The Sustainable Management of African Mahoganies (*Entandrophragma* spp.) in the Dzanga-Sangha Dense Forest Reserve, Central African Republic Through Studies of Regeneration Ecology

FINAL REPORT

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INTRODUCTION

The role of tropical forests in maintaining soil fertility, mitigating against erosion, providing vital resources to local people, maintaining local and regional weather patterns, and harboring rare and endangered species is well known (e.g., Richards 1996). The semi-deciduous forests of southwestern Central African Republic and southeastern Cameroon are of particular interest because they provide resources essential to the livelihood of forest peoples including both indigenous hunter-gatherers and Bantu peoples. In addition, they harbor extremely high densities of many endangered large mammals (Carroll 1988, Fay 1989, Stomeyer and Ekobo 1991). The biological diversity of these forests is only beginning to be understood as exciting discoveries have been made in terms of rare carnivores (Ray 1997), new species of small mammals (Ray pers. comm.) and species of plants newly described to science (Faden, in letter 1997).

In recent years timber exploitation has increased throughout much of central Africa and has been one of the most important economic activities in the Central African Republic and Cameroon for over two decades (Gartlan 1989, Telesis 1991). Loggers are moving into more remote areas of Cameroon, Gabon, the Republic of Congo, and the Central African Republic to get high value timber. Conservationists have recognized the desire of the governments of Central African Republic and Cameroon to obtain a diverse suite of benefits from the forest and the need to work with timber companies to maintain a matrix of managed forest suitable to wildlife outside protected areas in the region (Hall 1993, Weber and Rabinowitz 1996, Fimbel et al. 1996).

The African mahoganies, including species from the genus *Entandrophragma,* are some of the most highly desired timber species of the region (Gartlan 1989). In the semi-deciduous forests of southeastern Cameroon, the Central African Republic and northern Republic of Congo, *Entandrophragma* spp. have dominated the list of high value trees extracted for over two decades (Hall 1993, Carroll 1996, Fimbel et al. 1996). However, one often noted characteristic of forests where these species are found is the relative paucity of individuals from these species within the small and/or intermediate size classes (e.g. Aubreville 1949, Jones 1955, Okali and Ola-Adams 1987, Swaine and Hall 1988, Fickinger 1992). This gap in size class distribution and the lack of regeneration is of particular concern because, without the possibility of recruitment, there is no economic incentive to wait for trees to mature before reentering concessions. As species are eliminated from the forest matrix, exploitation will shift to less valuable species. Without attention to regeneration, such repeated high grading can lead to marked differences in species composition and forest structure. Ultimately, the forest can become highly degraded where few of the original benefits (be it timber production, non-timber forest products, or conservation) are realized.

Recent efforts have focused on sustainable forest management in both southeastern Cameroon and Central African Republic (Projet API de Dimako 1995, Petrucci and Tandeau de Marsac 1994, Plouvier et al. 1998). The regeneration issue of *Entandrophragma* spp. has begun to be addressed with surveys of natural regeneration in Central African Republic (however authors point to flaws in sampling design that apparently render data useless) and a

limited study of seed dispersal (Petrucci and Tandeau de Marsac 1994). In addition, growth studies have been undertaken in both logged and unlogged forest (Projet API de Dimako 1995). While these studies will undoubtedly play an important role in the management of *Entandrophragma* spp. and silviculture in these forests, few studies have attempted to address the issue of where and how the seedlings of different *Entandrophragma* species establish and grow best within the forest matrix. Such information is extremely important to the sustainable management for these species as it will ultimately help determine whether or not individuals of a given species will recruit into the forest canopy.

In July 1998 a research project to understand the regeneration requirements of African mahoganies (*Entandrophragma* spp.) began in the Dzanga-Sangha Dense Forest Reserve of the Central African Republic. The basic premise of the project is that no attempt at sustainable forestry, where the needs of competing objectives are addressed, is possible if the regeneration of the principal timber species is not assured. This report describes project activities.

RESEARCH SITE

The Dzanga-Sangha Dense Forest Reserve, located in southwestern Central African Republic (Figure 1), was chosen as the site of this research because of 1) the historical importance of timber exploitation within the region, 2) the importance of timber exploitation to conservation management of the region (Figure 2), and 3) the historical and continued dominance of *Entandrophragma* spp. on the list of exploited species (between 85 and 100%, depending upon the company), and 4) the presence of as yet unexploited forest.

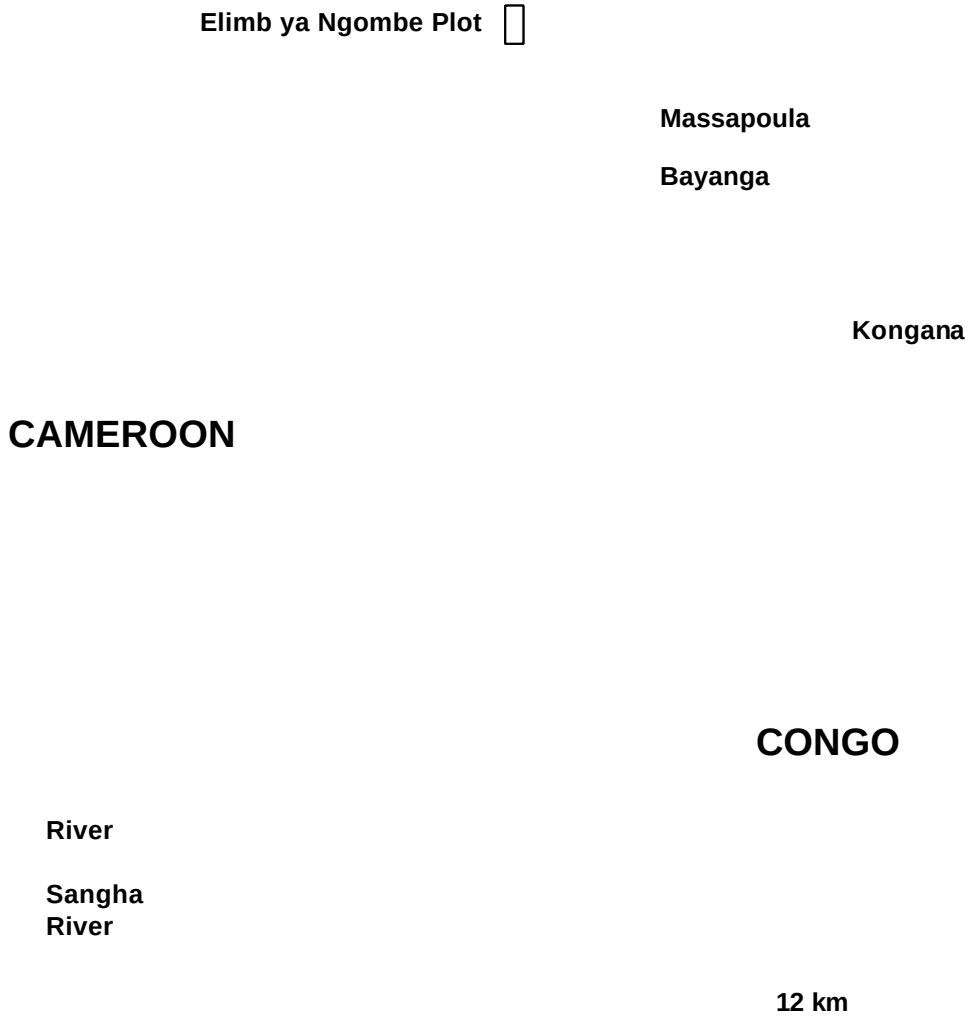

Figure 1. Study Site in Southwestern Central African Republic.

Figure 2. WWF Technical Advisor Checking Diameters of Logs Harvested in the Dzanga-Sangha Dense Forest Reserve.

OBJECTIVES

1. To assess the distribution of *Entandrophragma* spp. at the meso-scale in relation to resource gradients (i.e. soil fertility, soil moisture, and light).

2. To understand the resource requirements of *Entandrophragma* spp. seedlings through experimental treatments in nurseries and forest gaps.

3. To understand if and how differential resource utilization effects regeneration in unlogged forests.

4. To make silvicultural recommendations based on these findings to improve timber exploitation techniques within the Dzanga-Sangha region.

5. To Contribute to the sound management of the Dzanga-Sangha Dense Forest Reserve.

EXPERIMENTAL APPROACH

To design appropriate silvicultural manipulations for species in the genus *Entandrophragma*, it is critical that their performance under different conditions be understood. While the species may survive and even thrive under a variety of conditions, they may have narrow regeneration niches within the forest. Therefore, if foresters attempt manipulations aimed at attaining natural regeneration in inappropriate sites, regeneration will likely fail. Conditions go far beyond understanding their light requirements since tropical soils can also be highly variable in both moisture and nutrient status (see e.g., Clark 1998).

The overall experimental design of this study combines nursery and out-planting experiments with studies of the actual distribution of *Entandrophragma* spp. across the landscape. Performance standards serve as indicators of the species' regeneration potential under different conditions both where resources are strictly controlled (nursery) and those that better reflect those of the real world (out-plantings). Studies of the distribution of *Entandrophragma* spp. on a 100 ha plot permit an evaluation of hypotheses assessing the relationship between where trees are found within the forest matrix and resource gradients. This combination of seedling performance under different levels of resource availability and the relationship of trees to these resource gradients in natural forest provide an understanding of how resource availability at the seedling stage affects the ability of seedlings to survive and recruit to mature tree stages. This understanding, in turn, can be harnessed and incorporated by foresters in natural forest management to improve regeneration.

ACTIVITIES

Nursery Experiments

Fertility-Moisture Experiments

An evaluation of the distribution of *Entandrophragma angolense*, *E. candollei*, *E. cylindricum*, and *E. utile* suggested a shift in relative abundance of these species by region within tropical Africa. These distributions were hypothesized to be related to apparent differences in fertility and/or moisture status of the soil (Hall 1998). An experiment was therefore designed to determine how seedlings of each species respond to differences in fertility and moisture and to determine to what degree differential performance along moisture and/or fertility gradients might influence the distribution of each species at different spatial scales. The seedling stage was chosen as it is considered the stage most likely to influence the variation in adult abundance (Grubb 1977, Gunatilleke et al. 1997).

In July 1998, a field trip was made to Bayanga, Central African Republic to begin the organization of the nursery experiment. Twenty-five soil samples were collected from ridge tops

and valley bottoms in the vicinity of Bayanga and Kongana (≈ 40 km east of Bayanga). These were transported to the United States where they were analyzed for both total and available nutrients to guage the variability in soil fertility across the Dzanga-Sangha Dense Forest Reserve and determine suitable soils for nursery trials.

In addition both seeds and seedlings of *Entandrophragma* spp. were collected from the forest and transplanted or germinated in nursery sacs (Figure 3). Seedlings were watered regularly and kept at approximately 15% full sunlight. *Entandrophragma* spp. within the region fruit at different times of the year (Hall, personal observation) such that collecting seeds and/or seedlings of exactly the same age was impossible. Additionally, because seed viability of *Entandrophragma* spp. declines rapidly with time (Synnott 1975, Taylor 1960) and stored seeds are often attacked by insects (Synnott 1975, Hall, personal observation), collection and storage of seeds for germination at the same time was determined impractical if not impossible under existing conditions. Nevertheless, all seedlings used in nursery trials were less than one year old and only some individuals of one species (*E. utile*) had begun to put out compound leaves (which can occur as early as four months, Hall, unpublished data).

Figure 3. *Entandrophragma cylindricum* Germinants in Mixed Forest in the Dzanga-Sangha Dense Forest Reserve.

Construction of nursery hangers began in September 1998 and was completed in December of the same year (Figure 4). In November 1998, soils were transported from selected high and low fertility sites within the forest, where soils were collected in mixed forest near *Entandrophragma* spp. Soils were collected from the upper 15 cm of the mineral soil at Mossapoula (high fertility soil) and Kongana (low fertility soil) sites and sieved through 2 mm

mesh to eliminate large organic matter. Subsequent fertility analysis reconfirmed the fertility status of soils used in nursery trials.

Figure 4. Nursery Hangars in Bayanga.

Figure 5. Transplanting Seedlings for Nursery Experiments.

Seedlings were transplanted to 20 liter nursery sacs filled with sieved forest soil (Figure 5). Three fertility and two moisture treatments were tested in a factorial design and included Massapoula soil with nutrient addition, Massapoula soil without nutrient addition, and Kongana soil. Moisture treatments consisted of evermoist and drought stressed soils. Details of experimental design are found in (Hall 2000, Appendix I).

After transplanting and before the beginning of the nursery experiment, 16 seedlings of each species and/or cohort were harvested to allow the calculation of dry mass of seedlings at time zero. Subsequent harvests were completed at six months and at the end of the experiment at 12 months. During these harvests 12 and 16 individuals of each species per treatment (3 fertility x 2 moisture = 6 treatments) were harvested and weighed. Moist mass was determined by plant part (simple and compound leaves, stems, coarse and fine roots) and plant tissues were subsequently dried and transported to the United States for final processing.

Light Experiment

A light experiment was also completed as part of nursery studies. This experiment lasted for six months and included six individuals of three species (*E. angolense*, *E. cylindricum*, and *E. utile*) and two of *E. candollei* per treatment. This experiment was limited by lack of seedling material but included three light treatments ("full" sunlight, moderate light, and low light). The objective of this experiment was to gauge the importance of light while waiting for the opportunity to begin a more detailed light experiment (i.e. a subsequent fruiting of *Entandrophragma* spp.). Initial and final seedling heights and diameters at root collar were measured for this experiment.

During the months of August through November 1999, seeds and wildlings of *E. angolense* and *E. cylindricum* were collected and transplanted and/or germinated in nursery soil as above. They were subsequently placed in four light treatments (full sunlight, moderate sunlight, moderate sunlight with limited day length, and low sunlight with limited day length). Due to lack of material, two individuals per shelter of one year old *E. utile* were placed within each of the three shelters of the full, moderate and low sunlight treatments. This light experiment began in mid November 1999; additional *E. utile* obtained from seeds produced in February 2000 were added to the experiment. Seedlings were processed for this experiment as for the nutrient-fertility combination experiment. This experiment is ongoing.

Spatial Distribution of *Entandrophragma* spp. at the Meso-Scale and Soil Fertility

In January 1999, three reconnaissance trips were undertaken to determine a suitable location for a large plot where studies of the spatial relationships of *Entandrophragma* trees could be studied. From late February to early April of the same year, technicians laid out a 100 hectare plot along a ridge-valley system on the western bank of the Sangha River across from the confluence of the Sangha and Yobé Rivers. Layons or transects were cut through the forest understory where lines were sighted with a pocket transit and compass. Layons were cut at 100 meter intervals to create a 500 meter x 2000 meter grid system. Soil samples were then

collected in the upper 15 cm of the mineral soil along a 2000 meter transect to provide an initial characterization of soil fertility on the plot. In addition, samples were collected under four randomly selected *Entandrophragma utile* trees.

In August 1999, work resumed on the 100 hectare plot. A Criterion™ Survey Laser was used to map the grid system on the plot and provided a three dimensional map. All *Entandrophragma* $\geq$ 10 cm diameter at breast height (dbh) were located, tagged, and then measured to determine dbh. In addition, micro-topographic and crown position were recorded. Finally, all trees were mapped with the survey laser. This phase of the plot work was completed in early November 1999.

In February and March 2000, soils samples were collected on the plot. Soil samples were collected at 100 meter intervals across the entire plot such that samples were obtained from all intersections of layons. As described above, samples were collected from the upper 15 cm of the mineral soil with the use of a 3 ½ cm diameter soil auger. Soil samples were also collected below 25 randomly selected individuals of each species of *Entandrophragma* $\geq$ 30 cm dbh. Because only 11 individuals of *E. utile* met this criteria on the plot, additional soil samples were collected opportunistically below *E. utile* across the Dzanga-Sangha Dense Forest Reserve. Collection of soil below trees was accomplished with the use of a soil probe where four samples were taken from the corners of a square surrounding the trees and then bulked. Soil samples were air dried and transported to the United States for analysis.

Out-Planting Experiment

Collection of seeds and seedlings for placement in out-plantings began in August 1999. Seeds and recently germinated seeds of *E. angolense* and *E. cylindricum* were collected from the forest and placed in the nursery as described above for nursery experiments and where seedlings were placed in soil fertility that they would be out-planted into. The objective of this experiment is to compare performance between species under different soil fertility, moisture, and light conditions in the field. Due to high mortality observed in a seed and seedling predation study initiated in August 1999, this experiment was postponed until seedlings reached the stage where this was diminished (approximately 15 cm tall). Because seedlings reached this point at the beginning of the dry season, out-planting was postponed until the rains returned at the end of March 2000. This also permitted the collection and germination of sufficient *E. utile* to allow its inclusion in the experiment. Insufficient *E. candollei* seeds and/or seedlings were available.

A total of eight 25 meter diameter gaps were located in mixed forest adjacent to where fertile and infertile soils were collected for the nursery experiment. Massapoula gaps were located in down slope areas while Kongana gaps were located on or near ridge tops. It is assumed that Massapoula gaps have higher soil moisture throughout the dry season than Kongana gaps such that relatively moist fertile and dry infertile conditions are obtained. Eight individuals of each species were planted out into gap center and adjacent understory for each of these gaps in early April 2000. Gypsum blocks were placed in each gap and understory combination at depths of 15 and 50 cm to track moisture. Finally, seedlings were tagged and initial heights and diameters at the root collar were measured.

Collaborative Activities with the University of Bangui

In January 1999, contact was made with the Chef de Département de Biologie and the Dean of the Faculté des Sciences of the Université de Bangui to arrange for two Master's students to undertake projects associated with *Entandrophragma* research as subjects of their Theses. Contacts continued over the ensuing months and, upon completion of their final exams, two students traveled to Bayanga to begin field work under the supervision of project's principal investigator.

Figure 6. University of Bangui Masters Student Preparing Exclosures in Seed and Seedling Predation Experiment.

Vincent Medjibe studied the relationship between wind, branches and dispersal direction of *Entandrophragma* seeds. Details of his study are included in (Medjibe 2000). He chose five isolated *Entandrophragma* spp. and censused seeds in all 2 m x 2 m squares on a 1 hectare (100 m x 100 m) grid system where the seed producing *Entandrophragma* was in

the center. In addition wind direction and intensity was measured with use of a wind sock placed on top of the Dzanga-Sangha Project water tower and hand held wind speed meter. Measurements were taken on 11 days from 6:00 AM to 6:00 PM during the *E. cylindricum* and *E. angolense* fruiting periods. Finally, branches originating from the stem of each of the five *Entandrophragma* seed trees were mapped.

Michel Ndotar studied seed and seedling mortality of *Entandrophragma* spp. Details of his study are found in Ndotar (in prep.). He selected four sites within three forest types (*Gilbertiodendron* stands, mixed forest stands, and regenerating fallow) and placed two cages of different grill diameter (1 ½ cm x 1 ½ cm and 3 cm x 3 cm) over a 1 m x 1 ½ m plot (Figure 6). A third plot was left uncovered in each site. He randomly distributed 30 viable seeds of *E. angolense* and placed 30 germinating seeds (wing still on cotyledons and first two leaves not yet fully formed) of *E. cylindricum* within each plot. Each site was visited weekly and seed and seedling fates recorded for a period of three months.

In November 1999, the Master's students returned to Bangui to begin analysis of their results and writing of their Master's Theses. Drafts were completed and defended in January and February 2000 respectively. Vincent Medjibe has incorporated comments and submitted the revised and final version of his Thesis. Michel Ndotar is still revising his Thesis (he teaches secondary school in Bangui and supports a family as well).

In March 2000, additional funding was secured from CARPE (via the Biodiversity Support Program) to permit Mr. Medjibe and Mr. Ndotar to do a short course in computers. They completed their training on Microsoft Word and Excel at the end of May 2000 (Appendix II).

SUMMARY OF RESEARCH RESULTS

Results of nursery experiments and the evaluation of the distribution of *Entandrophragma* spp. at the meso-scale are presented in Hall (2000, Appendix I). Spatial analyses found trees $\geq$ 30 cm dbh for all four *Entandrophragma* species studied to be non-randomly distributed. Performance evaluations of nursery experiments suggest that three of the four species studied respond to soil fertility but that the dominance of *E. cylindricum* throughout the region may be due to its ability to grow better under low moisture conditions than congeners. Both *E. candollei* and *E. utile* grew better than *E. angolense* and *E. cylindricum* under low light conditions. It is suggested that *E. candollei* and *E. utile* may segregate into low light, low nutrient and low light, high nutrient microsites.

Insufficient plant material and the fortuitous early evaluation of seed and seedling predation studies delayed the out-planting experiments such that no evaluation of these experiments is possible at this time. Nevertheless, early results from two unplanned experiments more than compensate for the lack of these data. Early results of seed and seedling predation experiments show very high mortality rates due to seed predation by rodents (Ndotar, in prep.). This is true for all forest/habitat types and clearly plays a role in limiting passage of individuals from the seed to seedling stage. Fungal attack and insect damage were also found to be important in different forest/habitat types (Ndotar, in prep.). Results of seed dispersal

studies suggest that the orientation of branches is more important than wind direction in determining dispersal direction (Medjibe, 2000). This study question's the wisdom of cutting trees down wind of *Entandrophragma cylindricum* to favor regeneration in the Bayanga region.

PROJECT CONSTRAINTS

Given the political and economic turmoil within the Central African Republic at the time, this research project was completed with relatively few problems. Nevertheless, there were a few problems that are worth noting when funders and researchers are considering future endeavors in the Dzanga-Sangha Dense Forest Reserve.

Logistical constraints were the single biggest obstacle to completion of field research in a timely manner. The lack of a research vehicle prohibited the principle investigator's ability to easily move around the study site and between the capital and the study site. While funds were provided to rent vehicles from the Dzanga-Sangha Project, project constraints (including lack of vehicles and regulations regarding which vehicles could be made available to researchers) often made this problematic. This resulted in the principal investigator often waiting days to obtain a vehicle to travel both between the Reserve and the capital and within the project site. This is in spite of the fact that the time lag was often reduced by both WWF's Technical Advisors and Dzanga-Sangha Project staff's extraordinary willingness to juggle schedules.

An additional constraint was the constant scramble for lodging in Bayanga. This constraint was largely overcome by the generosity of WWF staff to house the principle investigator and other researcher's assistance in identifying short term housing options. This is only a problem to the extent that either WWF or the Dzanga-Sangha Project wish to encourage future research in the Dzanga-Sangha Dense Forest Reserve. If research plays a role in the long term management of the Reserve, it is strongly recommended that funds be secured to construct a modest facility capable of accommodating researchers.

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out plot locations, and transport equipment from the United States. Nadine Laporte provided funding for soil fertility analysis for samples collected on the plot. Andrea Turkalo provided the survey laser. Mark Ashton, Graeme Berlyn, David Harris, John McKenna, Christoph Oertle, Kristin Saltonstall and Kristiina Vogt all contributed at different levels to discussion of research design. Franco Bokombo, Patrice Fane, Jonas Honisse, Modigbe, Mbango, Robert Ngaibona, Mathieu Nguenssem as well as numerous other individuals helped in setting up and harvesting the nursery experiment and measuring the plot. Finally, assistance from the Bangui office of WWF is acknowledged.

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