Functional relationship between crop raiding by the savannah elephant and habitat variables of the Red Volta Valley in north-eastern Ghana

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Abstract

We investigated the degree to which crop raiding by elephants in the Red Volta Valley is a function of: the density and diversity of their natural browse, extent of degradation of their habitat, and proximity of crop enclaves to the nearest forest boundary. We assessed 50 m x 5 m quadrats for browse and for agents of degradation (m^2 of quadrat area clear-felled, burned, and surface mined), and we adopted records of crop-raiding rates in 2000–2002 for correlation with habitat variables. We estimated the distance of affected enclaves from the forest, river and village using GIS; the total size of crop fields in a locale provided an estimate of the extent of cultivation. Using correlation and regression analysis, we examined for each locale the association between rate of crop-raiding incidents and the density and diversity of browse, size of crop fields, and distance of affected enclaves from the forest, river and village. We used a stepwise regression model to establish a functional relationship between crop raiding and the enumerated habitat variables. Second-order jackknife and Michaelis-Menten asymptotic estimators showed that the density and diversity of browse was near optimum. About 99% of the vegetation area sampled was burned, and 0.35 ha of vegetation was clear-felled for firewood. No evidence of mining was recorded. There was a significant inverse association between crop raiding and distance of affected enclaves from the forest, while the association between crop raiding and density and diversity of browse and the extent of degradation were not significant. A stepwise regression model gave a functional relationship between the observed rate of crop-raiding incidents and proximity of crop enclaves to the forest as $Y = 25.105 + 3.2 - 9.73X$ (Y = rate of crop-raiding incidents and X the distance from enclave to the forest boundary). Contrary to speculation, crop raiding in the study area is not influenced by the status of browse, extent of degradation or size of cultivated fields. Thus, mitigation measures should include relocating farms away from forest reserves, while measures aimed at reducing the density of farms or replanting of the forest should be de-emphasized as they will not necessarily reduce crop raiding.

Additional key words: locale, enclave

Résumé

Nous avons étudié la mesure dans laquelle la maraude des cultures par les éléphants dans la vallée de la Volta Rouge dépend de: la densité et la diversité de leur broutage naturel, l'ampleur de la dégradation de leur habitat et la proximité des enclaves de cultures à la limite de la forêt la plus proche. Nous avons évalué des quadrats de 50m x 5m pour le broutage et les agents de dégradation (m^2 de superficie de quadrats coupés à blanc, brûlés, et la surface exploitée par les mines), et nous avons adopté des données des taux de maraude des cultures de 2000 à 2002 pour la corrélation avec les variables d'habitat. Nous avons estimé la distance des enclaves affectées à partir de la forêt, de la rivière et du village en utilisant le SIG. La superficie totale des champs cultivés dans un endroit a donné une estimation de l'étendue des cultures. En utilisant la corrélation et l'analyse de régression, nous avons examiné pour chaque endroit l'association entre le taux d'incidents de maraude des cultures et la densité et la diversité du broutage, la superficie des champs cultivés, et la distance des enclaves affectées à partir de la forêt, de la rivière et du village. Nous avons utilisé un modèle de régression par étapes pour établir une relation fonctionnelle entre la maraude des cultures et les variables énumérés de l'habitat. Des estimateurs asymptotiques de second ordre de Jackknife et de Michaelis-Menten ont montré que la densité et la diversité du broutage étaient quasi optimales. Environ 99% de la zone couverte de végétation échantillonnée avait été brûlée, et 0,35ha de végétation avait été coupée à blanc pour le bois de chauffage. Aucune preuve de l'exploitation minière n'a été enregistrée. Il y avait une association inverse significative entre la maraude des cultures et la distance des enclaves affectées à partir de la forêt, tandis que l'association entre la maraude des cultures, la densité et la diversité du broutage, et l'ampleur de la dégradation, n'étaient pas significatifs. Un modèle de régression par étapes a donné une relation fonctionnelle entre le taux observé d'incidents de maraude des cultures et la proximité des enclaves cultivées de la forêt de $Y = 25.105 + 3.2 - 9.73X$ (Y = taux d'incidents de maraude des cultures, et X la distance de l'enclave à la limite de la forêt). Contrairement aux spéculations, la maraude des cultures dans la zone d'étude n'est pas influencée par l'état du broutage, l'ampleur de la dégradation ou la superficie des champs cultivés. Ainsi, les mesures d'atténuation devraient inclure la délocalisation des fermes loin des réserves forestières, tandis que les mesures visant à réduire la densité des exploitations agricoles ou la replantation de la forêt sont moins importantes car elles ne réduiront pas nécessairement la maraude des cultures.

Mots clés supplémentaires: endroit, enclave

Introduction

The extent of natural browse—expressed in terms of density, diversity and structure of woody vegetation—is one of the key habitat requirements by elephants (McShane 1987; Sukumar 1990, 2003). A large proportion of the elephant's natural diet is from browse. Browse forms over 50% of their diet (Bell 1985) and elephants need to take in 4–6% of their weight in browse each day. Barnes et al. (1995) observed a positive correlation between elephant crop raiding and habitat status and reported that increased crop-raiding levels are directly related to habitat degradation. In localities where natural vegetation is cleared for crops or burned, fewer browse resources are available (Okoumassou et al. 1998; Sam et al. 1998) and elephants are thought to seek alternative sources of food within crop fields (Sukumar 2003).

The spread of agriculture is a major source of habitat degradation (Hoare & Du Toit 1999). As human population grows, the need for more farmland has caused further degradation of elephant habitat and shifting of crop fields further into areas previously occupied by elephants (Sam et al. 1998; Hoare & Du Toit 1999; Sukumar 2003). As a result incidents of elephant crop raiding have intensified where crop fields are widespread and where enclaves of cultivation have shifted closer into the elephants' range (Sukumar 1990, 2003; Oppong et al. 2008).

Uncontrolled and recurrent incidents of wildfire are said to pose a great constraint on habitat and resource availability to wildlife in some savannah ecosystems (Oteng-Yeboah & Asase 2001). In the Red Volta Valley, fire is not controlled or used as a management tool as prescribed for wildlife protected areas in the climaxed savannahs (McShane 1987; Spinage 1994). Burning vegetation is common even at the latter part of the dry season (Ayigsi 1997; NCRC 1999, 2000) when fires are most intense and thus kill rather than support the growth of seedlings in the recruitment class (Oteng-Yeboah & Asase 2001). This type of burning could have an adverse impact on browse and cover for elephants.

Artisanal mining in the Red Volta Valley is common in the dry season. Two methods are commonly used: pit (or surface) mining, and alluvial mining. In the former, local artisans use hoes and other hand-held implements to dig up the soil and process it for gold ore. In the process vegetation cover is removed and several pits filled with water are left behind. Alluvial mining involves collecting alluvial silt from the riverbed. The practice is sporadic along sections of the river during the dry season.

Elephants in the Red Volta Valley use the forest reserves as a natural refuge and raid crops in fields adjacent to the reserves (Jachmann 1992; Stalmans & Anderson 1992; Sam 1994; Okoumassou et al. 1998). However, knowledge of the key variables that influence the rate of crop-raiding incidents is scanty and speculative. Previous workers have suggested that the rate of elephant crop-raiding incidents could be associated with degradation of the elephant's natural habitat and to dwindling browse resources (Ayigsi 1997; Okoumassou et al. 1998; Sam et al. 1998; Adjewodah et al. 2003; Adjewodah 2004). Considering the socio-economic effects of crop damage on the local communities and their implications for the conservation of elephants in the Red Volta Valley, a rigorous analysis of the factors that influence elephant crop raiding in the area is necessary.

In this paper, we examine the association between elephant crop raiding and some key variables in the Red Volta Valley of Ghana. The objectives of the study were to 1) identify from a set of potential cause factors variables that might influence local elephant crop raiding and 2) develop a cost-effective statistical model for determining the rate of elephant crop-raiding incidents.

Study area

The Red Volta Valley comprises a network of adjoining forest reserves—Red Volta East, Red Volta West, Gambaga Scarp East, Gambaga Scarp West, and Morago East Forest Reserves—and adjacent off-reserve woodlands, fallow land and crop fields (latitude 10°30' to 11°00' N, longitude 0°45' to 0°00' W). The Red Volta Valley falls within Talensi–Nabdam, Bawku West and Bongo Districts of the Upper East Region of Ghana (Fig. 1). The vegetation is savannah woodland and consists of deciduous short trees and shrubs (Oteng-Yeboah 2001; Barnes et al. 2006b). The banks of the Red Volta, White Volta and Morago rivers are lined with gallery forest.

The forest reserves harbour transboundary elephant migratory routes that link the Red Volta Valley to Kabore–Tambi National Park and Nazinga Game Ranch (in south central Burkina Faso), and to Fosse-aux-Lions National Park in northern Togo (Sebogo & Barnes 2003; Barnes et al. 2006a). About 1,049 km^2 of the Red Volta Valley comprising the above forest reserves and adjoining fallow woodlands is uninhabited and thus potentially available for elephants.

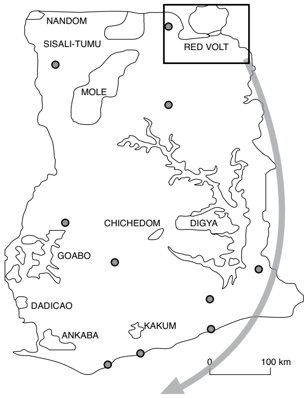
The Forestry Services Division of the Forestry Commission manages the Red Volta forest reserves to protect watersheds. Wildlife management is not a major priority. The area experiences two climatic seasons: dry and wet. The wet season extends from May to November and the dry season from December to April. Mean annual rainfall is about 896 mm with an annual peak in July, August and September. The dry period is characterized by desiccating north-east winds known as harmattan, which bring dust and haze from the Sahara Desert. The dry season is also characterized by a high incidence of wildfires between December and February, and during this period wildfire damage to vegetation extends over a large portion of the study area (Adjewodah 2004).

The main economic activity of the people is rainfed subsistence agriculture. Farm sizes are small and range from 0.1 ha to 7.3 ha (Adjewodah et al. 2005). Crops common to the area include millet, maize and groundnut. The Red Volta Valley has been discussed in further detail elsewhere (Sam et al. 1998; Adjewodah et al. 2005).

Materials and methods

With the help of a topographical map, we divided the uninhabited natural area of the Red Volta Valley into 18 locales. Each of the locales measured 7.63 km x 7.63 km and encompassed the gallery forest along the Red Volta, White Volta and Morago rivers, and adjoining savannah fallow lands. We randomly selected six locales—Bongo, Buing, Kusanaba, Morago, Sakote and Tilli—as the focal areas of the study. The selected locales were put into grids at 5-minute intervals (on both the longitudinal and latitudinal axes), resulting in sub-units referred to as cells (Fig. 2). A locale consisted of about 18 cells each measuring 1.8 km x 1.8 km. We randomly selected 10 cells from each locale. We delineated a 1,000-m-long transect within each cell. We determined the terminal coordinates of each transect from a field map beforehand, and field groups used a GPS, a compass and tape measure to follow the transect line. Using the tape measure, we measured 2.5 m on both sides of the transect line to create 50 m x 5 m segments (quadrats) along each transect. There were 20 adjoining segments or quadrats along each transect. We surveyed 52 transects instead of 60, as 8 of the selected transects fell in inaccessible terrain and were not surveyed.

To quantitatively describe habitat available to and used by elephants, we enumerated the vegetation in 4 of the 20 quadrats, that is, in every 5th segment along the 1000-m transect (Oteng-Yeboah 2001**).** We tallied trees above diameter at breast height (dbh) by species and diameter classes, and tallied shrubs over 30 cm tall by species. Trees and shrubs selectively browsed by elephants of the neighbouring Kabore-Tambi National Park (Spinage 1985) provided the basis for identifying browse species among the enumerated plants.



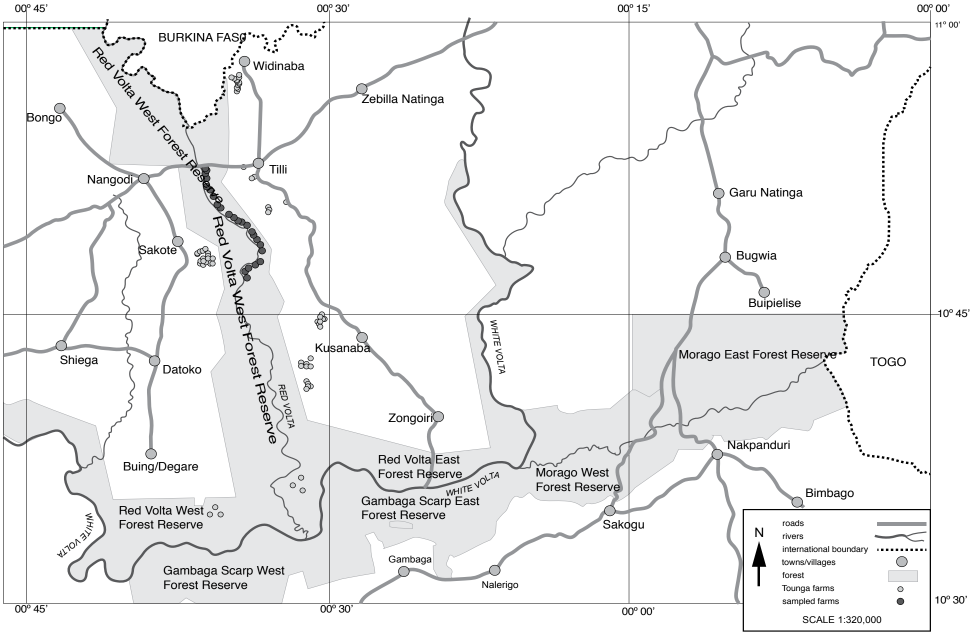


Figure 1. Location of the Red Volta Valley in north-eastern Ghana and the study area.

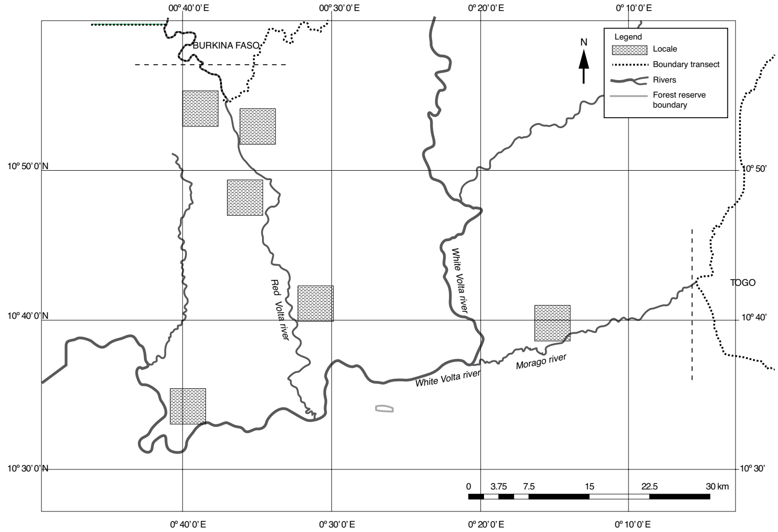


Figure 2. The Red Volta ecosystem showing the research locales and transects.

For extent of degradation, we measured the cross-sectional area (in m^2) of mining pits within each of the selected 50 m x 5 m vegetation quadrats and took size measurements (in m^2) of the area of the quadrat clear-felled for firewood and the area (in m^2) affected by wildfire. We obtained distance measurements of enclaves of cultivation to the nearest forest boundary by estimating the mean distance of a random sample of farms from the reserve boundary. We also measured the distances of enclaves of cultivation to the nearest village (human settlement) and to the Red Volta River using GIS. We adopted the size of crop field recorded and rate of elephant crop-raiding incidents reported in 2000–2002 (Adjewodah et al. 2005) for correlation with the extent of browse and the other habitat variables.

We estimated browse using the density of woody stem and Michaelis-Menten species diversity measurements (Gotelli & Colwell 2001; Sukumar 2003). We used the statistical programme EstimateS (Colwell 2005) for rigorous extrapolation and interpolations of the empirical sample-based dataset, and computed sample-based rarefaction curves of the diversity and density of browse by repeated resampling (Gotelli & Colwell 2001). We calculated the second-order jackknife and Michaelis-Menten species richness and diversity indices for each locale. ANOVA was used to compare the density of browse and non-browse species among locales, and the independent *t*-test to compare density of browse species with the density of all other enumerated species. Species diversity indices including observed species richness, second-order jackknife, and Michaelis-Menten estimators (Gotelli & Colwell 2001) provided a test of homogeneity or otherwise of the habitat in the six locales in relation to distribution and diversity of woody plants.

We used Pearson moment product correlation test (Zar 1999) to determine the association between browse density and the rate of elephant crop-raiding incidents. Standard linear regression was used to determine the type and strength of the relationship between rate of elephant crop-raiding incidents and distance of affected enclaves from the nearest forest boundary. Spearman correlation was used to estimate the association between the rate of incidents and size of crop field.

We used Statistical Programme for Social Sciences (SPSS Inc. 2007) to build a model of the rate of crop-raiding incidents following the Stepwise Strategy (Dytham 2003). The statistical package identified the key factor(s) of rate of crop raiding (dependent variable) in a locale from a set of habitat variables: 1) size of crop field cultivated in the locale, 2) density of woody stem, 3) density of browse, 4) distance of enclave from the forest boundary, 5) distance of enclave from the Red Volta River, and 6) distance of the locale's enclave from settlement. The analysis produced a function between crop raiding and the selected cause factor(s). We added and subtracted the variables listed above in steps using only those combinations and slopes that generated a better fit (Dytham 2003). This allowed a stepwise algorithm to choose the most important factor(s) and to select a 'best' model for predicting the rate of elephant crop raiding in the study area. We used ANOVA to test the acceptability of the model from a statistical perspective, and used a histogram and normality plot of the residuals to check the assumption of normality of the error term. We based the model on the equation below (Zar 1999):

$$Y_j = a + b_1X_{1j} + b_2X_{2j} + b_3X_{3j} + \dots + b_mX_{mj} + e_j$$

where

Y_j = number of incidents in the jth locale

a = the intercept (the value of Y when X_1, X_2 and X_3 are zero)

m = number of predictors (or independent variables)

b_1 = correlation coefficient of the 1st variable

X_{1j} = denotes the jth observation of variable X_1

e_j = is the error in the observed value for the jth case

Results

A total of 12,948 trees and shrubs were enumerated during the study. About 16% ($n = 67$) of the species recorded were categorized as elephant browse based on a list of browse species compiled by Spinage (1985) (Table 1). All the browse species were present in each of the locales, except for *Borassus aethiopum,* which was recorded only in Sakote (Table 1).

The density of browse species was not significantly different between locales (ANOVA: $F_{5,66} = 0.52$, $P = 0.774$, homogeneity of variances, $P = 0.487$). When the density of all enumerated plants was compared (Table 2), ANOVA indicates that neither was the density of plants in general significantly different between the locales ($F_{5,46} = 0.44$, $P = 0.818$).

To further explore the data for any variations among locales, the density of browse species was compared with the density of all other enumerated species to determine relative abundance (Table 3). In this instance

Table 1. Density and distribution of elephant browse in the Red Volta Valley

Browse species	Density (no. of stems/m^2)					
	Bongo	Buing	Kusanaba	Morago	Sakote	Tilli
Acacia hockii	0.288	0.042	0.252	0.093	0.207	0.093
Acacia nilotica	0.372	0.002	0.218	0.013	0.464	0.013
Borassus aethiopum	0.000	0.000	0.000	0.000	0.001	0.000
Combretum sp.	0.264	0.129	0.473	0.231	0.126	0.231
Detarium microcarpum	0.057	0.652	0.070	0.032	0.006	0.032
Gardenia ternifolia	0.082	0.032	0.013	0.017	0.010	0.017
Lannea acida	0.011	0.004	0.006	0.005	0.002	0.005
Mitragyna sp.	0.028	0.021	0.001	0.000	0.00	0.013
Piliostigma thonningii	0.050	0.018	0.117	0.042	0.019	0.042
Pteleopsis suberosa	0.155	0.351	0.137	0.156	0.142	0.156
Terminalia macroptera	0.235	0.218	0.196	0.288	0.198	0.288
Vitellaria paradoxa	0.098	0.136	0.161	0.073	0.087	0.073

Table 2. Density of woody plants enumerated in six localities of the Red Volta Valley

Locale	Density (no. of stems/m^2)									
	T_1	T_2	T_3	T_4	T_5	T_6	T_7	T_8	T_9	T_{10}
Bongo	0.381	0.296	0.235	0.340	0.357	0.251	0.153	0.293	0.092	–
Buing	0.195	0.195	0.263	0.400	0.367	0.289	0.326	0.325	0.268	0.052
Kusanaba	0.327	0.244	0.336	0.257	0.233	0.187	0.131	0.233	0.188	0.152
Morago	0.389	0.290	0.188	0.174	0.085	0.362	0.143	–	–	–
Sakote	0.328	0.450	0.340	0.060	0.340	0.115	–	–	–	–
Tilli	0.227	0.249	0.205	0.334	0.408	0.061	0.202	0.238	0.138	0.162

T_y = transect y; – = missing data

Table 3. Number of stems per m^2 of both browse and other woody plants in six locales in the Red Volta Valley

	Density (no. of stems/m^2)		
Locale	Non-browse woody plants (range)	Non-browse woody plants (mean)	Browse (mean)
Bongo	0.09–0.38	0.266	0.137
Buing	0.05–0.40	0.268	0.134
Kusanaba	0.15–0.33	0.229	0.137
Morago	0.14–0.39	0.233	0.079
Sakote	0.06–0.45	0.272	0.105
Tilli	0.06–0.41	0.222	0.080

independent *t*-test indicates there is a significant difference between browse and non-browse species, and thus affirmed the dominance of the former group of plants (Levene's test of equality of variances: $P > 0.05$; *t*-test, df = 10, $P < 0.05$).

Observed species richness (S_{ob}), second-order jackknife, and Michaelis-Menten estimators were computed (Table 4) and compared for differences in diversity of species. The Kruskal-Wallis test indicates homogeneity of the habitat in relation to plant diversity (species richness: chi-square = 5, $P > 0.05$; second-order jackknife: $P > 0.05$; Michaelis-Menten: chi-square = 5, $P > 0.05$).

The observed species diversity (richness) within locales was compared with the Michaelis-Menten asymptotic estimate. An independent sample *t*-test showed no significant difference between the observed species richness (S_{ob}) and the projected Michaelis-Menten asymptote (Levene's test of equality of variances: $P > 0.05$, *t*-test for equality of means $P = 0.198$). Species rarefaction curves (based on a series of 100 randomizations) showed close similarity of the vegetation within the locales (Fig. 3).

Table 4. Composition and diversity estimates for 208 vegetation quadrats within the six locales (standard deviations are in brackets)

Locale	Observed species richness (S_{ob}) [1]	Density (SD) [2]	Michaelis-Menten estimate [3]	2nd-order jackknife estimate [4]	Singletone (SD) [5]	Doubletone (SD) [6]
Bongo	32	0.38 (0.09)	33.38	37.42	1.71 (1.06)	2.35 (0.90)
Buing	37	0.20 (0.10)	42.04	48.03	4.15 (2.15)	3.49 (2.10)
Kusanaba	42	0.23 (0.07)	48.37	50.16	4.01 (2.34)	4.52 (1.88)
Morago	48	0.23 (0.12)	58.14	49.51	3.05 (3.37)	4.01 (3.57)
Sakote	39	0.27 (0.15)	47.61	42.51	4.64 (2.4)	4.60 (2.11)
Tilli	34	0.23 (0.09)	37.92	40.65	1.84 (1.48)	2.76 (1.68)

[1] S_{ob} Observed species richness estimated as number of species expected in the pooled samples given the empirical data
[2] Stem density (of all diameter classes) per square metre
[3] Michaelis-Menten estimate of species richness: an asymptote estimator
[4] Second-order jackknife richness estimator (mean among runs)
[5] Singletone mean: number of species with only one individual in the pooled quadrats
[6] Doubletone mean: number of species with only two individuals in the pooled data

Extent of habitat degradation in the Red Volta Valley

Evidence of wildfire was recorded in most of the quadrats sampled, and about 99% of the vegetation area sampled was severely burned (Table 5). There was no evidence of mining in any of the vegetation plots, and 0.35 ha involving 14 quadrats (n = 208) was clear-felled for firewood (Table 5).

The vegetation was dominated (73–82%) by small plants with girth size less than 5 cm diameter (Table 6), typical of a fire pro-climax (savannah) habitat. Plants within size 25–35 cm were the least common, making up only 3% of total plants enumerated; 5% of plants were within size class 15–25 cm and 4% were greater than 35 cm in girth size (Table 6).

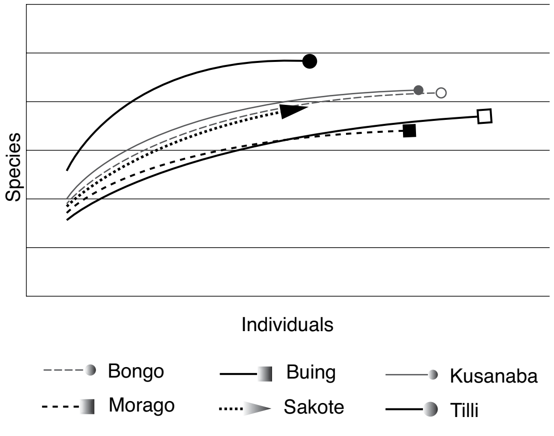


Figure 3. The mean species accumulation curve (observed species richness) of woody stems in six locales of the Red Volta Valley elephant range.

In this analysis, density of woody stem and species diversity (weighed by the Michaelis-Menten species richness) provided an estimate of browse, and quadrat area burned or clear-felled provided an estimate of degradation (Table 7).

Pearson product–moment correlation indicates a weak association between the rate of incidents and density (Pearson: $r = 0.806$, df = 5, $P > 0.05$), diversity (Pearson: $r = -0.007$, df = 5, $P = 0.98$) of browse. Similarly, there was no significant association between rate of incidents and quadrat area burned (Pearson product moment correlation: $r = -0.557$, df = 5, $P = 0.329$), and clear-felled (Pearson product moment correlation: $r = -0.016$, df = 5, $P = 0.979$). The extent of cultivation in a locale is estimated by the size of crop field (Table 7). When the analysis was run, Spearman correlation indicated a positive but weak association between size of cropland cultivated and rate of crop-raiding incidents ($r = 0.25$, df = 5, $P = 0.63$).

The mean distance of a sample of farms from the nearest forest reserve boundary provides an estimate for proximity of an enclave to the forest reserve (core elephant habitat) (Table 8). Correlation analysis shows a significant association between crop raiding and proximity of fields to the forest reserve. The number of crop-raiding incidents markedly increases with decreasing distance to the forest reserve (Pearson product moment correlation: $r = -0.96$, df = 5, $P = 0.002$) (Fig. 4).

Correlation analysis indicates an inverse association between the rate of crop-raiding incidents and distance

Table 5. Extent of habitat degradation observed in six locales

Locale	Vegetation burned by fire			Vegetation clear-felled	
	No. of quadrats burned	Area (m^2)	% of area sample	No. of quadrats	Area (m^2)
Bongo	36	9,000	100	0	0
Buing	34	8,500	100	3	750
Kusanaba	36	9,000	100	8	2,000
Morago	28	7,000	100	2	500
Sakote	24	6,000	100	1	250
Tilli	32	8,000	100	0	0

Table 6. Distribution of vegetation among five diameter classes in six locales within the Red Volta Valley

Locale	Diameter class in cm (%)					Number of		
	< 5	5–15	15–25	25–35	> 35	Plants	Transects	Trees/ha
Bongo	82	7	3	4	4	2,400	9	804
Buing	73	12	7	4	4	2,684	10	724
Kusanaba	79	8	6	3	4	2,294	10	481
Morago	73	16	5	2	4	1,696	7	654
Sakote	81	10	4	2	3	1,635	6	518
Tilli	76	10	7	4	3	2,239	10	537

Table 7. Rate of incident, extent of cultivation, extent of browse and habitat degradation in six locales of the Red Volta Valley during 2000–2002

Locale	No. of elephant crop-raiding incidents	Extent of cultivation[a] (ha)	Density and diversity of browse			Extent of habitat degradation	
			Mean density of browse species	Mean density of all species	Diversity index (Michaelis-Menten)	Quadrat area burned (ha)	Quadrat area clear-felled (ha)
Bongo	9	250.6	0.137	0.266	33.38	0	0
Buing	9	585.2	0.134	0.268	42.04	8,500	750
Kusanaba	18	221.9	0.137	0.229	48.37	9,000	2,000
Morago	6	462.7	0.079	0.233	58.14	7,000	500
Sakote	45	1,104.6	0.105	0.272	47.61	6,000	250
Tilli	3	250.6	0.080	0.222	37.92	8,000	0

[a] Adjewodah et al. 2005

of crop fields from the Red Volta River (Pearson product moment correlation: $r = -0.43$, df = 5, $P = 0.39$), but the association was not statistically significant. In contrast, the association between the rate of crop-raiding incidents and distance of the nearest village to the affected fields is not significant ($r = -0.213$, $P = 0.68$) (Fig. 5).

Functional relationship between crop raiding and habitat variables

A functional relationship between the rate of crop-raiding incidents and some key habitat variables was determined using a regression model. Eleven potential variables of the rate of crop raiding are considered in this analysis (Table 9).

Stepwise algorithm chooses 'distance of the affected farmed enclave to the forest boundary' as the only predictor of rate of elephant crop raiding in a locale. Equation 1 provides the relationship between the rate of crop-raiding incidents and proximity of farmed enclave to the forest.

$$Y = 25.105 + 3.2 - 9.73X \qquad \textit{(Equation 1)}$$

where

Y = expected rate of incidents

X = distance of the affected enclave from the nearest forest boundary

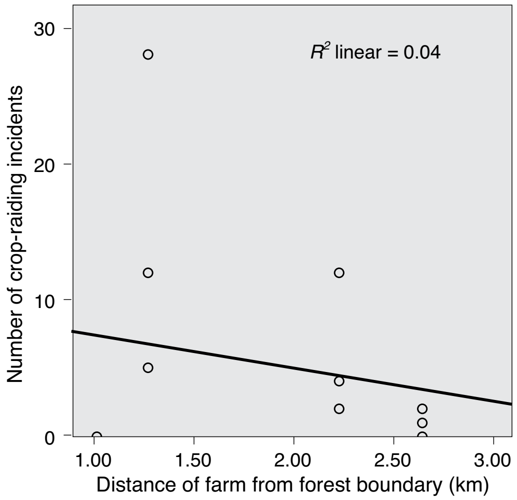


Figure 4. Relationship between distance of cultivated enclaves from the forest, and annual rate of elephant crop raiding in Red Volta Valley in 2000–2002.

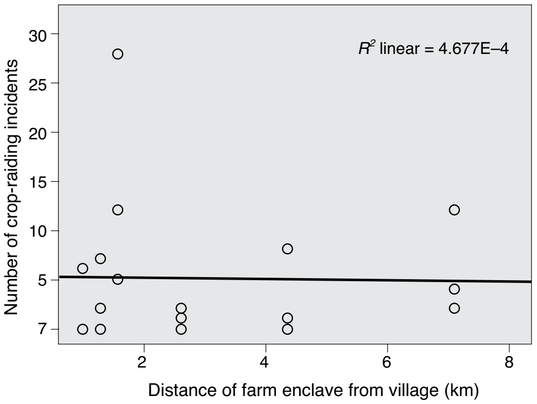


Figure 5. Relationship between number of crop-raiding incidents and distance of cultivated enclaves from the nearest village.

Table 8. Proximity of cultivated enclaves to the nearest forest reserve boundary, the Red Volta River, and settlements, and the annual frequency of elephant crop-raiding in the Red Volta range during 2000–2002

Locale	Mean distance of farm enclave or affected farms (km)			Crop-raiding incidents (no.)			
	from main village	to Red Volta Valley	from forest boundary	2000	2001	2002	Mean
Bongo	1.28	5.24	2.9	0	2	7	3
Biung	4.36	7.99	2.50	8	0	1	3
Kusanaba	7.10	8.26	2.23	2	12	4	6
Morago	4.24	14.45	3.00	0	6	0	2
Sakote	1.58	4.81	1.27	28	5	12	15
Tilli	2.62	5.33	2.65	0	1	2	1

Rate of incidents = Intercept + standard error of estimate + coefficient x distance of enclave from forest boundary *(Equation 2)*

The model, equation 1, is arrived at when the standard error estimate and coefficients of the regression (Table 10) are accounted for in equation 2. It indicates an inverse relationship between rate of crop-raiding incidents and distance of the affected enclave from the forest boundary, and predicts a best guess of the rate of incidents in a locality of the Red Volta to average 4.83 ± 2.75 crop-raiding incidents per annum. The model states that the expected rate of crop-raiding incidents in a locale is equal to 25.1 x distance of enclave from the forest minus 9.73. For Sakote, where distance of enclave to forest boundary is 1.27 km, the predicted rate of crop-raiding incidents using this model is 15.95 incidents per annum.

The ratio of the regression and residual sums of squares indicates that 70% of the variation in crop-raiding incidents is explained by the model (regression sum of squares = 98.79, residual = 42.04, total = 140.8; $R^2 = 0.72$). Furthermore, ANOVA indicates that the variation explained by the model is not due to chance ($F = 9.40$, $P = 0.037$). The histogram and normality plot of the residuals fairly follows the shape of the normal curve (Fig. 6).

The multiple correlation coefficient (R) is examined for the strength of the relationship between the model-predicted values and the observed rate of crop-raiding incidents. When this was carried out, stepwise regression indicated a high correlation coefficient ($R = 0.838$), and a strong coefficient of determination ($R^2 = 0.702$). As a further measure of the strength of the model fit, the standard error (2.24 incidents per annum) compares favourably with the standard deviation of incidents (of 2.75 incidents per annum).

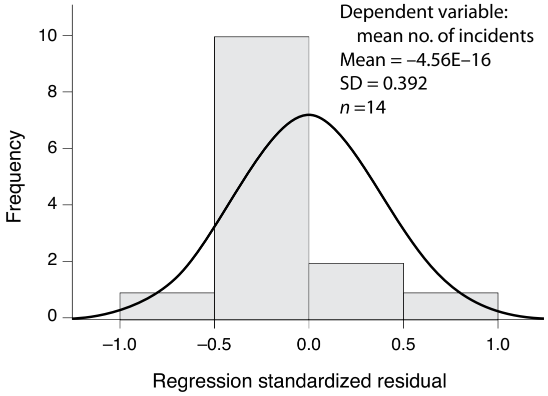


Figure 6. Histogram and normality plot of the residuals against rate of crop-raiding incidents.

Discussion

The Red Volta Valley holds adequate browse resources for elephants; 2 out of every 10 woody plants are edible for them. In the savannah of Uganda, examination of the stomach contents of elephants revealed only 25 species in their diet, which compares with the 11 browse species recorded in the Red Volta Valley. Woody stems were homogeneously distributed among locales, and the abundance, diversity and richness of browse were near the asymptotic estimates or optimum values expected for the area.

Evidence of damage to the vegetation by wildfire was widespread. Though an assessment of the impact of fire on elephant browse was beyond the scope of this study, observations from elsewhere in Ghana (Oteng-Yeboah & Asase 2001) indicate that uncontrolled fire can constrain the availability of resources to wildlife. For instance, it can be assumed from the results that only 20–30% (plants that are 5 cm dbh or larger) of the enumerated plants in the Red Volta are actually available to elephants, as the animals browse from 1 to 2 m above ground level (Spinage 1994). Plants in the recruitment stage (< 5 cm dbh), which form a majority of the specimens enumerated, fall short of the preferred browse height and elephants would not select them.

The results however indicate there is no marked association among crop raiding, the extent of browse and habitat degradation. Though some level of association was found between the rate of crop-raiding incidents and the extent of cultivation within a locale, this association was weak and lacked statistical significance. In parallel, Sukumar (2003) found no clear relationship between crop raiding and the status of elephant habitat in the immediate vicinity of cultivated fields, and noted that crop raiding by elephants was influenced by several attributes of their habitat which were not mutually exclusive, but interrelated in a complex fashion that was poorly understood.

Table 9. Potential predictor variables of the rate of elephant crop-raiding incidents in six localities of the Red Volta Valley

Locale	Crop area destroyed (ha)	Woody plant density (no./m^2)	Diversity index	Raids (no./yr)	Farmers (no.)	Area cultivated (ha)	Distance of enclave (km)			Area burned (ha)	Area cleared (ha)
							from village	to river	from forest		
Bongo	5.438	0.266	33.38	3	114	251	1.28	5.2	–	–	–
Buing	0.6	0.268	42.04	3	195	585	4.36	8.0	–	8,500	750
Kusanaba	3.184	0.229	48.37	6	82	222	7.10	8.3	2.33	9,000	2,000
Morago	2.653	0.233	58.14	1	160	463	4.24	14.0	–	7,000	500
Sakote	5.878	0.272	47.61	15	398	1,105	1.58	4.8	1.27	6,000	250
Tilli	0.634	0.222	37.92	1	112	251	2.62	5.3	2.65	8,000	0

– = missing data

Table 10. Coefficients of regression and collinearity statistics of regression model

Model 1	Unstandardized coefficients		Standardized coefficients	T	Sig.	Correlations			Collinearity statistics	
	B	Std. error	Beta			Zero-order	Partial	Part	Tolerance	VIF
(Constant)	25.105	6.743		3.723	0.020					
Distance of farms from forest boundary	−9.730	3.174	−0.838	−3.066	0.037	−0.838	−0.838	−0.838	1.000	1.000

Barnes et al. (2003) found that the rate of crop raiding was proportional to the density of farms. Similarly, Sukumar (1990) found that the frequency of crop raiding during different months of the year was proportional to the area of land under cultivation. However, they made these observations at conflict sites where elephants are present year round. In the Red Volta Valley, the elephant population is seasonal and the extent and rate of crop raiding is more dependent on the migration of elephants into the study area across the frontier with Burkina Faso (Adjewodah 2004). In 2003, no crop-raiding incident was reported even though the size of cultivated land and crop availability had not changed markedly from previous seasons when incidents were high (Adjewodah et al. 2005). This was attributed to a marked change in the elephant migration pattern (Adjewodah 2004), as elephants from Burkina Faso did not arrive in the study area during the crop-raiding season (Sawadogo 2003).

A marked association between the rate of crop-raiding incidents and proximity of enclaves to the forest was observed. This confirms suggestions by previous workers (Sam et al. 1997; NCRC 1999, 2000) that elephant preference for forest reserves means farms nearer the forest are at greater risk of being affected. This preference thus provides scientific evidence to support suggestions that relocating farms away from the forest reserve will result in a reduced rate of crop-raiding incidents in the Red Volta Valley. Stepwise algorithm regression analysis selected ‘distance of affected enclave to the forest boundary’ as the variable that best accounts for the rate of crop-raiding incidents in a locale. The other potential variables were ignored by the stepwise algorithm because after adding ‘distance of enclave to the forest’ none of them made any significant addition to the model. Taking Sakote, for instance, where the distance of the locale’s farmed enclave is only 1.27 km from the forest boundary, the predicted rate of crop-raiding incidents generated by the model (15.948 incidents per annum) compares closely with the observed rate, which is 15 incidents per annum. The model does a good job of modelling the rate of incidents in a locale as the R^2 value of 0.72 means that the model explains about 70% of the variation in rate of incident. The significant F statistic further indicates that the prediction of rate of incidents using the model is statistically reliable.

Conclusion

The mention of inadequate browse resources as an underlying cause of elephant crop raiding in the Red Volta Valley is not upheld by this study. The Red Volta Valley holds adequate browse resources for elephants and the diversity of woody plants is near the optimum expected value for the area. Evidence of bush burning was extensive and poses the greatest threat to elephant browse resources relative to pit mining and clear-felling of vegetation. The high percentage of enumerated plants within the recruitment size is a manifestation of the effect of fire on vegetation.

The rate of crop loss can be predicted from proximity of cultivation to the nearest forest boundary but is not markedly influenced by the extent of degradation and the diversity of woody plants. Thus a mitigation plan targeted at relocating fields away from the forest reserves will yield a positive outcome, while measures aimed at reducing the density of farms or replanting of the forest with browse species may not necessarily reduce the rate and extent of elephant crop raiding in the study area.

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References

Adjewodah, P. 2004. Habitat status, population and distribution of the African savannah elephant (*Loxodonta africana*) in north-eastern Ghana. IUCN/AfESG Project SG0203, Nairobi. Unpublished project report.

Adjewodah, P., Murphy, A., and Mason, J. 2003. *Mitigating elephant crop raiding: The Red Volta Valley experience, Ghana.* Available http://iucn.org/themes/ssc/sgs/afesg/hec/pdfs/hecrvvrep.pdf.

Adjewodah, P., Beier, P., Sam, M.K., and Mason, J.J. 2005. Elephant crop damage in the Red Volta Valley, north-eastern Ghana. *Pachyderm* 38:39–48.

Ayigsi, J. 1997. Volta–Morago community elephant reserve project: summary of field report. Nature Conservation Research Centre, Accra. Unpublished.

Barnes, R.F.W., Adjewodah, P., Ouedraogo, L., Godwin, P., Seynou, O., Tiendrebeogo, C. and Pousga Célestin Zida, C.P. 2006a. A route map for the preparation of management plans for the transfrontier ecosystem between Mali, Burkina Faso and Ghana. Project report. IUCN/AfESG, Burkina Faso. 54 pp. Unpublished.

Barnes, R.F.W., Adjewodah, P., Ouedraogo, L., Héma, E., Ouiminga, H. and Pousga Célestin Zida, C.P. 2006b. Transfrontier corridors for West African elephants: The PONASI–Red Volta and Sahelian Corridor Project. IUCN/AfESG, Burkina Faso. 50 pp. Unpublished.

Barnes, R.F.W., Azika, S. and Asamoah-Boateng, B. 1995. Timber, cocoa and crop-raiding elephants: a preliminary study from southern Ghana. *Pachyderm* 19:33–38.

Barnes, R.F.W., Boafo, Y., Nandjui, A., Dubiure, U., Hema, E.M., Danquah, E. and Manford, M. 2003. An overview of crop raiding by elephants around the Kakum Conservation Area: Part 2. Technical report. Elephant Biology and Management Project, Africa Program, Conservation International. Unpublished.

Bell, R.H.V. 1985. Elephants and woodland—a reply. *Pachyderm* 5:17–18.

Colwell, R.K. 2005. *Estimates: statistical estimation of species richness and shared species from samples.* Version 7.5. User's guide and application. Published at http://purl.oclc.org/estimates.

Dytham, C. 2003. *Choosing and using statistics: a biologist's guide.* Oxford, UK: Blackwell Science.

Gotelli, N.J. and Colwell, R.K. 2001. Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecological Letters* 4:379–391.

Hoare, R. and Du Toit, J.T. 1999. Coexistence between people and elephants in the African savannahs. *Conservation Biology* 13:633–639.

Jachmann, H. 1992. Movement of elephants in and around the Nazinga Game Ranch, Burkina Faso. *Journal of African Zoology* 106:27–37.

McShane, T.O. 1987. Elephant–fire relationships in combretum/terminalia woodland in Southwest Niger. *African Journal of Ecology* 25:79–94.

[NCRC] Nature Conservation Research Centre. 1999. The micro-best practices project: report of the ecological baseline survey in the Red Volta River Valley of the Upper East Region. Project report 1999. Nature Conservation Research Centre/Technoserve, Accra, Ghana. Unpublished.

[NCRC] Nature Conservation Research Centre. 2000. The micro-best practices project: monitoring report on the ecological impact of the project for the second period. TechnoServe Inc., Accra, Ghana. Unpublished.

Okoumassou, K., Barnes, R.F.W. and Sam, M. 1998. The distribution of elephants in north-eastern Ghana and northern Togo. *Pachyderm* 26:52–60.

Oppong, S.K., Danquah, E. and Sam, M.K. 2008. An update on crop raiding by elephants at Bia Conservation Area, Ghana, from 2004 to 2006. *Pachyderm* 44:59–64.

Oteng-Yeboah, A.A. and Asase, A. 2001. Wechiau Community Hippo Sanctuary: Earthwatch Itineraries, June 2000–February 2001. Botanical Surveys. Nature Conservation Research Centre, Accra. Unpublished.

Sam, M.K. 1994. A preliminary survey of elephants in Northern Ghana. Project report 1994. Ghana Wildlife Department, Accra Ghana. Unpublished.

Sam, M.K., Barnes, R.F.W. and Okoumassou, K. 1998. Elephants, human ecology and environmental degradation in north-eastern Ghana and northern Togo. *Pachyderm* 26:61–68.

Sam, M.K., Haizel, C. and Barnes, R.F.W. 1997. Crop-raiding by elephants during the 1996 harvest season in the Red Volta Valley (Upper East Region, Ghana). Project report, 1997. Wildlife Department, Accra, Ghana. Unpublished.

Sawadogo, B. 2003. Etude et cartographie des mouvements et des zones de conflicts des éléphants entre le Parc Nationale de Po dit Kabore Tambi et la frontière du Ghana le long de la Volta rouge. Project report. IUCN/AfESG, Nairobi, Kenya. Unpublished.

Sebogo, L. and Barnes, R.F.W. (eds.). 2003. Action plan for the management of transfrontier elephant conservation corridors in West Africa. Technical Report, 2003, IUCN/AfESG Ouagadougou, 49 pp. Unpublished.

Spinage, C.A. 1985. The elephants of Burkina Faso, West Africa. *Pachyderm* 5:2–5.

Spinage, C.A. 1994. *Elephants*. London: T and AD Poyser Ltd.

SPSS Inc. 2007. *Statistical programme for data analyses.* USA: Polar Engineering and Consultancy.

Stalmans, M. and Anderson, J. 1992. The forest elephants of Togo. *African Wildlife* 46:71–75.

Sukumar, R. 1990. Ecology of the Asian elephant in southern India. II. Feeding habits and raiding patterns. *Journal of Tropical Ecology* 6:33–53.

Sukumar, R. 2003. *The living elephants: evolutionary ecology, behaviour, and conservation.* New York: Oxford University Press.

Zar, J.H. 1999. *Biostatistical analysis*. Upper Saddle River, NJ: Prentice Hall.