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Determinants of human–elephant conflict in a land-use mosaic

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Summary

1. The resolution of direct conflict between humans and elephants in Africa has become a serious local political issue in recent years, and a continental conservation problem. 'Problem elephants' damage crops, food stores and water sources, and sometimes threaten human life.
2. Eighty per cent of the African elephant's range lies outside formally protected areas, and inadequate management of human–elephant conflict is frequently a precursor to further decline in the numbers and distribution of elephants. Conflict appears to be increasing in an assortment of African ecosystems as the agricultural interface with elephant range expands.
3. The present study recorded incidents by problem elephants in small subdivisions of a 15 000 km^2 elephant range. The level of problem elephant activity over 3 years showed huge variation and could not be explained by elephant density, proximity of a protected area, area of human settlement, human density or local rainfall.
4. It is proposed that the irregular and unpredictable nature of human–elephant conflict incidents in the study area mainly depended upon the behavioural ecology of individual elephant bulls.
5. This study proposes a statistic to quantify problem elephant activity in Africa which can be used to compare the intensity of problem incidents between different ecosystems at different times: 'elephant incidents per square kilometre of human settlement area per year'. Spatial analyses of appropriate data at the human–elephant interface may yield a more predictive understanding of the conflict process.

Key-words: African elephants, agriculture, conflict intensity, elephant bulls.

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Introduction

Elephants *Loxodonta africana africana* Blumenbach 1797 and *Loxodonta africana cyclotis* Matschie 1900, were probably a major obstacle to the evolution of arable farming in precolonial Africa (Parker & Graham 1989a; Barnes 1996). Within elephant range in both savannas and forests, agriculturalists could probably only prosper in large, well-defended villages (Laws, Parker & Johnstone 1975). From the nineteenth and early twentieth centuries, extensive Arab and European penetration of Africa changed the relationship between man and elephant (Hanks 1979; Eltringham 1990). Diverse factors contributing to this change were the advent of a cash value for ivory, firearms, tsetse fly control measures, improved medical and veterinary care, cash crop production and the widespread imposition of colonial government.

Early management of wildlife in African colonies involved widespread elephant control shooting (Swynnerton 1923) but, despite a general decline in range and numbers (Said *et al.* 1995), elephants have continued to be in conflict with agricultural man in many parts of Africa for most of the twentieth century (Brown 1968; Kinloch 1972; Parker 1983; Parker & Graham 1989b; Eltringham 1990; Barnes 1996). 'Problem elephants' are animals that extend their range into human settlement, commonly to feed on a wide variety of cultivated food and cash crops but also sometimes damaging food stores,

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water installations or fences and barriers, and occasionally injuring or killing people. Efforts to mitigate the conflict at the interface between expanding agriculture and shrinking elephant range (Bell 1984; Hoare 1995) have met with rather limited success.

Human–elephant conflict has recently become a topic of major concern in elephant conservation (Kangwana 1993, 1995; Dublin 1994) because it has immediate negative effects on both people and elephants and is also frequently a precursor to further decline in the African elephant range. Barnes (1996) warns that human–elephant conflict in the forest elephant range is as serious a conservation problem as in the savanna elephant range. There has been an increase in the reported incidence of human–elephant conflict in the last decade (Kangwana 1995). While such conflict is almost certainly becoming more widespread as expanding agriculture lengthens the human–elephant interface, the judgement that conflict is actually becoming more intense remains unsubstantiated. The impression of an increase may have arisen due to widespread publicity and political interest in the problem. Thus, human–elephant conflict must be quantified and hypotheses on causal factors must be tested before any management recommendations can be made to ameliorate its effects.

Accounts of direct interaction between humans and elephants have mostly been descriptive of the problem at one or more sites (Nicholson 1968; Waithaka 1993; Kiiru 1995a; Ngure 1995). Only recently has some quantification of human–elephant conflict been carried out. In the savanna elephant range, problem elephant activity shows a seasonal peak, usually corresponding to the late wet season, because the majority of incidents involve elephants destroying maturing food crops (Hoare 1995; Kangwana 1995; Kiiru 1995a; Tchamba 1995). In some semi-arid areas of Zimbabwe and Kenya, elephant damage to food crops accounts for 75–90% of all incidents by large mammal pest species in each district every year (Hoare & Mackie 1993; Waithaka 1993). In the forest elephant range of Gabon, Lahm (1996) confirmed that crop raiding by elephants also mostly occurred during the wet season. Crop raiding by elephants is almost exclusively a nocturnal activity (Bell 1984; Thouless 1994; Hillman-Smith *et al.* 1995; Hoare 1995), suggesting that offenders seek to minimize the associated risk. Where elephants are exceptionally bold, crepuscular raiding activity may be encountered. Irrespective of the circumstances and damage levels inflicted, penetration by an elephant into a settled area demonstrates a temporary expansion of its range that potentially exposes it to disturbance or predation by humans.

Barnes, Asika & Asamoah (1995) offer an hypothesis that increasing crop raiding levels depend upon increasing elephant densities, the latter having been brought about by shrinkage of the elephant range. Even if elephant densities remain static, Barnes, Asika & Asamoah (1995) in Africa and Sukumar (1991) in Asia have proposed that loss of elephant range increases the probability of contact between elephants and human settlement and thus leads to an increase in crop raiding. This suggests an association between the amount of land transformed by agriculture and the level of problem elephant activity. Problem elephant incidents occur in settled areas of Africa with a wide range of human densities (from $< 5\,km^{-2}$ to $> 150\,km^{-2}$; Newmark *et al.* 1994; Thouless 1994) but for these incidents to occur in the higher range of human density, where permanently resident elephants have been eliminated, a nearby elephant refuge (Bell 1984) must exist. Therefore, it could be predicted that crop raids should increase in proportion to the availability of a secure refuge for elephants (e.g. a protected area). Another hypothesis to consider is that crop-raiding levels depend on rainfall. Higher rainfall, which increases the biomass and yield of dry land crops, could be predicted to lead to an increase in elephant crop raids.

While the distribution and frequency of problem elephant activity is easily recorded, its intensity has to be judged quantitatively, often alongside the effects of other agricultural pest species (Msiska & Deodatus 1991; Lahm 1996; Wunder 1997). Measurement of conflict incident levels have used 'raid frequency indices' at conflict sites. At Kasungu and Liwonde, Malawi, an ordinal 4-value scale was used, based on incident levels per growing season (Deodatus & Lipiya 1991; Simons & Chirambo 1991) while at Shimba Hills, Kenya, the statistic 'mean incidents per household per fortnight' was employed (Kiiru 1995b). In India, Sukumar (1990) used 'raiding days per village per month'. Judgements based on economic assessments of the damage are problematic in Africa because data are usually provided from multiple sources in eco-climatic zones of inherently low agricultural potential (Thouless 1994). Economic assessments also exclude many of the social 'opportunity costs' associated with living with elephants (DHV 1992; Thouless 1994).

This study recorded problem elephant incidents in spatial subdivisions of one ecosystem over 3 years. The analysis is concerned with judging the intensity of elephant raids and exploring associations with possible explanatory variables: local elephant density, proximity of a protected wildlife area, local human density, amount of human settlement, and rainfall. A simple raid-frequency index was proposed that can be used to compare different sites suffering from problem elephant activity. Sizes and types of elephant groups responsible for problem incidents were also analysed.

STUDY AREA

The northern Sebungwe is a region of some 15 000 km^2 situated in north-west Zimbabwe, forming part of the Zambezi river basin immediately to the south of Lake Kariba. The elevation varies from 475 m above sea level at the Kariba lakeshore to over 1200 m on the Zambezi escarpment inland; the mean elevation is 700–800 m with generally undulating topography. The climate is semi-arid, characterized by a single wet season from November to March and a long dry season from April to October. Mean annual rainfall shows great variation both within the region and between years, but the long-term mean is 680–750 mm per year (Hutton 1991). The natural land cover is deciduous woodland savanna dominated by 'mopane' *Colophospermum mopane* Kirk, and 'miombo' *Brachystegia* spp. Taub. and *Julbernadia globiflora* Troupin vegetation, interspersed with abundant riparian fringes on the extensive northward drainage and occasional small, dense thickets (Timberlake, Nobanda & Mapaure 1993).

Land tenure consists of protected areas (PAs) for wildlife and communal lands with varying degrees of human settlement (Fig. 1). PAs are national parks and safari areas in which the settlement of people is prohibited; they form three large but separate blocks and are under the control of the wildlife authorities of central government. Intervening communal lands (CLs) are areas where people and some wildlife are both resident and have to coexist. The communal land areas fall into the three administrative districts of Binga, Gokwe and Kariba, which since 1990 have each had authority to manage their own wildlife under a national programme called CAMPFIRE (Communal Areas Management Programme for Indigenous Resources) (Taylor 1993a; Child 1995). Districts are further subdivided administratively into wards, which vary from approximately 150 to 700 km^2 in area. Some wildlife management functions of the districts are being devolved to ward level.

The regional elephant population is dispersed throughout both PAs and CLs in the region but is isolated by extensive human settlement from other regions of Zimbabwe that contain elephants (DNP & WLM 1996). Continuous immigration of people caused severe loss of elephant range in the region, which resulted in rising elephant densities in the contracting range up to 1980 (Cumming 1981). The region was fully cleared of tsetse fly in the mid 1980s, allowing accelerated immigration of people from other parts of Zimbabwe who have continued to transform the land cover for subsistence agriculture (Timberlake, Nobanda & Mapaure 1993). This region thus encapsulates many of the factors acting simultaneously upon rural African people and ele-

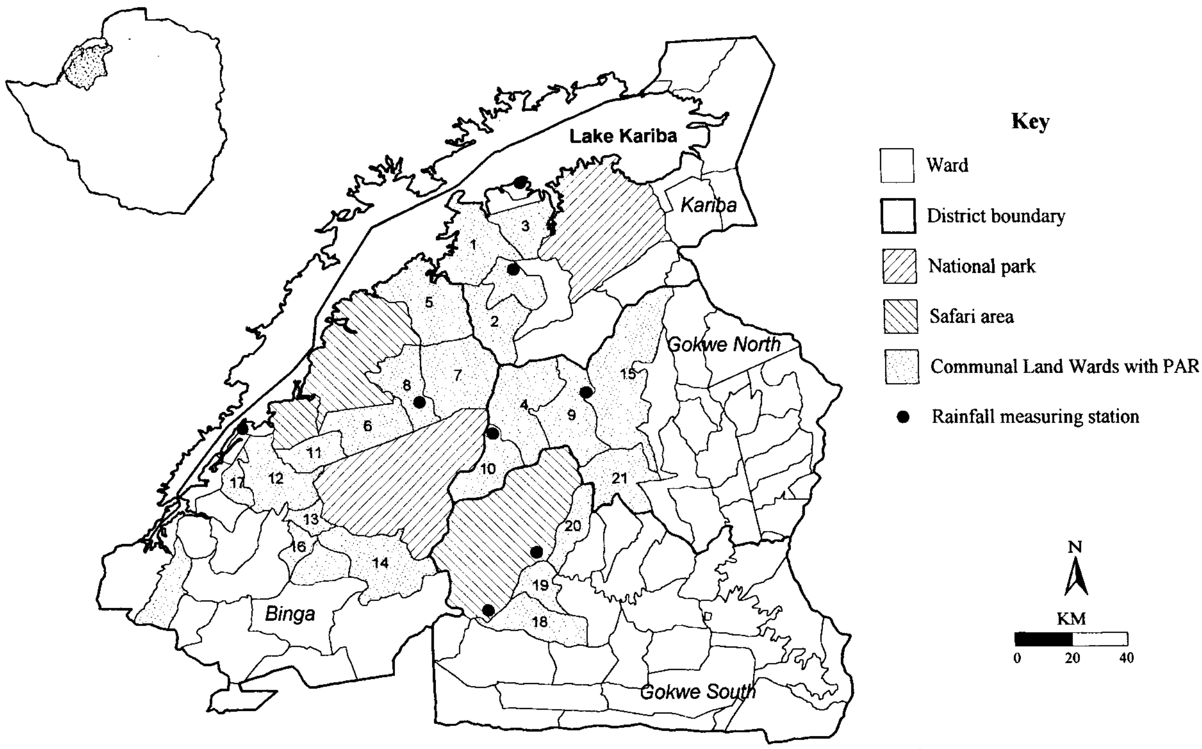

Fig. 1. Land tenure in the Sebungwe region of north-west Zimbabwe showing communal land wards from which problem elephant incidents were recorded.

phants. In the land-use mosaic, human expansion has been continuous for 45 years and the full spectrum of wildlife conservation endeavour, both traditional (Cumming 1981) and contemporary (Taylor 1993b), is represented.

Methods

DATA COLLECTION

As part of the technical support to CAMPFIRE, training workshops were organized in the three study districts to teach enumerators (reporters) in wards (Fig. 1) to collect information on 'problem animals' causing damage to human life or property. To ensure full coverage, larger wards had several reporters. In practice, these problem animal reporters (PARs) placed reporting emphasis on incidents involving the potentially dangerous wildlife species: elephant, buffalo *Syncerus caffer* Sparrmann, hippopotamus *Hippopotamus amphibius* L., lion *Panthera leo* L., spotted hyaena *Crocuta crocuta* Erxleben, and crocodile *Crocodilus niloticus* Laurenti. A PAR visited the site of each individual problem animal incident in his area as soon as possible after the occurrence and described the details on a data sheet.

This reporting system provided standardized data that could be summarized to establish the frequency, distribution and severity of problem animal activity in each ward. Data on all elephant incidents for the years 1993, 1994 and 1995 were summarized by ward. A total of 1823 problem elephant incidents occurring in 21 wards, was used in the analysis (Table 1).

Detailed maps of the Sebungwe region exist (Department of the Surveyor General 1985) and a 1:25 000 aerial photography series was taken in mid-1993 (Cumming & Lynam 1997). A regional elephant census is undertaken annually by aerial survey (DNP & WLM 1996). Data on land tenure and administrative boundaries, human settlement patterns, and elephant distribution and abundance, obtained from these sources, have been stored in electronic format, using a geographical information system (GIS) computer program (Atlas GIS: Strategic Mapping Inc., 3135 Kifer Rd, Santa Clara, CA 95051, USA). Area measurements, multilayered

Table 1. Problem elephant incidents in the Sebungwe region's wildlife wards. Wards are numbered as for Fig. 1 and ranked by elephant density. Elephant and human densities are measured in individuals km^{-2}. Settlement coverage is expressed as a percentage area of the ward. The problem elephant index is obtained by dividing the three year mean of incidents by the settlement area (= mean number of incidents km^{-2} of settlement per year)

Ward Name	Map No.	Problem elephant incidents 1993	1994	1995	3 year mean	Elephant density (km^2)	Human density (km^2)	PA* frontage (km)	Ward area (km^{-2})	Settlement coverage (% area)	Problem elephant index
Mola B	1	–	38	42	40	1·1	6·4	0	531	15	0·49
Negande	2	63	117	35	72	1·0	4·8	0	654	14	0·81
Mola A	3	–	98	25	62	0·9	13·5	6	295	39	0·53
Nenyunka	4	42	31	14	29	0·7	13·3	19	627	35	0·13
Tyunga	5	13	29	4	16	0·5	4·6	28	627	11	0·22
Sinansengwe	6	40	30	19	30	0·4	4·0	67	397	18	0·42
Nabusenga	7	17	17	9	15	0·3	9·5	14	606	23	0·08
Nagangala	8	44	34	14	31	0·3	7·0	50	448	46	0·13
Madzivazvido	9	34	39	51	41	0·2	20·5	16	518	50	0·16
Simchembu	10	64	109	26	66	0·1	22·1	73	359	51	0·36
Nsenga	11	36	60	13	37	0·1	10·6	30	225	35	0·46
Sikalenge	12	18	25	8	17	0·1	8·0	16	499	30	0·11
Kabuba	13	23	23	4	17	0·1	10·5	48	608	21	0·13
Muchesu	14	28	21	21	24	0·1	19·0	9	114	40	0·41
Chireya	15	6	2	12	7	0·02	20·9	0	1021	68	0·01
Lubu	16	14	5	4	8	0	17·5	0	157	–	–
Manjolo	17	7	7	0	5	0	23·4	0	133	–	–
Sai 2	18	58	45	52	52	0	36·0	25	332	–	–
Sai 3	19	9	3	8	7	0	19·6	16	554	–	–
Masuka	20	28	119	55	67	0	27·9	33	235	–	–
Nemangwe	21	3	5	3	4	0	21·8	6	440	–	–
Totals		549	857	419				449	9277		
Means		26	41	18	29	0·39	15·1	21	442	33	0·30

PA = Protected area.

maps and some analyses have been produced for the region with the aid of this program (Cumming & Lynam 1997).

Elephant density (elephants km^{-2}) was calculated from annual aerial census data in the years 1993, 1994 and 1995 (Mackie 1994; Mackie 1995; DNP & WLM 1996). A 3-year arithmetic mean of elephant density for each census stratum was used in the analysis, to smooth out unavoidable census variation due to differences in habitat conditions between years. As census strata do not match ward boundaries, the ward boundaries (Fig. 1) were overlaid onto the mean elephant density in each stratum. The GIS calculated the mean elephant density for each ward (Table 1). Elephants in the Sebungwe region exhibit very little seasonal movement (Hoare 1997), so dry season density is also considered applicable to the wet season when problem elephant activity peaks. The six wards without figures for elephant density (Table 1) were not covered by the annual elephant census or the aerial photography series, because they are known to have no permanently resident elephants.

Human density (persons km^{-2}) for wards (Table 1) was available directly from the 1992 national census (Government of Zimbabwe 1992). If the ward abutted a PA, the length of this boundary was measured by the the GIS computer program and termed 'PA frontage' for the ward (Table 1).

The presence of transformed land cover on aerial photographs (indicating fields or villages) was used to quantifiy human settlement at a resolution of a quarter of a square kilometre (Cumming & Lynam 1997). The total area transformed by human activity in each ward in km^2 was termed 'settlement coverage' and expressed as a percentage of the total area of each ward (Table 1). The six wards without figures for settlement coverage (Table 1) are those not covered by the aerial photography series. These are the same wards that are not covered by the elephant census.

Monthly rainfall figures were obtained from eight rainfall stations in the region (Fig. 1) and annual rainfall was calculated for each of the three study years. Wards were assigned the annual rainfall figure of the nearest measuring station.

Sizes and types of elephant groups responsible for problem elephant incidents were recorded by the PARs. Size–frequency distribution and sex–frequency composition of problem elephant groups were calculated and compared with those of male and female groups in the CL elephant population, obtained from other parts of simultaneous elephant study in the region (Hoare 1997).

An assumption was made that reporting effort was uniform in each ward since the training programme for the PARs was similar in all districts. Three years of records (n = 1823) may have helped to minimize some inevitable local variation in reporting effort.

DATA ANALYSIS

Associations between the number of problem elephant incidents and five independent variables (elephant density, protected area frontage, settlement coverage, annual rainfall and human density) were tested. A total of 61 data points were available from 21 wards over 3 years. With these data there are valid theoretical concerns that (i) using all 61 data points sampled from only 21 wards constitutes pseudoreplication of observations (Hurlbert 1984), and (ii) nonparametric methods using ranks do not readily extend to the analysis of several explanatory variables (Zar 1996). In practice, however, huge variation of problem incidents between years in the same wards reinforces the contention that elephant–human interactions are primarily spatial and thus poorly described by numeric means (Hoare & du Toit 1999). Also, the main variable of interest, elephant density, can only be derived from aerial counts, which are not of sufficient frequency or accuracy to meet the assumptions of a parametric analysis like regression, especially at the spatial resolution of a ward.

Therefore, the relative contribution of each variable is presented using two statistical methods: (i) Spearman rank correlation (r_s) using all data points over 3 years gives a significance level but cannot account for the variation between years so (ii) a summary of percentage variation (r^2) across wards between years reveals the magnitude of effect. The latter method uses a log-transformation of the data to try to approximate assumptions of a parametric model.

In relationships where the correlation was significant but weak (elephant density and protected area frontage), the independent variable was subdivided into high, medium and low categories. Differences in the number of problem elephant incidents per category were compared.

In the 15 wards for which settlement coverage was available, a raid frequency index was calculated, using the area of human settlement. The mean number of elephant incidents for the three study years was divided by the settlement area in each ward to give a 'ward problem elephant index', i.e. an arithmetic mean of problem elephant incidents per km^2 of settled area per year (Table 1). Association between the problem elephant index and settlement coverage in each ward was examined.

Results

Elephants in the Sebungwe consumed or damaged maize *Zea mays* L., millet *Pennisetum glaucum* L.,

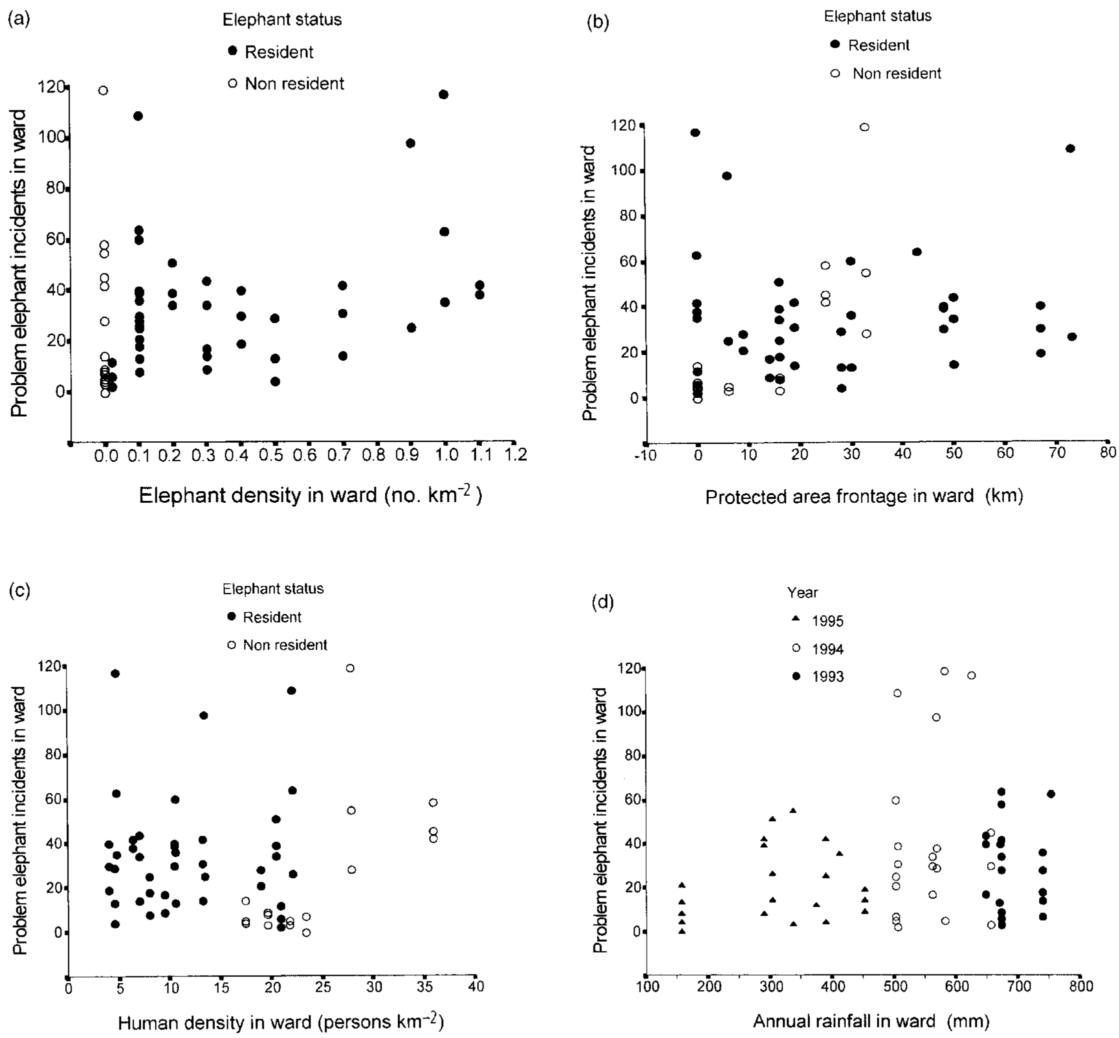

Fig. 2. The relationship between problem elephant incidents over 3 years and selected variables in 21 communal land wildlife wards in the Sebungwe region of Zimbabwe: (a) elephant density, (b) protected area frontage, (c) human density and (d) annual rainfall.

sorghum *Sorghum bicolor* Pers., cotton *Gossypium hirsutum* L., beans *Vigna unguiculata* Macf. groundnuts *Arachis hypogaea* L., melons *Citrullus lanatus* Mansf. and sunflowers *Helianthus annuus* L., raided grain stores and occasionally injured or killed people.

Problem elephant activity occurred in all wards examined, whether elephants were resident or not, the range of incident totals being similar in wards with or without resident elephants (Fig. 2a–c). Six wards without resident elephants suffered attack from animals in nearby refuges, but not all these refuges were protected areas. In two cases (ward numbers 16 and 17) the elephant refuges may have been other CL wards.

Association of incident levels with elephant density (Fig. 2a) and with protected area frontage (Fig. 2b) was significant but weak (Tables 2 & 3). There was a significant difference in incidents between elephant density categories (Hoare 1997) (high $>0{\cdot}7$ km^{-2}; medium 0·3–0·6 km^{-2}; low $< 0{\cdot}3$ km^{-2}) with a chi-squared goodness-of-fit test ($\chi^2 = 175{\cdot}8$; d.f. = 2; $P < 0{\cdot}005$) but these followed no predicted trend: the highest density was the least different from expected values; intermediate density was the most different. There was a significant difference in incidents between frontage categories (0 km; 1–20 km; 21–40 km; 41–60 km; 61–80 km [$\chi^2 = 288{\cdot}1$; d.f. = 2; $P < 0{\cdot}005$]) but no predicted trend: the longest frontage contributed the least difference from expected values.

Incident levels showed very little statistical association with the human density range in wards (Fig. 2c; Tables 2 & 3). Total annual rainfall varied considerably between years in different wards (range 158–740 mm) but the range of incident levels remained similar (Fig. 2d). In the region overall, the most incidents occurred in the year with intermedi-

Table 2. Spearman rank correlation statistics for association between five variables and problem elephant incidents using (i) all incident data over 3 years, and (ii) a mean of incidents over 3 years

	All 3 years			Mean of 3 years		
Variable	r_s	n	P	r_s	n	P
Elephant density	0·385	61	0·002	0·047	21	0·053
Protected area frontage	0·352	61	0·005	0·298	21	0·190
Human density	−0·047	61	> 0·5	−0·188	21	0·41
Annual rainfall	0·228	61	0·076	0·085	21	> 0·5
Settlement coverage	−0·311	43*	0·042	0·038	15*	> 0·5

Settlement coverage only for wards with resident elephants.

Table 3. Percentage variation for association between five variables and problem elephant incidents in 21 wards in different study years (data were transformed as log[count + 1] and expressed as the coefficient of determination, r^2)

	R^2 (%)				
Variable	n	1993	1994	1995	Mean
Elephant density	21	20·8	13·0	4·6	12·8
Protected area frontage	21	12·8	3·4	0·5	5·6
Human density	21	1·6	0·1	5·1	2·3
Annual rainfall	21	0·07	1·8	7·1	3·0
Settlement coverage	15*	0·01	0·2	0·5	0·2

* Settlement coverage only for wards with resident elephants.

ate rainfall (1994) but the fewest occurred in the 1995 drought year when many crops failed to mature (Table 1). Association of incident levels with rainfall was statistically weak (Tables 2 & 3).

In the 15 wards with resident elephants, the problem elephant index ranged from 0·01 to 0·81 incidents km^{-2} of settled area per year with an overall mean of 0·3 incidents km^{-2} per year over a total of 2624 km^2 of settlement (Table 1; Fig. 3). The relationship between incidents and settlement coverage had not previously revealed any strong association (Tables 2 & 3).

The distribution of elephant raiding group sizes recorded on the reporting forms illustrates that most

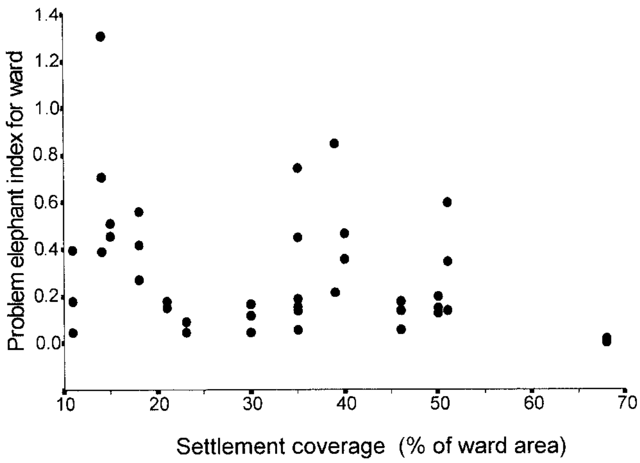

Fig. 3. The relationship between the problem elephant index (incidents km^{-2} of human settlement area per year) and settlement coverage for 15 communal land wildlife wards of the Sebungwe region, Zimbabwe.

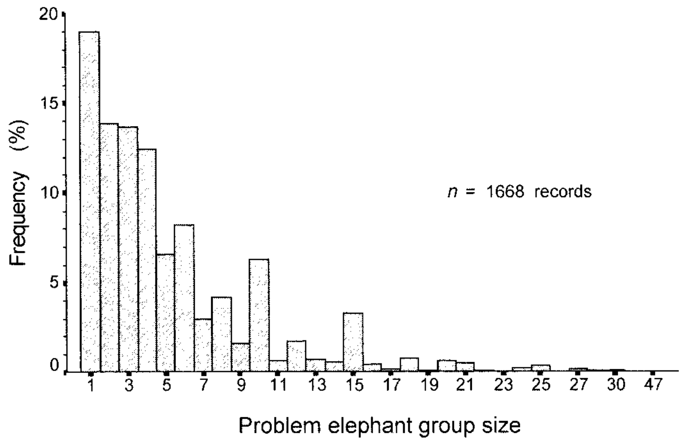

Fig. 4. Size–frequency distribution of problem elephant groups recorded from all communal land wildlife wards in the Sebungwe region of Zimbabwe 1993–95.

incidents are due to small groups (Fig. 4). Lone males accounted for 19% of total incidents. The range of raiding group size was 1–47 with 89% of raiding groups consisting of 10 animals or less. This agrees closely with reports where raiding elephant groups could be sexed with some confidence by PARs (n = 337): 79% of raids were perpetrated by male groups or lone males. A further 9% were mixed herds where both males and females were present. In only 12% of cases were cow groups recorded as being solely responsible and 50% of these were recorded from one district (Gokwe). The median size of raiding groups reported (M = 4; range 1–47; n = 1688) was the same as the median size of male groups sighted in the CL male population (M = 4; range 1–49; n = 381) but half the median size of female groups sighted in the CL population (M = 8; range 2–49; n = 396) (Fig. 5). The ratio of male to female groups in the CL elephant population at large, found in other parts of the present study (Hoare 1997) was 40:60%.

Because of problems quantifying availability of the different crop types to raiding elephants, analysing the selection of these crop types was not attempted. The ages of crops damaged by elephants, however, were assessed. A sample of incidents on all types of crops over the 3 years (n = 1122) showed that mature crops were selected in 62% of cases, intermediate growth stages selected in 35% of cases and early growth stages selected in only 3% of cases.

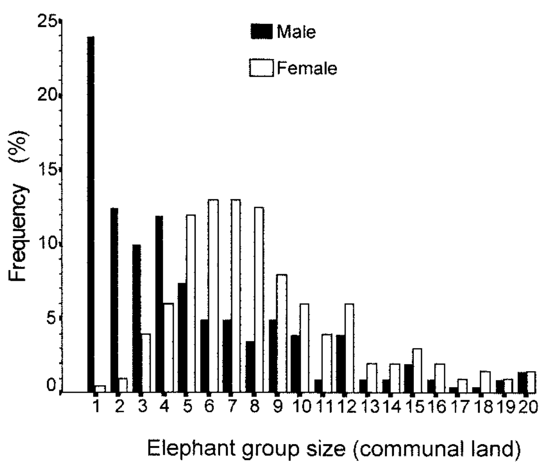

Fig. 5. Size–frequency distribution of male elephant groups (solid bars) and female elephant groups (open bars) encountered in the Sebungwe communal land elephant population 1993–96.

Discussion

This study examined the intensity of problem elephant activity in a sample of rural settlements practising subsistence agriculture within the same semi-arid ecosystem. Incident levels varied widely without corresponding local changes in the elephant population. PAs acting as elephant refuges in the Sebungwe are known to have almost twice the elephant density of refuges within the CL wards (DNP & WLM 1996) but neither the type of refuge nor the elephant density within it appeared to determine levels of problem elephant activity in adjacent human settlement. Substantial local variations in rainfall also suggest that better crops are not necessarily attracting more elephants to cultivated fields. Elephants appear to feed on whatever crops are available, preferring the mature growth stages.

Across the many differing situations where problem elephant activity occurred, only one condition was consistent: the preponderance of male elephant involvement in the problem incidents. Although this sex difference has been reported (Nicholson 1968; Bell 1984; Thouless 1994; Hoare 1995) it has not been previously quantified or explained. There are now several pieces of evidence which help to explain why the pattern of incidents due to problem elephant bulls can be irregular and unpredictable.

Other parts of this study involving radio-tracking individual elephants (Hoare 1997) showed that male elephants resident in CLs are found significantly closer to human settlement than females, and that the only elephants observed to penetrate into settlement in the daytime or penetrate into dense settlement were males. This suggests that some male elephants may have a degree of tolerance to human disturbance. Some authors studying elephant social organization have described 'bull areas', occupied predominantly by male elephants (Laws, Parker & Johnstone 1975; Martin 1978; Moss & Poole 1983). On boundaries where human settlements abut PAs, males have been shown to congregate, especially in the months when crops mature (Osborn 1998), and individual elephant bulls that are habitual fence breakers (Thouless & Sakwa 1995) or regular crop raiders (Lahm 1996; Osborn 1998) have been noticed in several countries.

Therefore, it is reasonable to propose that 'disturbance-tolerant' male elephants may live near the woodland/settlement interface. A proportion of these males are those responsible for problem elephant activity. Some may be 'habitual crop raiders' each responsible for many problem incidents. This means that an area harbouring a few habitual raiders may easily record similar incident levels to an area where there are many occasional raiders.

Studies on the Asian elephant *Elephas maximus* L., a genetically distinct genus but one with similar nutritional requirements to the African elephant, provide insights into the feeding ecology of individual problem elephants. Asian elephants are attracted to food crops because they are more palatable, more nutritious and have lower secondary defences than wild browse plants (Sukumar 1990). In addition, some crops (e.g. *Eleusine* spp. or millets) when ripe have high sodium and low silica and fibre contents, and are therefore especially attractive to elephants in the late wet season (Sukumar 1990). The influence of plant palatability on elephant crop raiding in Africa has also been referred to by Bell (1984) and Osborn (1998). Sukumar (1990, 1991) quantified the raiding frequencies of Asian elephants and the economic effect of the sexes on crops, and reported male effects as being more than five times those of females. Sukumar & Gadgil (1988) propose that this is due to a male strategy of risk-taking that maximizes reproductive success through better nutrition. There now appears little reason to doubt that this situation should also apply in Africa, and thus it can be considered consistent with the predictions of optimal foraging theory (Krebs & Davies 1991).

Data from this study showed also that problem elephant activity levels are not significantly related simply to the gross area of human settlement over which agriculture has increasingly transformed the land cover. The geometry of natural habitat fragmentation induced by agriculture (Hunter 1996) indicates that as wildlife range contracts in the face of human expansion, the interface of potential wildlife–human contact must increase. So, although problem elephant activity may now be more widespread because of a longer interface, it may always have been of similar intensity per unit area in semi-arid ecosystems in Africa because it depends on individual animals' behaviour. 'Frontline farms' near refuges may always have suffered the 50–65% of elephant depredations that they do today (Bell 1984; Hawkes 1991) but, unfortunately, sufficient comparative data is lacking in the present study area to test this idea.

The present study did not provide strong evidence for elephant problems depending on elephant population density. The data support an explanation whereby problem elephant incidents represent opportunistic feeding forays by a segment of the male elephant population, and the intensity thereof is dependent on the behavioural ecology of these individuals. The mechanisms apparently perpetuating human–elephant conflict in African savannas may thus be a combination of human settlement in a matrix of natural habitat, concentration of certain individual male elephants at the edges of a population's shrinking range and probable selection pressure on male elephants, which favours a risky strategy to derive better nutrition from crops. This 'male behaviour hypothesis' would accommodate both apparent increases in problem elephant activity over the last decade because of either wider distribution of incidents (Kangwana 1995) or higher probability of elephant contact with a longer range boundary (Sukumar 1990) as well as real increases where elephants compressed by shrinking range do, in fact, raid more frequently (Barnes, Asika & Asamoah 1995).

Research and management measures to ameliorate problem elephant activity can be simplified in the light of these findings, at least in the savanna component of the African elephant range. It is essential to use problem incident data collected by independent enumerators (Hoare & Mackie 1993; Thouless 1994) because information sourced from reports by farmers (Hawkes 1991; Newmark *et al.* 1994; Thouless 1994) is likely to be inaccurate or exaggerated. Local people are easily trained as enumerators and a reliable reporting system for the larger species of problem wildlife is inexpensive to run over large areas (Hoare & Mackie 1993).

The development of a relevant problem elephant activity index is important where data are available and the one developed in the present study is proposed as suitable for both spatial and temporal comparison of damage surveys. Measurement of the problem elephant activity in standard area units, which are used for both human and elephant densities (km^2), allows better comparison across widely differing physical situations and between different times than previous raid frequency indices (Deodatus & Lipiya 1991; Simons & Chirambo 1991; Kiiru 1995b), which have ranked raid intensity by individual farm, household or village. An area-based index avoids the pitfalls of (i) assessing economic damage per incident (Msiska & Deodatus 1991), and (ii) statistical comparison of situations where farms, villages or households vary in size and crop production. The proposed index assumes instead a certain amount of effect on humans and a certain risk to elephants for each raid. In the present study, large between-year variations suggest that the index should be calculated using several years' data.

The relationship between the relative abundance of elephant and human populations coexisting in African savannas has been proposed as being spatial rather than numeric (Hoare & du Toit 1999). Potential spatial influences on human–elephant conflict have periodically been mentioned, e.g. Matzke (1975) showed in southern Tanzania that there is more human–wildlife conflict in 'linear' settlements than in 'nucleated' or compact settlements, while Jachmann (1989) and Osborn (1998) suggest that more fertile soils, preferentially occupied by agriculturalists, may support better-quality forage to which elephants are always attracted. Investigating spatial relationships between human settlement configurations and problem elephant activity levels may be a particularly productive direction for future research.

Research initiatives on problem elephant behaviour could also concentrate on the male segment of an elephant population. Further investigation into which male individuals may be habitual problem animals might enable scarce management resources to be allocated more efficiently to the package of measures that currently represent elephant control options (Hoare 1995). Selective culling of habitual culprit animals, for example, by marketing them on regulated safari hunts (Taylor 1993b) has been recently attempted in Zimbabwe. This measure has had some success at replacing unworkable crop damage compensation schemes (Hoare 1995) as an alternative method of returning revenue to affected farming communities.

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