

## RESEARCH

# Elephant effect on forest physical structure and plant species composition in Salonga and Malebo (Lac Tumba landscape), Democratic Republic of Congo

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## Abstract

Data on the ecology of forest elephants are difficult to find. Therefore studies of forest elephant ecology are needed to support the species' management. With that perspective in mind, data on forest understorey types and key plant species that elephants feed on were collected in Salonga National Park (1996–2002) and Malebo (2006–2010), Democratic Republic of Congo. The objective of the study was to document the physical effects of elephants on understorey species and the relationship between elephant trails and elephant-dispersed plant species. About 94% of the openness of the understorey in Salonga National Park positively related with elephant abundance. Elephant trails influenced the distribution of plant species that elephants feed on at Malebo. Plant species whose fruits are eaten (and therefore dispersed) by elephants declined within 20 m of the trail centre while those on whose leaves elephants browsed increased, creating opposed gradients. Three optimum points were described, suggesting that trails move over time within a given width. Projecting the trends given by the gradient equations, a fourth optimum point would be reached at 76 m from the centre at which both types of plant species would be zero. We concluded that  $150 \pm 2$  m distance would define the minimum width of corridors connecting disconnected large elephant habitats.

**Additional keywords:** open understorey, elephant trails, fruit plant species

## Résumé

Les données sur l'écologie de l'éléphant de forêt sont difficiles à trouver. Ainsi, les études sur l'écologie de l'espèce sont nécessaires pour la gestion de l'espèce. Dans cette optique, les données ont été ainsi collectées sur les types de sous-bois et les espèces de plantes alimentaires clés pour les éléphants dans la Salonga (1996–2002) et Malebo (2006–2010), République Démocratique du Congo. L'objectif de l'étude fut de documenter les effets physiques de la présence des éléphants sur les sous-bois et la relation entre les pistes des éléphants et les espèces de plantes qu'ils dispersent. Environ 94% de l'ouverture des sous-bois dans le Parc National de la Salonga fut positivement liée à l'abondance des éléphants. Les pistes d'éléphant influencent la distribution des plantes sur lesquelles se nourrissent les éléphants de Malebo. Les nombres de plantes dont les fruits sont

consommés (donc dispersés) par les éléphants baissent dans une bande de 20 m du centre de la piste tandis que ceux des plantes dont les feuilles sont consommées par les éléphants croissent, créant ainsi deux gradients opposés. Trois points optimums ont été décrits, suggérant que les pistes d'éléphants fluctuent au cours du temps dans une bande donnée. En projetant les tendances issues des équations de ces deux gradients, un quatrième optimum est inféré à 76 m du centre des pistes auquel point les deux types de plantes seraient zéro. Sur base de cette donnée, nous avons conclu que la bande minimale pour des corridors reliant les habitats fragmentés des éléphants serait autour de la distance de  $150 \pm 2$  m.

**Mots clés supplémentaires :** sous bois ouvert, pistes des éléphants, espèces des plantes fruitiers

## Introduction

One of the most important findings of the first round of activities implemented by the programme known as Monitoring of Illegal Killing of Elephants (MIKE) was that most of what was thought to be known about the African forest elephant was based, at best, on informed guesses (Blake and Hedges 2004). Even simple things such as population estimates have been drawn from non-standard methods, poor quality or incomplete datasets. That reality was even more sobering when detailed ecological knowledge of the species in Central African forests was brought into the balance (Guy 1976; Leuthold 1977; Ben-Shahar 1993, 1998, 1999; Prins et al. 1994; Dublin 1995; Bossen 1998; Gibson et al. 1998; Demeke and Bekele 2000; McKnight 2000; Moss 2001; Nyakaana et al. 2001; Shannon et al. 2011; Vanak et al. 2012). Ecological data (ranging ecology, feeding ecology, population ecology, etc.) on African forest elephants are scarcely available (Blake 2002). Current knowledge on the forest elephant is extrapolated from the regions of Dzanga Sangha and Nouabalé-Ndoki (e.g. Blake et al. 2001; Blake 2002; Blake and Inkamba-Nkulu 2004; Blake et al. 2009; Campos-Arceiz and Blake 2011).

Elephants are said to play key ecological roles and had been termed to be ecosystem engineers (Blake 2002). They shape the physical environments in which they occur (Laws 1970; Verschuren 1987; Dublin et al. 1990; Chapman et al. 1992; Höft and Höft 1995; Lindsay 1996; Blake 2002; Calenge et al. 2002; Guldemond and Van Aarde 2007; Pretorius et al. 2011; Shannon et al. 2011). Physically, where they occur in sizeable densities elephants induce the changes in habitat structures (Laws 1970; Dublin et al. 1990; Sam et al. 1998; Lombard et al. 2001); they open light gaps (Calenge et al. 2002) from which light-dependent tree species profit. They also shape the biological conditions in areas in which they reside: they disperse seeds throughout different habitats and

at great distances (Blake 2002), thereby increasing seed survival probabilities (Howe and Westley 1997). Available evidence abounds in the savannah ecosystems, with studies in areas such as Botswana (Ben-Shahar 1998, 1999), Shimba Hills and Tsavo National Parks, Kenya (Höft and Höft 1995) and Serengeti National Park, Tanzania (Lamprey et al. 1974). In the context of forest elephants, however, available evidence is limited to a few case studies in some sites. These cases include Kibale Forest in Uganda (Chapman et al. 1992) and Virunga National Park in the Democratic Republic of Congo (Verschuren 1987) where quantitative field data are available.

Therefore, we felt the need to undertake a study of the effects of elephants on physical structures (Lamprey et al. 1974; Lindsay 1996) of the understorey in Salonga National Park (NP), which is the first objective of this paper, and the effects of elephants on plant species they feed on along elephant trails in Malebo region (the second objective of this paper). The third objective was to define the minimum width strip of a corridor for elephants to connect two blocs of forest in an environment where human activities occupy a larger portion of the landscape.

## Study sites

Salonga NP is a protected area of  $\sim 36,560$  km<sup>2</sup> ( $1^{\circ}00'00''$ – $3^{\circ}30'00''$ S;  $20^{\circ}00'0''$ – $22^{\circ}45'00''$ E). Gazetted in 1969, it is the largest forested national park in Africa. Salonga NP is located in the central Congo Basin in the Democratic Republic of Congo (DRC, Figure 1). Its habitats comprise three major forest types within which large areas of secondary forests are found: hydromorphous, semi-deciduous and islands of evergreen forests (Evrard 1958, 1987; Inogwabini 2006; Reinartz et al. 2006). The area is traversed by many rivers, including some major tributaries of the Tshuapa system such as Lomela, Salonga, Yenge, Luilaka and Lokolo. Areas along

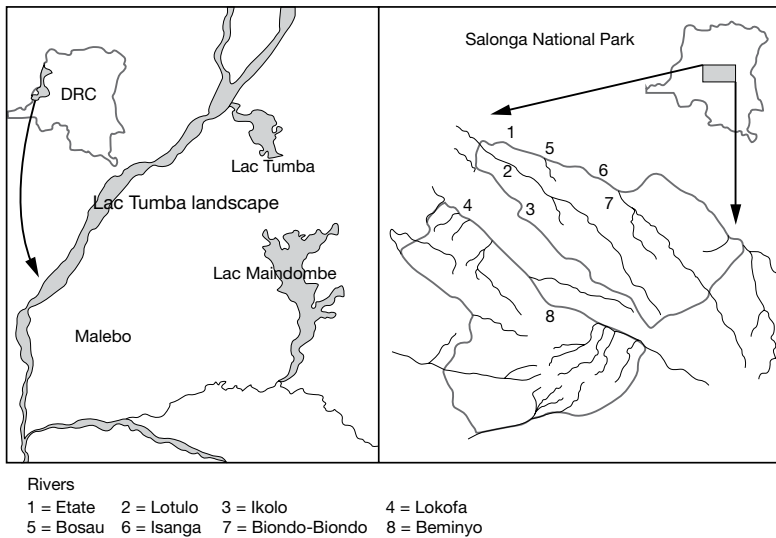


Figure 1. Salonga NP and location of Malebo within the Lac Tumba landscape, Democratic Republic of Congo.

rivers are permanently or seasonally inundated and are covered by various stages of successional plant communities adapted to hydromorphic soils, e.g. *Uapaca*, *Pandanus*, *Raphia* and *Guibourtia* (Evrard 1958, 1987; Reinartz et al. 2006). The westernmost regions of Salonga NP are in the lowest platform of the Cuvette Centrale, whose major characteristics are flat topography and low altitude (300 m). The topography rises up eastward reaching approximately 700 m (Evrard 1968; Matuka 1975; Gauthier-Hion et al. 1999), at which heights the terrain becomes a non-undulating plateau. On the plateau, the habitat is predominantly mixed mature lowland tropical forest (Evrard 1968; Kortlandt 1995; Gauthier-Hion et al. 1999), characteristically composed of species such as *Scorodophloeus zenkeri*, *Anonidium mannii*, *Polyalthia suaveolens* and *Diospyros* sp. Patches of *Gilbertiodendron dewevrei* occur in Salonga NP although in less extensive unbroken areas (Evrard 1968; Kortlandt 1995). Marantaceae stands (*Haumania librechtsiana* and *Megaphrynium macrostachii*) are frequent in understoreys, and in some particular areas of the northern sector, constitute pure mono-dominant vegetation stands (Inogwabini 2006).

The Malebo region (02°00'00"–2°45'00"S; 16°10'00"–17°12'00"E) is in the Lac Tumba landscape, which straddles the provinces of Bandundu and Equateur in western DRC (Inogwabini et al. 2007a, b). Malebo is located at its southern edge, which is located

on the northern edge of the Bateke Plateau (Inogwabini et al. 2006). (Figure 1). The habitats at Malebo are a forest–savannah mosaic ecotone ecosystem that divides the northern swampy forests and the southern savannahs (Inogwabini et al. 2005; Inogwabini 2013). Forests in this region are essentially forest galleries composed of terra firma mixed mature forest with species such as *Gilbertiodendron dewevrei* and *Entandrophragma* sp., of which 45–50% of the understorey is made of Marantaceae species such as *Haumania librechtsiana* and *Megaphrynium macrostachii*. Some of these galleries were logged in the recent past (ca.

25–30 years) to extract wenge (*Millettia laurentii*), a highly priced hard blackwood (Inogwabini 2013). The savannahs of the region are woody, dominated by *Hymenocardia acida* and *Annona senegalensis*.

Blake et al. (2007) estimated elephant density in Salonga NP to be 0.05 individuals/km<sup>2</sup> or a total of 1,900 elephants remaining in this vast forested area. This contrasts sharply with results reported by Alers et al. in 1992 when elephants were estimated at 8,330 individuals for both sectors of Salonga NP. Blake et al. (2007) attributed this decline to poaching, which has occurred in Salonga NP over decades. The elephants at Malebo were surveyed recently by Inogwabini et al. (2011), but limited sample sizes could not allow estimating the population. However, the sign encounter rates (0.33 dung piles/km) indicated that the relative elephant abundance in this region was, in magnitude, about the same as the population in Salonga NP. Lack of previous survey data would not allow any sensible comparison but local communities can still remember the time when herds of elephants were out in the savannahs and blocked the passage to humans, and when poachers invaded the region in search of ivory. This anecdote clearly indicates the elephant population in Malebo has also decreased. Malebo is not in a protected area but has been proposed to become a community-managed area.

## Materials and methods

During a large mammal survey in Salonga NP from 1997 through 2005, data were collected from both forest reconnaissance and line transects from nine zones in the park (Reinartz et al. 2006). These data consisted of forest types, forest understoreys and estimated forest canopy covers. Transects of variable lengths were laid out in 11 field sites for a total effort of 100 km. In 7 of the 11 sites, transects were 1 km long; in the remaining zones they were 1.5 km long. Dung piles were counted along transects and habitat categories noted at each 100-m interval along transects and when each dung pile was encountered. Habitat categories included forest types, forest canopy cover and understorey. Forest categories were similar to those used by numerous other studies in Central Africa (e.g. Hall et al. 1997; White and Edwards 2000; Reinartz et al. 2006; Inogwabini et al. 2007a): mixed mature forest, old secondary forest and young secondary forest. Also following the Central African standards, these categories were associated with different types of canopy (open or closed) and different understoreys (open, woody, Marantaceae, lianas and mixed). Understoreys were defined as in White and Edwards (2000), Reinartz et al. (2006) and Inogwabini (2010) where open understorey meant few plant species and good visibility in the range of  $\geq 50$  m from where one stands; woody understorey was composed essentially of tree saplings; Marantaceae understorey was essentially composed of Marantaceae plants, either *Haumania liebrechtsiana* or *Megaphrynium macrostachyum* or both at the same location, characterized by dense ground vegetation made up of free-standing and liana-like species of herbaceous plants, mostly wild ginger and Marantaceae (Fay 1991). Liana understorey was essentially composed of different species of lianas; mixed understorey was composed of plants of different life forms (saplings, lianas, Marantaceae, etc.). Understorey was defined, using Primack and Corlett (2009), as the vertical layer of forest between the ground and 8–10 m above the ground. Physical understorey structures are composed of terrestrial herbaceous vegetation, thickets and shrubs. By definition, these physical forest structures define the horizontal openness or visibility, which is defined as how far one can see while in a given forest type.

In the Malebo region (2007 through 2010), elephant trails were identified for the general elephant

monitoring programme. First, key plant species were defined as those plants on which elephants fed (Inogwabini et al. 2011). These plants were classified in two categories: category 1 was composed of species on whose fruits elephants fed and category 2 included species on which elephants browse leaves and young saplings. To detect seed deposition and seed survival probability gradients of key fruit species with distance from trails, 50-m long line transects were laid perpendicular to trails. Mean trail width was 30 cm (range 15–50); the 50-m transect length was used because it represented the mean deviation from the permanent elephant trails. When fresh elephant signs deviated from the permanent trail, we followed the new path until it was no longer clearly identifiable, at which point a GPS point was recorded. Mean distance between the end points of elephant deviation from the permanent trails were calculated *post hoc* to define how far away on either side of the permanent trail elephants would venture. The mean calculated deviation equalled 50 m ( $\pm 5$ ). On a strip of 1 m on both sides of these transects, key species trees were identified and counted. Their diameters at breast height (dbh) were also measured and their height estimated. Distance along transects was noted, and perpendicular distances to individual key species trees were measured.

### Analytical framework

Because none of the 11 sites had sufficient elephant dung piles to allow calculation of elephant densities per site, we calculated the encounter rates that represent a relative abundance of elephant (Buckland et al. 1993; Hall et al. 1997; Strayer 1999; Walsh and White 1999). Encounter rates were calculated as the total numbers of dung piles found in each zone divided by the total length of transects in those zones (Buckland et al. 1993; Hall et al. 1997; Walsh and White 1999). Counts of forest types and understoreys were summed up and divided by the total of forest types in each site to give percentages of each forest understorey present in each of the 11 sites surveyed. To assess if there was a relationship between the openness of understorey categories and elephant relative abundance, we plotted percentages of open understorey for each site against the elephant dung pile encounter rate for each site. We then ran a linear regression to see if the openness of the understorey was explained by relative dung pile abundance.

The analytical approach for gradients was to track changes in abundance of key species (numbers of trees) in relation to distance from the centre of the trail. Counts of key plant species were lumped into intervals of 5 m (i.e. 1–5, 6–10, etc.), and frequencies per interval were calculated (Landesberg et al. 2003). As suggested by Landesberg et al. (2003) to detect patterns of gradient in relation to distance from trails, a de-trended correspondence analysis of frequency (Dale 1999) using an exponential regression model, a sinusoidal function and a polynomial model were used, with species frequency as the dependent variable and distance from trail the independent variable. The three models were compared for the best fit (Landesberg et al. 2003), and the model that had the smallest Akaike information criterion (AIC) value was chosen as the one that explains variations of plant species distribution in relation to distance from trails. Curves of the gradient of two types of key plant species were plotted on the same figure to find their intersection points, using SPSS 9.0. We defined a corridor following Osborn and Parker (2003) and Jones et al. (2012) as a band of suitable habitat linking several larger forest blocks to ensure movement of elephants. This definition was translated into geographical area by projecting the trends given by the gradient equations above by taking the last optimum point. Optimum points are points where the two gradients intersect.

## Results

Plots of dung pile encounter rates against percentages of understorey openness (Figure 2) show that open understoreys are positively related to dung encounter rates; the higher the encounter rates the more open the forest understorey. In Salonga NP, the site with the highest encounter rate (Lotul'Iyomi = 3.2 dung piles/km) had the highest percentage of open understorey while sites with the lowest encounter rates (Bekongo, Bonima, Eate, Ikolo and Isakokeli, all with 0 dung piles/km) had the least open understoreys (Figure 2). Linear regression ( $y = 0.2386x + 0.055$ ) model indicated that ~94% ( $R^2$

= 0.9437) of presence of open understorey could be explained by the presence of dung piles.

Of the three models, the one that presented the best fit was the polynomial model, using order 4. This model indicated that ~86% ( $R^2 = 0.86$ ) of species that composed category 1 had a better fit for the polynomial equation of order 4 that follows:  $Y_1 = 0.0036x^4 - 0.3126x^3 + 4.654x^2 - 22.105x + 34.75$  while 86% of species that composed category 2 responded to a polynomial equation of order 4:  $Y_2 = -0.0772x^4 + 1.9035x^3 - 15.469x^2 + 43.763x - 16.833$  ( $R^2 = 0.88$ ; Figure 3). Within the distance of 50 m from the centre of the elephant trail, both curves intersected 3 times (Figure 3): at 7 m, 26 m and 48 m. This indicates that if there would be a fourth point, it would be around 76 m but at this point all elephant-dependent plants would equal zero. This distance from the centre was considered to represent the minimum width of a corridor in this region. When trying to use a 250-m buffer, as suggested by Osborn and Parker (2003), the corridor encroached into savannahs used for cattle raising in the region.

Figure 3 shows that category 1 key plant species decrease from 17 trees at 5 m from the centre of elephant trails down to 1 tree at around 20 m. They then increase to reach another peak (14 trees) at around 40 m. The same Figure 3 also shows that category 2 species increase from the mean of 14 trees at 5 m to 30 at 17.5 m, decreasing from there to 0 trees around 35 m from which point they increase again to the mean of 5 trees at around 50 m. Plant species

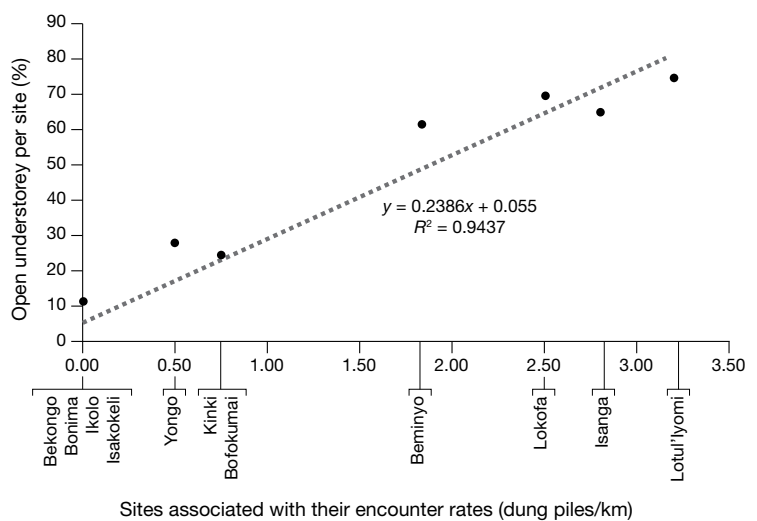


Figure 2. Open understorey (%) per site plotted against dung encounter rates.

measured were those that were identified by Inogwabini et al. (2011) to constitute the major diet of elephants at Malebo. They included *Plagiostyles africana*, *Entandrophragma* sp., *Irvingia* sp., *Anonidium mannii*, *Desplatia dewevrei* and *Musanga cecropioides*. Tree dbh varied between the intervals, generally decreasing from the interval 0–5 m where the largest trees were found (mean dbh ~52 cm; range = 10–159 cm) whereas the small trees were those that were located at 21–25 cm from permanent elephant trails (Figure 4).

**Discussion**

Effects of elephants on ecosystems in which they dwell have been documented from different sites across Africa (Western 1989) and would seem self-evident. However, there is little documentation of such hardly surprising inferences. Evidence of seed dispersing and reports on elephants structuring physical habitat where they occurred abound in the savannah ecosystems (Lamprey et al. 1974; Ben-Shahar 1993, 1999) but is scanty in the context of tropical forests of Central Africa (Blake and Hedges 2004). Data on the ecology of the forest elephant are difficult to find. Under circumstances of high density and limited movement elephants may even destroy seeds they sow (Gauthier-Hion 2003) and damage their habitats (Ben-Shahar 1998). Figure 2 indicates that open forest understorey was related to relative abundance of elephants, which has been also documented in other forests of the Congo Basin (Vanleeuwe et al. 1998), albeit without quantitative measures. The same patterns emerged from other regions where elephants cleared the understorey vegetation (Mipro et al. 2000). In the Congo Basin, the same patterns were described by Blake (2002) in Nouabale-Ndoki, Republic of Congo, by Carroll (1988) in Dzanga-Sangha, Central African Republic, and by Stromayer and Ekobo (1992) and Ekobo (1995) in southeastern Cameroon.

These patterns can be explained by the fact that elephant movements are concentrated along well-defined trails and that they disperse seeds (Tchamba 1998; Blake 2002) along these trails. The seeds they disperse should be deposited at greater quantities on

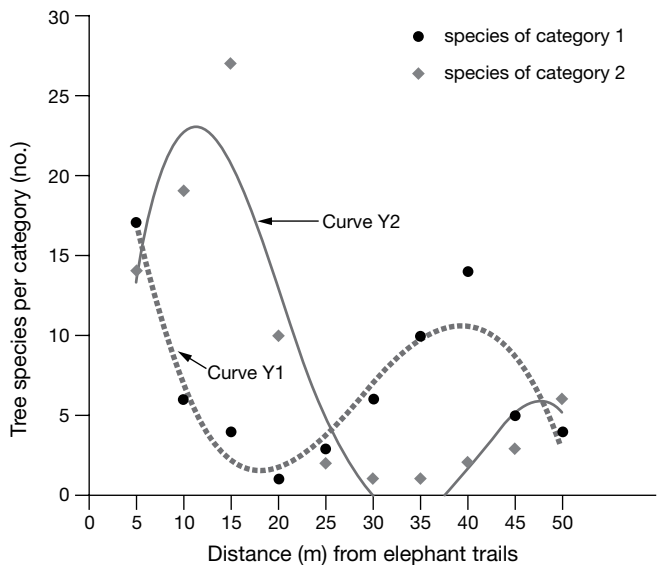


Figure 3. Plants eaten by elephants and their distribution near elephant trails in the Malebo region.

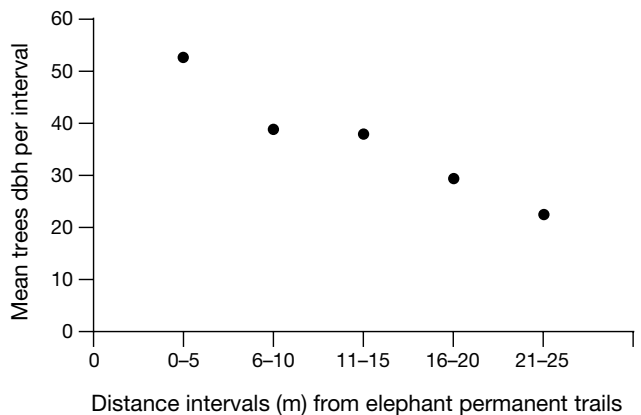


Figure 4. Mean tree diameter at breast height (dbh) per distance intervals from the centre of permanent elephant trails.

and near elephant trails. This would imply that seed density of elephant-dispersed fruits (and therefore their trees) decreases with distance from permanent elephant trails. For this category of species, it is known that elephants browse both saplings and trees close by their trails and usually kill them. These species’ survival probability is likely to increase with distance from elephant trails, as a consequence of decreased elephant activity with distance from trail.

Hence, this study shows that two competing gradients emerge with respect to the distribution of key fruit plant species and key leaf plant species with distance from elephant trails. The first gradient may

reflect seed deposition rate, which decreases with distance from trails, and the second is a mimic of tree survival probability, which increases with distance from trails. As suggested by Kent and Coker (1992), there are theoretical ecological optimum points (3 in 50 m from trails of Malebo; Figure 3) where these two gradients intersect. These points are where seed deposition (as depicted by the category 1 species), germination (depending on multiple factors not documented herein), and survival (as depicted by category 2 species) are maximized. Of course, the locations of these points depend on other factors, such as the effects of canopy, soil and water regimes.

The fact that there are three ecological optimum points indicates a swing in trail emplacements over time. This fact has been documented in earlier studies in Central Africa (Vanleeuwe and Gauthier-Hion 1998; Vanleeuwe et al. 1998) and does clearly demonstrate that trails are displaced over time to locations where optimal germination occurs and which subsequently produced greater concentrations of fruit trees. As time goes on, seed survival probability will increase in areas where trails were previously located as a consequence of a shift in elephant activity towards areas that previously had no fruiting trees. With the swing in trails emplacement over time, Figure 3 also shows that there is a positive feedback loop between elephants and the changes they induce in forest species composition. In this perspective, elephants and plants on which they feed may be thought of as a system of mutualistic exploitation through which elephants reintroduce key plant species and these species maintain elephant presence. In the absence of external disturbance by people, elephants and key plant species interaction is likely to be a self-maintaining mutualistic system (Kot 2001). However, as suggested by Crawley (1997), this self-maintaining mutualistic system is inherently related to elephant densities. Space plays a critical role in this system, as already indicated by Wilson (2000) and Jansen and De Roos (2001). With current trends in the conservation of forest elephants and given the mutualistic system of elephant–plant interactions, a potential consequence that might be expected at the landscape scale is that the fragmentation of habitat as a result of logging concessions, roads and increased human settlements will lead to a concentration of both elephants and mutualistic plant species in closed units (Kangwana 1995; Sam et al. 1998; Wasilwa 2003). This will result in elephants destroying the plant species on which they feed and physically destroying

other species within their ecosystems as was the case in other areas (Calenge et al. 2002), inevitably leading to heightened human–elephant conflicts (Tchamba 1995, 1996; Hoare 1999; Wasilwa 2003) and, in the long run, to the annihilation of elephants (Baxter 1996).

A more practical outcome of this study is learning that the two gradients meet again in 76 m from the centre of the elephant trails. This suggests that a 76-m width on each side of elephant trail (making a total of 152 m) would provide a minimum necessary strip to allow elephants to move freely from one point to other. Metrics defining ecological corridors are not easily available. Therefore, this result is critical, as the elephant population at Malebo is in a logging concession. Of course, this is just the minimum width on both sides of permanent trails and should not be taken as all that is needed for planning purposes, as there is need to account for other criteria that contribute to the definition of ecological corridors.

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