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Enrichment of logging gaps with moabi (*Baillonella toxisperma* Pierre) in a Central African rain forest

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ABSTRACT

Studies of regeneration in African rain forests suggest that without silvicultural treatments, natural succession in logging gaps may not result in the establishment of timber species. In this paper we present the results of an experimental enrichment planting with moabi (*Baillonella toxisperma* Pierre), a valuable and important timber species harvested in Central Africa. Although forest gaps are generally considered as favourable for the regeneration of this species, a survey conducted in a forest concession in south-eastern Cameroon provided an estimate of only 12.7 seedlings ha^{-1}, suggesting that the species was, in fact, poorly represented in logging gaps within the study area. To further investigate the dynamics of the moabi in logging gaps, 795 seeds were sown in 15 logging gaps and 410 nursery-raised seedlings were planted in 15 other gaps. A biannual monitoring program over a 30-month period showed a lower survival rate for seedlings from sowing (75.9%) compared to that of nursery-raised seedlings (95.3%). Planted seedlings reached an average of 229.3 cm tall whereas seedlings from sowing were 167.5 cm tall, with the observed difference roughly corresponding to the average height of the nursery-raised seedlings at the time they were introduced to the logging gaps. After 30 months, the diameters of planted seedlings (16.8 mm) were also greater than those of the directly sown individuals (12.5 mm). Forest gap characteristics significantly influenced the growth of the plants. Factors accounting for the differences were total solar radiation, the soil content of coarse sand, the topographic position of the gap, the vegetation cover and the density of *Macaranga* spp. Whilst total solar radiation had a positive influence on growth, the remaining factors had impacted growth negatively. A streamlined technique was tested by planting 7 seedlings in 250 gaps. Without additional site maintenance, 29.3% of the moabi seedlings emerged naturally from the competing vegetation after 24 months. With biannual maintenance some 89.4% of seedlings became successfully established. Clearance operations had no significant influence on the height of plants whilst plant diameter was greater in cleared gaps. The total cost of the enrichment technique was 5.5 EUR per gap without maintenance and 7.5 EUR per gap with a single maintenance measure. Whilst long-term monitoring is needed, this study suggests a high survival rate of moabi introduced in logging gaps, and a growth rate 10 times higher than previously reported under canopy cover. These findings, combined with the low costs of the enrichment technique, support the use of silvicultural measures in logging gaps to restore the forest.

1. Introduction

Numerous measures have been introduced via national regulations and certification schemes in Central Africa aiming to improve forest management. Forest companies are now obliged to develop detailed management plans including components on surveys and statistical analyses, recruitment calculations, adapted rotations, increased harvest diameter limits and reduced impact logging techniques (Fargeot et al., 2004; Bayol and Borie, 2004). Such interventions are needed to reduce damage to residual forest stands and to ensure timber yields for the next rotation, i.e. 20–30 years after the first logging event. However, these interventions are primarily focused on maintaining forest structure and protecting ecological functions, but not on ensuring the regeneration needed for sustained production in the long term.

Once logging damage has been controlled, one of the most important considerations for achieving long-term sustainability is securing sufficient regeneration of commercial species (Pena-Claros et al., 2008). The issue is of particular relevance in African rain forests where many species suffer regeneration failures (Doucet, 2003; Kouadio, 2009). Furthermore, relatively little is known about the regeneration of commercial tree species and little

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effort has gone into understanding the reasons for consistent regeneration failures after logging (Hall, 2008).

Processes controlling the regeneration of tropical trees are strongly influenced by disturbance resulting from gaps generated by natural treefalls or harvesting operations (Makana and Thomas, 2005). Harvesting of tropical forests in Central Africa is characterized by selective logging of 0.7–2 trees ha^{-1} (Ruiz Pérez et al., 2005). Whilst the resulting canopy opening may be similar to natural canopy gaps there are, however, considerable differences in terms of increased vegetation damage and soil compaction as a result of using heavy machinery to extract the trees (Whitman et al., 1997).

The ecological role of gaps in the dynamics of tropical rain forests has been widely documented (e.g. Denslow, 1980; Putz, 1983; Brokaw, 1987; Uhl et al., 1988). However, few studies have focused on the regeneration of commercial tree species in this environment. Canopy gaps are believed to facilitate the regeneration of non-commercial species at the expense of commercial ones (Brokaw, 1985; Denslow, 1987; Kyereh et al., 1999; Dalling and Hubell, 2002; Babaasa et al., 2004). In fact, light conditions at ground level are one of the main factors affecting the establishment and growth of seedlings (Denslow and Hartshorn, 1994; Agyeman et al., 1999). Light conditions on the ground are dependent on the size of the canopy gap, its shape, the height of the neighbouring forest canopy and the latitude (Canham et al., 1990). The influence of soil characteristics on the growth of some species has also been highlighted (Lopes et al., 2008; Hall, 2008).

Coates and Burton (1997) suggested a gap approach for the development of silvicultural systems. Enrichment techniques of logging gaps have already been tested in American and Asian tropical forests (Mokhtaruddin et al., 2001; d'Oliveira, 2000; Schulze, 2008; Lopes et al., 2008) but, although previously suggested (Hall, 2008), they have not yet been tested in African rain forests. In this study, the moabi, *Baillonella toxisperma* Pierre (*Sapotaceae*), a commercial species with intermediate light requirements also classified as "struggling gambler" (Oldeman and Van Dijk, 1991), has been identified as a suitable candidate species for testing enrichment techniques in Central African forests.

B. toxisperma is one of the most emblematic African trees. This species is in fact archetypal of the disputed resource (Vermeulen and Doucet, 2005), and its very valuable timber is highly regarded by logging companies (Wilks, 1990). Local African people also utilise the species: for instance, its bark has many medicinal properties, its fleshy fruits are edible and the high quality oil extracted from its seeds is used both in cooking and for cosmetic purposes (Fotso, 1995). It is estimated that *B. toxisperma* timber is exploited at a rate of 100,000 m^3 a year (ATIBT, 2008). In 2000, the amount of bark traded in Cameroon was estimated at 3.2 t whilst data on oil production is still scant (Louppe et al., 2008). The high demand for products from this species is predicted to result in a strong decline in its abundance in the medium term (Debroux, 1998), and the International Union for the Conservation of Nature (IUCN) has already classified the species as "vulnerable" (IUCN, 2008). The African country of Gabon has recently banned logging of the species for a period of 25 years, and has also suggested a reforestation campaign (Decree 137/PR/MEFEPA).

The present study was conducted in a 176,000 ha forestry management unit situated in the district of Dja, in the southeast of Cameroon. There, we investigated the utility of a silvicultural approach for regenerating stands of *B. toxisperma* in artificial canopy gaps created by selective logging. We compared the effectiveness of two methods – sowing seeds directly and planting nursery-raised seedlings of *B. toxisperma* – in terms of survival and growth. The local conditions (i.e. logging gap characteristics) and the need to regularly eliminate the competing vegetation were also considered to evaluate the success of our enrichment experiment. Furthermore, the costs associated with logging gap planting with *B. toxisperma* were also calculated.

2. Materials and methods

2.1. Biological model

With a natural distribution from southern Nigeria to the Democratic Republic of Congo, *B. toxisperma* is among the largest trees of the African continent (Vivien and Faure, 1985). It is a monoecious species that typically produces abundant, dry season fruits every 3 years or so (Debroux, 1998). The species bears fruit from approximately 70 cm in diameter at breast height (dbh). The fruit is a spherical berry about 6 cm in diameter. Seeds have a high but rapidly decreasing germination capacity (Debroux et al., 1998). Dispersal of the seeds is mainly by Man, elephants (*Loxodonta africana*), chimpanzees (*Pan troglodytes*), gorillas (*Gorilla gorilla*) and several species of rodents. Germination is semi-hypogeal and the important reserves of the cotyledons allow an initial growth of about 40 cm (Debroux, 1998; Nimbot Mamba, 2005). *B. toxisperma* is known to survive under a wide range of light conditions. The seedling is shade-tolerant despite showing a very slow growth rate under poor light conditions. For instance, Debroux (1998) found that under a closed canopy cover some 119 years of growth would be necessary to obtain individuals of 10 cm in dbh. In places where light conditions are high, the growth rate of the seedling can also be reduced due to the shade created by more light-demanding concurrent species, whose growth rates are usually faster. As a consequence, canopy gaps may constitute an ideal environment for the establishment and development of *B. toxisperma* seedlings (Debroux, 1998).

2.2. Study area

The study was conducted in the forest concession granted to the company Pallisco in the Dja district (Mindourou), east province of the Republic of Cameroon (Fig. 1). The study area is located between 3°10′–3°44′N and 13°20′–13°52′E, and covers a surface of 176,000 ha.

In the region, the annual rainfall is up to 1650 mm, with two distinct rainy seasons (August to November and March to June) alternating with two dry seasons. The average air temperature is 24 °C. The relief is relatively flat with altitude varying from 600 to 760 m with some shallow but obvious depressions. The river system draws a regular meshing of small valleys with flat and swampy bottoms. Soils are derived from metamorphic rocks and are mainly ferrallitic red or typical yellow in colour (Feteke et al., 2004).

The forest is intermediate between the evergreen and semi-deciduous types with a 30 m high canopy. It is characterized by the presence of numerous *Euphorbiaceae* and *Olacaceae*. Among the larger tree species, the *Meliaceae* and various *Sterculiaceae* and *Ulmaceae* are well-represented (Letouzey, 1968). *B. toxisperma* is present in low densities: 0.1 stem ha^{-1} (dbh ≥20 cm). The local population structure of *B. toxisperma* was estimated from a survey of 0.6% of the total land area of the forestry concession (ca. 1056 ha out of 176,000 ha) and is presented in Fig. 2 (Feteke et al., 2004). Stems with dbh between 20 and 29 cm accounted for more than 40% of the total observations. Mature individuals (dbh ≥70 cm) were present at a density of 0.03 stem ha^{-1} and marketable trees (dbh ≥100 cm) were only recorded at a density of 0.02 stem ha^{-1}.

2.3. Study design

2.3.1. Natural regeneration of B. toxisperma in logging gaps

To estimate the presence of *B. toxisperma* in logging gaps, 174 gaps from 6 to 9 months of age were selected within an annual