Journal of Applied Ecology (1990), **27**, 1055–1087

ILLEGAL EXPLOITATION OF BLACK RHINOCEROS AND ELEPHANT POPULATIONS: PATTERNS OF DECLINE, LAW ENFORCEMENT AND PATROL EFFORT IN LUANGWA VALLEY, ZAMBIA

BY N. LEADER-WILLIAMS, S. D. ALBON AND P. S. M. BERRY*

*Large Animal Research Group, Department of Zoology, 34A Storey's Way, Cambridge CB3 ODT and *PO Box 33, Mfuwe, Zambia*

SUMMARY

(1) At the start of the 1980s, conservationists in Africa gave a high priority to protecting the largest remaining populations of black rhinos and elephants from illegal exploitation. This study documents the demise of both species in the Luangwa Valley, Zambia.

(2) Sightings and captures by law enforcement patrols were used to monitor (i) changes in rhino and elephant numbers during 1947–69 and 1979–85; (ii) their motivation and success at capturing offenders involved in illegal activity during 1979-85; and (iii) the distribution of illegal activity in relation to patrol effort and the abundance of rhinos and elephants during 1979–85. Sightings were analysed with log-linear models and population trends for elephants and rhinos so derived compared favourably with accurate methods of counting both species.

(3) Elephants increased at an instantaneous annual rate of +0·06 from 1947 to 1969, causing the 'elephant problem' of the 1960s and 1970s. Sightings of rhinos and elephants were negatively correlated in different areas of Luangwa Valley during this period.

(4) The overall rates of decline of rhinos and elephants were −0·63 and −0·12 during 1979-85, following rapid increases in the price of rhino horn and ivory on world markets. These declines arose from illegal activity as most skulls had their trophies removed.

(5) Sightings of rhinos and elephants changed at different rates in each area of Luangwa Valley. Rhinos declined in all areas at rates ranging from −0·99 to −0·24, but elephants increased in some areas due to local immigration. By 1985 there was a positive correlation between sighting rates of rhinos and elephants.

(6) Despite these large declines in rhino and elephant numbers, law enforcement units were motivated and successful at capturing offenders involved in illegal activity in Luangwa Valley during 1979–85.

(7) Most staff in law enforcement units spent about half each month patrolling on foot under remote and difficult conditions. Offenders caught on foot patrols provided information for making arrests more successfully on vehicle patrols. Arrests were made cost-effectively and about 40% of operating costs were recovered from found and seized ivory.

(8) Offenders involved in less serious illegal activity originated from most areas of Luangwa Valley. In contrast, well-organized armed gangs exploited rhinos and elephants and originated from areas outside Luangwa Valley. Offenders who exploited rhinos and elephants were delivered sentences that did not uphold wildlife laws.

(9) Signs of illegal activity, such as poachers, their camps and fresh carcasses, were encountered throughout the year. Encounters of illegal activity generally showed consistent trends across years within different areas, but most trends in illegal activity were complex rather than exponential across time.

(10) Increased patrol effort affected levels of illegal activity. Poachers and camps tended to be seen less often in more heavily patrolled areas even though these held a relative abundance of quarry. Finds of fresh carcasses declined with rhino and elephant numbers, but also were found less frequently in areas of heavier patrol effort.

(11) Differences in patrol effort were related directly to rates of change in rhino and elephant abundance, and were sufficient to create areas of relative safety which

experienced local immigrations of elephants and lower declines of rhinos. However, predictions suggest that a decline in rhinos could only have been prevented if all available manpower in law enforcement units had been concentrated in one small area. Law enforcement staff need to be deployed at effective densities of at least one man per 20 km^2 of protected area.

(12) The overall conclusion was that the manpower within law enforcement units was effective at capturing poachers, but was too small to provide protection to the large populations of rhinos and elephants over such a vast area as Luangwa Valley.

INTRODUCTION

The decline of black rhinos (*Diceros bicornis* L.) and elephants (*Loxodonta africana* (Blumenbach)) in most countries of Africa in recent years has been of major concern to conservationists and wildlife managers. An estimated population of 65 000 black rhinos in 1970 had fallen to 3800 rhinos by 1986 (Hillman 1981; Western & Vigne 1985; Cumming, du Toit & Stuart 1990). Changes in elephant numbers have been harder to determine because large populations occur in rainforest, but trends are generally downward (Douglas-Hamilton 1987). The high price of ivory and rhino horn on world markets throughout the past two decades (Martin 1982; Parker & Amin 1983; Douglas-Hamilton 1987) has encouraged illegal exploitation. Various internal problems within African countries have exacerbated this situation, including their economic situation, corruption, the increased availability of sophisticated weapons, and the resentment of conservation areas by local people (Marks 1984; Abel & Blaikie 1986; Douglas-Hamilton 1987; Bell 1987; Leader-Williams 1990). Hence, illegal (as defined by current wildlife laws) or traditional (in the eyes of local people) exploitation of wildlife within conservation areas for both subsistence and economic gain is commonplace (Marks 1976; Pullan 1981; Abel & Blaikie 1986; Bell 1986a). Many attempts have been made to reverse recent declines arising from illegal exploitation, including enforcing bans on trade in rhino horn (Martin 1982), regulating ivory quotas (Martin 1986) and *in situ* protection of rhinos and elephants (Cumming & Jackson 1984; Western 1987, 1989).

Even though African governments and conservation organizations have devoted considerable, but scarce, resources to *in situ* protection, few attempts have been made to analyse objectively the results achieved for particular management actions (Leader-Williams & Albon 1988). Clearly the goal of conserving rhinos and elephants has not been met during the past two decades by countries in East and Central Africa which formerly possessed large populations of both species (Western & Vigne 1985; Douglas-Hamilton 1987; Cumming *et al.* 1990). Following the theoretical principles of conservation biology (e.g. Soulé 1986), the African Elephant and Rhino Specialist Group gave highest priority in the early 1980s to protection of the large populations of rhinos and elephants in the Selous in Tanzania and the Luangwa Valley in Zambia (AERSG 1984). A conservation initiative in the Luangwa Valley funded law enforcement patrols, but failed to prevent illegal exploitation of rhinos and elephants (Leader-Williams & Albon 1988). Because this represented one of the most serious losses on a continent-wide basis, this paper aims to provide feedback for those wishing to improve field-based attempts to conserve both species *in situ*. The first part of this paper uses data from law enforcement patrols to quantify historical and recent changes in elephant and rhino abundance. Two subsequent parts show that law enforcement units caught many offenders but that patrol effort determined the distribution of illegal activity and the rates of rhino and elephant decline. Hence, units were too understaffed and underfunded to cover such a large area as Luangwa Valley effectively. This suggests that a shortage of manpower, and ultimately of

resources, within other African conservation agencies may have contributed to the failure to identify realistic conservation goals for rhinos and elephants (Cumming, Martin & Taylor 1984; Bell & Clarke 1986; Leader-Williams & Albon 1988).

STUDY AREA AND LAW ENFORCEMENT PATROLS

Luangwa Valley occupies 63000 km^2 in NE Zambia (Fig. 1) and can support a high biomass of large animals (Naylor *et al.* 1973; Bell 1982). The four national parks (NP) were cleared of their human populations when established in 1938, whereas seven game management areas (GMA) support low-density populations of subsistence cultivators and hunters. The study area is surrounded by various tribal chiefs' areas and trunk roads (Fig. 1).

In the early 1970s, the Luangwa Valley contained a population of *c.* 100000 elephants (Caughley & Goddard 1975). It was also estimated to hold between 4000 and 12000 black rhinos, though they were never counted accurately (Naylor *et al.* 1973). At that time, park infrastructure and law enforcement efforts began to collapse, and elephant and rhino populations were depleted by illegal activity (Douglas-Hamilton *et al.* 1979). Save the Rhino Trust (SRT) established two anti-poaching units (APU) in 1979 and 1980: APU 1 based close to South Luangwa NP had responsibility for patrolling in Luangwa Valley; APU 2 was based close to Lower Zambezi NP and Luano GMA, two other areas believed to hold important populations of rhinos and elephants. Two further units were formed in 1984: APU 3 based close to North Luangwa NP (NLNP) and APU 4 near the western boundary of SLNP (Fig. 1). Six areas of unequal size in Luangwa Valley were patrolled during 1979–85: North Luangwa NP (NLNP); South Luangwa NP North sector (SLNP North), Core area (SLNP Core), South sector (SLNP South) and Nsefu sector (SLNP Nsefu); Lupande GMA (GMA). Data from these six areas are used in all three parts of the paper. Lukusuzi NP, Luambe NP and other GMAs in Luangwa Valley were patrolled infrequently. Data collected in Lower Zambezi NP (LZNP) and Luano GMA during 1984 and 1985 are only presented in the second part of the paper.

Records from foot patrols by Game Department rangers provided data on rhinos and elephants in Luangwa Valley during 1947–69, and records from foot and vehicle patrols carried out by SRT provided data on animal and carcass distributions, captures of offenders and levels of illegal activity during 1979–85. Patrols were undertaken in all months of the year and were of different sizes and lengths. Encounter rates per effective patrol day were used as the standard unit of patrol effort to make the encounter rates equivalent to 'catch per unit effort' indices of fisheries management (see Bell 1986b). Data collected by scouts provided an accurate record of events (cf. Bell 1986b) and scouts recorded missing values rather than inaccurate ones when doubtful about the accuracy of their sightings.

PATTERNS OF DECLINE

Evaluation of the success of protection measures requires an accurate assessment either of total population size or of an index of abundance, and the subsequent monitoring of population trends. Elephants can be counted from the air in savannah and woodland areas (Laws 1969; Caughley & Goddard 1975). However, aerial counts of black rhinos have not been completed with any confidence or without correction factors (Goddard 1967a), except by undertaking repeated counts over a small area (Western 1982). The

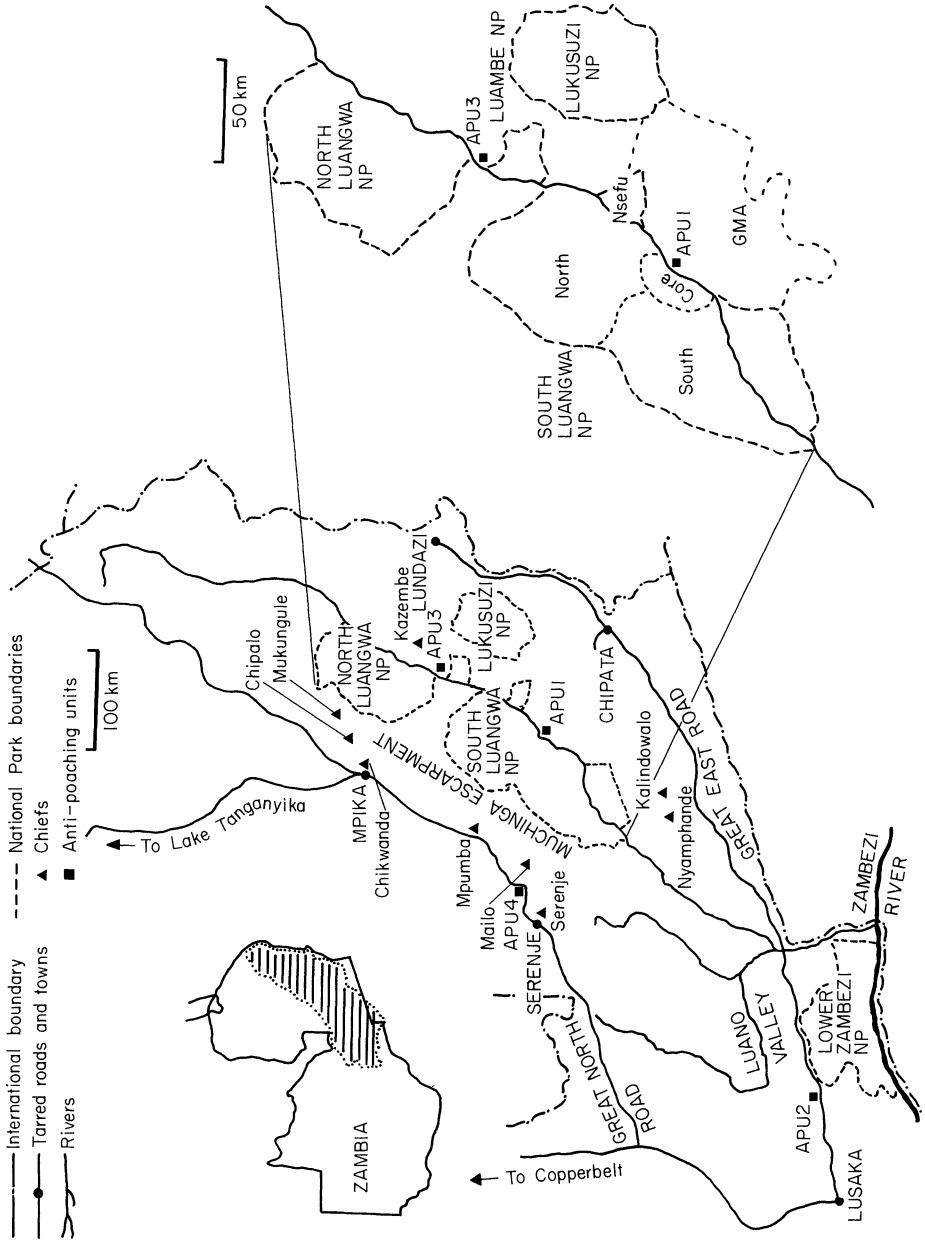

FIG. 1. Map of the study area showing the position of major trunk roads and towns, of Luangwa, Luano and Lower Zambezi Valleys, of national parks and various tribal chiefs' areas and of the areas patrolled by anti-poaching units.

most accurate method for counting rhinos involves individual recognition (Goddard 1967b), but repeated counts are impossible over a large area (Leader-Williams 1988; Kiwia 1989). However, even if aerial counts were feasible for both species, repeated counts necessary to monitor population trends over large conservation areas are expensive. We analyse changes in an index of rhino and elephant abundance from data collected routinely by foot patrols to show that such data provide a useful and sensitive measure of population trends, and analyse differences in the patterns of population change of rhinos and elephants in different areas of Luangwa Valley, Zambia.

Methods

Field records

Records are derived from forty-five patrols by eleven different Game Department rangers during 1947–69, and from 781 foot patrols by SRT during 1979–85. For each day out on foot patrol the following were recorded:

(i) sightings of elephant herds and/or of elephants, and of rhinos;
(ii) numbers of skulls of elephants and rhinos, both intact and with trophies axed off by poachers (only for 1979–85).

Records from patrols during 1947–69 and 1979–85 were allocated to the different areas of Luangwa Valley (Fig. 1) on the basis of routes followed. If two or more areas were entered during the course of a single patrol, the number of patrol days and encounters were entered separately for each area. Thus, 63 and 864 lines of data described encounters from 1947–69 and 1979–85, respectively.

Analysis of animal sightings

The data for all encounters were heavily skewed towards zero values, and a log-linear model with a Poisson error distribution was fitted. Variables that might affect encounter rate during 1979–85 were systematically incorporated into each model and comprised the following: month, patrol length, patrol length^2, number of scouts, APU, area, year fitted as a categorical variable. Statistical interactions between encounter rate, year and area were also investigated to check the spatial heterogeneity of animal sightings. The best model for an encounter rate resulted from excluding those variables whose incorporation resulted in no significant reduction in deviance (Table 1). Encounters for 1947–69 were analysed in a similar way. However, as APU differences were not applicable and no information was available on patrol size, these variables were omitted from the models for the early data. Exponential curves were fitted through all data points by adding year as a linear variable ($v$year), as shown for rhino sightings in one area during 1979–85 (Fig. 2). For clarity in subsequent figures, these curves are shown with mean annual encounter rates, adjusted for patrol length, number of scouts and month as described below, with sample sizes shown above each year.

The anti-poaching unit undertaking the patrol had no effect on the model for rhino sightings during 1979–85 (but where this affected models for elephants, encounter rates were standardized for APU 1 which undertook most patrols in Luangwa Valley). However, systematic incorporation of all other variables into the model for rhinos resulted in a reduction in deviance (Table 1). Therefore, encounters of rhinos were calculated by substituting estimates into model G. This model showed that the month in which a patrol was undertaken affected the likelihood of sighting a rhino. A clear seasonal pattern emerged in which few rhinos were seen by scouts in the late wet and early cool dry season (March–May) when the grass was long, but sightings increased during the hot dry

TABLE 1. Goodness-of-fit tests for incorporation of variables into the log-linear model for rhino sightings during 1979–85. Models A–H are compared with the model in the row above, whilst models I–N are compared with model G. The values of χ^2 are for the terms included (A–H) or excluded (I–N) in the successive model. The coefficient of the terms in model G were used in to predict sightings for standardized values of patrol length, number of scouts, month and year in the subsequent analysis. The deviance explained by model G was calculated as (null − G/null) × 100 = 35·6%

	Variable											
Model	Month	Length	Length^2	Scouts	Area	*v*year	*v*year × Area	APU	Deviance	χ^2	d.f.	*P*
Null									2603			
A	1								2506	97	11	***
B	1	2							2506	0	1	N.S.
C	1	2	3						2459	47	1	***
D	1	2	3	4					2454	5	1	*
E	1	2	3	4	5				2012	442	9	***
F	1	2	3	4	5	6			1755	257	1	***
G	1	2	3	4	5	6	7		1676	79	9	***
H	1	2	3	4	5	6	7	8	1672	4	3	N.S.
I		2	3	4	5	6	7		1759	83	11	***
J	1		3	4	5	6	7		1735	59	1	***
K	1	2		4	5	6	7		1714	38	1	***
L	1	2	3		5	6	7		1684	8	1	**
M	1	2	3	4		6	7		1761	85	9	***
N	1	2	3	4	5	6			1754	78	9	***

* $P < 0{\cdot}05$; ** $P < 0{\cdot}01$; *** $P < 0{\cdot}001$.
N.S., not significant.

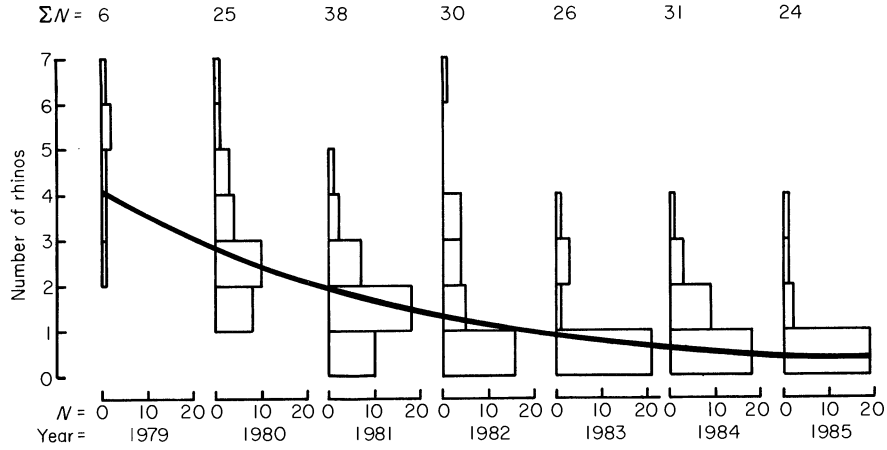

FIG. 2. Log-linear models were fitted to all data points, as shown for rhinos sighted by four scouts on a 7-days patrol in January in SLNP North. Horizontal axes represent *N* of sightings of different numbers of rhino in each year. This curve is shown again as part of Fig. 5 but with adjusted means rather than individual data points.

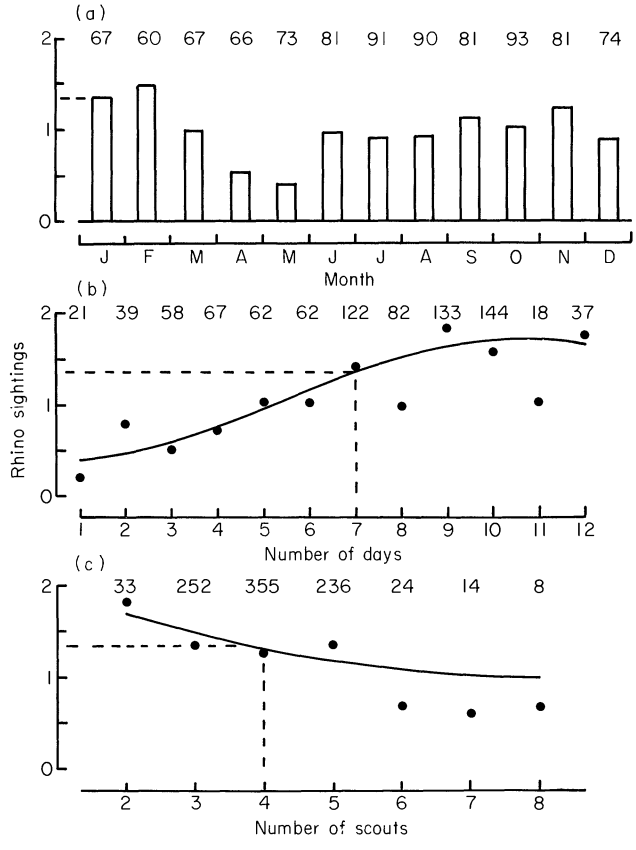

FIG. 3. Effects of three variables upon log-linear models of rhino sightings. Numbers of rhino sighted in SLNP North (a) in different months by four scouts on a 7-days patrol in 1982; (b) by four scouts on patrols of different lengths during January 1982; (c) by different numbers of scouts on a 7-days patrol in January in 1982. Months were incorporated into the model as categorical variables, whilst patrol lengths and scout numbers were incorporated as linear variables. Sample sizes are shown above each graph. Subsequent figures show sightings adjusted as if they had been made by four scouts on a 7-days patrol in January, and dashed lines show an adjusted sighting frequency of 1·3 rhinos for all patrols in SLNP North in 1982 (see Figs 2, 5).

season and peaked in the early wet season months of January and February (Fig. 3a). The likelihood of sighting rhinos increased, but at a decelerating rate, on patrols of up to 12 days (Fig. 3b). The larger a patrol the less likely they were to see a rhino (Fig. 3c). Because mean patrol length and size approximated to 7 days and four scouts, respectively (see Law Enforcement), all sightings in the model were adjusted as if all patrols had been of this length and size and been made in January.

Overall estimates for the Westbank

Because relatively regular aerial counts of elephants have been undertaken on the 'westbank' of Luangwa River (Caughley & Goddard 1975; Douglas-Hamilton *et al.* 1979; Kaweche & Lewis 1986), some of the present data were amalgamated into comparable Westbank estimates. Frequencies of sighting rhinos and elephants were available from four areas (NLNP, SLNP North, Core and South), comprising *c.* 80% of the Westbank

aerial census area. Hence, an overall estimate for the instantaneous rate of change on the Westbank was derived from

$$\Sigma(f_i \times a_i)/(\Sigma a_i),$$

where f = frequency of sighting and a = size (km^2) of the ith area.

Analysis of carcass finds

This analysis aimed to quantify the proportions of axed and intact skulls encountered by patrols in different areas, to determine whether or not changes in the frequency of sighting rhinos and elephants arose from illegal activity. Axed or intact skulls of rhinos and elephants were entered as binomial variables and analysed using a generalized linear model (Cox 1970; McCullaugh & Nelder 1983). Data for the years 1979–82 and 1983–85 were grouped. Year groups and area were the only variables incorporated into the model, following a procedure similar to that described for the earlier log-linear models. This extends an earlier analysis of rhino skulls (Leader-Williams 1988).

Results

Sightings of rhinos

There was no clear trend of increase or decrease in sightings of rhinos during 1947–69. The best model for rhinos during this period explained 75·1% of the deviance and year had no effect on the model. Therefore, data on rhino sightings were combined for all years between 1947–69 (Fig. 4). However, the frequency of rhino sightings differed between areas (Table 2). Even then, rhinos were sighted infrequently within GMAs. Within NPs on the Westbank of Luangwa River, rhino sightings decreased from north to south. Overall sightings of rhino within the four areas on the Westbank during 1947–69 are shown as a single point for comparison with sightings in the same areas during 1979–85 and with the world market price of rhino horn (Fig. 4). This comparison shows that a marked decline of −0·63 in rhino sightings occurred after the rapid increase in price of rhino horn during the mid-1970s.

Numbers of rhino sighted in1979 and their rates of decrease during 1979–85 differed between the various areas of Luangwa Valley, but there were too few patrols to Luambe and Lukusuzi NPs to make accurate estimates of rates of decline in those two areas (Fig. 5). The instantaneous rate of decline of rhinos calculated from sightings by patrols in SLNP Core gave a similar result to the very accurate method of monitoring individually recognized rhinos within part of the same area (−0·24 vs. −0·29: Leader-Williams 1988). Instantaneous rates of decline calculated from patrol sightings differed between −0·24 in SLNP Core and −0·99 in NLNP (analysis of covariance: $\chi^2 = 62{\cdot}86$, d.f. = 5, $P < 0{\cdot}001$). By 1985, scouts rarely saw rhinos in any area of Luangwa Valley, except in SLNP Nsefu at an estimated frequency of 1·04 and, more commonly, in SLNP Core at a frequency of 1·78 rhinos per 7-days patrol (Fig. 5). The overall rate of decline of −0·63 for rhinos on the Westbank of Luangwa River (Fig. 4) arose because (i) there were high rates of decline amongst the frequently sighted rhinos in two large areas (NLNP and SLNP North), and (ii) the lower rates of decline occurred only in one small area (SLNP Core) or in one large area where few rhinos were sighted initially (SLNP South).

Sightings of elephants

Numbers of elephants sighted increased at an instantaneous rate of 0·06 year^{-1} during 1947-69 in all areas of Luangwa Valley (Fig. 6). The best model for elephant sightings

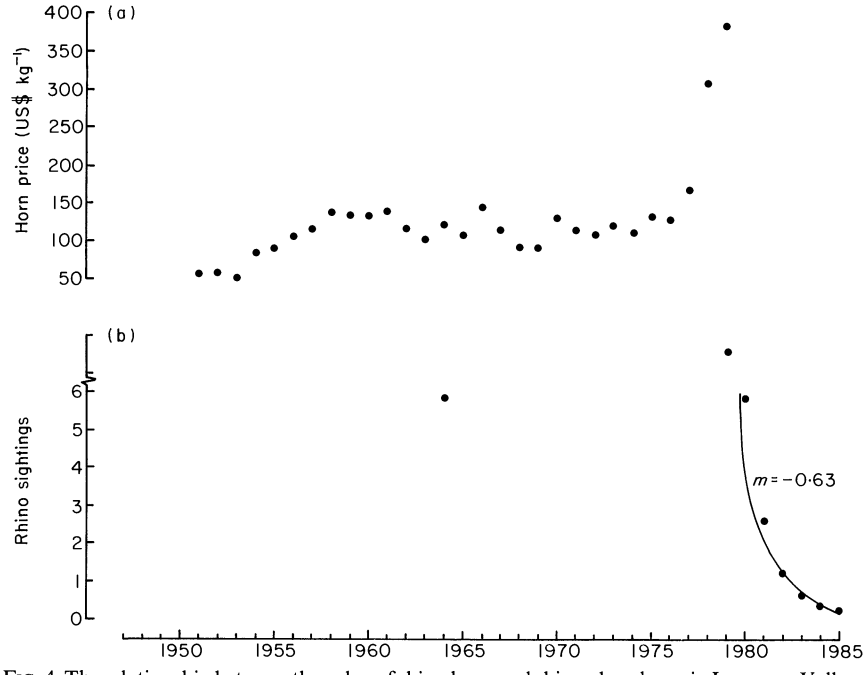

FIG. 4. The relationship between the value of rhino horn and rhino abundance in Luangwa Valley, shown as: (a) the price of horn (US$ kg^{-1}) imported to Japan during 1951–80 (from Martin 1983), corrected for inflation with a base of 100% in 1980 (using import price indices for all commodities imported to Japan, from figures supplied by the Department of Trade and Industry, London); (b) rhino sightings on the Westbank of Luangwa River during 1947–69 and 1979–85. The model for 1947–69 included month (standardized to January), patrol length (standardized to 7 days) as a quadratic, and area. The model for 1979–85 is for four scouts on a 7-days patrol in January and uses data from four areas on the Westbank (see Methods) from Fig. 5.

TABLE 2. Differences in frequency of sighting rhinos and elephants on a 7-days patrol in January during 1947–66, and rates of change in elephant herds and elephant numbers during 1979–85, and mean herd size in 1985, in different areas of Luangwa Valley

	Frequency of sightings during 1947–66				Rate of change over 1979–85 in		
	Rhinos	*N*	Elephants	*N*	Elephant herds	Elephant numbers	Herd size in 1985
Westbank							
NLNP	10·5	5	49	5	−0·42	−0·30	6·3
SLNP-North	6·6	8	67	7	−0·21	−0·04	7·8
SLNP-Core	4·5	7	69	7	+0·11	+0·30	6·0
SLNP-South	0·7	8	85	8	+0·10	+0·33	8·2
Eastbank							
SLNP-Nsefu	—		—		+0·18	—	10·5
GMA	3·4	27	30	20	+0·18	+0·25	8·0

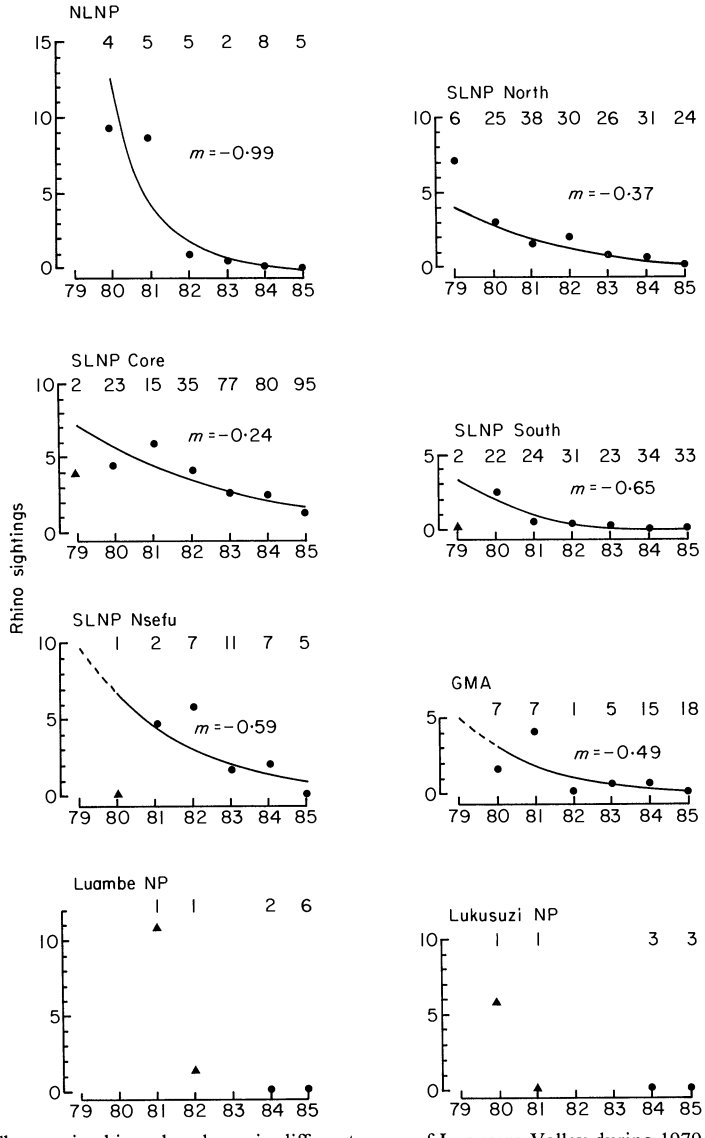

FIG. 5. Changes in rhino abundance in different areas of Luangwa Valley during 1979–85. The model included month (standardized to January), patrol length (standardized to 7 days) as a quadratic, scouts (standardized to four), area, year and the interaction between area and year, and explained 35·6% of the deviance. Individual area and year values are depicted as adjusted means for each year in each area (with sample sizes above year values). Instantaneous rates of decline were assessed for six areas by including year as a linear variable. Some areas were not patrolled, or patrolled only lightly in 1979 or 1980, so rates of decline were calculated from the first year with >2 patrols, thus omitting triangles. Dashed lines show extrapolations based on rates of decline from 1980 or 1981, as appropriate.

during this period explained 67·2% of the deviance, and included area and year as variables, but a year × area interaction had no effect on the model. Thus, elephant sightings increased at the same rate within each area but sightings differed between areas (Table 2). Elephant sightings were, like rhino sightings, relatively low in the GMAs.

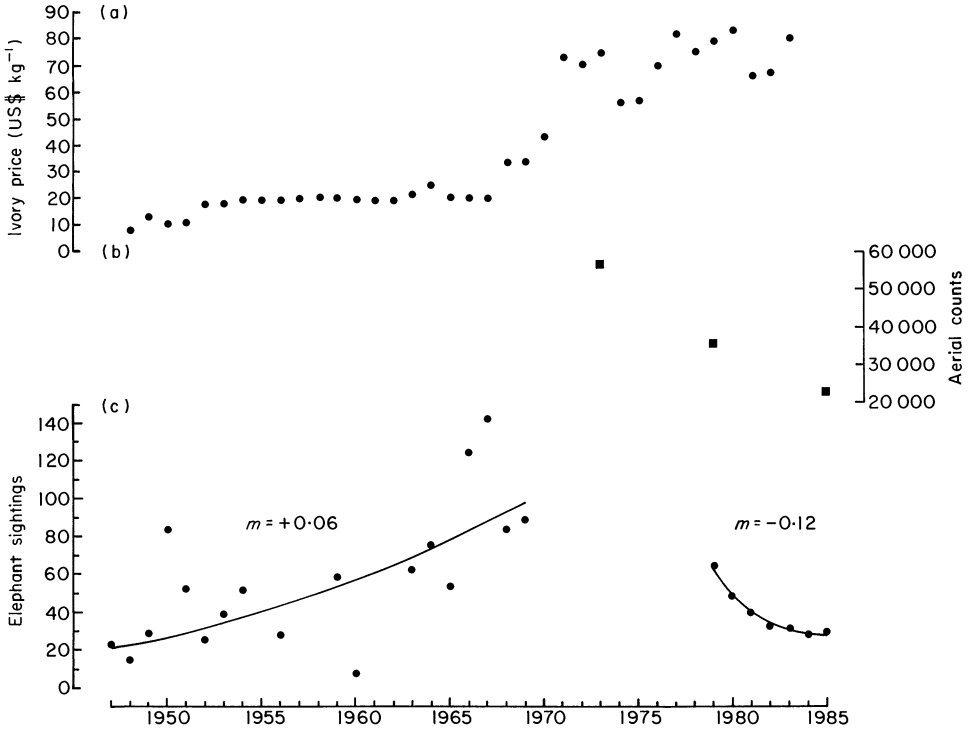

FIG. 6. The relationship between the value of ivory and elephant abundance in Luangwa Valley, shown as: (a) the price of ivory (US$ kg^{-1}) imported to Japan during 1950–85 (converted from figures in yen in Caldwell (1988) using rates supplied by the Bank of England), corrected for inflation (see Fig. 4); (b) aerial counts of elephants on the Westbank of Luangwa River (see Methods) in 1973, 1979 and 1985 (from Caughley & Goddard 1975; Douglas-Hamilton *et al.* 1979; Kaweche & Lewis 1986); (c) elephant sightings on the Westbank of Luangwa River during 1947–69 and 1979–85. The model for 1947–69 included month (standardized to January), patrol length (standardized to 7 days) as a quadratic, area and year as a linear variable. The model for elephant numbers during 1979–85 included all variables and uses data from four areas on the Westbank (see Methods).

However, elephant sightings on the Westbank increased from south to north and were negatively correlated ($y = -0{\cdot}27 + 24{\cdot}09$, $r^2 = 0{\cdot}98$, $P < 0{\cdot}02$) with rhino sightings. The increasing frequency of sighting elephants on the Westbank during 1947–69 are shown for comparison with sightings during 1979–85 and with the world market price of ivory (Fig. 6). The overall rate of decline in elephant numbers on the Westbank during 1979–85 calculated from sightings by foot patrols was similar to the instantaneous rate of decline calculated from aerial counts between 1973–85 ($-0{\cdot}12$ vs. $-0{\cdot}07$). This decline followed upon the increase in price of ivory upon world markets in the 1970s.

The frequency of sighting elephant herds changed at different rates in the various areas of Luangwa Valley between 1979 and 1985 ($\chi^2 = 302{\cdot}72$, d.f. $= 5$, $P < 0{\cdot}001$), and again there was an insufficient sample of sightings to estimate rates of change in Luambe and Lukusuzi NPs (Fig. 7). Instantaneous rates of change in herds sighted varied from $+0{\cdot}18$ in two areas to $-0{\cdot}42$ in NLNP. Elephant numbers changed in a similar way to sightings of herds, though the sample of numbers of elephants sighted was too small to make an estimate of rates of change for SLNP Nsefu. The only difference was that rates of increase

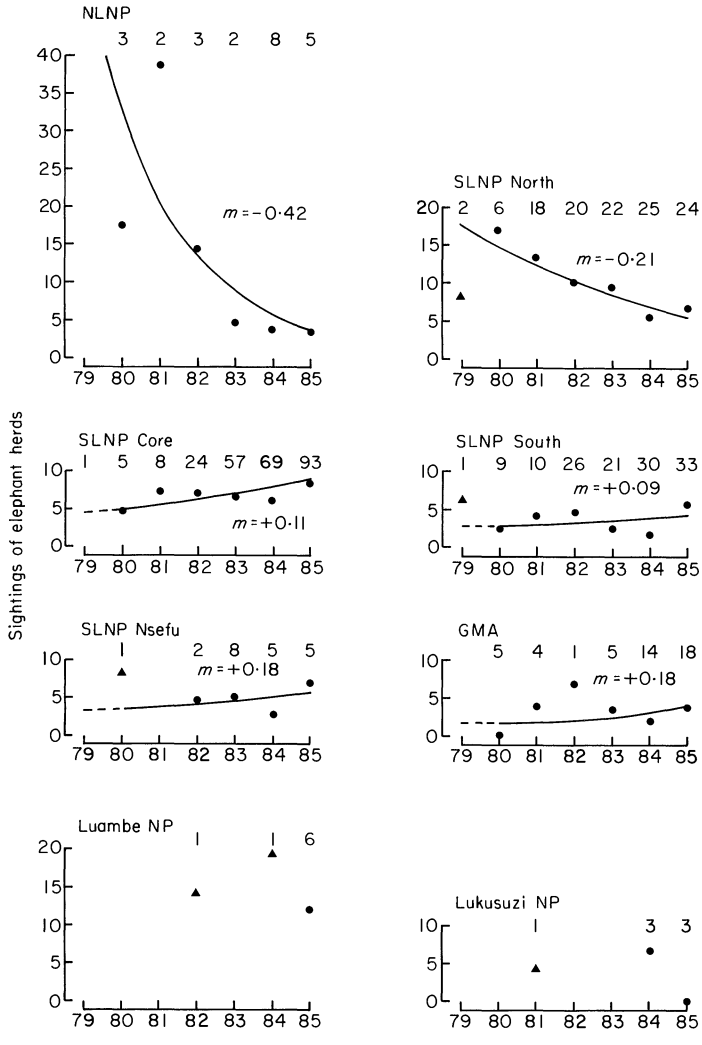

FIG. 7. Changes in elephant abundance in different areas of Luangwa Valley during 1979–85. The model included month (standardized to January), patrol length (standardized to 7 days) as a quadratic, scouts (standardized to four), anti-poaching unit (standardized to APU 1), area, year and the interaction between area and year, and explained 52·1% of the deviance. Instantaneous rates of increase or decrease were assessed as in Fig. 5.

in numbers were consistently higher, and rates of decrease lower, than for herds (Table 2). This difference arose because herd size increased at a similar rate in all areas (Fig. 8). Even though the slope of the increase did not differ between areas ($F_{9,381} = 0{\cdot}82$, $P > 0{\cdot}10$), there was a difference in elevation ($F_{9,390} = 3{\cdot}82$, $P < 0{\cdot}001$). The largest herds were found in SLNP Nsefu (Table 2), but there was no obvious explanation for area differences in herd size. The overall decline of $-0{\cdot}12$ in elephant sightings on the Westbank (Fig. 6) arose because (i) declines occurred in abundant subpopulations in large areas, and (ii) increases only occurred either in one small area or in one large area holding few elephants initially,

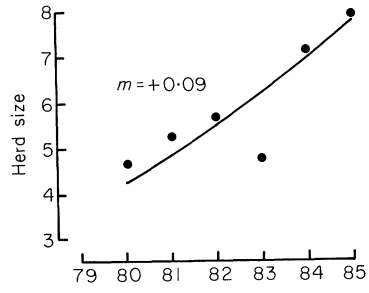

FIG. 8. Increase in the size of elephant herds in Luangwa Valley during 1980–85, shown only for SLNP North. Herd size increased at a similar rate in all areas, but the size of herds differed between areas (Table 2).

as for rhinos. By 1985, however, there was a positive correlation between the frequency of sighting rhinos and elephant herds ($y = 0{\cdot}37x - 1{\cdot}45$, $r^2 = 0{\cdot}93$, $P < 0{\cdot}05$).

Finds of carcasses

Patrols usually found a preponderance of axed skulls in all areas of Luangwa Valley in both earlier and later year groups (Table 3). Because axed skulls indicate that animals were shot for their trophies by hunters (Leader-Williams 1988), it can be concluded that changes in the frequencies of sighting rhinos and elephants (Figs 5, 7) arose largely from illegal activity.

TABLE 3. Proportions of axed rhino and elephant skulls found in different areas of Luangwa Valley during earlier (1979–82) and later (1983–85) years

		Rhinos		Elephants	
Area and year group		*N*	Axed	*N*	Axed
NLNP	Early	23	0·77	142	0·60
	Late	8	0·92	185	0·96
SLNP-North	Early	66	0·75	286	0·78
	Late	6	0·92	188	0·76
SLNP-Core	Early	12	0·38	107	0·72
	Late	16	0·69	184	0·64
SLNP-South	Early	8	0·77	117	0·77
	Late	2	—	73	0·86
SLNP-Nsefu	Early	1	—	3	—
	Late			13	0·31
Luambe NP	Early	2	—	2	—
	Late			42	0·93
Lukusuzi NP	Early			1	—
	Late	2	—	4	1·00
GMA	Early			8	0·63
	Late	1	—	62	0·89

Discussion

Sightings of rhinos and elephants by foot patrols undertaking routine law enforcement duties appear to provide a sensitive index of population trends. The technique described has provided comparable results for rates of decrease to the more accepted and most accurate methods for counting both species. In the case of rhinos, an individually recognized group living within half of SLNP Core declined at an instantaneous rate of $-0{\cdot}29$ year^{-1} between 1981 and 1985 (Leader-Williams 1988) compared with the rate of $-0{\cdot}24$ calculated for the whole area from patrol sightings between 1979 and 1985 (Fig. 5). For elephants, three aerial counts on the Westbank (Caughley & Goddard 1975; Douglas-Hamilton *et al.* 1979; Kaweche & Lewis 1986) suggested a decline of $-0{\cdot}07$ year^{-1} between 1973 and 1985, compared with an overall rate of $-0{\cdot}12$ calculated from patrol sightings between 1979 and 1985 (Fig. 6).

These results permit confidence in the technique and methods of analysis. They show the value of routine data, collected at no extra expense than the costs of collation and analysis, in monitoring population trends. Furthermore, these data were collected only at a very basic level and used the simple index of sightings per day. More complex data, such as sightings in a given strip width, could also be collected routinely to yield information on densities (Bell 1986b). However, the main duties of law enforcement patrols are to prevent illegal activity and to apprehend offenders. Hence, burdening patrols with more sophisticated data collection requirements must be weighed against their vigilance and effectiveness at law enforcement.

In spite of its relative crudeness, the technique has quantified the build-up in elephant numbers after the setting up of reserves in the 1940s and 1950s (Fig. 6). These reserves provided elephants with protection from hunting and from the burgeoning human population, and the build-up arose probably as much from local immigration as from natural increase. The resultant 'elephant problem' of the 1960s and early 1970s was evident in Luangwa Valley (Caughley 1976; Hanks 1979; Abel & Blaikie 1986) and many other areas of Africa (Laws 1969; Laws, Parker & Johnstone 1975).

The elephant problem of the early 1970s has been superseded by a rapid rise in the price of both ivory and rhino horn on world markets (Martin 1982; Parker & Amin 1983; Caldwell 1988) that has resulted in drastic declines of both species within the conservation areas of most countries in Africa (Western & Vigne 1985; Douglas-Hamilton 1987; Cumming *et al.* 1990), including Luangwa Valley (Figs 4, 6). Because axed skulls were found far more frequently throughout Luangwa Valley during 1979–85 than the intact skulls suggestive of natural deaths (Table 3), the declines were due mainly to illegal activity. However, the patterns of decline of rhinos and elephants differ (Figs 5, 7). First, the overall rate of decline of the more numerous elephants was lower than that of rhinos ($-0{\cdot}12$ vs. $-0{\cdot}63$). Secondly, though rhinos declined in all areas, albeit at different rates, elephant numbers increased in some areas, due probably to local immigration. This resulted in three major changes in distribution: (i) a series of localized compressions, as described for one area of Luangwa Valley (Lewis 1986); (ii) an overall increase in the size of elephant herds (Fig. 8); and (iii) a realignment of the early inverse relationship between elephant and rhino numbers to a direct relationship. Suggestions that rhinos and elephants may compete (Leuthold 1978) were supported, but not confirmed, by the correlation for the relatively undisturbed Westbank populations during 1947–69. However, by 1985 there was a direct correlation between the remaining rhinos and elephants throughout all areas of Luangwa Valley. The causes of these differences relative

to patrol effort and the distribution of illegal activity will be discussed in the final part of the paper.

LAW ENFORCEMENT

The anti-poaching initiative in Luangwa Valley failed to protect rhinos and elephants from commercial exploitation. This part of the paper aims (i) to assess the motivation of anti-poaching units in Luangwa Valley, (ii) to examine their success in localizing the origin of those involved in illegal exploitation of rhinos and elephants, and (iii) to determine the extent to which Zambia upheld its own wildlife laws from an analysis of sentences given to offenders.

Methods

Motivation

The effective time spent by each scout on foot patrol measures the commitment of anti-poaching units (Bell 1986b). Patrol lengths were counted as the number of days that scouts were patrolling on foot in the bush away from vehicles. The number of scouts per patrol × number of days on patrol was summed for each month and divided by the number of scouts in each APU, to provide a measure of the 'effective time scout^{-1} month^{-1}'.

Captures

Offenders were caught by both foot and vehicle patrols. On foot patrols, as many offenders, weapons and trophies were caught or seized as possible. Offenders were interrogated for their names, village and chief's area, and any other useful intelligence information. Offenders were placed in one of three categories depending on whether they were hunting elephants or rhinos, possessed ivory or rhino horn, or whether they only possessed trophies such as meat or hides from other animals. Guns were classified as automatics (including semi-automatics), rifles, muzzle-loading guns and shotguns. The number of tusks and rhino horns seized was also recorded. The small samples of offenders caught, and weapons and trophies seized, in SLNP Nsefu, and in Luambe and Lukusuzi NPs were combined into an Eastbank NP category. Similarly, offenders caught in Lupande and other GMAs in Luangwa Valley were combined into a Luangwa GMA category. The size of gangs encountered in different areas was normally distributed and compared by analysis of variance, and numbers of trophies seized were compared by Kruskal–Wallis ANOVA and Mann–Whitney *U*-test. Proportions of different categories of offender caught and of weapons seized were compared using the *G*-test.

Vehicle patrols were undertaken for a variety of reasons, e.g. (i) upon escape of part of a gang encountered by a foot patrol; (ii) upon receipt of information of unlawful possession of prescribed trophies such as rhino horn, elephant ivories or government trophies such as meat or skins, or of possession of unlicensed firearms; (iii) on an *ad hoc* basis usually by setting up road-blocks at strategic points on the major trunk roads. Offenders caught, and weapons and trophies seized, were categorized as described for foot patrols. Elephant/rhino offenders caught on vehicle patrols comprised both escapees from foot patrols and those in illegal possession of ivory or rhino horn who may not themselves have been involved in offences within the NP. Proportions of different categories of offenders, weapons and trophies resulting from different areas, APUs and types of patrol were compared using the *G*-test.

Sentencing of offenders

Arrested offenders were charged and tried with the scouts acting as witnesses, and judgements were available for offenders captured on foot and vehicle patrols by APU 1 between 1979 and 1985. Wildlife offences were charged under the headings of unlawful hunting, unlawful entry, unlawful possession of proscribed or government trophies (CAP 316), and unlawful possession of firearms (CAP 111). After December 1982, offences involving elephants and rhinos were distinguished in law, and offenders then became liable for a mandatory prison sentence of between 5 and 15 years (Section 139 of Act No 32 of 1982). The proportions of different types of sentence delivered to offenders involved in elephant/rhino and other offences were compared with the *G*-test. The size of fines and length of prison sentences were examined for skewness and regressed on year.

Results

Motivation of foot patrols

Patrols comprised a mean of three to five scouts because of the possibility of encountering large gangs of poachers armed with automatic weapons, especially in Luangwa Valley (Fig. 9). Patrols varied in length from 1–2 days to several weeks and averaged 5–9 days per patrol in different years. As a result, the effective time spent on patrol varied from *c.* 11 to *c.* 17 days scout^{-1} month^{-1} for 1979–85.

Captures on foot patrols

A total of 173 poaching gangs was encountered by foot patrols between 1979 and 1985 and the size of 163 gangs was recorded (Fig. 9a). Gang sizes differed between areas ($F_{7,155} = 7{\cdot}26$, $P < 0{\cdot}001$) and were large (*c.* 7–9 men) in NLNP, SLNP North, Core and SLNP South. Gangs were smaller (*c.* 2–4 men) in the Eastbank NPs, Luangwa GMAs, LZNP and Luano GMA.

A total of 438 offenders was arrested from the 139 gangs. There was no bias in the success of capturing different categories of offender because the ratios of elephant/rhino : non-elephant/rhino gangs did not differ from the total captures in each area (all $P > 0{\cdot}10$). Thus, the larger sample of total captures (Fig. 9b) was used for comparing the overall difference ($G = 141{\cdot}58$, d.f. $= 6$, $P < 0{\cdot}001$) between areas. More offenders were involved in elephant/rhino incidents in SLNP North and Core than in NLNP ($G = 10{\cdot}21$, $P < 0{\cdot}005$) or in SLNP South ($G = 48{\cdot}97$, $P < 0{\cdot}001$). However, there was no difference between the frequency of elephant/rhino offenders in SLNP South and Eastbank NPs ($G = 0{\cdot}41$, $P > 0{\cdot}10$) and none between the frequency of either category of offender in Luangwa GMAs, LZNP and Luano GMA ($G = 5{\cdot}88$, d.f. $= 2$, $P > 0{\cdot}05$).

A total of 193 guns was captured from poaching gangs and the proportions of the various categories of guns captured differed ($G = 29{\cdot}37$, d.f. $= 6$, $P < 0{\cdot}001$) between areas (Fig. 9c). More automatic weapons and fewer muzzle-loading guns were captured from gangs in NLNP and SLNP North than in SLNP South ($G = 11{\cdot}09$, d.f. $= 2$, $P < 0{\cdot}005$). Muzzle-loading guns predominated in Eastbank NP and Luangwa GMA, and in LZNP and Luano GMA ($G = 0{\cdot}22$, $P > 0{\cdot}05$).

A total of 434 elephant tusks and twenty rhino horns was seized from forty-eight different poaching gangs by foot patrols. There was no difference ($H = 0{\cdot}44$, d.f. $= 3$, $P > 0{\cdot}10$) in the numbers of tusks recovered from gangs in NLNP, SLNP North, Core area and South (Fig. 9d), and more tusks were recovered from gangs in these Westbank NPs than from the other areas ($U = 91{\cdot}5$, $z = 2{\cdot}28$, $P < 0{\cdot}05$). The rhino horns were recovered

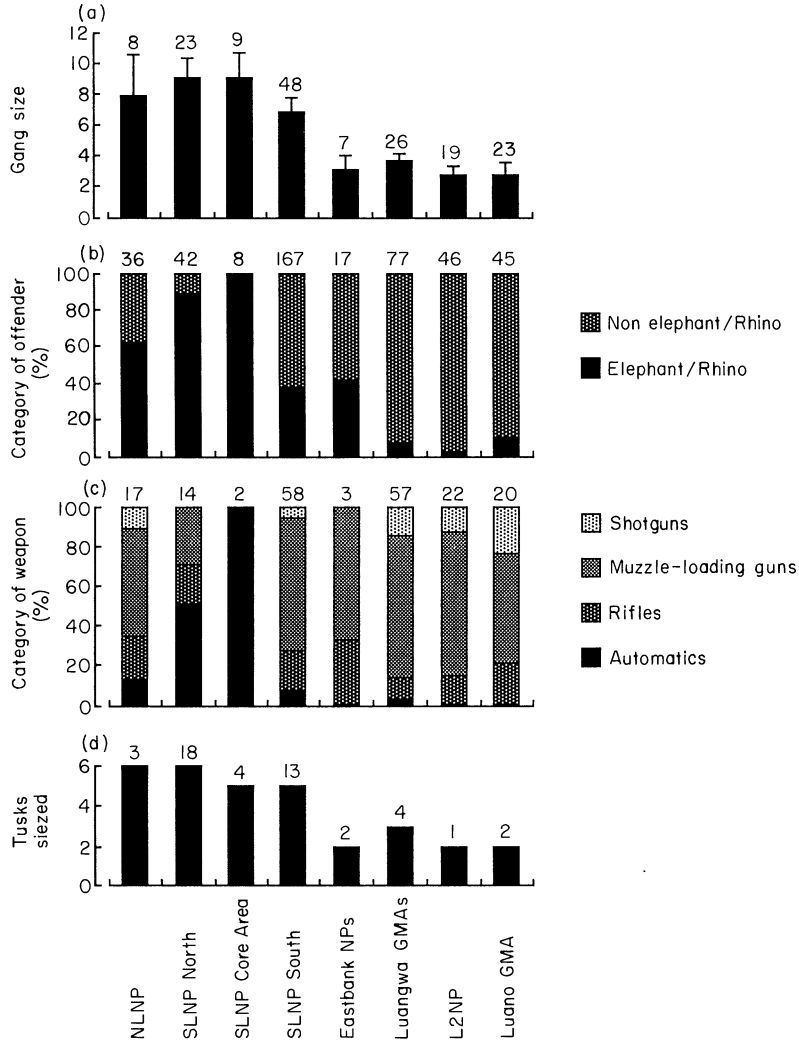

FIG. 9. The activities of offenders in different areas of Luangwa, Lower Zambezi and Luano valleys, shown as: (a) mean ± SEM size of gangs; (b) the proportion of offenders involved in elephant/rhino and other offences; (c) the proportions of each category of weapon seized; and (d) the median number of tusks recovered from gangs. Sample sizes are shown above bars.

from eight of the same gangs in various areas of SLNP, and gangs had a mean of 2·5 ± 0·26 horns when captured.

Captures on vehicle patrols

Few vehicle patrols were carried out compared with numbers of foot patrols undertaken by each APU (Fig. 10). However, a total of 364 offenders was arrested on vehicle patrols, at a higher success rate per patrol (all $P < 0{\cdot}01$) (Fig. 10a). The proportions of elephant/rhino and other categories of offender (Fig. 10b) caught by APU 1 and 3 did not differ between foot and vehicle patrols ($G = 0{\cdot}09$ and $0{\cdot}12$, $P > 0{\cdot}10$). However, APU 2

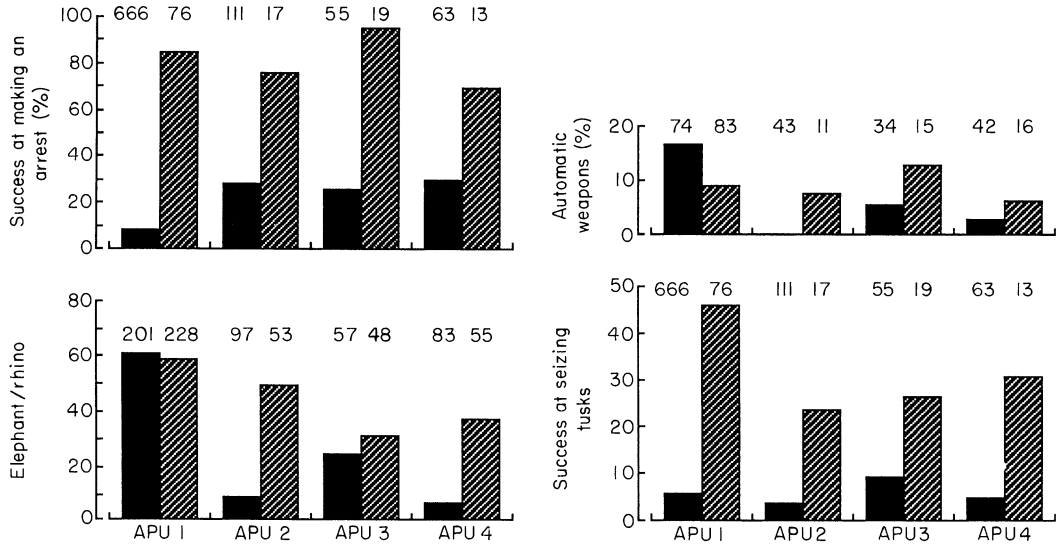

FIG. 10. Comparison of the success of making arrests and seizing weapons and trophies on foot (■) and vehicle (▨) patrols by different anti-poaching units.

and 4 enhanced their success at arresting elephant/rhino offenders on vehicle patrols ($G = 31{\cdot}86$ and $16{\cdot}83$, $P < 0{\cdot}001$). This was achieved primarily on road-blocks placed on the Great East and North roads (Fig. 1), respectively.

A total of 125 weapons was seized from poachers but the proportions of automatics to other weapons seized on vehicle patrols were not enhanced by any APU (Fig. 10c: all $P > 0{\cdot}10$). Furthermore, a total of 302 elephant tusks and eight rhino horns was seized and, as with success of arrests, tusks were recovered more successfully on vehicle than on foot patrols (Fig. 10d) by three APUs (all $P < 0{\cdot}005$).

Area of origin of offenders

A total of 331 offenders was charged with hunting in the NPs of Luangwa Valley. All but one of these poachers were Zambians. Most elephant/rhino offenders caught in SLNP came from Chief Mpumba's, Chief Mailo's and Chief Serenje's areas, and the smaller sample caught in NLNP came mainly from Chief Chikwanda's area (Fig. 11). These chiefs' areas are situated outside Luangwa Valley, above the Muchinga Escarpment (Fig. 1). Only three of the offenders were arrested after being caught for a second time. The areas of origin of other offenders showed a less clumped distribution, and a higher proportion of offenders came from chiefs' areas situated within Luangwa Valley. In addition, some offenders came from chiefs' areas outside Luangwa Valley and from mining townships on the Copperbelt (Figs 1, 11). Hence, there was no overall correlation (both $P > 0{\cdot}05$) for either SLNP ($r_s = 0{\cdot}316$, $t = 1{\cdot}75$, d.f. $= 21$) or NLNP ($r_s = 0{\cdot}113$, $N = 8$) between the areas from which elephant/rhino and other offenders originated. However, both categories of offender ($N = 73$) caught hunting within Luangwa GMAs came largely from chiefs' areas within the GMA. The few offenders caught within Luambe NP ($N = 4$) and Lukusuzi NP ($N = 8$) also came from areas within Luangwa Valley.

A total of 98 offenders was arrested for possession of ivory or rhino horn on vehicle patrols originating from the three Luangwa APUs. All but one were Zambians and

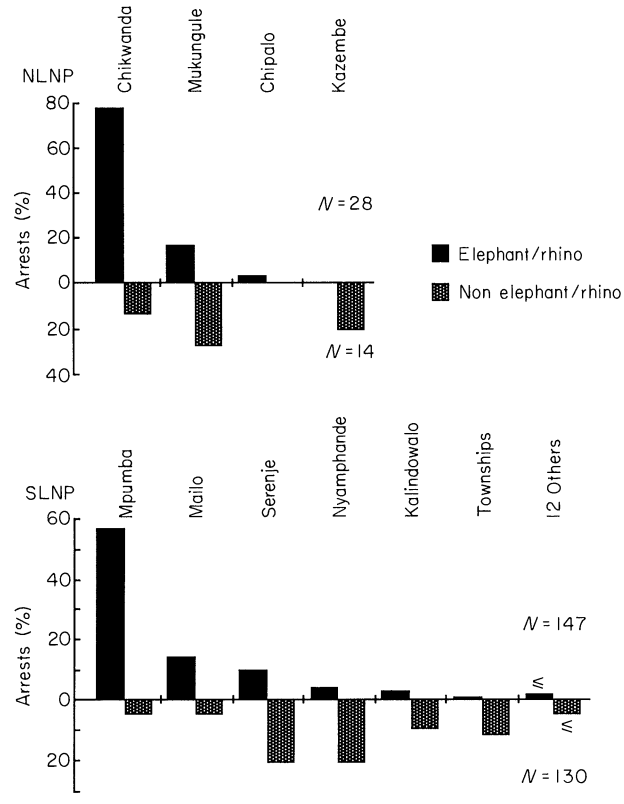

FIG. 11. The areas of origin of elephant/rhino and other offenders captured in NLNP and SLNP. (Fig. 1 shows the location of chiefs' areas.)

amongst their number were two chiefs and three game scouts. The remaining offenders came from thirty-two different chiefs' areas, including those within and outside Luangwa Valley. Only two offenders were re-arrested for a second offence. People arrested for other offences on vehicle patrols by the Luangwa APUs came from an even wider spread of chiefs' areas. This also applied to the predominantly meat- and firearms-based arrests made by APU 2 from Luano and Lower Zambezi valleys.

Sentencing of offenders

Judgements are available for 343 offenders captured on foot and vehicle patrols by APU 1 between 1979 and 1985. Fifty-one offenders are excluded from the analysis: forty-eight (14%) were acquitted for various reasons such as inadmissible evidence or loss of trophies, or given suspended sentences. The proportions of acquittals were similar for both elephant/rhino and other offenders (14% for each). A further three offenders turned informers and were not sentenced. The types of sentence delivered to the remaining 292 offenders ranged from strokes of the cane (usually given to minors), to fines and terms in prison (Fig. 12a). There was an overall difference in the proportions of fines to prison sentences given to elephant/rhino and other offenders before and after 1983 ($G = 40{\cdot}77$, $P < 0{\cdot}001$). Prison sentences were given more frequently to elephant/rhino than to other

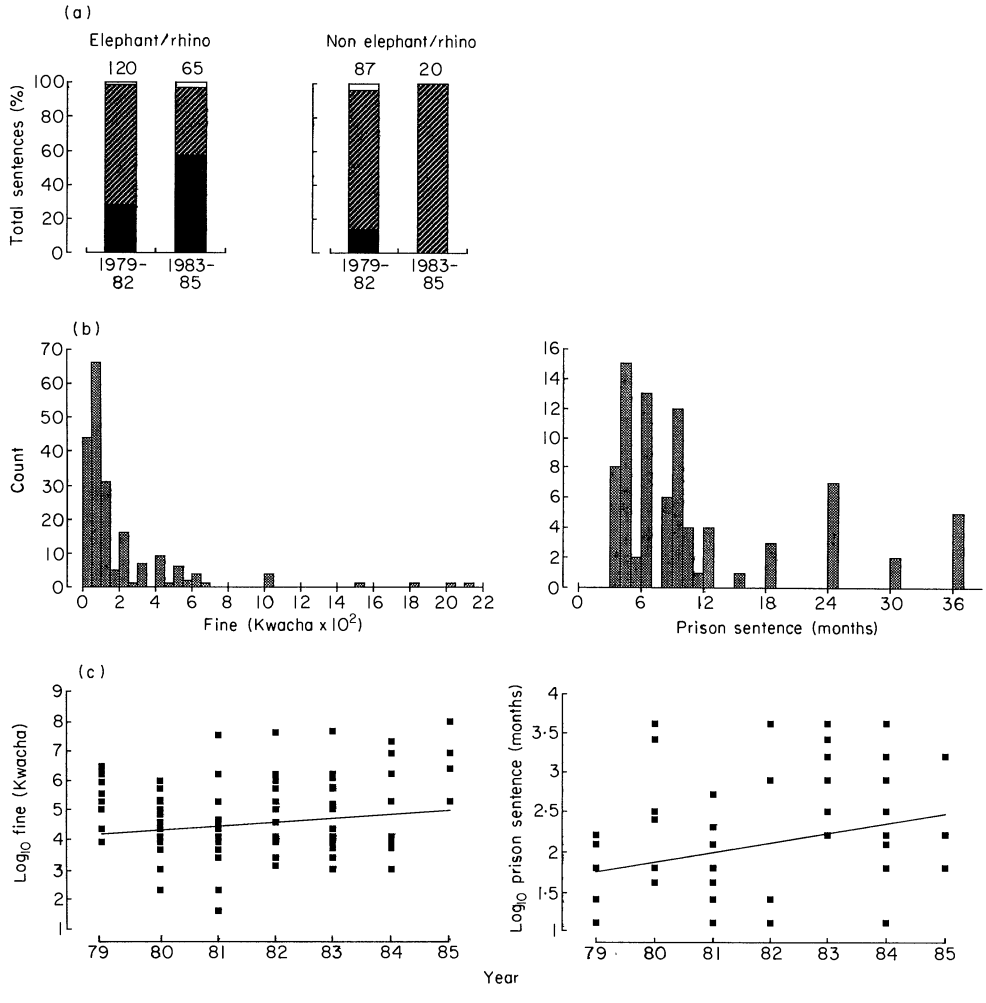

FIG. 12. The sentences given to offenders caught by APU 1 during 1979–85: (a) the proportions of different types of sentence (■ prison, ▨ fines or □ beating) given to elephant/rhino and other offenders before and after the change in law of December 1982 (see Methods); (b) the skewed distributions of fines and prison sentences; and (c) the slight but significant increases in the size of sentences delivered during 1979–85.

offenders both during 1979–82 ($G=6{\cdot}43$, $P<0{\cdot}02$) and 1983–85 ($G=20{\cdot}08$, $P<0{\cdot}001$). Prison sentences were given more often to elephant/rhino offenders after 1983 ($G=14{\cdot}46$, $P<0{\cdot}001$) but not to other offenders ($G=1{\cdot}41$, $P>0{\cdot}10$).

Data for both the size of fines and length of prison sentences were skewed (Fig. 12b) and therefore were log-transformed. Regressions of $\log_{10}$ fines and of $\log_{10}$ prison sentences on year were undertaken for both elephant/rhino and other offenders. There was no difference in slope between elephant/rhino and other offences for either size of fines ($F_{1,198}=3{\cdot}49$, $P>0{\cdot}05$) or length of prison sentences ($F_{1,79}=0{\cdot}61$, $P>0{\cdot}10$). Therefore, common lines were fitted for all offences and show that the size of fines ($y=0{\cdot}13x+4{\cdot}07$,

$r^2 = 0{\cdot}03$, $P < 0{\cdot}05$) and lengths of prison sentences ($y = 0{\cdot}13x + 1{\cdot}61$, $r^2 = 0{\cdot}15$, $P < 0{\cdot}001$) delivered to offenders increased slightly between 1979 and 1985 (Fig. 12c).

Discussion

The drastic declines in rhino and elephant numbers in Luangwa Valley during 1979–85 (Figs 4, 6) did not result from lack of motivation amongst law enforcement staff. Each scout spent around half of each month actively patrolling on foot in the bush, under arduous conditions away from homes and families. In addition, staff undertook vehicle and investigative patrols, escorted offenders to the police for charging and appeared as witnesses in often protracted or delayed court cases. Under Zambian law, offenders had to appear in court in the district where the offence was committed. In some cases this entailed journeys of up to 2000–3000 km to attend court (Fig. 1). Therefore, field staff spent a considerable proportion of time on patrol.

Furthermore, foot patrols caught large numbers of offenders, and this permitted an almost similar number of offenders to be caught more effectively on vehicle and other investigative patrols (Fig. 10), as in law enforcement operations in Malawi (Chinzinga 1986). In addition, the Zambian government used this knowledge to mount two army and police operations in November 1981 and June 1985 which arrested *c.* 250 further offenders. Overall, the anti-poaching operation was cost-effective. Its spending over the years 1979–85 from monies donated by conservation and aid organizations and from individual donors amounted to an equivalent of US$ 1·09 million. Hence, the average cost of capturing 1483 offenders by the four anti-poaching units during this period was equivalent to $730 man^{-1}, far lower than the cost of similar law enforcement exercises in developed countries (Glover 1982). Furthermore, the value of 1394 tusks seized from poachers and recovered from the field could be offset against these costs. Taking into account both declining tusk weights and increasing ivory prices (Martin 1986), APUs' recovered $371 200 worth of ivory, or around 40% of their total costs.

More importantly, the foci of illegal exploitation were identified. The base for less serious offences such as subsistence hunting for meat and possession of muzzle-loading guns was very widespread in all areas of Luangwa, Lower Zambezi and Luano valleys (Figs 9, 11). Such conflicts of interest between wildlife legislation and rural people living in or around African conservation areas are commonplace (Marks 1984; Abel & Blaikie 1986; Bell 1986a, 1987). In contrast, offenders exploiting ivory and rhino horn in SLNP and NLNP mostly originated from more localized areas outside Luangwa Valley (Figs 1, 11). Large gangs, well-armed with sophisticated weapons (Fig. 9) could remove large quantities of ivory from the NP (forty-eight tusks were recovered from one gang). Their bases above the Muchinga Escarpment provided convenient road access for the dispersal of illegal trophies, either south to Lusaka or north to Lake Tanganyika and thence to Burundi (Martin 1986; Caldwell 1988). Even though these commercial operators were restricted to four main areas, the few recaptures amongst the offenders suggested a large number of people were involved. Hence, the small field staff involved in the anti-poaching effort could not prevent declines in rhino and elephant abundance.

Anti-poaching efforts were not helped by magistrates who misinterpreted the intentions of their country's own wildlife laws. Clearly fines do not deter commercial gangs because they can be paid off by middlemen or by sale of valuable trophies. Hence, the law was changed in December 1982 (CAP 316), with the intention that elephant/rhino offenders should be given mandatory 5–15-years prison sentences. Even though

magistrates tended to deliver more prison sentences to elephant/rhino offenders, mandatory prison sentences were not delivered to all elephant/rhino offenders from1983 onwards (Fig. 12a). Furthermore, magistrates did not distinguish between elephant/rhino and other offences in terms of the severity of sentences. Even after 1983, the maximum prison sentences delivered to elephant/rhino offenders were 36 months (Fig. 12b). The wording of the law could be interpreted in this way because magistrates did not consider that offenders captured in possession of ivory or rhino horn could be proven to be involved in illegal trafficking.

If it is to retain (now in effect re-build) its elephant and rhino populations within conservation areas like NLNP and SLNP for sustainable development (Government of Republic of Zambia 1985; Abel & Blaikie 1986), the Zambian government will have to think seriously about how it will promote such objectives within the areas outside Luangwa Valley that provide the focus for offenders. Clearly the major declines that occurred in both elephant and rhino numbers during 1979–85 could not be blamed on anti-poaching units who were motivated and effective at catching poachers.

PATROL EFFORT

The final part of this paper presents an objective analysis of the deterrent capability of anti-poaching patrols for policy makers and wildlife managers who might wish to plan more effective *in situ* conservation measures in future. We examine the distribution of illegal activity and its inter-relationships with patrol effort and animal abundance to determine whether poachers avoid well-patrolled areas and concentrate upon areas with abundant quarry. Specifically, we aim to test these predictions and show that patrol effort determines (i) the distribution of illegal activity, and (ii) the rate of change of rhino and elephant abundance.

Methods

Field records

The following encounters were recorded daily as indices of illegal activity.

(i) Total poachers comprised all men encountered in a NP and provided an index of concurrent illegal activity that could be sighted within a range of around 100 m or less, depending on topography and habitat.

(ii) Camps, temporary shelters from cut branches and fires for cooking, provide a retrospective index of recent illegal activity that can be detected within a range of around 50 m or less.

(iii) Fresh carcasses, flesh-covered rhino or elephant carcasses encountered with trophies axed off, provide a retrospective index of very recent and successful illegal activity that was detectable from a distance (by looking for vultures) but which was confirmed from a short range.

Each area received a different number of separate patrols and of patrol days during 1979–85 (Fig. 13). At one extreme the remote 4636 km^2 NLNP received only thirty patrols totalling 322 patrol days during 1979–85. In contrast, SLNP Core, with an area of 400 km^2, had one or two patrols permanently devoted to it from 1982 (Leader-Williams 1985) and received a total of 337 patrols comprising 2260 patrol days during 1979–85. As there is a direct correlation between numbers of separate patrols and of patrol days across all areas and over all years ($y=1{\cdot}81x+0{\cdot}125$, $N=40$, $r^2=0{\cdot}93$, $P<0{\cdot}001$), patrol effort is considered only in terms of numbers of patrol days.

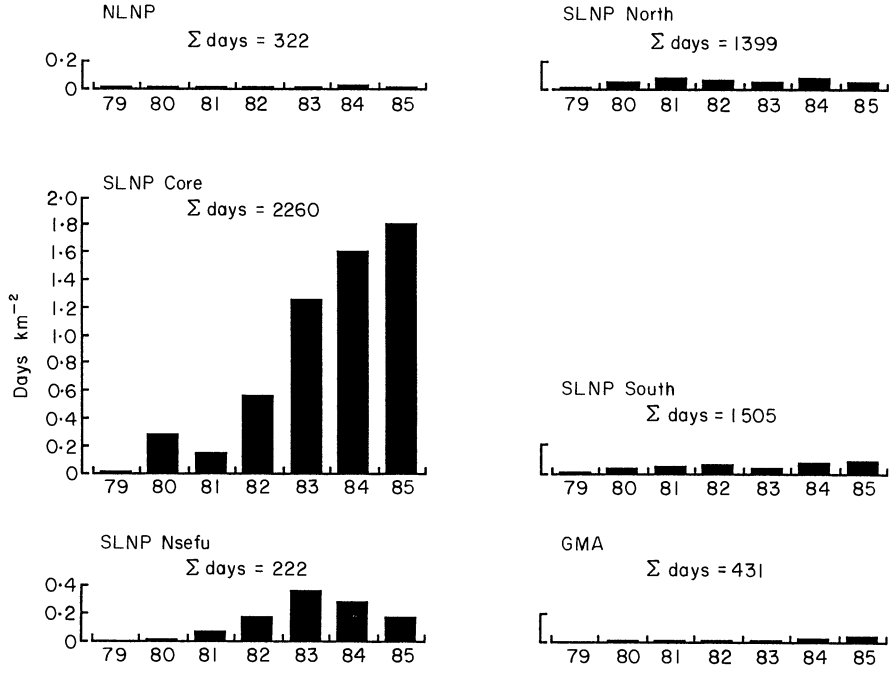

FIG. 13. Patrol effort devoted to six different areas of Luangwa Valley during 1979–85. Histograms show the effort in days per unit area, whilst the total days patrolled in each area are given above each histogram.

Analysis of illegal activity

The data for all encounters were heavily skewed towards zero values and had a Poisson distribution. As with encounters of elephants and rhinos, a log-linear model with a Poisson error distribution was fitted using all data points. Variables that might affect encounter rate were systematically incorporated into each model, with year fitted as a categorical variable. Statistical interactions between encounter rate, year and area were also investigated to check the spatial heterogeneity of illegal activity.

Inspection of the categorical data points showed that exponential curves, fitted with year as a linear variable ($v$year), did not always provide an adequate fit because rates of change for each index of illegal activity were not consistent between or within areas. Hence, separate area models were fitted for these encounters in the four areas for which there were sufficient data. Where rates of change were not constant within areas, a significant improvement in the model was achieved by adding year as a quadratic ($v\text{year} + v\text{year}^2$). As sample size was relatively small for each area, data for different months were combined into three seasons (wet: December–March: cool dry: April–July; hot dry: August–November) to reduce the degrees of freedom in each model. As with rhinos and elephants, the best model for each encounter in any area resulted from excluding those variables whose incorporation resulted in no significant reduction in deviance. Similarly, all encounters are adjusted in the models as if they had been made by four scouts on a 7-day patrol in January, or in the wet season in the case of separate area models.

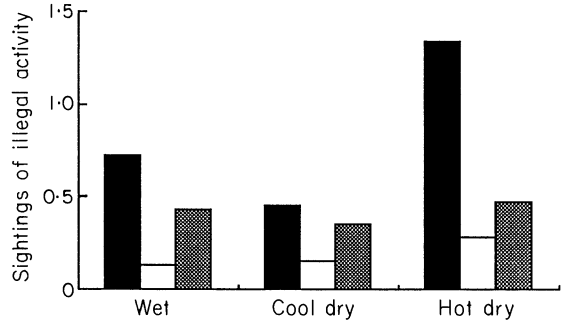

FIG. 14. Changes in encounters of each index of illegal activity during different seasons of the year: poachers (■), camps (□), and fresh carcasses (□). Histograms are derived from log-linear models fitted separately to data from SLNP North and represent mean encounter rates adjusted as if they had been made by four scouts on a 7-days patrol in 1982.

Analysis of patrol effort and illegal activity

Annual mean encounter rates of animal sightings (Figs 5, 7) and of illegal activities in different areas were derived from the best combined categorical models for each encounter. The annual effort devoted by patrols to each area was derived from (annual total of days on patrol/size of area) (Fig. 1). Simple and multiple regressions of indices of illegal activity (y) on $\log_e$ effort (x_1) and animal sightings (x_2) in all areas were performed to determine whether illegal activity was distributed in areas where there was least patrol effort and most quarry. Estimates of animal sightings were imprecise in certain areas in 1979 or 1980 because they were patrolled on two occasions or less at the start of the anti-poaching operation (see Figs 5, 7). Thus, four data points for rhinos and six for elephant herds were excluded from the analysis to prevent outlying points exerting an undue influence upon the regressions. As a result the models represent a conservative estimate of the relationships between patrol effort and illegal activity.

Analysis of patrol effort and change in animal abundance

Here, we extend an earlier analysis, which considered only the overall declines and total patrol effort during 1979–85 (Leader-Williams & Albon 1988), by using annual data with all its associated variability. Rates of change in animal abundance between individual years were determined from annual mean sighting rates of rhinos and elephant herds (Figs 5, 7) with (sightings in year_i − sightings in year_{i+1})/(average of sightings in year_i and year_{i+1}). Because each area patrolled was of a different size and held different numbers of rhinos and elephants at the start of each year, the annual effort in each area was calculated as $\log_e$ [(patrol days in year_i + year_2)/2]/size of area/sightings in year_i. Simple regressions of rates of change in abundance on effort in all areas and in all years were undertaken to determine if animals declined fastest in areas where there was least effort. Data points for 1979 and 1980 based on two or fewer patrols in each area were again omitted, as above.

Results

Signs of illegal activity

Indices of illegal activity were encountered throughout the year (Fig. 14). The frequency of encountering camps and fresh carcasses varied less in different seasons than encounters of poachers, who could be seen much more easily in the hot dry season when

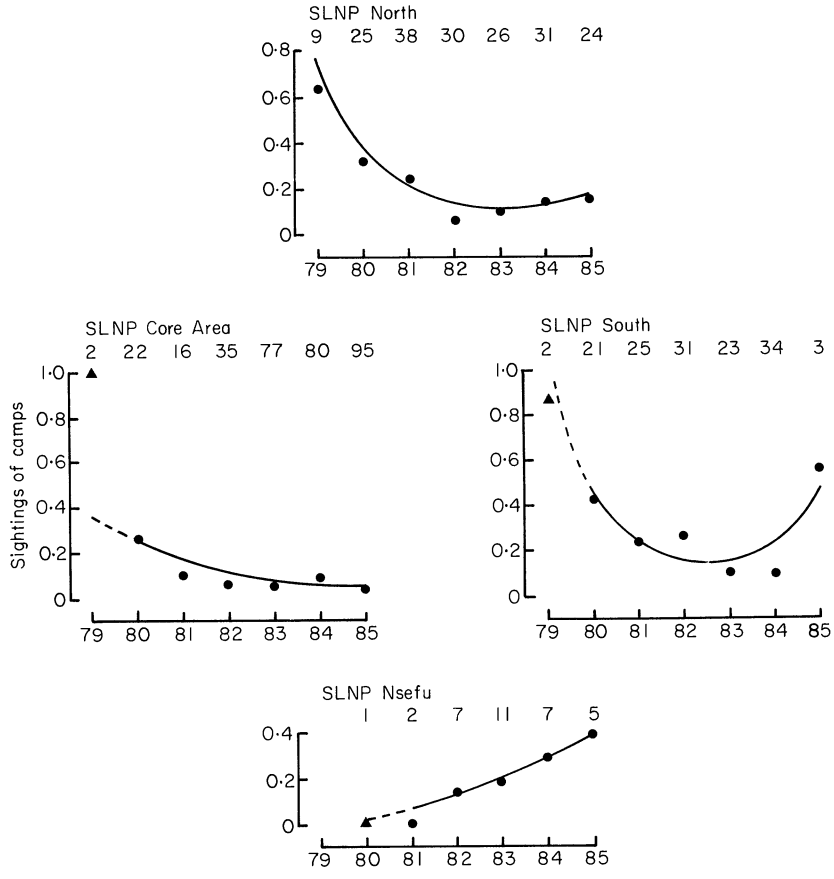

FIG. 15. Changes in encounters of camps in four different areas of Luangwa Valley during 1979–85, shown as encounter rates adjusted as if they had been made by four scouts on a 7-days patrol in the wet season. Values are derived from log-linear models fitted separately to data from each area, and are depicted as means for each year in each area (with sample sizes above year values). Curves for each area, fitted with year as a linear variable (either *v*year or *v*year^2), included variables and explained deviances in each model as follows: SLNP North: season, length, APU, *v*year and *v*year^2 – 29·2%; SLNP Core area: length, scouts and *v*year – 15·9%; SLNP South: season, length, length^2, *v*year and *v*year^2 – 34·6%; SLNP Nsefu: *v*year – 34·8%.

grass was short. Indices of illegal activity were encountered at different frequencies in each area and showed contrasting patterns of change over time between areas. However, the models for encounters of poachers (not shown), camps (Fig. 15) and fresh carcasses (Fig. 16) usually showed consistent patterns of change within areas during 1979–85. In SLNP North, encounter rates for poachers, camps and fresh carcasses all decreased initially and increased latterly (Figs 15, 16). In SLNP Core area, encounters of poachers and of fresh carcasses showed steady increases initially with the suggestion of a decrease latterly (Fig. 16). In contrast, encounters of camps decreased steadily (Fig. 15). In SLNP South, encounters of poachers and fresh carcasses tended to show a constant rate of decline, but encounters of camps decreased initially and increased latterly. Finally, in SLNP Nsefu, encounters of poachers and camps increased steadily, but finds of fresh carcasses did not

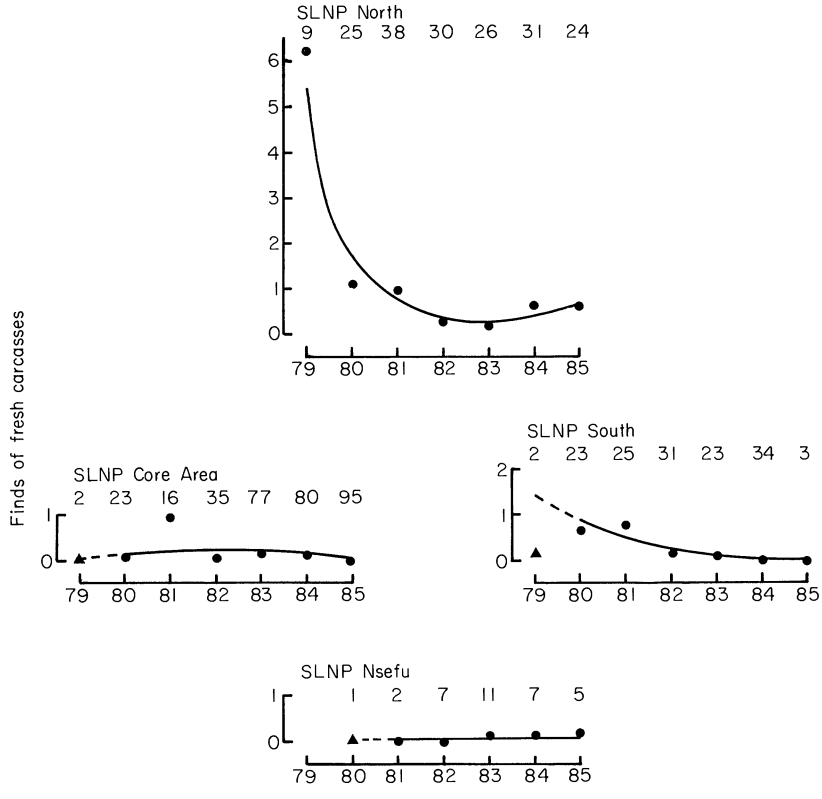

FIG. 16. Changes in encounters of fresh carcasses in four different areas of Luangwa Valley during 1979–85, fitted as for camps in Fig. 15. Curves for each area included variables and explained deviances in each model as follows: SLNP North: length, length^2, scout, *v*year and *v*year^2 – 21·7%; SLNP Core area: length, length^2, scouts, *v*year and *v*year^2 – 15·1%; SLNP South: scout and *v*year – 20·8%; SLNP Nsefu: nil.

change over time. Overall, illegal activity was encountered less frequently in SLNP Core and Nsefu than in SLNP North and South.

Patrol effort and illegal activity

Patrol effort and the abundance of quarry had somewhat different effects upon the distribution of each index of illegal activity. Multiple regressions both of sightings of poachers on patrol effort and elephants and of poachers on rhinos tended to be significant (Table 4), even though influential outlying data points from early years with few patrols were excluded. There was a stronger negative relationship between camps and effort (Fig. 17), but the availability of quarry did not affect the distribution of camps, since the partial regressions for elephants and rhinos indicate no significant reduction in the residual sums of squares (Table 4). Unsurprisingly, finds of fresh carcasses were positively related to the abundance of elephants and rhinos as shown by both simple and partial regressions. However, there was a negative relationship between finds of fresh carcasses and patrol effort, as partial regressions indicate a significant reduction in the residual sums of squares (Table 4; Fig. 18). Thus, increased patrol effort can reduce finds of fresh carcasses and the chances of successful outcome to illegal activity.

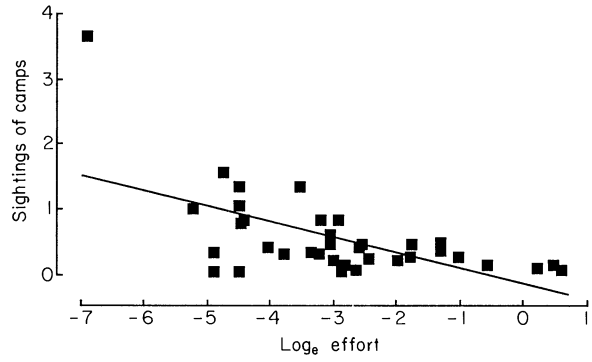

FIG. 17. Relationship between finds of camps and levels of patrol effort in different areas during 1980–85 (see Methods). The simple regression is of the form $y = -0{\cdot}235x - 0{\cdot}162$, $r^2 = 0{\cdot}318$, $P < 0{\cdot}001$ (see also in Table 4).

Patrol effort and change in animal abundance

Patrol effort had a direct effect upon rates of change in animal abundance. There was a direct relationship between annual changes in rates of sighting, both of rhinos and elephant herds in each year in each area, and patrol effort, per unit area (Fig. 19). Even though elephants were killed throughout Luangwa Valley, sightings of elephant herds showed overall increases in four areas, due to local immigration (Fig. 7). Thus, rates of change observed in elephant herds are a compound measure both of rates of loss due to illegal exploitation and of rates of local immigration/emigration, which could not be

TABLE 4. Relationships between indices of illegal activity, patrol effort and availability of quarry, shown as slopes of simple and multiple regressions and their levels of significance

Variable		Simple regression	Partial regression	Significance of multiple regression
y	*x*			
Poachers	x_1 Ln effort	−0·176†	−0·168†	=0·05
	x_2 Rhinos	−0·107†	−0·101†	
Poachers	x_1 Ln effort	−0·176†	−0·171†	=0·05
	x_2 Elephants	−0·038†	−0·043†	
Camps	x_1 Ln effort	−0·235***	−0·235***	<0·001
	x_2 Rhinos	−0·006	−0·003	
Camps	x_1 Ln effort	−0·235***	−0·223***	<0·002
	x_2 Elephants	+0·008	−0·002	
Carcasses	x_1 Ln effort	−0·157†	−0·168*	<0·01
	x_2 Rhinos	+0·131*	+0·136**	
Carcasses	x_1 Ln effort	−0·157†	−0·167	<0·05
	x_1 Elephants	+0·028*	+0·003*	

† $P < 0{\cdot}10$; * $P < 0{\cdot}05$; ** $P < 0{\cdot}01$; *** $P < 0{\cdot}001$.

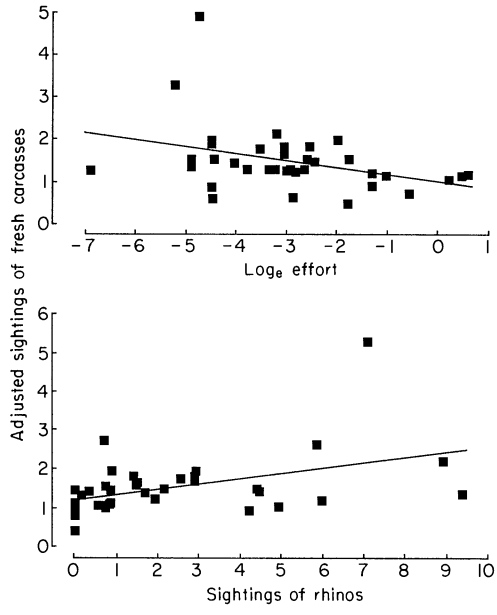

FIG. 18. Relationships between finds of fresh carcasses and both levels of patrol effort (adjusted for rhino sightings) and sightings of rhinos (adjusted for patrol effort) in different areas during 1980–85. Values are shown as (adjusted fresh carcasses + 1) to avoid those close to zero being adjusted to negative values. The regression equations are of the form $y = -0{\cdot}167x + 1{\cdot}032$, $r^2 = 0{\cdot}132$, $P < 0{\cdot}05$ and $y = 0{\cdot}136x + 1{\cdot}029$, $r^2 = 0{\cdot}189$, $P < 0{\cdot}01$ (see also in Table 4).

quantified separately using sightings by patrols. Hence, the relationship for elephant herds (Fig. 19b) only permits the conclusion that increased patrol effort created havens of relative safety in areas where there were few elephants initially, into which some elephants from less safe areas then moved.

In contrast, rhinos do not move to areas of relative safety, and rates of decrease calculated from sightings by patrols represent actual losses from illegal exploitation. Therefore, the relationship for rhinos (Fig. 19a) can be used to predict the effort that it would have been necessary to prevent illegal exploitation. At one extreme, the regression predicts that, to have achieved 0% change in rhino numbers, it would have been necessary to devote 1100 patrol days each year to the 400 km^2 SLNP Core to protect the average 5·8 rhinos sighted there per patrol in 1980. However, even by 1985, this area still received only 724 patrol days. At the other extreme, it would have been necessary to devote 26400 patrol days each year to the 4636 km^2 NLNP to protect the average 12·1 rhinos sighted per patrol in 1980. In fact, NLNP received only a total of 322 patrol days during the whole of 1979–85 (Fig. 13).

Discussion

Patrol effort has a considerable effect upon the distribution of illegal activity and rates of change in rhino and elephant abundance. However, conservationists' aspirations in the early 1980s to protect large populations of rhinos and elephants *in situ* were not fulfilled (AERSG 1984; Western & Vigne 1985). Many African countries that had large populations of rhinos and elephants also had low ratios of law enforcement staff and national conservation department expenditure relative to the size of their conservation

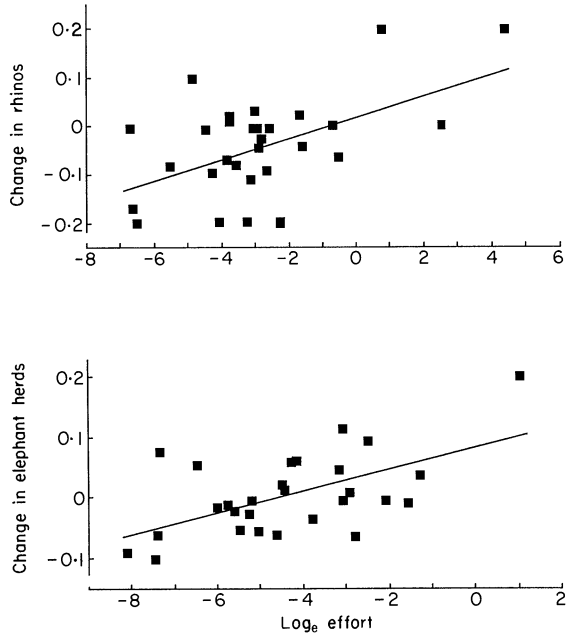

FIG. 19. Relationships between annual changes in sighting rates of rhinos and of elephant herds and in patrol effort in different areas during 1980–85 (see Methods). The simple regressions are of the form $y=0{\cdot}217x+0{\cdot}178$, $r^2=0{\cdot}256$, $P<0{\cdot}005$ for rhinos and $y=0{\cdot}178x+0{\cdot}824$, $r^2=0{\cdot}318$, $P<0{\cdot}002$ for elephant herds.

areas (Cumming *et al.* 1984; Bell & Clarke 1986). Furthermore, the grants donated by international conservation agencies, though large relative to the sums they could afford, added only a few US$ per km^2 and few men were therefore available to prevent the declines of rhinos and elephants within such a large area as Luangwa Valley (Leader-Williams & Albon 1988). However, rates of change of both species varied between different areas (Figs 5, 7) and this led us to examine whether or not law enforcement patrols in Luangwa Valley had any deterrent capability, both in relation to the distribution of illegal activity and to changes in animal abundance.

No independent measures of actual changes in levels of illegal activity are available to compare with indices resulting from the present analysis, so we can only assume that, as for rhinos and elephants, the routine data collected by patrols and analysed in a similar way provide an acceptable index of illegal activity. Hence, it is encouraging that direct or indirect indices, such as sightings of poachers and camps and finds of fresh carcasses, change in a consistent pattern in most areas (Figs 15, 16). It is also clear that illegal exploitation of rhinos and elephants has become a year-round occupation (Fig. 14), in contrast to traditional hunting which is practised mainly in the hot dry season, when there are no crops to tend (Richards 1939; Marks 1976). Consequently, law enforcement efforts must continue year-round.

Predictions that gangs hunting rhinos and elephants illegally should avoid heavily patrolled areas yet seek areas with more abundant quarry were largely fulfilled (Table 4). The six areas patrolled regularly each experienced different levels of patrol effort relative to their size, and encounters with men tended to be less frequent, whilst camps were

certainly seen less frequently, in areas of high patrol effort (Table 4, Fig. 17). In particular, encounters of camps decreased steadily in SLNP Core (Fig. 15), where gangs avoided advertising their presence, but which they tended to enter increasingly (Table 4) due to the relative abundance of quarry there towards 1985 (Figs 5,7). Unsurprisingly, fresh carcasses were seen less often as the overall abundance of rhinos and elephants declined. However, as this index represents the successful outcome of illegal activity, it is pertinent that increased patrol effort reduced finds of fresh carcasses (Fig. 16, Table 4).

The anti-poaching units in Luangwa Valley were greatly understaffed, given the levels of illegal activity aimed at rhino and elephant populations during 1979–85. Predictions from the relationship between changes in rhino numbers and patrol effort (Fig. 19) suggest that 1100 patrol days per year should have been devoted to the 400 km^2 SLNP Core to have prevented the decline of rhinos found there initially. In fact only 110 days were spent there in 1980, rising to 724 days by 1985 (Fig. 13). At their most effective, most scouts spent 17 days $month^{-1}$ on foot patrol, and a patrol usually consisted of four scouts because of the dangers of encountering large gangs armed with automatic weapons (see Law Enforcement). Given this, the predicted 1100 patrol days would have required the permanent stationing of five patrols within SLNP Core and, therefore, all the manpower of one anti-poaching unit staffed by 18–23 scouts to police this one small area. Conversely, the 26400 patrol days required annually for NLNP would have required a permanent complement of 130 patrols or 520 staff. Expressed in terms of staff densities these values suggest that protection requires at least one man per 9–19 km^2, in close agreement with rules-of-thumb suggested previously of at least 1 man per 20 km^2 for rhinos and other similarly valuable species such as gorillas (Bell & Clarke 1986). Indeed, the highly successful mountain gorilla conservation programme in Rwanda has been achieved with forty-five scouts in an area of 120 km^2, a density of one man per 2·6 km^2 of protected area (Harcourt 1986). Given that only fifty-six staff were available for the whole of Luangwa Valley during 1985, it is scarcely surprising that conservation measures for rhinos and elephants were unsuccessful.

Results from Luangwa Valley illustrate a dilemma that will have to be faced increasingly in Africa. Poor countries often have large areas of national parks theoretically under protection, yet relatively few staff in national conservation agencies actually to undertake law enforcement duties. In a survey of manpower relative to overall size of protected areas in different African countries in 1980, staff: area ratios varied from one man per 580 km^2 to one per 7 km^2 (Cumming *et al.* 1984; Bell & Clarke 1986). In countries with low staff densities, such as Zambia with one man per 300 km^2, it would appear necessary for national conservation agencies and external funding bodies to make selective decisions about how much of their protected areas and valuable species they can afford to patrol at effective staff densities. The need to concentrate effort and be selective when resources are short does not come easily to conservationists (Leader-Williams & Albon 1988; Parker & Graham 1989), but is a policy that is readily accepted by military tacticians or businessmen (von Clausewitz 1976, p. 204; Kraushar 1985, p. 45).

Other options to increase patrol coverage within protected areas might include reducing patrol size, increasing time spent in the field, using helicopters or aeroplanes. However, all these options require increased infrastructural input, the first needing well-armed and trained patrols with effective logistical support, the second needing better servicing, provisioning and paying arrangements for staff, and the third needing good vehicular and mechanical support (Bell 1986c; Tatham 1988). Unfortunately, all these three options are less readily affordable or available in poor countries already in a state of

infrastructural collapse. For example, in 1980 the total recurrent expenditure on conservation in the whole of Africa was around US$75 million year^{-1}, compared with US$167 million in 1979 for the United States alone (Morse 1980; Bell & Clarke 1986). Thus, efforts to apprehend closed season violators of white-tailed deer are sophisticated and meet with considerable success (Glover 1982). Perhaps the most effective option to increase the effectiveness of *in situ* protection in Africa is to make more arrests outside protected areas (Bell 1986b; Tatham 1988). However, this requires achieving a balance between making arrests on vehicle patrols using intelligence information and maintaining adequate protection in the field. This balance is made very difficult if there are high levels of corruption and little political support such that offenders, once caught, are given inappropriate sentences (Fig. 12).

CONCLUSION

This paper has shown that the declines of rhinos and elephants occur due to problems originating outside protected areas. The price of rhino horn and ivory on world markets (Martin 1982; Parker & Amin 1983) has caused a well-organized trading chain to arm large gangs to enter protected areas to cull large numbers of rhinos and elephants for trophies eventually exported to consumer countries (Cumming 1987). The depletion of Africa's rhinos and elephants can only be halted by international and national political decisions that result in an overall conservation plan for both species (Western 1987; Tatham 1988). Such plans will need to achieve several objectives: (i) to reverse the price spirals for trophies on world markets (Western 1989); (ii) to involve local people in the benefits of, and decisions concerning, conservation areas (Abel & Blaikie 1986; Bell 1987); (iii) to hand down realistic deterrents to those who continue to offend in conservation areas so that making arrests outside protected areas becomes worthwhile (Bell 1986b); and (iv) either to find additional funds necessary to attain the manpower levels documented in this paper as being necessary to maintain the infrastructure and integrity of conservation areas or, alternatively, to concentrate efforts upon smaller areas (Leader-Williams & Albon 1988; Parker & Graham 1989).

ACKNOWLEDGMENTS

N.L.-W.'s fieldwork was undertaken with permission from NPWS with the support of G. B. Kaweche and G. Mubanga. Financial support was provided largely by the People's Trust for Endangered Species and the Norwegian Agency for International Development, with additional grants from the Fauna and Flora Preservation Society and the New York Zoological Society. Sponsorship of project logistics and costs in Zambia was organized by Rover Zambia, Dunlop Zambia and Zambia Oxygen through SRT. C. L. P. Mwale and M. J. Faddy arranged for scouts in SRT to collect data on anti-poaching patrols, and A. M. Rosser helped greatly with their collation. The use of log-linear models was suggested by D. Brown. The manuscript was prepared whilst N.L.-W. held a Leverhulme Research Fellowship and a grant from the Conder Trust for Conservation.

REFERENCES

AERSG (1984). Assessing conservation priorities. *The Status and Conservation of Africa's Elephants and Rhinos* (Ed. by D. H. M. Cumming & P. Jackson), pp. 24–45. IUCN, Gland.

Abel, N. O. J. & Blaikie, P. (1986). Elephants, people, parks and development: the case of Luangwa Valley, Zambia. *Environmental Management*, **10,** 735–751.

Bell, R. H. V. (1982). The effect of soil nutrient availability on community structure in African ecosystems. *The Ecology of Tropical Savannas* (Ed. by B. J. Huntly & B. H. Walker), pp. 193–216. Springer-Verlag, Berlin.

Bell, R. H. V. (1986a). Traditional use of wildlife resources within protected areas. *Conservation and Wildlife Management in Africa* (Ed. by R. H. V. Bell & E. McShane-Caluzi), pp. 297–315. Peacecorps, Washington.

Bell, R. H. V. (1986b). Monitoring of illegal activity and law enforcement in African conservation areas. *Conservation and Wildlife Management in Africa* (Ed. by R. H. V. Bell & E. McShane-Caluzi), pp. 317–351. Peacecorps, Washington.

Bell, R. H. V. (1986c). Conditions of service in a conservation agency. *Conservation and Wildlife Management in Africa* (Ed. by R. H. V. Bell & E. McShane-Caluzi), pp. 529–542. Peacecorps, Washington.

Bell, R. H. V. (1987). Conservation with a human face: conflict and reconciliation in African land use planning. *Conservation in Africa: People, Politics and Practice* (Ed. by D. M. Anderson & R. Grove), pp. 79–101. Cambridge University Press, Cambridge.

Bell, R. H. V. & Clarke, J. E. (1986). Funding and financial control. *Conservation and Wildlife Management in Africa* (Ed.by R. H. V. Bell & E. McShane-Caluzi), pp. 543–546. Peace Corps, Washington.

Caldwell, J. R. (1988). Current trends in ivory trade and prices: patterns of demand and consumption. Paper presented to WWF Workshop at Lusaka, Zambia on 10 April 1988. IUCN World Conservation Monitoring Centre, Cambridge.

CAP 111. *Chapter 111 of the Laws of Zambia.* Government Printer, Lusaka.

CAP 316. *Chapter 316 of the Laws of Zambia.* Government Printer, Lusaka.

Caughley, G. (1976). The elephant problem: an alternative hypothesis. *East African Wildlife Journal*, **14,** 265–283.

Caughley, G. & Goddard, J. (1975). Abundance and distribution of elephants in the Luangwa Valley, Zambia. *East African Wildlife Journal*, **13,** 39–48.

Chinzinga, B. A. (1986). Law enforcement progress in Kasungu National Park. *Conservation and Wildlife Management in Africa* (Ed. by R. H. V. Bell & E. McShane-Caluzi), pp. 371–380. Peacecorps, Washington.

Cox, D. R. (1970). *The Analysis of Binary Data.* Methuen, London.

Cumming, D. H. M. (1987). Zimbabwe and the conservation of rhinos. *Zimbabwe Science News*, **21,** 59–62.

Cumming, D. H. M., du Toit, R. F. & Stuart, S. N. (Eds) **(1990).** *African Elephants and Rhinos: status survey and conservation action plan.* IUCN. Gland.

Cumming, D. H. M. & Jackson, P. (Eds) **(1984).** *The Status and Conservation of Africa's Elephants and Rhinos.* IUCN, Gland.

Cumming, D. H. M., Martin, R. B. & Taylor, R. D. (1984). Questionnaire survey on the management and conservation of elephants and rhinos. *The Status and Conservation of Africa's Elephants and Rhinos* (Ed. by D. H. M. Cumming & P. Jackson), pp. 46–62. IUCN, Gland.

Douglas-Hamilton, I. (1987). African elephants: population trends and their causes. *Oryx,* **21,** 11–24.

Douglas-Hamilton, I., Hillman, A. K. K., Holt, P. & Ansell, P. (1979). *Luangwa Valley Elephant, Rhino and Wildlife Survey.* Report to IUCN/WWF/NYZS, Nairobi, mimeo.

Glover, R. L. (1982). Effectiveness of patrol techniques for apprehending deer poachers. *Proceedings of Annual Conference Southeastern Association of Fish and Wildlife Agencies*, **36,** 705–716.

Goddard, J. (1967a). The validity of censusing black rhinoceros populations from the air. *East African Wildlife Journal*, **5,** 18–23.

Goddard, J. (1967b). Home range, behaviour and recruitment rates of two black rhinoceros populations. *East African Wildlife Journal*, **5,** 133–150.

Government of Republic of Zambia (1985). *The National Conservation Strategy for Zambia.* IUCN, Gland.

Hanks, J. (1979). *A Struggle for Survival: The Elephant Problem.* Country Life Books, London.

Harcourt, A. H. (1986). Gorilla conservation: anatomy of a campaign. *Primates: The Road to Self-Sustaining Populations* (Ed. by K. Benirshke), pp. 31–46. Springer-Verlag, New York.

Hillman, K. (1981). *The Status of Rhino in Africa and an Action Programme.* Report to IUCN/WWF/NYZS Africa Rhino Group, Nairobi, mimeo.

Kaweche, G. & Lewis, D. M. (1986). *Luangwa Elephant Aerial Census.* Report to NPWS, Chilanga, Zambia, mimeo. (Quoted in *Pachyderm*, **8,** 1–10.)

Kiwia, H. D. (1989). Black rhinoceros (*Diceros bicornis* (L.)): population size and structure in Ngorongoro Crater, Tanzania. *African Journal of Ecology*, **27,** 1–6.

Kraushar, P. (1985). *Practical Business Development: What Works and What Does Not.* Holt, Rinehart & Winston, London.

Laws, R. M. (1969). The Tsavo research project. *Journal of Reproduction and Fertility, Supplement,* **6,** 495–531.

Laws, R. M., Parker, I. S. C. & Johnstone, R. C. B. (1975). *Elephants and Their Habitats.* Clarendon Press, Oxford.

Leader-Williams, N. (1985). Black rhino in South Luangwa National Park: their distribution and future protection. *Oryx*, **19,** 27–33.

Leader-Williams, N. (1988). Patterns of depletion in a black rhinoceros population in Luangwa Valley, Zambia. *African Journal of Ecology*, **26,** 181–187.

Leader-Williams, N. (1990). Allocation of resources for conserving African pachyderms. *International Union of Game Biologists Conference* (in press).

Leader-Williams, N. & Albon, S. D. (1988). Allocation of resources for conservation. *Nature*, **336,** 533–535.
Leuthold, W. (1978). Ecological separation among browsing ungulates in Tsavo East National Park, Kenya. *Oecologia*, **35,** 241–252.
Lewis, D. M. (1986). Disturbance effects on elephant feeding: evidence for compression in Luangwa Valley, Zambia. *African Journal of Ecology*, **24,** 227–241.
McCullaugh, P. & Nelder, J. A. (1983). *Generalised Linear Models.* Chapman & Hall, London.
Marks, S. (1976). *Large Mammals and a Brave People: Subsistence Hunters in Zambia.* University of Washington Press, Seattle.
Marks, S. (1984). *The Imperial Lion: Human Dimensions of Wildlife Management in Africa.* Westview, Boulder, Colorado.
Martin, E. B. (1982). *Run Rhino Run.* Chatto & Windus, London.
Martin, E. B. (1983). *Rhino Exploitation.* World Wildlife Fund, Hong Kong.
Martin, E. B. (1986). The ivory carving industry of Zambia. *Pachyderm*, **7,** 12–15.
Martin, R. B. (1986). Establishment of ivory export quotas and associated control procedures. *African Elephants* (Ed. by R. B. Martin, J. R. Caldwell & J. G. Barzdo), pp. 1-102. CITES Secretariat, Lausanne.
Morse, W. B. (1980). Wildlife law enforcement. *Proceedings of Annual Conference, Western Association of Game and Fish Commissions*, **60,** 162–180.
Naylor, J. N., Caughley, G. J., Abel, N. O. J. & Liberg, O. (1973). *Luangwa Valley Conservation and Development Project.* Report to UNDP/FAO, Rome.
Parker, I.S.C. & Amin, M. (1983). *Ivory Crisis.* Chatto & Windus, London.
Parker, I. S. C. & Graham, A. D. (1989). Men, elephants and competition. *Symposium of Zoological Society of London*, **61,** 241–252.
Pullan, R. A. (1981). The utilisation of wildlife for food in Africa: the Zambian experience. *Singapore Journal of Tropical Geography*, **2,** 101–113.
Richards, A. I. (1939). *Land, Labour and Diet in Northern Rhodesia.* International African Institute, London.
Soulé, M. E. (Ed.) **(1986).** *Conservation Biology: The Science of Scarcity and Diversity.* Sinaeur, Sunderland. Mass.
Tatham, G. (1988). The rhino conservation strategy in the Zambezi Valley code named Operation Stronghold. *Zimbabwe Science News*, **22,** 21–23.
von Clausewitz, C. (1976). *On War*, originally published in 1832 (Transl. & Ed. by M. Howard & P. Paret). Princeton University Press, Princeton.
Western, D. (1982). Patterns of depletion in a Kenya rhino population and the conservation implications. *Biological Conservation*, **24,** 147–156.
Western, D. (1987). Africa's elephants and rhinos: flagships in crisis. *Trends in Ecology and Evolution*, **2,** 343–346.
Western, D. (1989). The undetected trade in rhino horn. *Pachyderm*, **11,** 26–28.
Western, D. & Vigne, L. (1985). The deteriorating status of African rhinos. *Oryx*, **19,** 215–220.

(Received 30 October 1989; revision received 6 June 1990)