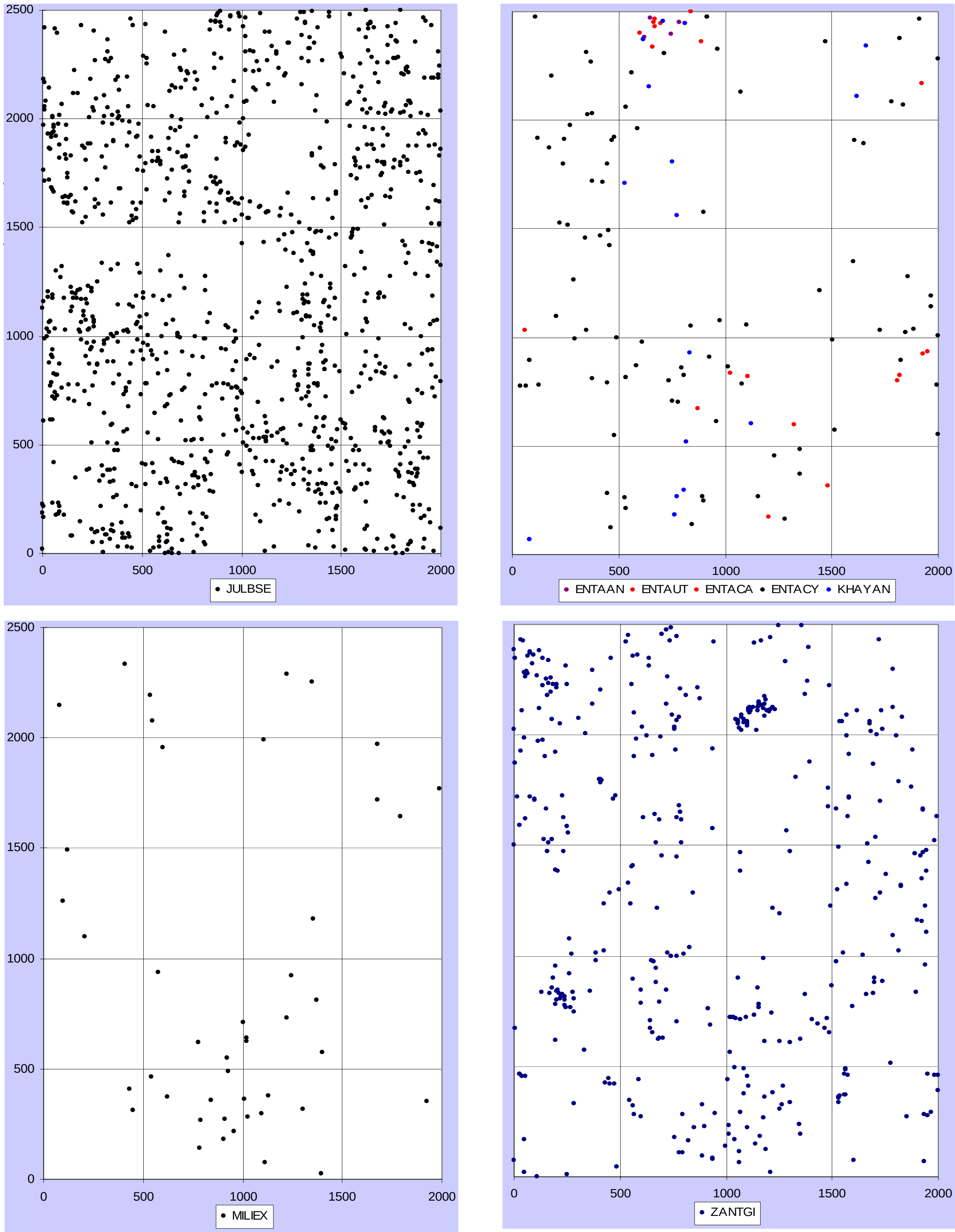

Fig. 11. Spatial distribution of *Julbernardia seretii*, African mahoganies, *Milicia excelsa* and *Zanthoxylum gillettii* in a 500-ha plot (2000m x 2500m) in ENRA concession, northeastern Congo basin. X and Y axes are in meters.

6. 3. Botanical surveys

Forest structure: Forest structure was considerably different between monodominant and mixed forest stands. Mixed forest had higher density of trees at the threshold of 10 cm than monodominant stands, whereas the later had more trees than the former at the 30 cm diameter cut-off. Higher density of large trees resulted in higher basal area in monodominant stands (Table 5).

Table 5. Mean stem density and basal area (standard errors in parentheses) in 50 0.1-ha plots mixed and monodominant stands in eastern Ituri Forest. Each forest type was represented by 25 plots totaling a combined area of 2.5ha.

Forest type	⩾ 10 cm dbh		⩾ 30 cm dbh	
	Stems ha^{-1}	Basal area (m^2 ha^{-1})	Stems ha^{-1}	Basal area (m^2 ha^{-1})
All plots	441 (15.0)	26.19 (1.2)	78.6 (4.0)	19.49 (1.2)
Monodominant	400 (21.8)	29.30 (1.6)	87.6 (5.4)	23.66 (1.6)
Mixed	482 (17.6)	23.08 (1.5)	70.0 (5.5)	15.32 (1.5)

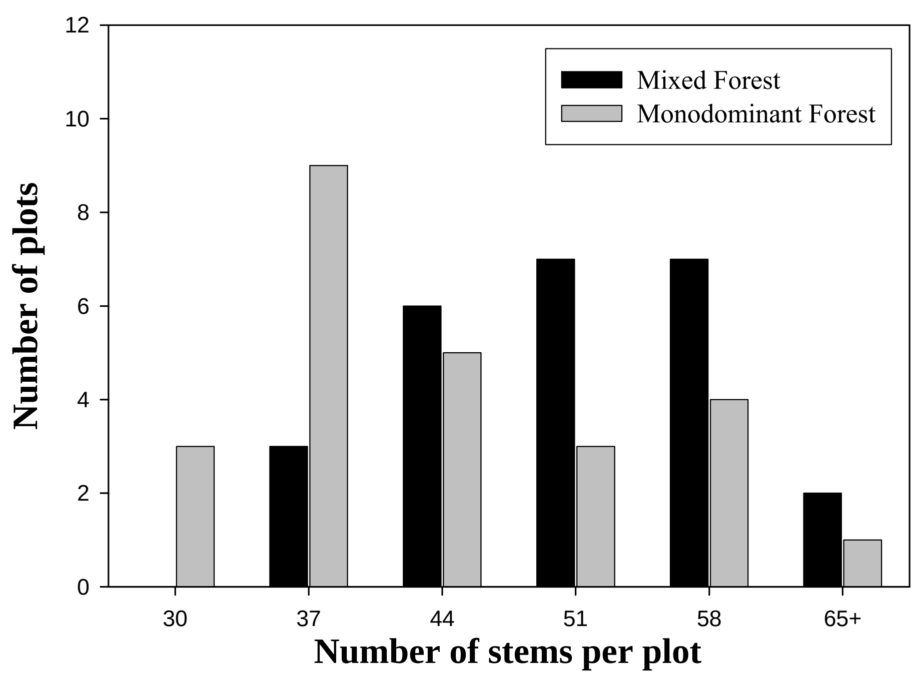

Figure 12. Distribution of stem density per 0.1-ha plots in mixed and monodominant stands in eastern Ituri Forest.

There was considerable variation in stem density among plots in each forest type. For trees ≥ 10 cm, stem density ranged from 210 to 660 trees ha^{-1} in monodominant forest plots and from 350 to 730 trees ha^{-1} in mixed forest ones. On average, mixed forest plots had more trees than monodominant plots but the later showed higher level of variation in tree density (Fig. 12). Variation in stem density was lower in monodominant than in mixed stands for trees ≥ 30 cm dbh. For this diameter cut-off, stem density ranged from 40 to 150 trees ha^{-1} in monodominant forest plots and from 20 to 140 trees ha^{-1} in mixed forest plots.

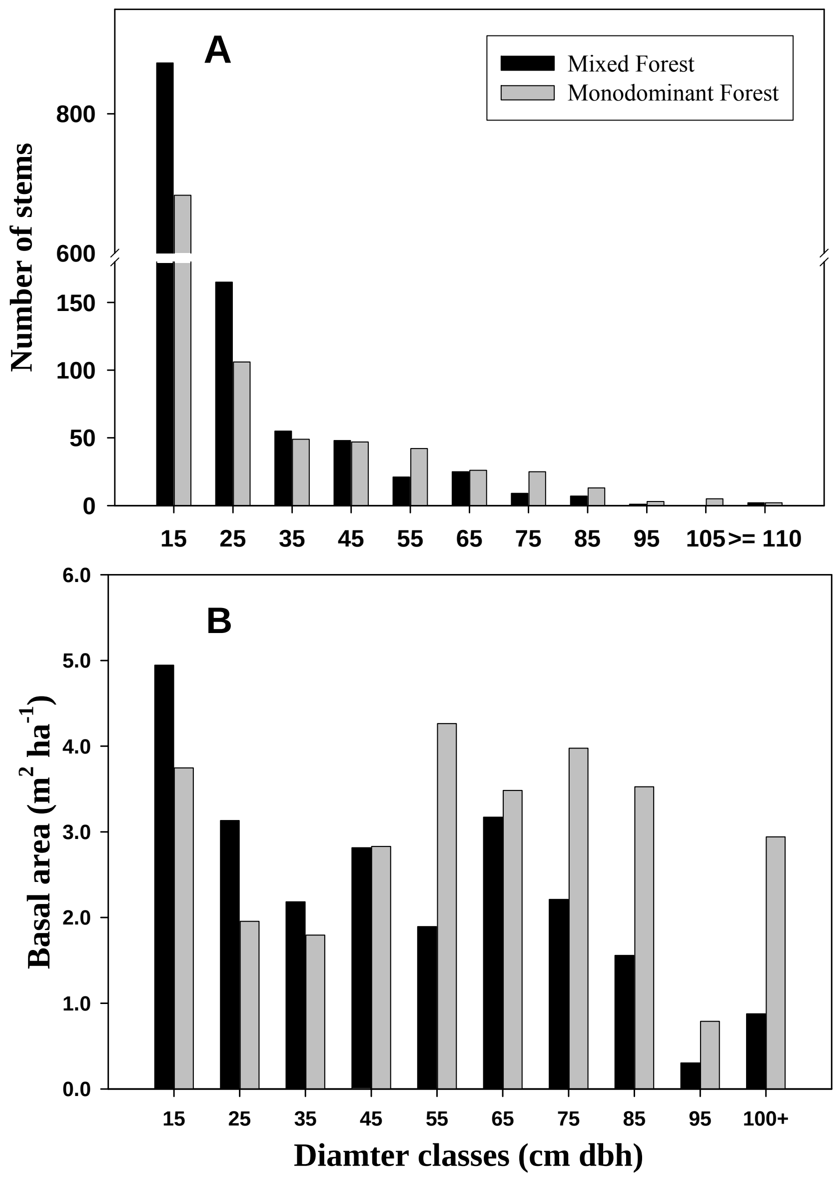

Figure 13. Distribution of stems density and basal area in mixed and monodominant stands in eastern Ituri Forest. Labels on the x-axis are midpoints of diameter intervals.

Mean number of trees dropped rapidly for 10 cm diameter intervals in both forest types (Fig. 13A). Mean density of trees less than 20 cm dbh was 271.2 in monodominant and 342.4 trees ha^{-1} mixed forest stands, whereas the size class between 20 and 50 cm dbh averaged only 80 and 112.4 trees ha^{-1} in monodominant and mixed forest, respectively. There were very few trees with diameter above 100 cm. Monodominant forest averaged 3.2 trees ha^{-1} for that size class and mixed forest had mean density of only 0.8 trees ha^{-1}.

The distribution of basal area across size classes showed two peaks (Fig. 13B). The first peak corresponded to the smallest size class (< 20 cm dbh) in both forest types. The second peak occurred at the diameter class between 50 and 60 cm dbh for monodominant forest, while it was located in the size class between 60 and 70 cm dbh in mixed forest.

Tree species diversity: In total, 168 different taxa were recorded within the 5 ha surveyed for botanical inventories. Of these, 150 taxa were identified to species level, 12 to genus level and 6 taxa were identified to family level. Two individuals were unidentified. More tree species were recorded in mixed forest plots (147 species) than in monodominant forest plots (79 species). With an average of 21.8 species per plot mixed forest plots were significantly more diverse than monodominant forest plots, which had on average only 11.3 species per plot. Shannon's diversity index showed similar patterns, being much greater in mixed than in monodominant forest plots (Fig. 14).

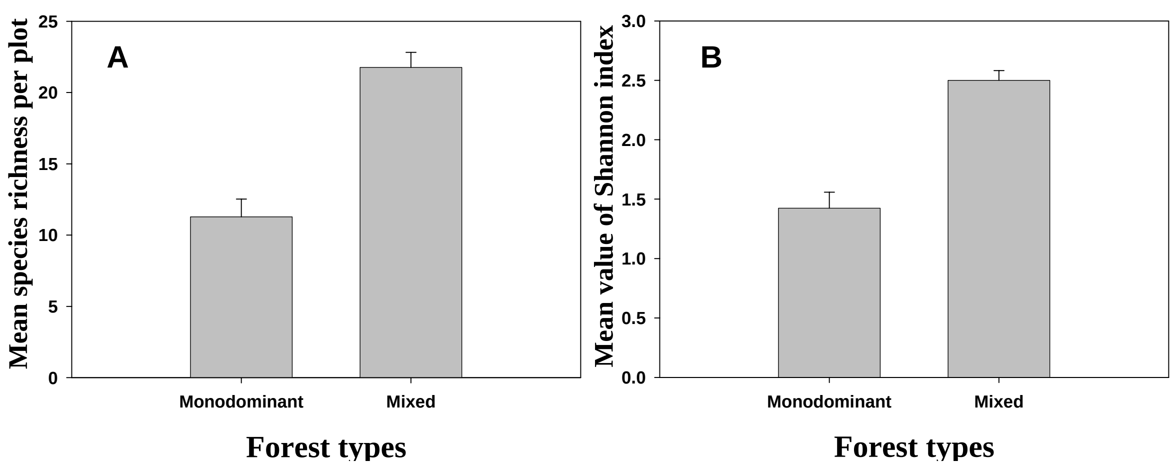

Figure 14. Comparison of mixed and monodominant stands for trees ≥ 10 cm dbh in eastern Ituri Forest. A: Mean number of species per plot, B: Mean value of Shannon-Wiener diversity index.

Higher species richness in mixed forest was partly due to higher tree density in this forest type. There was a strong positive relationship between species richness and tree density. The relationship between tree density and species richness was similar in both forest types, but for comparable tree density mixed forest plots had significantly more species than monodominant ones (Fig. 15).

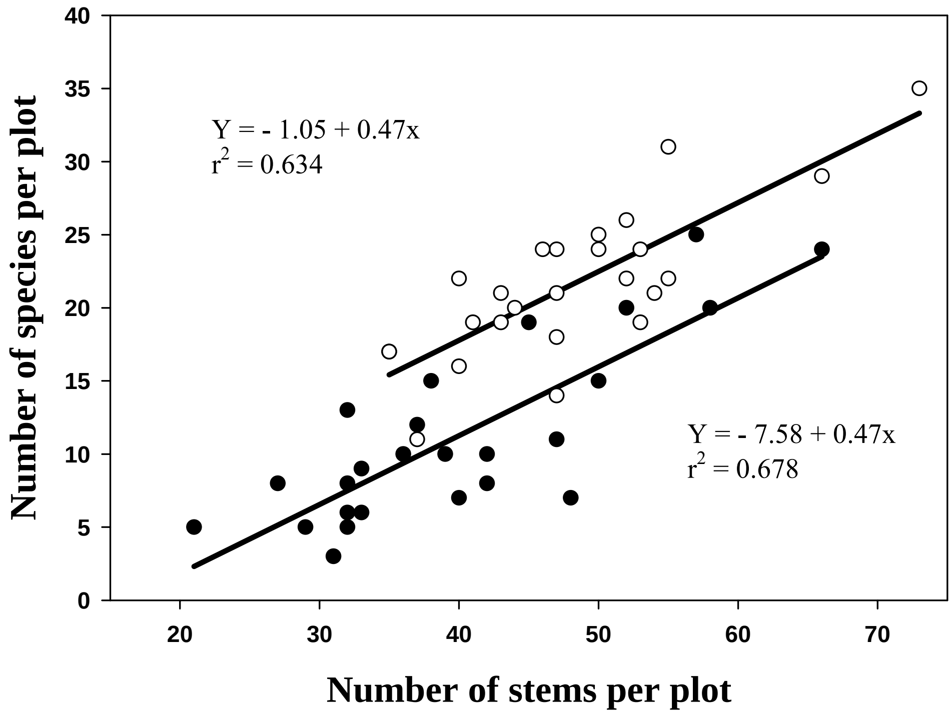

Figure 15. Relationship between stem density and species richness in 0.1-ha plots for trees ≥ 10 cm dbh in mixed and monodominant stands. Filled symbols correspond to monodominant forest plots; open symbols represent mixed forest plots.

<u>Species relative abundance, dominance and tree diversity</u>: More than half of all the trees above 10 cm dbh were accounted for by a single species in monodominant stands where individuals of *G. dewevrei* represented 55.4% of all stems. In mixed forest, species relative abundance was less unevenly distributed (Table 6). The most abundant species, *J. seretii*, made up 31.4% of total abundance. The five most abundant species (6% of the total number of species) comprised 75% of the stems and 40 species (51%) accounted for 95% of the stems in monodominant stands. In mixed stands, 23 species (16%) and 122 species (83%) represented 75% and 95% of total abundance, respectively.

In both forest types, canopy trees (≥ 30 cm dbh) showed higher levels of unevenness in the distribution of relative species abundance than trees ≥ 10 cm dbh. *G. dewevrei* accounted for 75% of canopy trees in monodominant forest plots whereas *J. seretii* made up 49% of canopy trees in mixed forest plots. Only four species out of eighteen and nine species out of 42 had at least one stem per hectare in monodominant and mixed stands, respectively.

Table 6. Species accounting for at least 1% of the basal area of trees ≥ 10 cm dbh and their density in monodominant and mixed stands in eastern Ituri Forest, Democratic Republic of Congo.

Monodominant forest			Mixed forest		
Species name	% of total basal area	Stems ha^{-1}	Species name	% of total basal area	Stems ha^{-1}
Gilbertiodendron dewevrei	73.4	222.0	*Julbernardia seretii*	39.6	151.6
Julbernardia seretii	8.6	22.4	*Alstonia boonei*	5.6	4.8
Alstonia boonei	2.0	3.2	*Albizia gummifera*	5.2	6.4
Erythrophleum suaveolens	1.7	2.4	*Erythrophleum suaveolens*	4.6	5.2
Albizia gummifera	1.3	0.8	*Gilbertiodendron dewevrei*	3.7	21.6
Rinorea oblongifolia	1.3	26.8	*Cola lateritia*	3.2	13.6
Cola lateritia	1.1	4.4	*Zanthoxylum gillettii*	2.9	2.0
Total	**89.4**	**282**[1]	*Strombosia pustulata*	2.1	13.6
			Entandrophragma cylindricum	2.1	0.8
			Klainedoxa gabonensis	1.4	1.6
			Greenwayodendron suaveolens	1.2	10.0
			Desplatsia dewevrei	1.1	10.4
			Pancovia harmsiana	1.1	19.2
			Celtis adolfi-friderichii	1.1	2.8
			Diospyros bipendensis	1.0	15.6
			Total	**75.9**	**279.2**[1]

[1] Overall stem density is 400 stems ha^{-1} in monodominant forest stands and 482 stems ha^{-1} in mixed forest stands.

While few species were very abundant, the majority of the species were rare. For trees ≥ 10 cm dbh, approximately sixty percent of all species had mean density of less than one tree per hectare in both monodominant and mixed forests. The proportion of species with less than one tree per hectare increased with size class. For stems ≥ 30 cm dbh only 22% of all species had at least one individual per ha in each forest type.

Both forest types showed high levels of dominance by tropical forest standard (Table 6). In monodominant forest stands, *G. dewevrei* accounted for 73.4% and 77.5% of basal area for trees ≥ 10 cm dbh and ≥ 30 cm dbh, respectively. In mixed forest stands, the dominant species (*J. seretii*) made up 39.6% and 41.9% of total basal area for trees ≥ 10 cm dbh and ≥ 30 cm dbh respectively.

High dominance by the most abundant canopy species was associated with a significant reduction in the total number of species for trees ≥ 10 cm dbh (Fig. 16). When the two forest types were taken separately, there was no significant relationship between dominance and species richness for mixed forest ($Y = 25.0 - 0.08x$, $r^2 = 0.073$), whereas this relationship was very strong for monodominant forest plots ($Y = 32.5 - 0.29x$, $r^2 = 0.712$). It can thus be inferred that the reduction in species richness is a result of dominance by *G. dewevrei*.

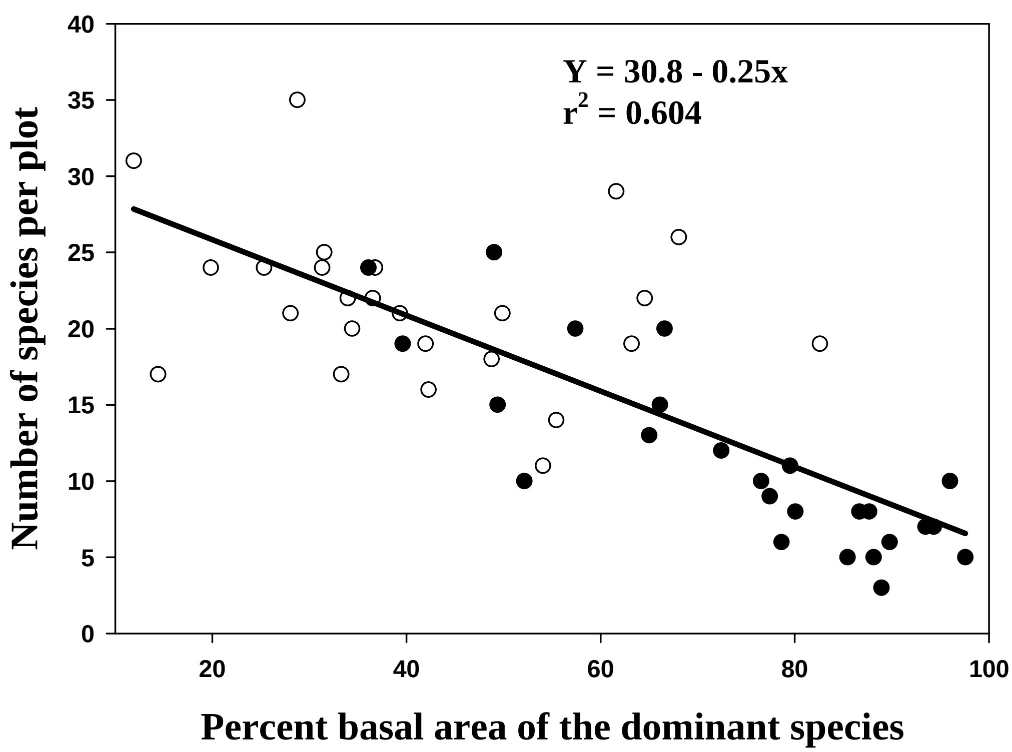

Figure 16. Relationship between dominance and species richness for trees ≥ 10 cm dbh. Filled symbols represent monodominant forest plots and open symbols mixed forest plots.

7. Discussion

7. 1. Timber inventory and forest management

The first step in managing a forest for timber production is to inventory the standing exploitable trees. The work of gathering inventory data involves estimating the total volume of merchantable wood from a measured sample. As with all statistical samples, volume estimates obtained from a measured sample contain a margin of error. These errors can vary widely depending on variability in forest structure and composition, disturbance history, etc. It is therefore recommended to complete 100% inventory of standing volume for exploitable wood prior to timber harvesting.

Pre-harvest timber inventories are useful for establishing a cost basis in new timber concessions, planning harvesting schedules, timber marketing, planning the establishment of logging roads, skid trails and log landings, the protection of exceptional sites, etc. In addition, timber inventories are undoubtedly the corner stone for preparing management plans for timber concessions.

7. 2. Abundance of timber trees and forest types

The area surveyed for this study was relatively poor in major timber species currently profitable on local and international markets. The top timber species harvested by ENRA (cfr. Fig. 6) averaged only approximately one individual per ha in the surveyed 500-ha plot. This density is considerably lower than that observed in other parts of ENRA concession. Rapid timber inventories conducted on a 100-ha plot at the eastern part of the concession in 2000 yielded timber density of ~ 2.5 trees per ha (Makana 2000). The paucity of major timber trees in the surveyed forest is largely due the prevalence of monodominant forest stands in the survey area. Monodominant forest represented 43% of the 500-ha plot, but this forest type had the lowest abundance of major timber tree species such as African mahoganies, *Milicia excelsa* and *Zanthoxylum gillettii*. These species are known to be strongly light demanding and their successful regeneration requires large canopy openings (Swaine & Hall 1988; Hall et al. 2003a, b; Makana & Thomas 2005, 2006). Heavy shade cast by the dense canopy of monodominant forest (Hart et al. 1989; Torti et al. 2001) is therefore a serious impediment to the regeneration of these light demanding trees, resulting in low abundance of major timber trees. Low canopy forest stands had the highest density of top timber species, particularly African mahoganies. This forest type is thought to result from past natural or anthropogenic disturbance events that destroyed closed canopy forest stands, thereby allowing the regeneration of light demanding timber species (see Lamb 1966; Snook 1996).

Two lesser-known timber species, *Julbernardia seretii* and *Gilbertiodendron dewevrei*, were very abundant, averaging 2.2 and 2.3 trees per ha respectively. These densities are underestimates of real timber abundance for the two species as only large trees of exceptionally good form were counted for the present timber inventories. A systematic inventory of the two species in 50 0.1-ha subplots within the 500-ha plot yielded densities of 4.6 and 12 trees per ha above the minimum harvestable diameter (60 cm dbh) for *J. seretii* and *G. dewevrei*, respectively. Both species occupy the highest end of shade tolerance continuum for canopy tree species in Central Africa and they regenerate abundantly under closed canopy (Richards 1996; Hart et al. 1989; Makana et al. 1998, 2004a). *G. dewevrei* was the dominant canopy species in monodominant forest stands, whereas *J. seretii* was the most abundant canopy species in mixed forests.

J. seretii and *G. dewevrei* possess hard and relatively heavy wood that has good technical properties (Anonymous 1992) and can serve for a wide variety of uses including flooring, decking, walls, door and window frames, cabinetmaking, construction, furniture, staircases, and flat sawn veneer (Fouarge et al. 1953; Katondi 1969; ACDI 1977; AITBT 1986; Phongphaew 2003). While *G. dewevrei* can be used indoor as well as outdoor, *J. seretii* is only recommended for indoor uses. Many other class 2 timber species such as *Erythrophleum suaveolens, Pycnanthus angolensis, Staudtia kamerounensis, Piptadeniastrum africanum, Guarea thomsonii*, etc. are present in the surveyed forest.

7. 3. Size distribution and inferred regeneration of major timber species

In the absence of regeneration data, static information on tree size or diameter class distribution can be used to infer the regeneration of tree species (Aubréville 1938; Newbery & Gartlan 1996; Condit et al. 1998). Species with many juveniles relative to adults (inverse J-shaped curve of size distribution) are believed to be regenerating well, whereas few juveniles are seen as an indication of poor regeneration. Most species analyzed in this study showed a humped form of diameter class distribution with few juveniles relative to adults, suggesting poor regeneration of these species. However, alternate explanation can also account for the prevalence of humped diameter class distribution in light demanding species. Wright et al. (2003) noted that light demanding species are generally rare as seedlings or saplings because trees in these size classes are ephemeral either dying quickly if shaded or growing rapidly into larger sizes if light conditions are adequate.

7. 4. Implication of low timber abundance to sustainable forest management

Low abundance of major timber species is widespread in Central Africa. In the area surveyed for this study, timber volume averaged roughly 5-6 m^3 ha^{-1} for major timber species with secure markets internationally. However, a few lesser-known timber species were present and relatively abundant in the studied forest. The inclusion of these species would substantially increase timber volume per unit area to exceed the current national average for timber volume in DRC's forests, which is estimated at 6-10 m^3 ha^{-1} (Kelvin 1993). This author estimated that yield of 50 m^3 or more can be attained in DRC's forests if a wider variety of timber species were harvested.

Highly selective logging means that logged forests are minimally disturbed by timber exploitation (White, 1994; Malcolm & Ray, 2000; Hall et al., 2003a). While low disturbance levels may be good for biodiversity conservation (Thomas 1991; Struhsaker

1997; Wilkie et al. 1998), their impacts on timber tree regeneration is more controversial. Field assessments have shown that major African timber species such as *Entandrophragma* spp., *Khaya* spp., *Milicia excelsa* and others do not regenerate well after selective logging (Mwima et al. 2001; Hall et al., 2003a, see also Fredericksen 1998). Most high-value African timber species are strongly light demanding and they require large canopy openings for their successful recruitment (Hall et al. 2003b; Makana & Thomas 2005, 2006; see Snook 1996). Intensification of logging by increasing the number of trees harvested by hectare may partly contribute to improve the regeneration of major timber species after logging. This can be done by harvesting a larger number of lesser-known species. Two good candidates for increasing logging intensity in the Ituri Forest are *G. dewevrei* and *J. seretii*. If these two species are regularly harvested, timber volume well over 50 m^3 ha^{-1} can be achieved, increasing the efficiency of harvesting operations and reducing the rhythm of forest degradation by concentrating logging on smaller areas.

Natural forest management, where sustained timber yield relies on the inherent regenerative power of the forest as opposed to extensive silvicultural treatments (Bawa & Seidler 1998) is the most currently used type of forest management in tropical forests. The natural regeneration of harvested species requires that sufficient number of seed trees are left in logged forest stands and that these trees are evenly dispersed in the forest stand (Plumptre 1995; Guariguaa & Pinard 19998). The very low abundance of major timber species poses a serious obstacle to the achievement of the threefold goal of economic viability, sustained yield and maintenance of biodiversity.

7. 5. Timber exploitation and biodiversity conservation

Low extraction rates of timber species are common in African forests (White, 1994; Malcolm & Ray, 2000; Hall et al., 2003a); and they result in larger forest areas being disturbed by logging operations. Logging companies construct new roads in remote forest areas that were previously inaccessible (Wilkie et al. 2000; Mittelman 2001). In regions where human population densities are high, such as in eastern DRC (Witte, 1992; Peterson, 2001), road construction in undisturbed forests facilitates spontaneous colonization of logged forests by landless agricultural colonists, resulting in the conversion of forested areas into agricultural lands and large-scale loss of biodiversity at local scales (Hart & Murphy, 1987; Makana & Thomas 2006). One way to promote biodiversity conservation while still preserving economic returns from forest management for timber production is to concentrate logging on smaller land base by intensifying timber harvesting. High logging intensity on smaller forest areas may increase profitability of forest operations, provide better regeneration of major timber species, maintain stumpage value, and protect biodiversity by reducing the rate of intrusion into mature undisturbed forest (Fredericksen 1998; Fredericksen & Putz 2003). The intensification of logging will protect biodiversity by reducing the impacts of over-hunting, wildfires, colonization and conversion, which are all facilitated by the increased accessibility of logged forests.

The low abundance of high-value timber species is a major obstacle to silvicultural intensification in Central African forests. Harvesting *G. dewevrei* and *J. seretii*, which are abundant may allow more intensive forest management for timber production in the Ituri Forest and elsewhere in the Congo basin. In eastern Congo basin, *G. dewevrei* and *J. seretii* occur in quasi monoculture stands or in association with each other over large areas. In addition, the harvesting of the dominant canopy tree species can result in higher tree and animal diversity (Plumptre 1996). Forest dominance by *G. dewevrei* is usually associated with a reduction in the diversity of plant as well animal species (Hart & Petrides 1987; Hart et al. 1989; Thomas 1991; Gubista 1999; Makana et al. 2004a). A decrease in the dominance by this species through the removal of its large trees for timber production can thus be expected to promote higher biodiversity in monodominant forest stands.

Given that *G. dewevrei* occurs in quasi monoculture stands over large areas, the intensive harvest of the species could result in heavy canopy opening and severe soil disturbance over large areas. The negative impacts of such logging practices on the conservation of biodiversity and forest regeneration can also be enormous given the fact that *Gilbertiodendron*-dominated forests are generally closely tied to low levels of light in the understory (Torti et al. 2001). Detailed studies on the response of species diversity and composition, and *G. dewevrei* seedlings to timber harvesting of different intensities are therefore needed to devise harvesting practices that may be compatible with the conservation of biodiversity and the natural regeneration of the species.

ENRA has already initiated efforts to expand the list of timber species they harvest and increase logging intensity by marketing less-known timbers that are common in its forest concession. The key species targeted by the expansion include *G. dewevrei, J. seretii, Guarea cedrata, Erythrophleum suaveolens, Tessmania africana*, and *Gnophyllum giganteum* (ENRA 2005). These species are primarily used to produce parquet.

Conclusions and recommendations

Four main findings were made in the present study. First, timber abundance is not evenly distributed in ENRA concession. The western part of the concession is relatively poor in timber trees than the eastern part. The prevalence of monodominant forest in the western part of the concession appears to be the main cause for this observation. Monodominant forest stands showed extremely low abundance of major timber species such as African mahoganies, Iroko (*Milicia excelsa*) and Olovongo (*Zanthoxylum gillettii*). Second, the apparent paucity of timber species in the surveyed area totally vanishes when one considers all the species listed as class II timbers and standing volume may rise to value greater than 50 m^3 per ha. Two species contribute to this phenomenal increase in timber abundance: *Gilbertiodendron dewevrei* and *Julbernardia seretii*. These species have good wood properties and they are particularly suited for parquet flooring. Third, major timber species showed little regeneration in undisturbed forests. African mahoganies, *Milicia excelsa* and *Zanthoxylum gillettii* had all a humped diameter class distribution with few juveniles relative to adults. Fourth, sustainable forest management for timber production in ENRA concession is difficult due to uncontrolled forest clearing for agriculture by illegal settlers. Although the surveyed area has not been logged yet, approximately 10% of the plot has already been cleared and converted to farmlands.

In the light of the observations above, some recommendations can be made to promote sustainable management of forest for timber production and conservation of biodiversity in ENRA concession, in particular, and in northeastern DRC generally.

1. *Intensification of timber harvesting*: current logging is extremely selective and it requires large areas of undisturbed forest, facilitating access to primary forest areas. It is therefore important that higher timber volume is harvested per unit area to reduce the rate of intrusion in primary forest. This can be achieved by systematically harvesting abundant timber species such as *Gilbertiodendron dewevrei, Julbernardia seretii,* and *Erythrophleum suaveolens*.
2. *Application of silvicultural techniques*: most major timber species are light demanding that do not regenerate well under closed canopy. These species also occur in low abundance such that few individuals are left after timber harvesting, resulting in insufficient seed input in logged forest. This constitutes a serious bottleneck for the regeneration of major timber trees in selectively logged forests. Silvicultural practices such as enrichment planting, seed addition into logging gaps or agricultural lands, and the tending of the regeneration of light demanding species can improve timber stocking in logged forests.
3. *Control of human invasion*: a major obstacle to sustainable forest management in ENRA concession is uncontrolled forest clearing for agricultural by illegal settlers. ENRA should continue to work with local communities representatives, traditional and local state authority (particularly at territorial level) to enforce the control of access to and use of forest resources in the concession. All forest clearing for agriculture should be forbidden in the concession. Recalcitrant farmers who ignore this legal rule (Article 44 of DRC forest code) should be brought to justice.

References

ACDI, 1977. Manuel de dendrologie. Inventaire forestier de la cuvette centrale – Région de l'Equateur, République du Zaîre. Agence Canadienne pour le Développement International, Québec.

AITBT. 1986. Atlas des bois tropicaux, Tome I – Afrique. Association Internationale Technique des Bois Tropicaux, Paris.

Anonymous. 1984. Guide de l'exploitant forestier: Normes, procédures et règlements sur la gestion des ressources forestières. 1ère partie. Département de l'Environnement, Conservation de la Nature et Tourisme, République du Zaïre.

Anonymous. 1992. Nouvelles essences commerciales d'Afrique: Limbali. *Bois et Forêts des Tropiques* 234: 69-72.

Aubreville, A. 1938. La forêt coloniale: les forêts de l'Afrique Occidentale Française. Paris, Société d'Editions Géographiques, Maritimes et Coloniales.

Bawa, K. S. & R. Seidler. 1998. Natural forest management and conservation of biodiversity in tropical forests. *Conservation Biology* 12: 46-55.

Boubli, J.P., J. Eriksson, S. Wich, G. Hohmann & B. Fruth. 2004. Mesoscale transect sampling of trees in the Lomako-Yekokora interfluvium, Democratic Republic of Congo. *Biodiversity and Conservation* 13: 2399-2417.

Brady, N.C. 1990. The Nature and Properties of Soils. 10th edition. MacMillan, New York.

Brower, J. E. & J. H. Zar. 1984. Field and laboratory methods for general ecology. Wm. C. Brwon Publishers, Dubuque, Iowa.

Condit, R., R. Sukumar, S. P. Hubbell R. B. Foster. 1998. Predicting Population Trends from Size Distributions: a Direct Test in a Tropical Tree Community. *American Naturalist* 152: 495 – 509

CTFT, 1989. Momento du forestier: Techniques rurales en Afrique. 3rd edition. Centre Technique Forestier Tropical, Minisitère de la Coopération et du Développment, Paris, France.

ENRA, 2005. Diverses essences débitées par ENRA utilisable pour la fabrication de parquet, ENRA, Beni, Nord Kivu, RDC.

Ewango, C.E.N. 2006. Diversity, distribution and edaphic specialization of vascular plants on the Ituri Forest inselberg, Democratic Republic of Congo. MSc. thesis, University of Missouri St. Louis, St. Louis, Missouri.

Fouarge, J., G. Gérard & E. Sacré. 1953. Bois du Congo. I.N.E.A.C., Brussels.

Fredericksen, T. S., 1998. Limitations of low-intensity selection and selective logging for sustainable forestry. *Commonwealth Forestry Review* 77: 261-266.

Fredericksen, T. S., F. E. Putz. 2003. Silvicultural intensification for tropical forest conservation. *Biodiversity and Conservation* 12: 1445-1453.

Grubb, P. 1982. Refuges and dispersal in the speciation of African forest mammals. In: G.T. Prance (ed.) Biological Diversification in the Tropics, Columbia University Press, NY, pp. 537-553.

Guariguata, M. R. & M. A. Pinard. 1998. Ecological knowledge of regeneration from seed in neotropical forest trees: implications for natural forest management. *Forest Ecology and Management* 112: 87-99.

Gubista, K.R. 1999. Small mammals of the Ituri forests, Zaire: diversity and abundance in ecologically distinct habitats. *Journal of Mammalogy* 8: 252-262.

Hall, J.S., D. J. Harris, V. Medjibe and P. M. S. Ashton. 2003a. The effects of selective logging on forest structure and tree species composition in a Central African forest: implications for management of conservation areas. *Forest Ecology and Management* 183: 249-264.

Hall, J.S., V. Medjibe, G. P. Berlyn and P. M. S. Ashton. 2003b. Seedling growth of three co-occurring Entandrophragma species (Meliaceae) under simulated light environments: implications for management in Central Africa. *Forest Ecology and Management* 179: 135-144.

Hart, J. A. 1986. Comparative dietary ecology of a community of frugivorous forest ungulates in Zaire. PhD Thesis, Michigan State University, Michigan.

Hart, T.B. 1985. The ecology of a single-species-dominant forest and a mixed forest in Zaire, Africa. PhD Thesis, Michigan State University, East Lansing, Michagan

Hart, T. B. and P. G. Murphy. 1987. Conflict of human interests in the Ituri Forest of Zaire: Implications for forest survival. In: A. E. Lugo, J. J. Ewel, S. B. Hecht, P. G. Murphy, C. Padoch, M. C. Schmink and D. Stone (eds), People and the Tropical Forest. A Research Report from the United States Man and the Biosphere Program. Washington, D.C., pp. 47-49.

Hart, T.B. & R. Ducarme. 2005. Forestry and conservation during a war fought over land and resources in the Democratic Republic of Congo. Forests and conflicts. *ETFRN News*, 43-44: 42-44.

Hart, T. B., J. A. Hart, and P. G. Murphy. 1989. Monodominant and species-rich forests of the humid tropics: causes for their co-occurrence. *Am. Nat.* 133: 613-633.

Hart, T. B., J. A. Hart, R. Dechamps, M. Fournier and M. Ataholo. 1996. Changes in forest composition over the last 4000 years in the Ituri basin, Zaire. In: van der Maesen L.J.G. et al. (eds), The Diversity of African Plants. Kluwer Academic Publishers, the Netherlands, pp. 545-563.

Katondi, J. 1969. Contribution à une étude de normalisation des bois du Congo. Ministère de l'Agriculture et du Développement Rural. République Démocratique du Congo, Kinshasa.

Kelvin, A. 1993. Estimate of timber production, capacity utilization and export potential in Zaire. *Commonwealth Forestry Review* 73: 175-180.

Lamb, F. B. 1966. Mahogany of tropical America: its ecology and management. University of Michigan Press, Ann Arbor.

Laveau, J. 1982. Étude Géologique du Haut-Zaïre. Genèse et Évolution d'un Segment Lithosphèrique Archéen. Musée Royale de l'Afrique Centrale, Annales, série n° 8, Sciences Géologiques 88, Tervuren, Belgium.

Laurance, W. F. 2001. Tropical logging and human invasions. *Conservation Biology* 15: 4-5.

Makana, J.-R. 1999. Forest structure, species diversity and spatial patterns of trees in monodominant and mixed stands in the Ituri Forest, Democratic Republic of Congo. MSc. thesis, Oregon State University, Corvallis, OR.

Makana, J.-R. 2000. Rapport préliminaire d'une mission de recherché sur la régénération des essences de bois d'oeuvre exploitées dans la concession forestière de l'ENRA-Beni en République Démocratique du Congo.

Makana, J.-R. 2004. Ecology and sustainable management of African mahoganies and selected of other timber species in northeastern Congo Basin, Democratic Republic of Congo. PhD thesis, University of Toronto, Toronto, Canada.

Makana, J.-R. & S.C. Thomas, 2005. Effects of light gaps and litter removal on the seedling performance of six African timber species. Biotropica 37: 227-237

Makana, J.-R. & S.C. Thomas, 2006. Impacts of selective logging and agricultural clearing on forest structure, floristic composition and diversity, and timber tree regeneration in the Ituri Forest, DRCongo. *Biodiversity and Conservation.*

Makana, J.-R., T. B. Hart and J. A. Hart. 1998. Forest structure and diversity of lianas and understory treelets in monodominant and mixed forest in the Ituri, Zaire. In: F. Dallmeier, J. A. Comiskey (Eds.), Forest Biodiversity Research, Monitoring and Modeling. Conceptual Background and Old World Case Studies. Vol. 20, Man and the Biosphere Series, pp. 429-446. The Parthenon Publishing Group, Pearl River, N.Y.

Makana, J.-R., T.B. Hart, D.E. Hibbs and R. Condit. 2004a. Forest structure and diversity in the Ituri Forest Dynamics Plots. In: E. Losos and E. Leigh, Jr. (eds.) *Tropical Forest Diversity and Dynamism: Findings from a Large-Scale Network*, University of Chicago Press, Chicago, pp.159-174

Makana, J.-R., T.B. Hart, C. Ewango, I. Liengola, J.A. Hart and R. Condit. 2004b. Ituri Forest Dynamics Plots, DRC. In: E. Losos and E. Leigh, Jr. (eds.) *Tropical Forest Diversity and Dynamism: Findings from a Large-Scale Network*, University of Chicago Press, Chicago, pp. 492-505

Malcolm, J. R. and J. C. Ray. 2000. Influence of timber extraction routes on Central African small-mammal communities, forest structure, and tree diversity. Conservation Biology 14: 1623-1638.

Mwima, P. M., J. Obua & H. Oryem-Origa. 2001. Effect of logging on the natural regeneration of Khaya anthotheca in Budongo Forest Reserve, Uganda. *International Forestry Review* 3: 131-135.

Newbery, D.M. and J.S. Gartlan. 1996. A structural analysis of rain forest at Korup and Douala-Edea, Cameroon. *Proceedings of the Royal Society of Edinburgh* 104B:177-224.

Ontario Institute of Pedology. 1985. Field manual for describing soils. 3rd edition. Ontario Institute of Pedology, Guelph.

Phongphaew, P. 2003. The commercial woods of Africa: a descriptive full-colour guide. Stobard Davies Ltd., Ammanford, UK.

Peterson, R. B. 2001. Conservation – For whom? A study of immigration onto DR Congo's Ituri forest frontier. In W. Webber, L.J. White, A. Vedder and L. Naughton-Treves (eds.) African Rain Forest Ecology and Conservation. An Interdisciplinary Perspective. Yale University Press, New Heaven, pp 355-368.

Plumptre, A. J. 1995. The importance of 'seed trees' for the natural regeneration of selectively logged tropical forest. *Commonwealth Forest Review* 89: 253-258.

Plumptre, A. J. 1996. Change following 60 years of selective timber harvesting in the Budongo Forest Reserve, Uganda. *Forest Ecology and Management* 89: 101-113.

Pomeroy, D. 1991. Centers of high biodiversity in Africa. *Conservation Biology* 7: 901-907.

Richards, P. W., 1996. The tropical rain forest: an ecological study. 2nd edition, Cambridge University Press, Cambridge, UK.

Snook, L. K. 1996. Catastrophic disturbance, logging, and the ecology of mahogany: grounds for listing a major tropical timber species in CITES. Botanical Journal of

the Linnean Society 122: 35-46.
Struhsaker, T. T., 1997. Ecology of an African Rain Forest: Logging in Kibale and the Conflit Between Conservation and Exploitation. University Press of Florida, Gainesville, Florida.
Thomas, S. C. 1991. Population densities and patterns of habitat use among anthropoid primates of the Ituri Forest, Zaire. *Biotropica* 23: 68-83.
Torti, S. D., Coley, P.D., and Kursar, T. A. 2001. Causes and consequences of monodominance in tropical lowland forests. *American Naturalist* 157: 141-153
WCS, 2005. Evaluation of small-scale logging in the Ituri-Aru Landscape in northeastern Democratic Republic of Congo. Unpublished report, Wildlife Conservation Society – DRC Program.
White, L. J. T. 1994. The effects of commercial mechanized selective logging on a transect in lowland rainforest in Lopé Reserve, Gabon. Journal of Tropical Ecology 10: 313-322.
Wilkie, D. S. and J. T. Finn. 1988. A spatial model of land use and forest regeneration in the Ituri forest of northeastern Zaire. *Ecological Modeling* 41: 307-323.
Wilkie, D. S., B. Curran, R. Tshombe and G. A. Morelli. 1998. Managing bushmeat hunting in Okapi Wildlife Reserve, Democratic Republic of Congo. *Oryx* 32: 131-144.
Wilkie, D. S., E. Shaw, F. Rotberg, G. Morelli and P. Auzel. 2000. Roads, development, and conservation in the Congo basin. *Conservation Biology* 14: 1614-1622.
Witte, J. 1992. Deforestation in Zaire: logging and landlessness. *The Ecologist* 22: 58-65
Wolfire, D. M., J. Bruner and N. Sizer. 1998. Forests and the Democratic Republic of Congo: opportunity in a time of crisis. World Resources Institute, Washington, D.C.
Wright, S. J., H. C. Muller-Landau, R. Condit, and S. P. Hubbell. 2003. Gap-dependent recruitment, realized vital rates, and size distributions of tropical trees. Ecology 84: 3174-3185.