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Elephant damage to trees of wooded savanna in Zakouma National Park, Chad

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ABSTRACT. Damage caused by elephants was monitored in two woodland stands of Zakouma National Park (Chad) between February and March 1998. The *Acacia seyal* savanna was more severely damaged (29.8% of trees damaged of which 13.2% severely) than the Combretaceae savanna (26.5% of trees damaged of which only 4.2% severely). Nearly all severely damaged trees showed resprouts (respectively 86.8% and 88.5% in Combretaceae and *A. seyal* savannas). Both low damage rate and low mortality rate indicate that no serious 'elephant problem' occurred in Zakouma National Park. Elephants selected trees to damage according to species and height. Such selection also occurred for severe damage in *A. seyal* savanna, but only height affected severity of damage in Combretaceae savanna. In both savannas, the plots close to a water point were the most frequently damaged. In Combretaceae savanna, the distribution of damaged trees was clumped. On the other hand, spatial auto-correlation was not significant for the severity or the frequency of damage in *A. seyal* savanna. Neither tree density nor diversity of woody species affected the spatial patterns of damage or severe damage.

KEY WORDS: *Acacia seyal*, Combretaceae, damage, spatial distribution, Sudanian savanna, tree height, tree species

INTRODUCTION

Elephant (*Loxodonta africana* Blumenbach) populations strongly decreased in Africa during the 1980s, mostly because of poaching for ivory (Barnes 1996). Later, after intensive control of illegal shooting and prohibition of ivory sales, elephant populations built up, particularly in some sanctuaries. Thus, several national parks are now confronted with increased damage resulting from abundant elephant populations (Tchamba 1996). This damage may in some

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cases lead to local extinction of tree species (Buechner & Dawkins 1961, Laws 1970).

In Zakouma National Park of south-east Chad, authorities are showing increasing concern for this problem. They need information about the extent of elephant damage on the vegetation, which could be used in formulating a management policy. Most studies published on the 'elephant problem' are devoted to the selection of trees by elephant according to characteristics measured at two levels: (1) individual characteristics, such as tree size or species (see Owen-Smith 1988 for a review); (2) ecological and environmental factors influencing the spatial distribution of damage, such as distance of trees from water (Field & Ross 1976, Napier Bax & Sheldrick 1963) or density of trees (Buechner & Dawkins 1961, Wing & Buss 1970).

Selection by elephants according to tree species has been reported by several authors in other national parks (Anderson & Walker 1974, Croze 1974*b*, Jachmann & Bell 1985, Laws 1970). Likewise, the intensity of damage by elephants has been found to vary among species (Buechner & Dawkins 1961, Jachmann & Croes 1991, Leuthold 1977). Most studies have shown that elephants cause slight damage to short trees more often than expected by chance (Caughley 1976, Laws 1970, Wing & Buss 1970) and push over large trees from which leaves could not be reached (Caughley 1976, Croze 1974*a*, Jachmann & Bell 1985).

Some authors have put forth the assumption that the elephant increases the availability of its food by breaking or uprooting trees (Pennycuick 1979). The preferred habitat of the elephants being secondary forest (Eltringham 1977), opening the vegetation cover would be beneficial to them. In addition, Barnes (1996) stated that elephants browsing in tree-fall gaps often maintain the shrubby and herbaceous vegetation growth in a productive state, which is advantageous to browsing ungulates. The damage elephants cause to the vegetation cover therefore has an indirect effect on other ungulate populations, which has considerable implications for management authorities. From a spatial point of view, one can thus expect most severe damage in the densest zones of wooded savanna. Other authors have stressed the importance of the proximity of water points in determining elephant damage (Ben Shahar 1993, McShane 1987). In the zones close to water, both the frequency and severity of the damage are generally considerable.

This paper provides an assessment of the extent of the 'elephant problem' in two small parts of Zakouma National Park, and attempts to explain what determines both the occurrence and the severity of the damage. This was done by sampling fresh elephant damage during the second half of February (late dry season) on two 2.25-km^2 areas in the Park. Our aims were (1) to assess the effects of tree height and species on the frequency and severity of damage and (2) to quantify the influence of three factors on spatial patterns of damage: proximity to water, tree density and diversity in woody species.

METHODS

Study area

Zakouma National Park (ZNP), which covers more than 3000 km^2, is located in south-east Chad, in the Salamat Wildlife Reserve (Figure 1). The climate is of the Soudano–Sahelian type (Aubréville 1950): the wet season lasts for 6 mo (April until October). The influence of the rains on the vegetation is still perceptible 2 mo after the end of this period; a dry season of 4 mo finishes the cycle. There is a marked inter-annual variability in the precipitation (on average 700 mm). The rains feed many ponds or basins in the eastern part of the park, which hold water either temporarily or permanently. The vegetation of the park quickly changes from the north to the south in relation to the difference in rainfall. *Acacia seyal* Del. savanna is dominant in the north, but is replaced by Combretaceae savanna (*Combretum glutinosum* Perr.) in the central part. The southern part of the park is mainly made up of Caesalpiniaceae savanna (*Afzelia africana* Smith). The elephant population, estimated at 1500 in 1995 (Dejace 1995), is Chad's largest. Elephants are primarily concentrated in the eastern part of the park during the dry season, where the density is close to 1 individual km^{-2} according to aerial count (S.E.C.A. 1991). The elephants move into the neighbouring areas soon after the arrival of the first rains.

Data gathering

Sampling took place between February and March 1998. Two sampling zones were delimited so that they were as representative as possible of the two main savannas found in the eastern part of ZNP: one was located in Combretaceae savanna, the other in *A. seyal* savanna (Figure 1). A river skirts the south of the study area in Combretaceae savanna, whereas in the *A. seyal* savanna, the nearest water point is located approximately at 1 km to the north. In each zone, 50 plots of 803 m^2 (circular plots of 32 m diameter), separated by 250 m, were sampled in a systematic way. For each plot, marked out by a rope, we noted for each tree of more than 2 m in height: (1) species, (2) height estimated visually by the observers, (3) presence of fresh damage, which occurred after the rainy season (any indication of elephant browsing less than 3 mo old) and (4) presence of resprouts on damaged trees. Fresh damage was easily distinguished in the field because the damaged part of the tree was not exposed to fire, whereas both savannas burned at the beginning of the dry season. The severity of the damage was evaluated on a scale of six classes: (1) no damage due to elephants, (2) some damaged branches, (3) at least one main branch broken or damage to a significant part (50%) of the crown, (4) trunk broken above 1 m height, (5) trunk broken below 1 m, (6) tree uprooted. Trees in categories (4) to (6) were considered to be severely damaged, and trees in categories (2) and (3) were considered to be slightly damaged.

Data analysis

We were interested in two variables characterizing elephant damage: (1) the proportion of damaged trees in the plots and (2) the proportion of severe damage among the damaged trees in the plots.

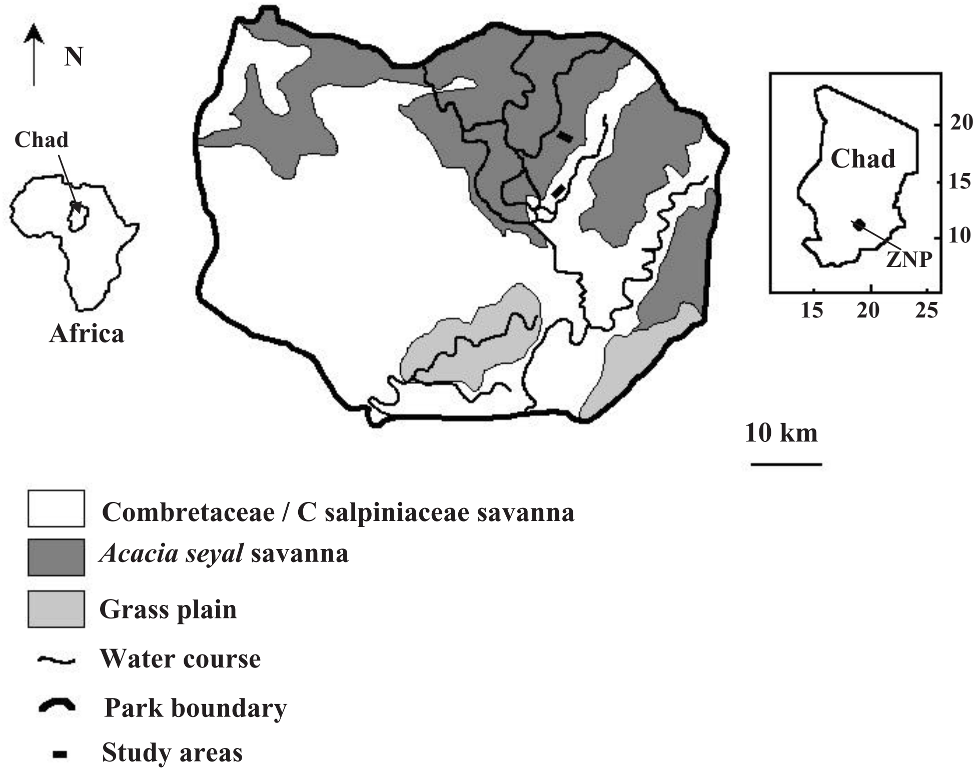

Figure 1. Location of the two study areas in Zakouma National Park (ZNP), Chad.

For both areas, we tested the effects of tree species and height on the probability of damage occurrence using ANOVA-like GLM procedures (Festa-Bianchet *et al.* 1998). We also looked for the effect of the sampling plot on the occurrence of damage. This effect was considered to be additive to the effects of tree species and height because the number of sampled trees was not large enough to allow the test of the interactions between sampling plot and the other factors. We repeated the same analyses for the occurrence of severe damage, restricting them to damaged trees.

The height of the trees taller than 2 m was rounded to the nearest metre. We kept for these analyses only the most abundant species *A. seyal*, *A. sieberiana* DC., *Balanites aegyptiaca* Del., *C. glutinosum*, and *Piliostigma reticulatum* DC. in Combretaceae-savanna plots. The following size classes of trees were used: (1) 2 m height, (2) 3 m, (3) 4 m, (4) 5–6 m and (5) > 6 m. In *A. seyal* savanna, we chose species *A. seyal*, *A. sieberiana*, *A. polyacantha* Willd. and *P. reticulatum* for analyses. Because numerous trees higher than 6 m were encountered in this area, the influence of height on damage was analysed to a finer degree than in the Combretaceae plots. The following size classes were used: (i) 2 m height, (ii) 3 m, (iii) 4 m, (iv) 5 m, (v) 6 m, (vi) 7 m, (vii) 8 m and (viii) > 8 m.

The spatial distribution of both damage and severe damage over the study areas was then investigated. We first computed the expected frequencies of damage from the fitted models in all sampling plots. Then, we considered whether the expected frequency of elephant damage was clumped in distribution. The existence of a possible spatial auto-correlation was tested with Geary's test (Chessel *et al.* 1997): let x be the expected frequency of either damage or severe damage. Two sampling plots having a common boundary were considered as neighbours. The variance of x was rewritten using the following formula:

$$Var\ (x) = \frac{1}{2} \sum_{(i)\ \text{neighbour}\ (j)}^{n} \frac{1}{n^2} (x_i - x_j)^2 + \frac{1}{2} \sum_{(i)\ \text{not neighbour}\ (j)}^{n} \frac{1}{n^2} (x_i - x_j)^2$$

Thus the 'total' variance of x may be considered as the sum of a 'local' component (i neighbour of j) and a 'global' component (i not neighbour of j). Let c be the ratio between the local variance and the total variance. Under the assumption that no spatial pattern of x occurs, c should be equal to 1. A ratio significantly lower than 1 indicates a clumped distribution of x (i.e. the local variance is lower than the total variance). The equality of c to 1 was tested using a permutation test (Chessel *et al.* 1997).

Using Spearman coefficients, we tested the correlation between the expected proportion of damage with three selected factors: (1) species diversity estimated by the Simpson index, (2) tree density, (3) distance from the plots to the nearest water point.

Scherrer (1984) noted that the Simpson diversity index is less biased than the Shannon index for samples of small size. This index was calculated as follows:

$$D = 1 - \sum_{k=1}^{R} \frac{n_k(n_k - 1)}{n(n - 1)}$$

Where R is the number of woody species present on the plot (i.e. richness) and n_k the number of trees of species k among n trees of the considered plot.

Generalized linear models were set up using GLIM software (Francis *et al.* 1993). Geary's tests were carried out using the ADE-4 program (Thioulouse *et al.* 1997).

RESULTS

In the Combretaceae savanna, there were 24 tree species with a mean tree density of 225 trees ha^{-1} (SE = 21.7). The *A. seyal* savanna had fewer tree species (only 11) but the mean tree density was higher (319 trees ha^{-1}, SE = 28.8).

Elephants damaged 26.5% and 29.8% of trees in the Combretaceae and *A. seyal* savanna respectively (4.2% and 13.2% severely damaged). Respectively 86.8% and 88.5% of the severely damaged trees showed the presence of resprouts in the Combretaceae and *A. seyal* savanna. On the other hand, in both savannas, all the slightly damaged trees showed the presence of resprouts. Considering the low percentage of severe damage, elephant did not cause high mortality of the trees (0.06% in Combretaceae and 1.5% in *A. seyal* savanna).

Combretaceae savanna

We examined 906 trees in this area (Figure 2). Damage occurred at different heights depending on the tree species (Table 1). All *P. reticulatum* and *A. sieberiana* taller than 6 m were damaged, whereas for *B. aegyptiaca* the probability of damage was low for tall trees (Figure 3a). The probability of severe damage did not vary according to the tree species. Most severe damage occurred on both short (2 m height) and tall trees (> 6 m, Figure 3b).

Only the frequency of damage was affected by the sampling plot. We used the estimates of the model to study the spatial pattern of the damage (Figure 5a). The expected probability of damage showed a highly clumped distribution ($c = 0.56$, $N = 43$, $P < 0.001$). There was a significant negative correlation between the expected probability of damage and the distance from the river (Table 2). The closer a plot was to the river, the higher the expected frequency of damage (Figure 6). On the other hand, neither tree density nor diversity affected this frequency. The spatial distribution of the severe damage was not investigated in Combretaceae savanna. Indeed, there was no significant effect of the sampling plot on this frequency (Table 1), i.e. the frequency of severe damage did not vary spatially.

Acacia seyal *savanna*

We sampled 1258 trees in this zone (Figure 2). Tree species, height and sampling plot affected the frequency of both damage and severe damage (Table 1). The most damaged species was *P. reticulatum* while the least damaged was *A. seyal* (Figure 4a). The three *Acacia* species all showed a high frequency of severe damage, *A. sieberiana* showing the highest frequency (Figure 4b). We found no severely damaged trees among the 45 sampled *P. reticulatum*. The trees 2 m and 6–7 m tall were more often damaged, and severe damage occurred more frequently on trees 6 m in height.

The sampling plot affected both the frequency of damage and the frequency of severe damage among damaged trees. The expected frequencies of both damage and severe damage were computed from these models to study the spatial pattern of the damage (Figure 5b, c). There was no significant spatial autocorrelation of the expected frequency of either damage ($c = 0.92$, $N = 48$, $P = 0.25$) or severe damage ($c = 0.81$, $N = 43$, $P = 0.07$). Neither tree density nor diversity affected this frequency (Table 2). As in Combretaceae savanna,

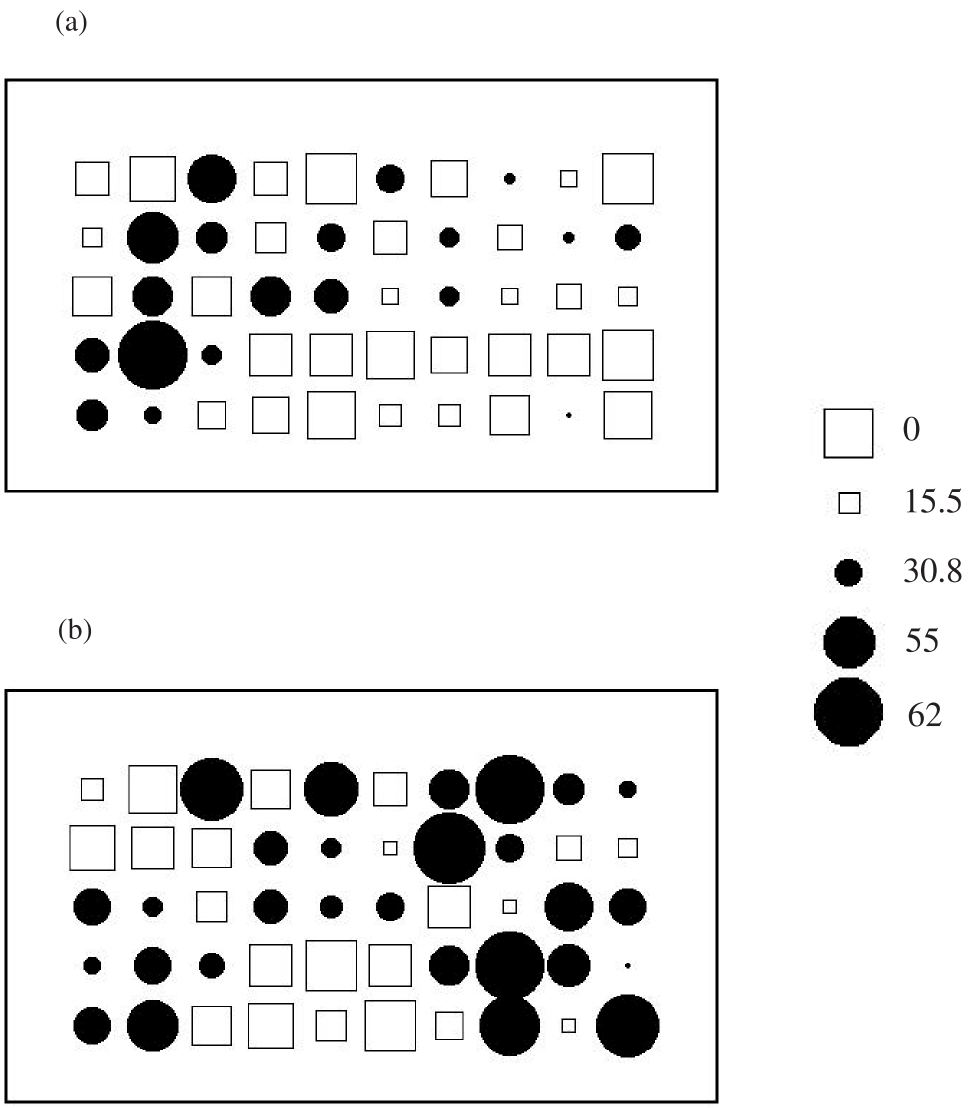

Figure 2. Map showing the number of sampled trees per plot (a) in Combretaceae savanna study area (906 sampled trees on all plots); (b) in *Acacia seyal* savanna study area (1258 sampled trees). Each area covered 1 km × 2.25 km.

the plots were damaged according to their distance from the nearest water point (Figure 6).

DISCUSSION

In both savanna types, the frequency of elephant damage varied according to tree species and height. These two factors also affected the probability of severe damage in *A. seyal* savanna whereas in Combretaceae savanna, only

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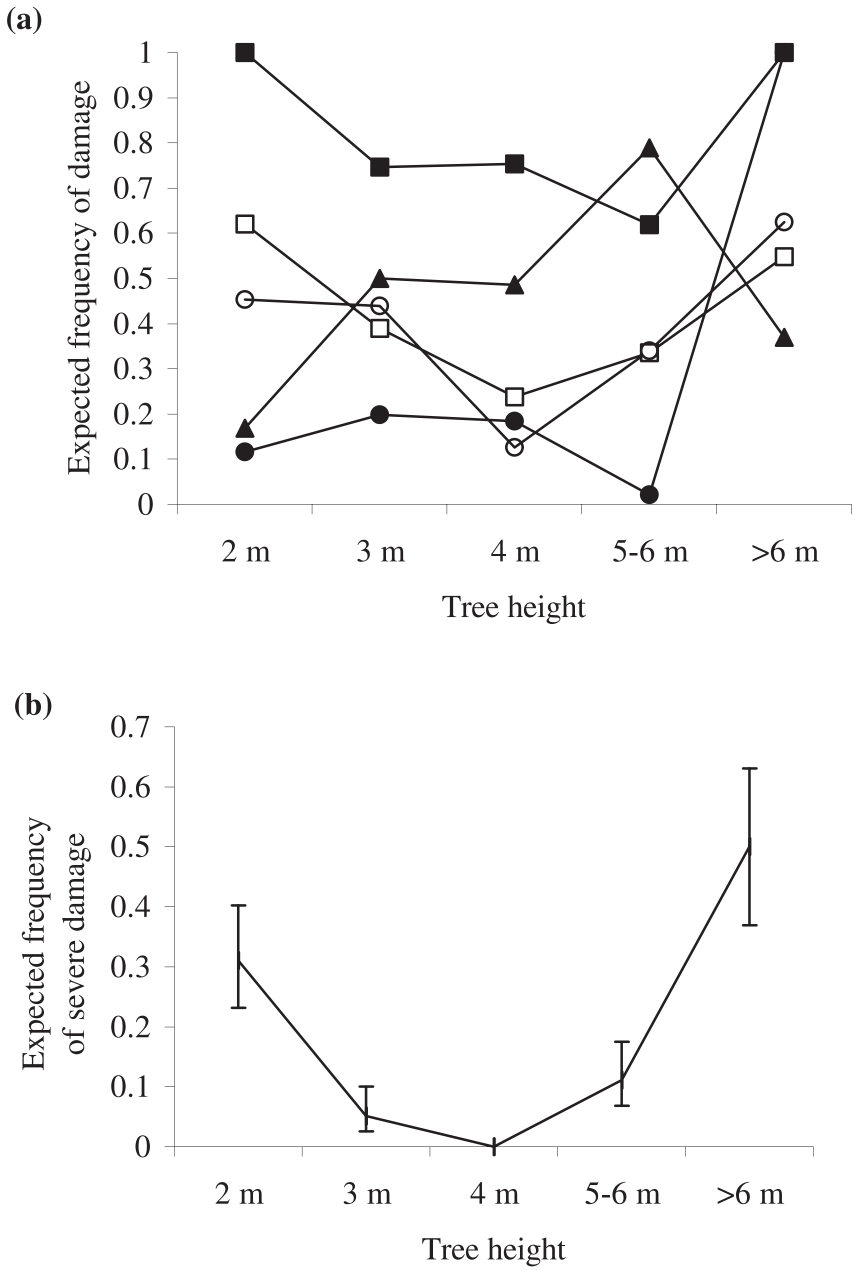

Figure 3. Expected frequency of (a) elephant damage in Combretaceae savanna according to tree species and tree height (Species: □ *Acacia seyal*, ■ *Acacia sieberiana*, ▲ *Balanites aegyptiaca*, ○ *Combretum glutinosum*, ● *Piliostigma reticulatum*); (b) severe damage among damaged trees in Combretaceae savanna according to tree height (± SE). The expected frequencies were computed from the model displayed in Table 1. The height of trees was rounded to the nearest metre. Data for sample plot 16 are illustrated.

Table 1. Results of likelihood-ratio tests in modelling effects of tree height, species, and sampling plot on probability of both occurrence of damage and occurrence of severe damage among damaged trees in Combretaceae savanna and in *A. seyal* savanna. Degrees of freedom are given in parentheses.

Effect		Combretaceae savanna		*Acacia seyal* savanna	
		Damage	Severe damage	Damage	Severe damage
Interactions between species and height	χ^2	46.0 (16)	16.4 (15)	20.6 (16)	21.5 (13)
	P	< 0.001	0.36	0.19	0.06
Species	χ^2	ND†	5.7 (4)	11.8 (3)	19.8 (3)
	P		0.22	0.008	< 0.001
Height	χ^2	ND†	10.1 (4)	23.7 (7)	17.5 (7)
	P		0.04	0.001	0.01
Sampling plot	χ^2	150 (45)	47.7 (37)	196 (48)	99.2 (42)
	P	< 0.001	0.11	< 0.001	< 0.001

†ND: these effects were not tested because of the significance of the interactions between species and height.

Table 2. Spearman coefficients between the expected frequency of either damage or severe damage and distance from the water, tree density, and diversity in woody species in Combretaceae savanna and in *Acacia seyal* savanna. Expected frequencies of damage were calculated from the model built in Table 1. Sample size is given in parentheses.

	Combretaceae savanna		*Acacia seyal* savanna			
	Expected frequency of damage†		Expected frequency of damage		Expected frequency of severe damage	
	R_S	P	R_S	P	R_S	P
Distance from water	−0.30 (46)	0.04	−0.34 (49)	0.02	−0.16 (43)	0.3
Simpson index	0.23 (44)	0.13	0.19 (48)	0.19	−0.13 (43)	0.40
Tree density	−0.12 (46)	0.42	−0.05 (49)	0.72	−0.24 (43)	0.12

† Correlation coefficients were not calculated for expected frequency of severe damage in Combretaceae savanna because no significant effect of the sampling plot occurred on this probability (Table 1).

the effect of tree height was significant. Elephant damage was not randomly distributed for *A. seyal* and Combretaceae habitats. The proportion of woody plants utilized by elephants increased with the proximity to water sources. 'Damage' showed a clumped distribution in Combretaceae savanna whereas 'severe damage' did not.

We sampled the damage caused during the dry season. We had no information about the damage caused during the wet season. However, many authors have highlighted that browsing is very low during the wet season, the elephants being mainly grazers (Field & Ross 1976, Napier Bax & Sheldrick 1963). In addition, elephants concentrate in the eastern part of ZNP in the dry season whereas their spatial distribution over the park is more uniform in the wet season (pers. obs.). Therefore, in our opinion, the sampled damage was representative of the damage caused during the whole year.

Extent of the 'elephant problem'

Although numerous trees were damaged by elephants, the proportion of severely damaged trees was relatively slight in Combretaceae (4.2%) and *A.*

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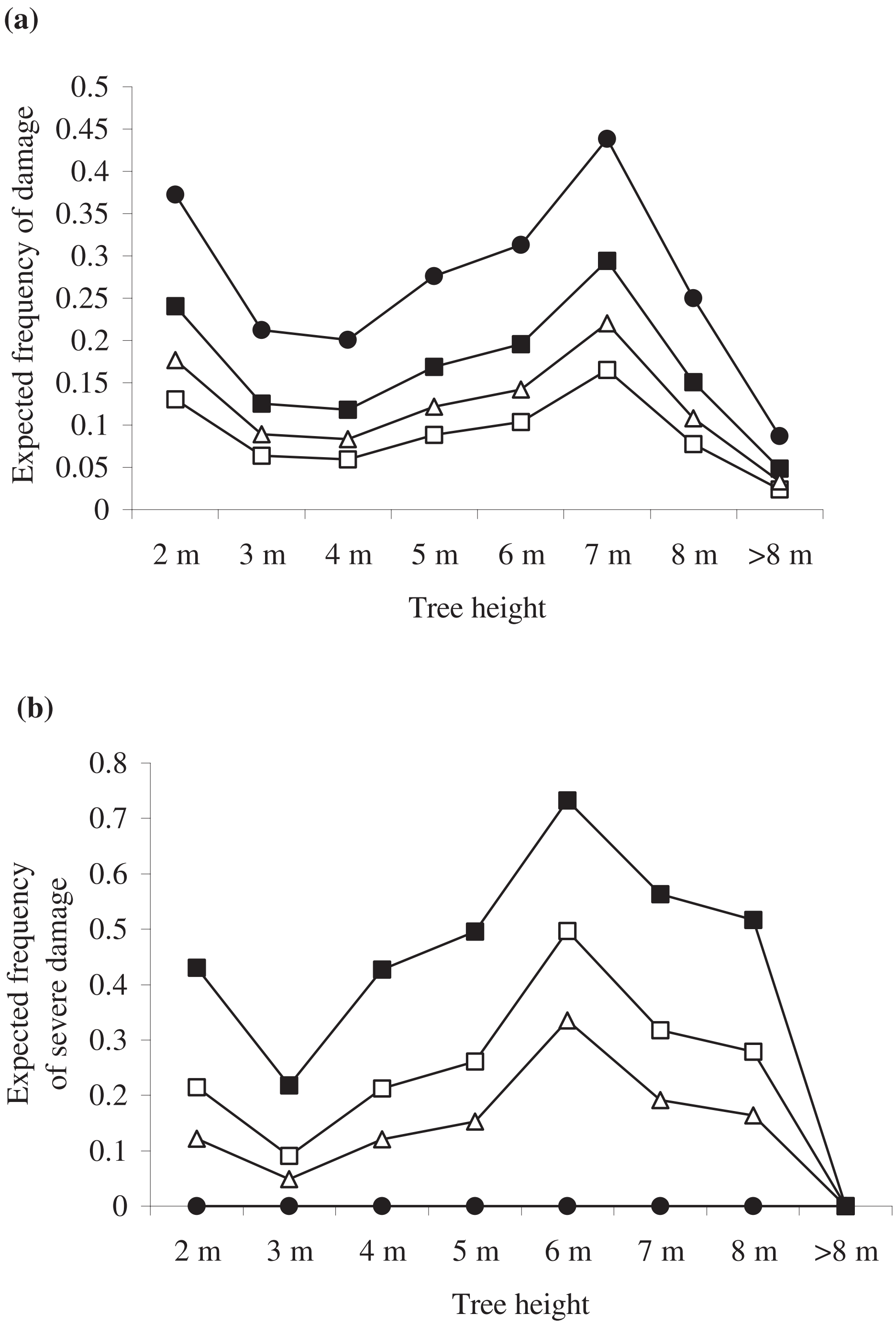

Figure 4. Expected frequencies of (a) elephant damage and (b) severe damage among damaged trees, in *A. seyal* savanna according to tree species and tree height. Species: □ *Acacia seyal*, ■ *A. sieberiana*, △ *A. polyacantha*, ● *Piliostigma reticulatum*. The expected frequencies were computed from the model displayed in Table 1. The height of trees was rounded to the nearest metre. Data for sample plot 1 are illustrated.

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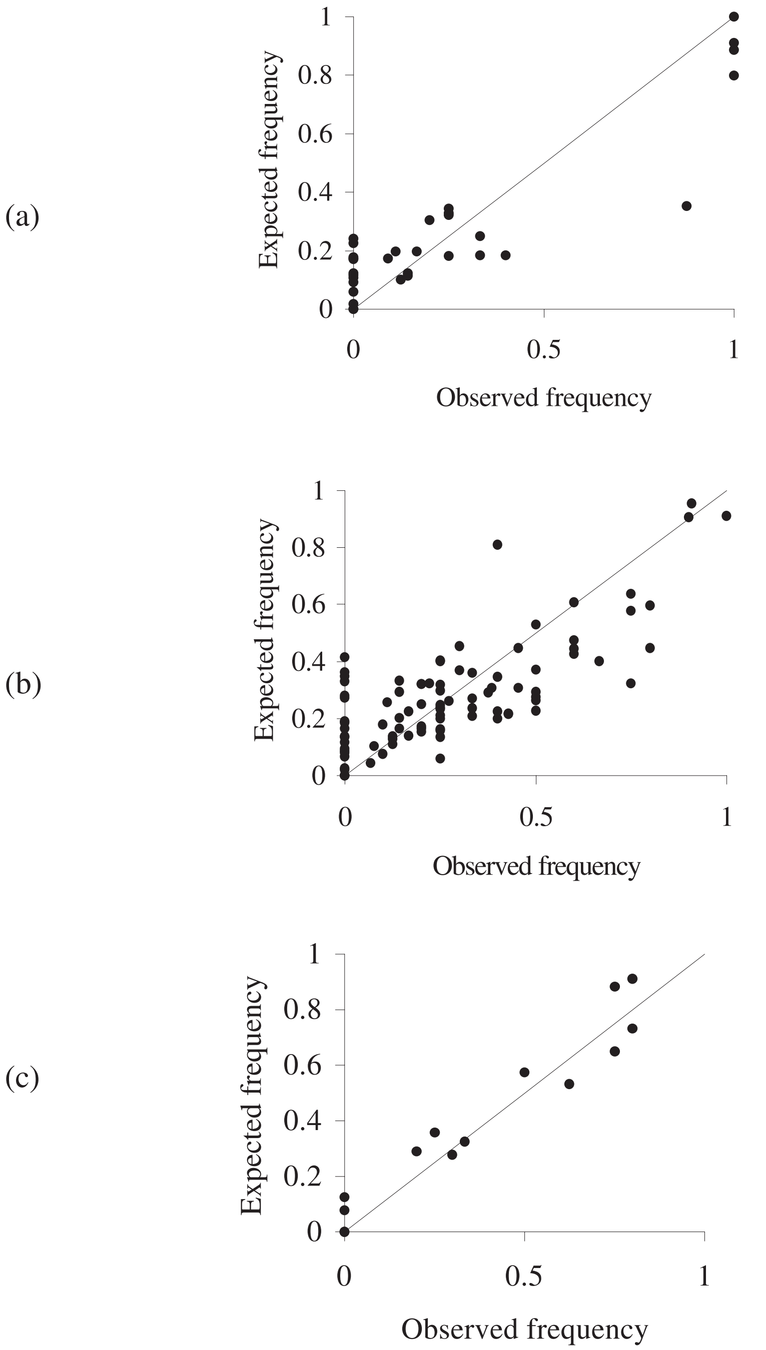

Figure 5. The expected frequencies of damage from the models fitted in Table 1 plotted against the observed frequencies computed in each class of tree height, tree species and sampling plot. Only the observed frequencies computed from classes containing at least four trees are displayed. (a) Model fitted to the frequency of damage in the Combretaceae savanna (correlation coefficient between the expected and observed frequencies: r = 0.91). (b) Model fitted to the frequency of damage in the *A. seyal* savanna (r = 0.767). (c) Model fitted to the frequency of severe damage in the *A. seyal* savanna (r = 0.967). The theoretical lines of equation: expected frequencies = observed frequencies are displayed.

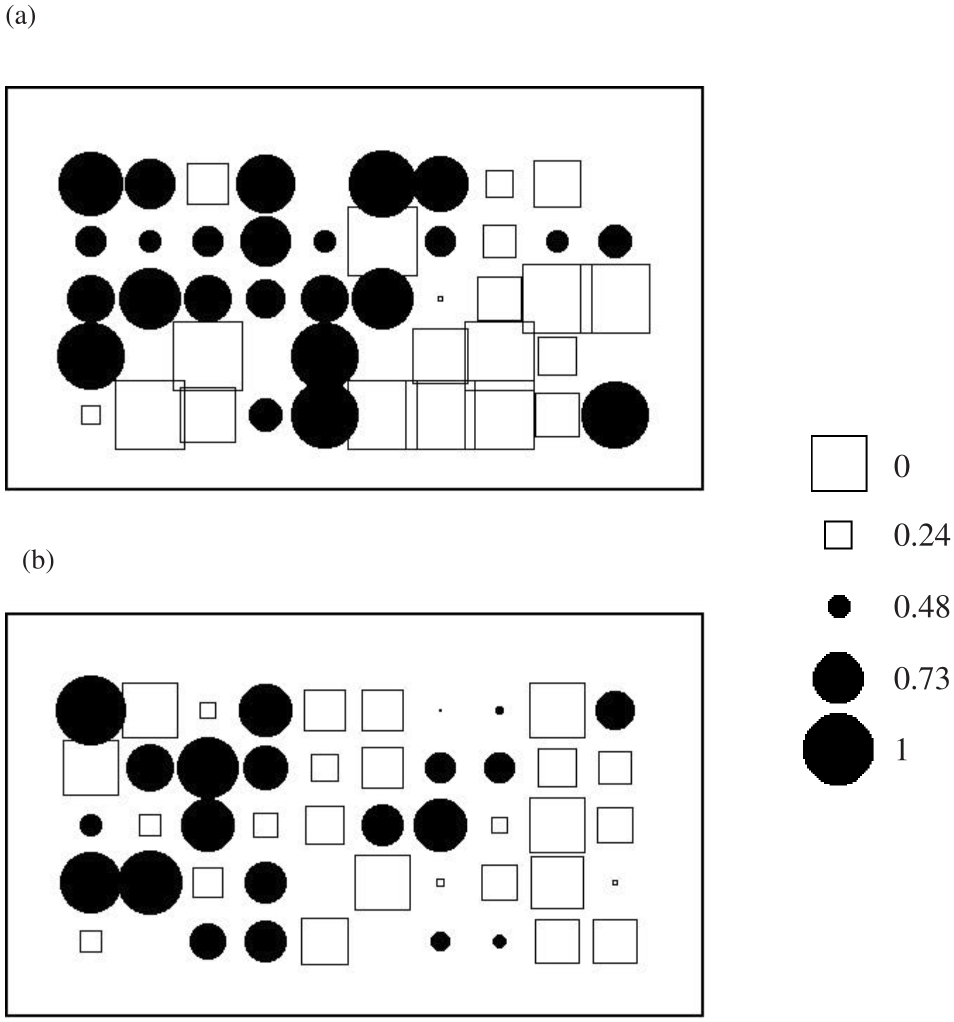

Figure 6. Maps of expected frequency of damage occurrence in both study areas (size: 1 km × 2.25 km). (a) Combretaceae savanna: a river skirted the plots located at the top of the sampled zone. (b) *Acacia seyal* savanna: a water point was located 1 km from the plots at the left of the sample zone.

seyal (13.2%) savanna. A patchy distribution of elephant damage was found in Combretaceae savanna. This kind of pattern has been previously noted in other environments (Ben Shahar 1993, Croze 1974*b*). Laws (1970) stated that the patchy distribution of damage is typical of the early stages of elephant damage problems. However, neither damage nor severe damage presented such a distribution in *A. seyal* savanna. Although we had no information about the tree regeneration, we think that the mortality of trees due to elephant (0.06% in Combretaceae plots and 1.5% in *A. seyal* plots) did not exceed their regeneration potential. Indeed, the mortality rate observed in our study area is relatively small in comparison with other areas, e.g. the Seronera, in the Serengeti

(Tanzania, 7% in the 1960s, Laws 1970), the Tsavo National Park (Kenya, 6% in 1968, Laws 1970), or the Rwenzori National Park (Uganda, 5.7% between 1968 and 1973, Eltringham 1980). These results suggest that the elephants do not yet constitute a threat for the woody vegetation in ZNP, at least in the areas represented by these plots.

Selection of trees according to height and species

Most previous studies have shown that damage caused by elephants is directly related to their feeding behaviour (Croze 1974*a*, Owen-Smith 1988, Wing & Buss 1970). Slight damage generally corresponds to direct effects of elephant browsing while severe damage occurs when elephants try to obtain leaves in the upper parts of the tree (Croze 1974*a*, Wing & Buss 1970).In some instances, tree-barking can lead to severe damage (Buechner & Dawkins 1961).

Several authors have reported that elephants show a feeding preference for short accessible trees, which may inhibit regeneration (see Owen-Smith 1988 for a review). In sampling plots of *A. seyal* savanna, we found that elephants selected short trees (2 m). Larger trees (> 6 m) were also frequently damaged, but they often presented severe damage (Figures 3 and 4). Owen-Smith (1988) noted that the maximum feeding reach of the elephant with the trunk is 6 m. This author stated that trees taller than 6 m may be pushed over, bringing higher branches within reach. By feeding from short trees and damaging large ones, elephants continuously remove the woodland cover (Jachmann & Croes 1991, Laws 1970, Wing & Buss 1970). Except for *P. reticulatum* (only 3.6% of sampled trees), all trees belonged to the genus *Acacia* in the *A. seyal* savanna. This may explain why elephant damage occurred at the same height whatever the tree species in the *A. seyal* savanna, whereas in the Combretaceae savanna, height of tree damage varied with the species.

Stokke (1999) and Stokke & du Toit (2000) highlighted sexual differences in impact of elephant on trees in Botswana. In their studies, females were more selective in the choice of feeding plots and trees than males (e.g. selection of different browsing height, different target species). We were unable to identify the sex of the elephants that damaged the trees in the field, precluding the test of this hypothesis in our study. Numerous factors may influence the choice of elephants for particular tree species (e.g. in crown type, rooting system and wood resistance; Croze 1974*b*). Owing to this, it is difficult to propose a general pattern of vulnerability of trees of ZNP to elephant damage.

Spatial pattern of damage

We found a highly significant variation of the frequency of damage among the sampling plots in both areas. Spatial variation of damage reflects the selection of the feeding places by the elephant. According to the literature, this selection may be due to several factors, such as the distance of plots from water (Field & Ross 1976, Napier Bax & Sheldrick 1963), tree density (Buechner &

Dawkins 1961, Wing & Buss 1970), plant species diversity (Ben Shahar 1993) and soil composition (Owen-Smith 1988). In our study, the distance from the water was a prevalent factor in the distribution of damage in both savannas (Figure 5). The reduced availability of water during the dry season forced the elephants to stay close to water points, and led to a major impact on the neighbouring trees (Owen-Smith 1988). On the other hand, the severity of damage among damaged trees was not influenced by the proximity of the water. The low frequency of severe damage near the water points seems to indicate that the tree foliage in the surroundings was still accessible and abundant enough to sustain the number of elephants present.

No significant effect of diversity appeared on damage or severe damage in both savannas. Elephant did not cause more damage to the plots where the different tree species occurred in more equal proportions than the plots where one species was dominant. Although some authors highlighted that elephants caused most frequent damage to isolated trees and zones with low tree cover (Buechner & Dawkins 1961, Wing & Buss 1970) this was not the case in our study in which there was no effect of tree density on either frequency or severity of damage. However, these results should be taken with caution. It is likely that we could not detect significant correlations because the variability of both densities and diversities was too low in the two sites. Although the number of sampled trees was high (a total of 2164 trees), the correlation was calculated with few sampling plots (< 50 in both savannas), and each study site covered only 2.25 km^2, a small area in comparison to the whole park (3000 km^2, Figure 1). The sampling zones were chosen in such a way that the conditions encountered in these areas (structure of the vegetation, density of trees, proximity of water points, species diversity) were as representative as possible of the average conditions encountered in the eastern part of the park. However, because of the small size of these areas, the full range of variation of the tested factors (density and diversity of trees, distance from water) have not been captured, which is the main limit to our study of the spatial pattern of damage.

Management implications

Our study was carried out on the damage caused by elephant during only one dry season. The impact of elephant on the woody vegetation was thus assessed at a small temporal scale, and the degree of damage recorded may be not typical of elephant damage over a period of years. Indeed, the 'elephant problem' may be considerably affected by factors such as poaching (Laws 1970) or drought (Leuthold 1977), factors which may vary significantly among years. We therefore recommend monitoring the variation of interactions between elephant populations and vegetation, although no serious 'elephant problem' seems to exist presently in ZNP.

The development of a biological indicator (Groupe Chevreuil 1996) based on the level of damage and severe damage would be a relevant tool for this type of monitoring. Our results may provide a basis for the development of such an index. The scheme should measure widely distributed plots rather than two sets of localized plots. We showed that elephant damage may present a patchy distribution, so the distance between sampling plots should be large enough to capture the full range of variation in tree damage, and to ensure independence among plots. Because level of damage may vary in space, the same plots should be sampled each year. The location of the sampled plots could be restricted to the eastern part of the park, where water is permanently available. This would allow damage to be monitored in the most threatened areas of the park. Satisfactory management of the elephant problem in ZNP will require detailed knowledge of the trends affecting damage and severe damage by elephant. Further studies should be carried out to develop a precise monitoring protocol.

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