RHINO POPULATION DYNAMICS, ILLEGAL HUNTING AND LAW ENFORCEMENT IN THE LOWER ZAMBEZI VALLEY IN ZIMBABWE

R.B. Martin
National Parks and Wildlife Management, Zimbabwe

This paper presents some results from a study carried out in 1988 in Zimbabwe. A second paper (this volume) gives the conservation strategy for black rhinoceros which was based on the research findings.

1. INTRODUCTION

The black rhino population in Africa has declined from some 65000 in 1970 to the present figure of less than 4000. Numbers in the black rhino's former range outside Zimbabwe have been reduced below the threshold at which wild populations are considered secure genetically and demographically.

Zimbabwe has the largest surviving black rhinoceros population on the continent - approximately 2000 animals. This population is distributed roughly as follows:

Zambezi Valley	700
Chizarira National Park	300
Hwange National Park	200
Chirisa Safari Area	200
Matusadona National Park	150
Chete Safari Area	100
Doma Safari Area	50
Commercial Farms	150
Communal Lands	150
TOTAL	2000

The rhino population in Zimbabwe has suffered heavy losses due to illegal hunting since 1984 (over 600 animals) and, despite a major effort in law enforcement in the past five years, there is no sign of cessation of illegal hunting and a high risk that the population will continue to decline.

Illegal hunting of black rhino now extends to the entire country. Hunters are entering along the entire northern border of Zimbabwe, and through sectors of the eastern, southern and western borders. The inception of illegal hunting by a few Zimbabwe citizens is aggravating the situation.

Extreme measures have been taken since 1984 to curtail illegal hunting. These include:

i) Commitments to rhino survival at the highest political level.

ii) Two significant revisions of legislation which introduced high penalties for illegal hunting and provided indemnity for persons engaged in wildlife protection.

iii) An intensification of law enforcement effort by government with the granting of increased staff and budgets.

iv) The taking of over 150 human lives so far in the protection of black rhino.

Concerns with the escalating costs of protecting rhino led to the Department of National Parks and Wild Life Management forming a working group in 1988 to examine the relationships between rhino population dynamics, illegal hunting and law enforcement effort in the Zambezi Valley. This working group consisted of Colin Craig, David Cumming, Kevin Dunham, Raoul du Toit, Deborah Gibson, Alistair Graham, Fay Robertson, Clive Swanepoel, Glenn Tatham, Russell Taylor and the author. The research results which are presented are a joint effort of this group.

2. OBJECTIVES OF THE RESEARCH PROGRAMME

2.1 To predict the likely outcome of the illegal hunting of rhino in the Zambezi Valley under the present conditions of funding, manpower and operational strategies available to carry out law enforcement.

2.2 To calculate the required increases in inputs which are necessary to reverse the downward trend, if it is found that rhino are unlikely to survive in a viable population under the present efforts to preserve them.

2.3 To recommend an alternative rhino conservation strategy if the required additional inputs predicted by Objective 2.2 are impossible to secure.

3. STUDY AREA

The area lies in the north of Zimbabwe along the middle Zambezi river between Cabora Bassa and Kariba Dams. It is bounded in the north by the Zambezi River which forms the international boundary with Zambia. In the north-east it has an international land boundary with Mozambique. The southern limits of the area lie in the escarpment which comprises Communal Lands such as Mukwiche and Urungwe.

The area includes the Charara, Urungwe, Sapi, Chewore, and Dande Safari Areas, Mana Pools National Park and Parts of the Dande Communal Land.

The Department of National Parks has stations at Nyamomba, Mana Pools, Kapirinengu, Marongora, Kanyemba and Mana Angwa. Bases for tourism and safari hunting are found at a number of semi-permanent camps mainly along the Zambezi River, and there is a Tsetse Department research station below the escarpment at Rukomechi.

National Parks staffing in the area is composed of some 100 game scouts led by about 10 officers and two ecologists.

The climate is hot and dry with an average annual rainfall of about 600mm. Severe droughts occurred in 1982-83 when the annual rainfall in two successive years was about 400mm.

The escarpment consists of basement gneisses and precambrian metamorphics. This is bounded by the Zambezi Valley fault along the edge of the Zambezi Valley proper to the north of which are deep sediments of the Karoo series and jurassic/cretaceous sediments. Within this the Chewore hills represent an inlier of precambrian similar to the main escarpment.

Along the Zambezi and its major tributaries there are extensive deposits of recent alluvium. In addition the valley floor has superficial deposits of various types of colluvium, some of which may be aeolium deposits from the late tertiary.

The escarpment carries a form of savanna woodland akin to miombo and dominated by *Brachystegia* ssp. and *Julbernardia globiflora.* This has been greatly modified by the combined effects of elephant and fire over most of the escarpment, including the Chewore hills, but some climax woodland remains in the far east in Doma Safari Area.

On the valley floor, there is a great heterogeneity of woodland types. Mopane woodland on heavier and more poorly drained soils is probably the most widespread type. Dry forest and thickets occur on sandy colluvial soils and *Acacia albida* parkland is found on some of the more recent alluvium, especially along the Rukomechi river and Mana Pools flood plain. Various other alluvial communities and riverine fringing forest occur along other water courses.

Large mammal herbivores include elephant, buffalo, eland, kudu, bushbuck, waterbuck, impala, sable, zebra, warthog and hippopotamus. Carnivores including lion, hyaena and jackal are numerous as are a variety of smaller mammals. Black rhino are found in all habitats throughout the area including the escarpment.

4. A POPULATION SIMULATION MODEL

It was decided to use a population simulation model (Fig.1) to approximate as closely as possible to the recent history of the rhino population and to use this model to predict future trends in the population. The model was to be fully stochastic in order to simulate demographic effects in small populations and it would be run in time units of months in order to incorporate seasonal processes.

It was originally intended to include density dependence in the model but, because the population age structure (deduced from the ages of skulls) was typical of a growing population and because the illegal hunting was likely to have reduced the population to below "carrying capacity", this feature was omitted.

The key processes in the model are discussed below.

4.1 Reproduction. The method of simulating breeding was to apply the relevant probabilities of conception to each individual female in the simulated population in each month of the time sequence under consideration (Fig.2). Sexes of offspring were chosen randomly. This required records to be kept of the immediate breeding history for each female and factors such as age, the availability of males for breeding and the effects of drought were taken into account.

4.2 Natural Mortality. Skulls of black rhino which have died naturally in the Zambezi Valley have been collected since 1975. Using the ageing criteria of Hitchins (1978) and making the assumption of a population growing at about 7% per annum, age-specific mortalities were calculated for both normal and drought conditions (Fig.3).

4.3 Illegal Hunting. We had to develop a theoretical basis for the relationship between the intensity of illegal hunting and the numbers of rhino killed. Our assumptions are as follows:

a) The number of rhino killed in any month (Nrd) is directly proportional to the number of hunting gangs (Ng) entering the study area;

b) The number of rhino deaths is further proportional to the number of weapons per gang (Nw). However, since the average number of weapons per gang was approximately 1.7, we simply made this variable implicit in the number of gangs entering the Valley;

c) It is to be expected that rhino are killed in greater numbers when their density is high. It is also likely that there is a maximum number which can be killed per day even at very high rhino densities simply because of the logistical demands of locating, killing and removing the horns. The highest kill rate we are aware of was 6 rhino killed in one day in 1984. We have postulated a relationship (Fig.4) of the form:

Kill rate: $Kr = Kmax.(1 - e^{-D/DO})$ rhinos per gang per day

where: Kmax is the maximum kill rate;
D is rhino density; and
DO is a constant.

d) Gangs kill rhino until they are detected (or flushed) by staff patrols. If they are not detected at all, the maximum duration of a hunting foray averages about 9 days, this limit being set by the amount of food they can carry and the need to return a load of rhino horns to the safety of their external base. Very little killing takes place after a gang is aware that it has been detected: at this stage it is mainly intent on flight. Thus the number of rhino killed is directly proportional to the number of days for which each gang is able to operate undetected (Dd).

This gives the following overall relationship for the number of rhino expected to die in any given month:

No. of rhino expected to die: Nrd = Ng x Nw x Kr x Dd

Illegal hunting was simulated (Fig.5) by drawing the number of gangs randomly from the table of monthly incursions during the period 1984-1988, establishing an instantaneous kill rate from the prevailing rhino density and applying the average number of days to detection from the relationship which follows (Fig.6). In this last sense the simulation was not truly stochastic: the number of days for which a given gang of poachers operated could also have been drawn randomly from a table of past records.

4.4 Law enforcement. In the previous section (4.3) it was postulated that the critical parameter determining the number of rhinos killed is the time taken to detect gangs of illegal hunters. In the relationship given **the only variable which law enforcement staff are able to influence is the number of days for which illegal hunting can take place.** This is a very important point and is central to the entire question of protecting rhino.

When illegal hunting began in 1984 the immediate response to the problem was to put all effort into apprehending or eliminating the intruders. This is completely understandable: the effort was (and still is) directed at stamping out poachers. At that stage it was assumed that the threat would disappear when a finite number of gangs had been eliminated. The data below show the fallacy in this reasoning.

Table 1: Numbers of known incursions by gangs into the Zambezi Valley

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	TOTAL
1984	0	0	0	0	0	5	0	0	0	0	3	2	10
1985	1	4	6	4	4	5	11	3	3	1	1	7	50
1986	5	8	0	4	4	2	3	6	2	2	6	3	45
1987	2	5	5	2	1	6	5	1	1	1	6	2	37
1988	5	3	5	6	6	6	4	0	0	1	6	4	46
TOTALS	13	20	16	16	15	24	23	10	6	5	22	18	188

It requires no statistical tests to show that from 1985-1988 there was no reduction in the numbers of incursions despite an intensified effort over the same period. There is a finite probability of any number of gangs between zero and 11 in any month of the year.

It would not be correct to state that there is no deterrent effect: we have no way of knowing how many more gangs might have entered the country or how much longer the gangs which did enter might have remained hunting had there been no effort to stop them. However, at best the data suggests an uneasy equilibrium between the rate of incursions and the law enforcement effort.

Once it is accepted that **illegal hunting cannot be eliminated** then the matter simply becomes a question of "for how long can gangs operate before they are detected?". The number of rhinos killed will be directly proportional to this time, assuming an average hunting capability for each gang.

It is to be expected that the more men there are searching for poachers, the shorter will be the time to find them. This suggests a very simple inverse relationship of the form:

Days to Detection = Constant / Number of men in the field

The only modification necessary to this relationship (Fig.6) is to truncate the maximum number of days to detection at 9 (if there were no men in the field, gangs would not remain hunting for more than 9 days).

The relationship assumes that:

- all men in the field are equally capable of detecting incursions.
- all men are effectively deployed and have an equal chance of detecting poachers.
- there is a constant effort per man in the Zambezi Valley.
- performance in detection of poachers has remained constant over the full period for which illegal hunting has been occurring.

None of these assumptions are in fact satisfied. Little can be done about the first two assumptions in the simulation model. We can expect some sort of "average" performance per man and we can expect that random chance probably plays a large part in the second assumption.

On the third assumption, we have assumed that the maximum number of days for which an individual can be reasonably expected to patrol each month is 15. The relationship between days to detection and staff density used in the computer simulation is initially based on a complement of 100 game scouts carrying out 15 patrol days per month in 10 000 sq.km. (i.e. a density of 1 man/100 sq.km). However, the actual number of days spent on patrol between 1984-1988 has been considerably lower than this target. For example, the record of the average number of patrol days per individual scout at Mana Pools is as follows:

Table 2: Mana Pools - average nights spent on patrol 1984-88 extracted from subsistence claims.

	1984	1985	1986	1987	1988
Days per scout:	3.5	7.6	8.5	11.0	10.0

It would not be correct to take these figures as representative of the patrol effort throughout the Valley. Many of the patrols carried out at Mana Pools in the early days of the anti-poaching operations were day patrols where the scouts returned to base at night and therefore this additional effort was not recorded. On other stations the record of subsistence claimed includes duties other than patrolling (e.g. accompanying safari hunters) and is not useful.

In order to obtain a measure of the relative effort from 1984-1988 we have examined the rate at which skulls of dead rhino were recovered from the field (a standing order to all patrols is to retrieve all rhino skulls whenever they are encountered in the field). The skulls of rhino killed in 1984/85 took several years to be recovered, whilst those in more recent years have been recovered more rapidly. The key statistics are shown in Table 3.

Table 3: Average nights spent on patrol 1984-88 in the Zambezi Valley (inferred from rhino skull collections

	1984	1985	1986	1987	1988
Days per scout:	2.59	2.59	3.07	9.86	11.0

The relationship between days-to-detection and number of men in the field has been corrected for each year based on the actual number of patrol days inferred from the above data. The method used was to specify an "efficiency" factor which was the ratio of actual days spent patrolling to the maximum possible days which could have been spent (15). This was used to reduce the effective density of men in the field and hence, from the relationship, a higher value of days-to-detection resulted.

Having made this correction it might be expected that the relative numbers of rhino killed in each year from 1984-1988 (corrected for the number of incursions) would be related to the degree of patrol effort in that same year. This is not the case and hence the fourth assumption is violated. Despite a very low patrol effort in 1984/85 relatively few rhino were killed (Table 4). The kill rate per incursion rose in 1986 and 1987 despite a marked increase in anti-poaching effort. In 1988 the kill rate dropped sharply.

Table 4: Rhinos killed, numbers of incursions and patrol effort

	1984	1985	1986	1987	1988
Rhinos killed by poachers	19	96	135	136	64
Numbers of known incursions	10	50	45	37	46
Average patrol days/scout	2.6	2.6	3.1	9.9	11.0
Kills per incursion	1.9	1.9	3.0	3.7	1.4

There are many possible explanations for the inconsistencies and the answer is probably a combination of these.

a) In the early stages of the "battle" poachers were naive and easy to catch. The relative ease with which the same poachers had killed rhino in Tanzania and Zambia might well have led them to believe that Zimbabwe would be "easy pickings".

b) By 1987 poachers had become very difficult to catch. Extreme precautions were adopted on every incursion, including anti-tracking measures, careful hiding of collapsible boats used to cross the river, and considerable counter-intelligence.

c) A number of factors combined to assist anti-poaching in 1988. The density of rhino close to the Zambezi was lower, making it necessary for poachers to make longer forays further into the country. The men in the field had a superb system of VHF radio communication which enabled a rapid response to every incident. The assistance of a helicopter greatly increased the ability to deploy patrols effectively and to deal with poachers when they were found.

d) Random effects could also have influenced the outcome in particular years. To a large extent chance enters into the detection of incursions and 1987 may have been an unlucky year.

e) By the end of 1987 the effects of four years of anti-poaching work may have influenced morale and performance of patrols. At the start of operations in 1984 everyone had hoped that the poaching threat could be quickly eliminated: by 1987 it was apparent that the struggle was going to continue for a long time. Men may have become weary of the war.

Whatever the explanation it was clear from the data that the simulation model could not reproduce the actual numbers of rhino killed in the correct sequence using the rules available to it. It would be necessary to introduce a "Performance Factor" for each year to reconcile the actual and theoretical numbers killed. The initial values for this factor are given below (Table 5), calculated as a multiplier required to adjust patrol effort. As such, they do not take into account the effect of decreasing rhino density over the years of illegal hunting. The final values were obtained by iteration during computer simulations.

Table 5: Calculation of performance factors for each year

		1984	1985	1986	1987	1988
Average patrol days/scout	(P)	2.6	2.6	3.1	9.9	11.0
Kills per incursion	(Q)	1.9	1/9	3.0	3.7	1.4
R = 1/(P x Q)		.202	.202	.108	.028	.065
Performance factor (R/.202)		1.00	1.00	.535	.137	.323

This performance factor is not intended to be a reflection of the relative effectiveness of staff in successive years: it could just as well reflect improved performance by poachers. It is no more than a factor to reconcile simulated numbers with the real numbers.

It would be valid to ask whether the entire simulation model becomes somewhat dubious when a factor such as this has to be introduced. Undoubtedly it is frustrating to the modeler when he cannot draw up a general set of rules which account for particular outcomes in each year. The factor is however important for the following reasons:

a) The model has been primarily constructed for predictive purposes from 1989 onwards. Thus it is extremely important to know the range of variation in "performance" (if it may be called that) which might arise in any defined relationship between the nominal anti-poaching effort and the numbers of rhino killed.

b) In simulating the period immediately after 1988, the simplest assumption is that law enforcement effort will remain as it was during 1988. In order to establish the performance factor for 1988 it is necessary to have correctly simulated all the immediately preceding years. At the start of 1988 the population should be at a level such that, after deducting the number of rhino killed and captured during the year, the population at the end of the year is equal to the present real population in the Zambezi Valley. The number of rhino killed during 1988 relies on the killing rate of rhino (which is density dependent) being correct for that particular phase of the population's history.

4.5 Drought. Drought is expected to have two effects on the rhino population. The fecundity of females may be reduced and the mortality of all animals may increase. In studying buffalo in the Zambezi Valley, Swanepoel (1990) noticed that the effects of drought were compounded if a poor rainfall season followed immediately after another poor season.

For this reason in any given year of simulation we have taken into account both the current season's rainfall and that of the previous season. In 1982 and 1983 the Valley suffered the two worst successive droughts in the history of rainfall records since 1943.

Rhino are described in the literature as breeding throughout the annual cycle (Smithers 1983). We have assumed that only in above average rainfall years this is the case. Fecundity was reduced in the model for the months of the dry season in a progressive manner depending on the severity of drought. The modifying probabilities of conceiving under various rainfall conditions are shown in Fig.7.

Mortality in drought years is taken from the records of animals found dead during the 1983-84 drought. Lacking any data to postulate a relationship dependent on the severity of drought we have simply assumed two states: drought years and non-drought years based on a rainfall threshold. In drought years an alternate age-specific mortality schedule is adopted (Fig.3).

The entire annual rainfall record from 1943 to date is programmed into the computer model. During simulation of the period prior to 1989 the actual rainfall values for the year concerned are used. From 1989 onwards when predictive simulation starts, rainfall was drawn at random from the past rainfall record.

4.6 Specification of conditions for any run. The simulation model permits a wide range of variables to be modified and initial conditions to be set for any run.

a) Longevity - this was normally set at a maximum age of 40 years.

b) Age at first conception - the mean, standard error and range of this parameter could be modified, but was generally held at 80 months for all runs with a standard deviation of 10 and a range of ± 20 months (Fig.8).

c) Interval between parturition and conception - the same parameters as for age at first conception could be modified, but in general we worked with a mean period of 28 months, a standard deviation of 8.5 and a range of ± 16 months (Fig.9).

d) Fecundity in older females - the age at which reduced fertility could be expected to manifest itself could be varied, but we worked with 25 years for all runs (Fig.10).

e) Effects of rainfall on conception - the values shown in Fig.7 were used for all runs.

g) Effect of male density on conception - we assumed that the probability of females conceiving would be halved when male density fell to a level of 1 male/1000sq.km (Fig.11).

h) Mortality - provision was made for adjusting neo-natal mortality, mortality in the middle years of life and senescence, but all runs were carried out using the default age-specific mortalities shown in Fig. 3.

i) Kill rate of rhino as a function of rhino density - the constant determining the characteristic of this negative exponential relationship was altered according to the requirement of the final population postulated. Crude data from the field suggest the average rate should be about 0.4 rhino per day of hunting by a gang at 1988 rhino densities.

j) Days to detection of poachers versus staff density - in this section the maximum value of a poaching tour, the present staff density and the number of days to detect a gang assuming 15 patrol days per month can be specified. For the three main simulation runs this last parameter was varied according to the kill rate specified in i) above.

k) Starting population - a range of populations could be loaded from disc according to the simulation requirement.

l) Specification of rainfall conditions for run - rainfall could be drawn at random from the past history of annual rainfall, held constant or specified. In practice, actual values were used for the period up to the end of 1988 and rainfall for 1989 onwards was drawn at random from the given data since 1943.

m) Specification of conditions for illegal hunting - despite a range of options for specifying the number of gangs of poachers, for all runs the actual number of incursions for the month concerned was used up to the end of 1988, and the number of gangs from 1989 onwards was drawn at random from the same distribution.

n) Specifications of conditions for law enforcement - this condition applies to the average number of patrol days per scout from 1989 onwards and the performance factor (Section 4.4). In examining different possible outcomes in the future the parameters were varied for each predictive run

o) Choice of Y axis range for graphic display of rhino population - this parameter was normally set once at the start of a sequence of runs, to suit the maximum number which the rhino population was likely to reach on any given simulation. During the simulation run the graphics display updated the rhino population every month and displayed the age pyramid, rate of population growth and numbers of rhino killed every year (Fig. 12).

p) Size of population - before entering any particular simulation run this subroutine permitted adjustment of the population size. Since all animals in the population were individually recorded, the algorithm for shrinking or expanding the population was fairly complex.

q) Specification of starting year and month - any particular run could be started at any date. This facility permitted simulating parts of a run which was extremely useful when iterating to find particular values needed for performance factors.

5. KEY STATISTICS USED IN THE SIMULATION

5.1 Past and present population of black rhino. An immediate difficulty in the model was the lack of precise data on either the present population size (1988) or its size at any time in the past. Although rhino had been counted on aerial surveys since 1980, it was known that the estimates were far lower than the true population. Despite efforts during 1988 to establish a correction factor for the number of rhino not seen during air surveys, the work was inconclusive. The feeling of the working group was that any given air survey estimate might need to be multiplied by a factor ranging from 2-5! Subjective opinions were that the 1988 population in the Zambezi Valley might lie anywhere between 250 and 1000 animals.

Because of this uncertainty, the rhino population as treated as one of the unknowns to be established through the modelling process. It was hoped that, given the known number of animals killed by poachers and the known number removed from the Valley by the Department's capture units between 1984 and 1988, only a limited range of population estimates would fit the scenario.

Therefore simulations were carried out assuming a population at the end of 1988 of 250, 500 and 1000 animals.

5.2 Numbers of rhino killed, captured. The numbers of rhinos killed over the period 1984-1988 is given in Table 6 below. The question arises whether there remain undetected rhino carcasses in the field which would cause the data in Table 6 to be an underestimate.

The skulls of all rhino found in the field are recovered by scouts and brought into the Mana Pools field station. Dunham (the ecologist at Mana Pools during the study period) estimated for each skull the period which had elapsed before it had been found and brought in to the station. Cumulative curves of the rate of recovery of these skulls indicate that over 95% of skulls are found within 12 months of the death of the animal. Therefore the only year for which it is valid to make a correction for the number of skulls still outstanding in the field is the current year. A correction factor of 1.4 was applied to the number of skulls for 1988.

Table 6: Rhinos killed and captured during the period 1984-1988

	1984	1985	1986	1987	1988
Killed by illegal hunting	19	96	135	136	64
Translocated from the Valley	20	40	60	110	69
TOTALS	39	136	195	246	133

Given these offtakes, and assuming a population growth rate of 7% (which was obtained from a simulation of the population with no illegal harvesting, but taking into account the drought years of 1982 and 1983) the expected population levels are given below for the three population scenarios discussed in section 5.1.

Table 7: Expected populations during the period 1980-88 given the offtake regime of Table 6 and final populations of 250, 500 & 1000.

YEAR (end)	Case 1	Case 2	Case 3	
1979	1135	804	656	. . . Starting population
1980	1214	860	702	
1981	1300	920	752	
1982	1390	984	804	
1983	1439	1053	860	
1984	1378	999	809	. . . Start of poaching
1985	1336	929	726	
1986	1229	793	576	
1987	1061	595	362	
1988	**1000**	**500**	**250**	. . . Final population

It is these values which any simulation will be expected to reproduce when the values of all parameters are correct.

5.3 Illegal hunting statistics. To establish the average killing rate of rhino at any particular density is extremely difficult. The asymptote for the curve of Fig.4 can be set at 6 rhino/day as this is the highest killing rate recorded in a high density area. The problem then lies in the choice of exponential constant to predict killing rate at lower rhino densities. Since the rhino population (and hence the rhino density) is unknown, assumptions have to be made. We have assumed that at the end of 1988 the kill rate is .39 rhinos/day in all three cases of population size (250, 500, 1000) based on crude calculations of the total days spent by poachers in the Valley and the total number of rhinos killed in that year.

Equally difficult is an estimate of the average number of days taken to detect poachers. We have only 9 reliable instances where we have known when poachers entered the Valley and when they were detected. These data vary from 1 to 9 days and do not provide any meaningful average.

The number of rhino killed in any year is proportional to the product of the number of days to detection and the killing rate. The same number of rhino can be accounted for by a high killing rate and a short time to detection, or by a low killing rate and a long time to detection. In 1988, to obtain the correct number of rhino killed given a final killing rate of .39 rhinos/day requires the detection time to be approximately 3 days. This detection time is probably a reasonable estimate according to anti-poaching staff.

Thus we have fixed the killing rate and the detection time at one point along the time series from 1980 - 1988. In order for the simulation to predict all the other population values of Table 7, each scenario requires different values for the constants defining the relationship between kill rate and rhino density, and detection time and staff density.

In the case where the final population at the end of 1988 is 1000 animals the slope of the kill rate versus density curve is low (i.e. kill rate does not increase rapidly with density) and the detection time is fairly long. In the case where the final population is 250, the slope of the kill rate curve is high (i.e. kill rate increases sharply with density) and detection times are fairly short. The case of a final population of 500 is intermediate.

An example of a simulation run is shown in Fig. 12.

6. SIMULATION RESULTS

6.1 Population growth prior to 1984. The default parameters chosen for fecundity and natural mortality result in an intrinsic population growth rate of about 7% after a stable age pyramid has been achieved. It can be seen from the three cases in Table 7 that although each final population is half of the previous one (i.e. 1000, 500, 250) this does not imply that the starting numbers in 1980 were in the same proportion. In the case where the 1988 population is 250 animals the implications of the decline are far more serious than with the larger population.

6.2 Illegal harvesting 1984-1988. Given adjustments permitted under the model rules such as the "performance factor" used to fine-tune the law enforcement effort in each year, it is not surprising that the model simulates the illegal offtakes very closely. In an average of ten runs the simulated offtake from the population in all cases matches the actual offtake with ± 10%. However, the purpose of the exercise was to extrapolate into the future from various scenarios rather than prove any point in the past.

6.3 Predictions of trends from 1989 onwards.

6.3.1 Assuming no alteration in the illegal hunting regime and law enforcement effort:

In each ease simulations were run keeping the detection time for poachers at the same level as at the end of 1988. The outcomes were as follows:

Table 8: Predicted rhino populations under present system

YEAR (start)	Case 1	Case 2	Case 3
1989	1000	500	250
2000	1197	358	70
Rate of growth (%)	1.6	-3.0	-11.0

In the case of the population of 1000 at the end of 1988, it is implied that the status of law enforcement during 1988 was sufficient to ensure a positive growth rate for the population.

6.3.1 Assuming an improvement in the law enforcement effort:

Tests were run examining the implications of reducing the detection time for incursions:

Table 9: Rate of growth of population v. detection time (days) for three levels of population in 1989

Detection time:	1	2	3	4	5	6	7	8	9
Population 1989:									
1000	4.9	3.8	2.0	0.0	-2.0	-3.2	-6.1	-6.3	-7.5
500	3.5	-0.1	-3.3	-7.0	-10.5	-14.7	-17.0	-21.0	-23.5
250	1.0	-6.9	-14.0	-23.0	-26.0	-33.0	-38.0	-40.0	-42.0

These data form a set of linear relationships (Fig.13). From the plots it is possible to make an educated guess about the present population in the Zambezi Valley. The scenario that the 1988 population was as low as 250 animals is unlikely to be correct. Law enforcement effort has not changed significantly since 1988, fewer incursions have taken place (emphasis has shifted to other parts of Zimbabwe and poachers in the Valley are now hunting elephant) and rhino sightings appear to be increasing. It is equally unlikely that the population was as high as 1000 animals in 1988 as this would imply roughly 1 rhino/10 sq.km which is not reflected in sightings or patrol reports. A reasonable estimate may be 500-700 animals which are increasing at a very low rate.

To improve the detection time for poachers implies an increase in law enforcement staff. From the above data, to bring about a positive growth rate of more than 2% in the middle scenario (500 rhino in 1988) implies reducing detection time to less than two days. To achieve this means increasing staff numbers to about 300 (from the present level of 100), assuming that the present efficiency and performance factors are as high as is likely to be achieved. To reduce the illegal hunting threat to very low levels implies even more staff. A growth rate of 5% would require 1man/20sq.km or 5 times the present staffing levels.

7. DISCUSSION

The construction of this model has highlighted a number of weak points - both of a theoretical nature and in the quality of input data. Population models may be relatively robust in the population dynamics of a species but they are woefully inadequate in catering for environmental effects or episodic events which may have a greater impact on survival than fecundity and natural mortality.

Although in this model we have attempted to allow for the effects of drought on fecundity and mortality our algorithms have no empirical backing. We were unable to incorporate spatial effects in the model because we simply did not have the behavioural data to predict dispersal patterns which might arise from differences in habitat and rhino densities. For example, it is to be expected that rhino would normally disperse from the most favourable habitats to the least favourable: however, if densities of rhino are reduced by killing in the most favourable habitats the dispersal might operate in reverse.

The lack of precise population data has greatly reduced the value of the model. Had we known precisely the number of rhino in the Valley, less effort would have gone into exploring scenarios designed to answer this question and more certainty could have been placed on the relationships between illegal hunting and rhino density.

The model has highlighted a failure to keep adequate records of law enforcement effort. For example, it ought to have been simple to obtain data of patrol days per month and intensity of coverage of the study area. It was not. Bell (1986) has emphasised the importance of monitoring law enforcement effort in relation to illegal activity in order to measure the degree of success in anti-poaching.

The important new theoretical relationships which have been developed in the model lack the critical data to calibrate them because of a failure to obtain certain information in debriefing poachers. The time to detection of poachers is probably the most important variable in the model and yet, despite several hundred incursions, we have little knowledge of the length of time each incursion has lasted. The rate of killing of rhinos is equally important and this cannot be deduced without accurate data of the numbers of rhino killed in a specific time.

From the foregoing it is obvious that the results from the model need to be treated with caution. The simulations have attempted iteratively to solve a large number of unknowns with too few fixed reference points. The process is somewhat akin to trying to solve a set of simultaneous equations where the number of unknowns is one more than the set of equations provided! At best the answer can only lie on a family of curves.

Having said all this, there is sufficient substance in the model to predict that the status of the rhino population is perilous in the extreme. The balance between illegal hunting and law enforcement is critically poised. An increase in the number of incursions or a decrease in the law enforcement effort would rapidly tip the scales in either direction.

Results obtained independently from other studies of illegal hunting (Leader-Williams 1990, Parker 1989, Bell 1986) confirm the basic requirements for law enforcement staffing levels. In many cases detection of illegal hunters may not require active patrolling but may be carried out from observation points. I have assumed that this requires no fewer men. Adequate manpower also becomes important when confronting heavily armed gangs of poachers.

Before leaving this topic, it is important to note a recent report on law enforcement in the Luangwa Valley, Zambia, by Richard Bell (May 1990). Bell analysed the law enforcement effort in both field patrolling and investigative work. He concluded that one day of good investigative work was equivalent to 28 days of patrolling.

Obviously this result may require modification for different field situations. Where illegal hunters are local and originate from the areas surrounding a park, investigative work is likely to produce the greatest results. In the Zimbabwe situation where most of the poachers come from outside our borders, investigations are more difficult unless there is a high degree of cooperation.

8. CONCLUSIONS

8.1 The data indicate that despite a major law enforcement effort to date there is no apparent decrease in illegal activity.

8.2 The critical parameter in determining the number of rhino killed illegally is the time taken to detect hunting parties.

8.3 To improve the status of the rhino population from one where it is currently in an uneasy balance with illegal offtake roughly matching population recruitment requires a significant increase in law enforcement effort. To achieve a positive population growth rate of about 2% will require the number of field staff to be tripled. The present staff densities are about 1man/100 sq.km. which require to be increased to at least 1man/33 sq.km.

8.4 We have calculated in considerable detail the total recurrent expenditure required to support law enforcement staff at densities of 1 man/20 sq.km. and 1 man/50 sq.km., including salaries, transport, field allowances, uniforms etc. In 1988 the amounts were

US$307/sq.km. and US$147/km respectively and, with inflation since 1988, the figures are now closer to US $400 and US $200. (Figs.14, 15).

8.5 From this, the annual recurrent expenditure now required by the wildlife department for successful protection of the 50 000sq.km. of rhino range in Zimbabwe should be about US $20 million per annum. The actual allocation from the government treasury is slightly over half of this amount. The rhino conservation strategy for Zimbabwe will have to be based on this reality.

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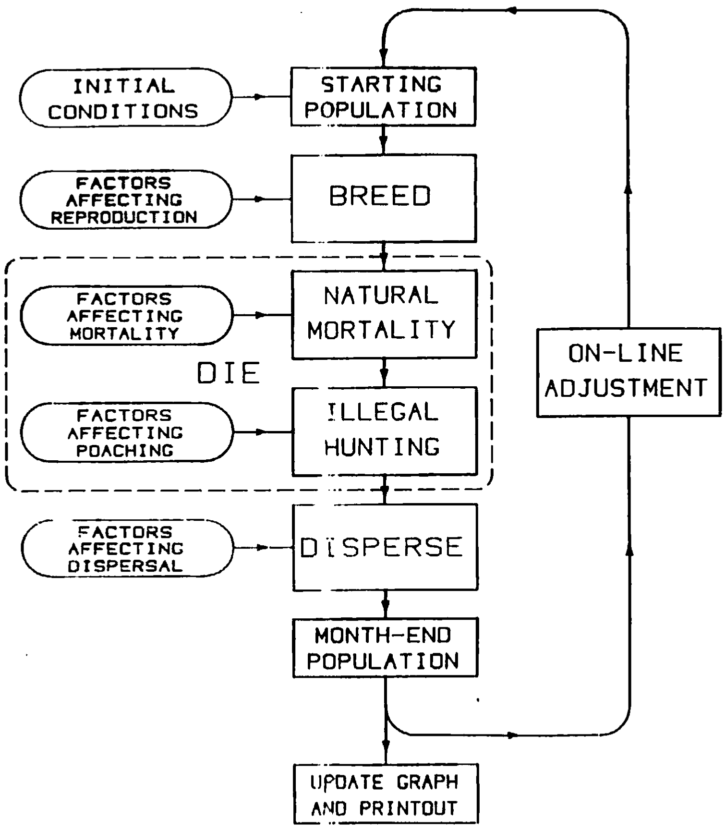

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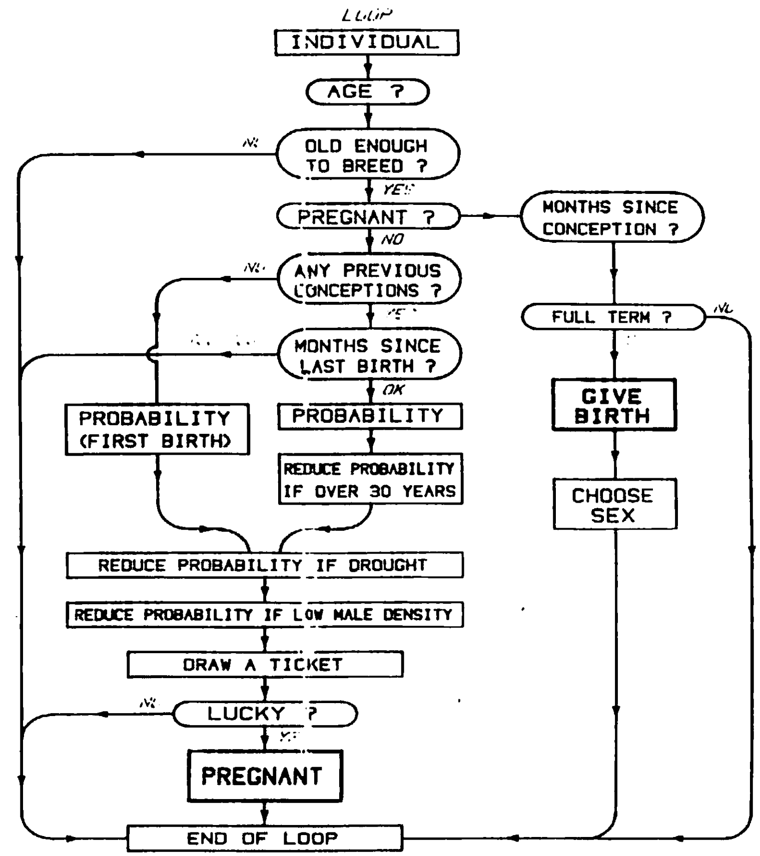

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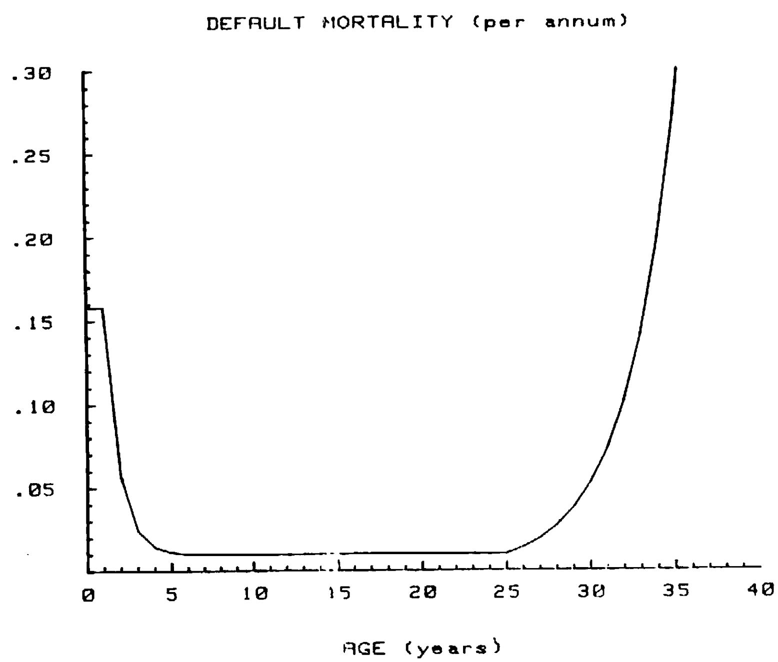

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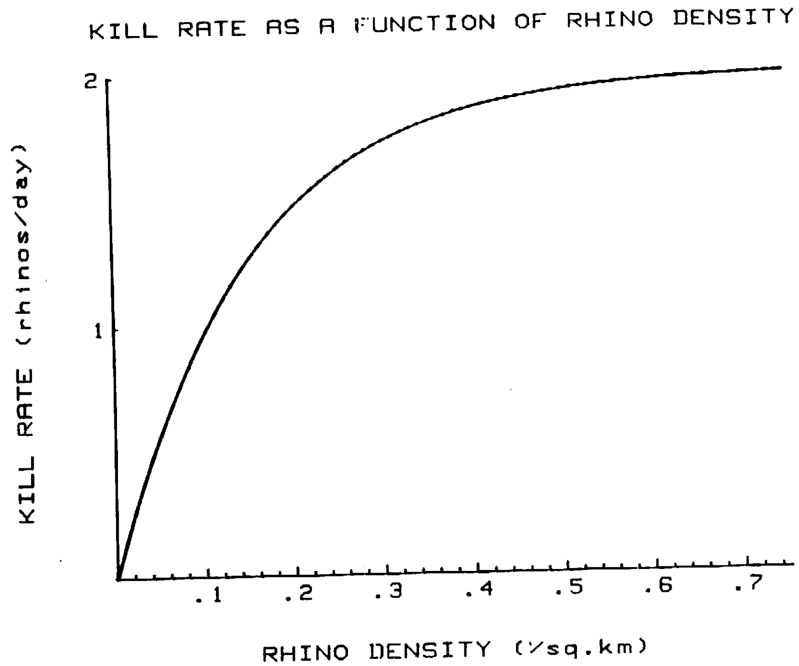

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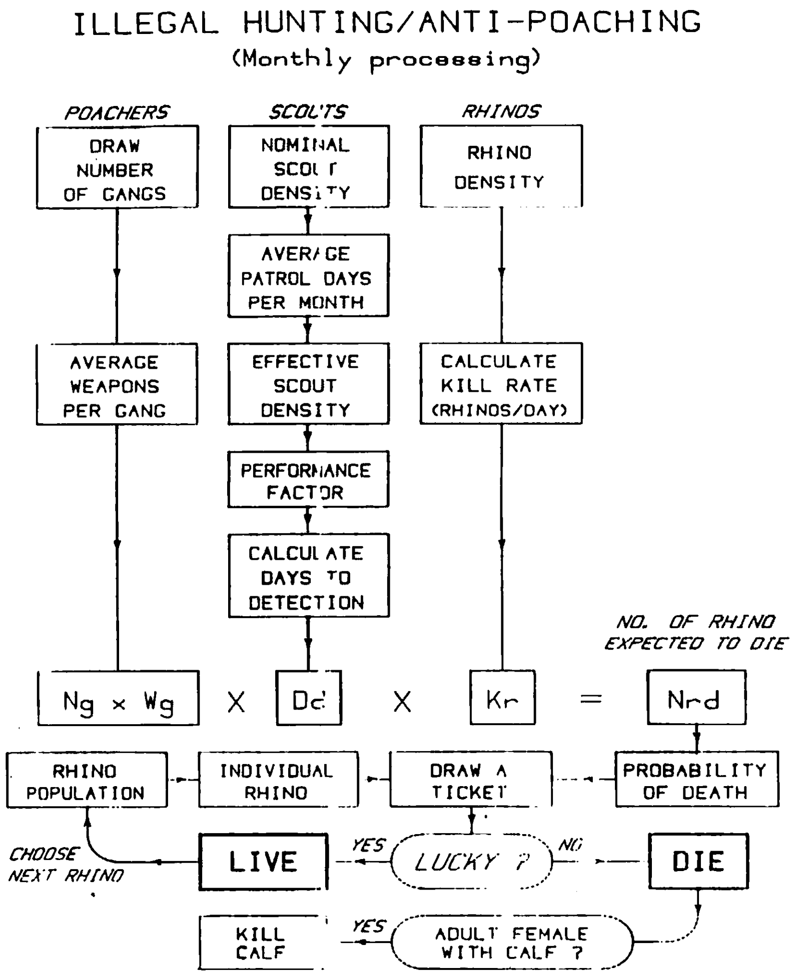

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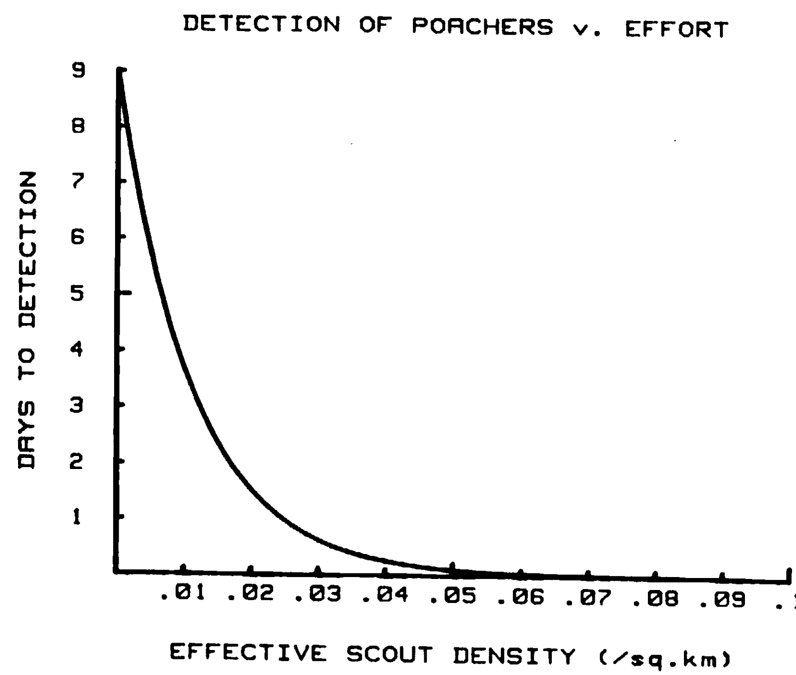

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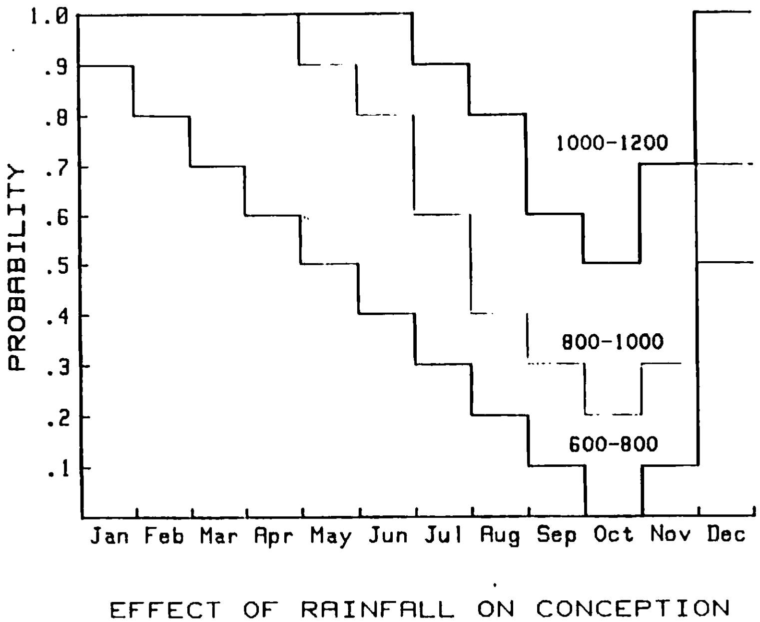

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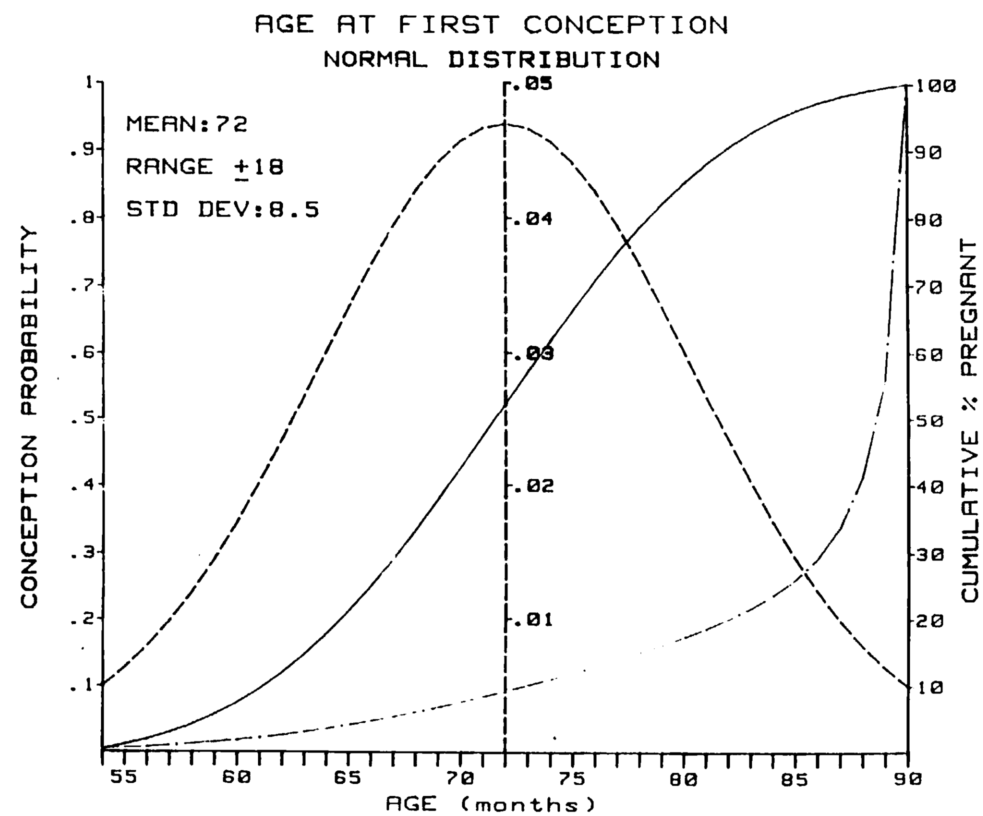

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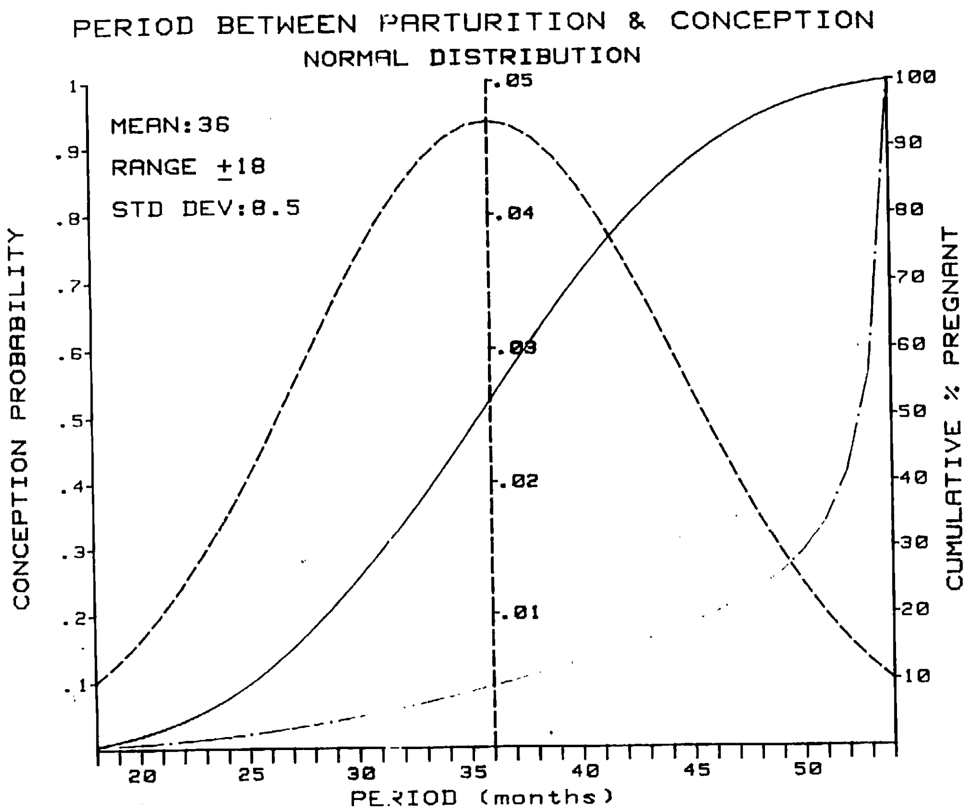

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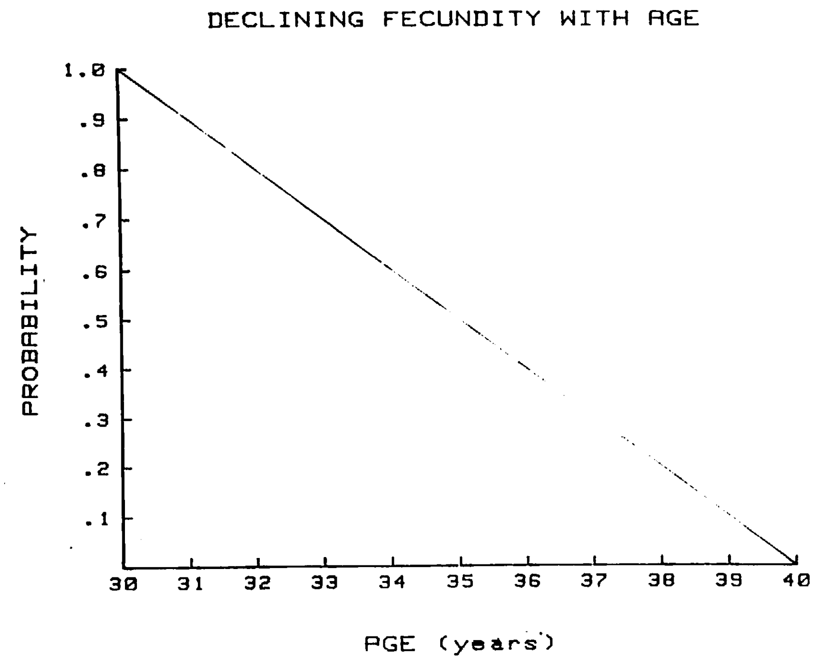

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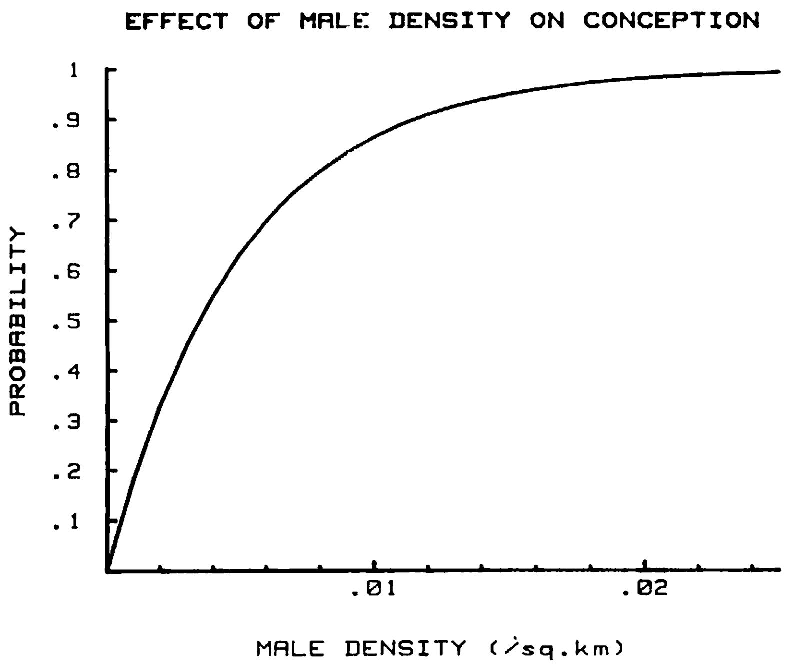

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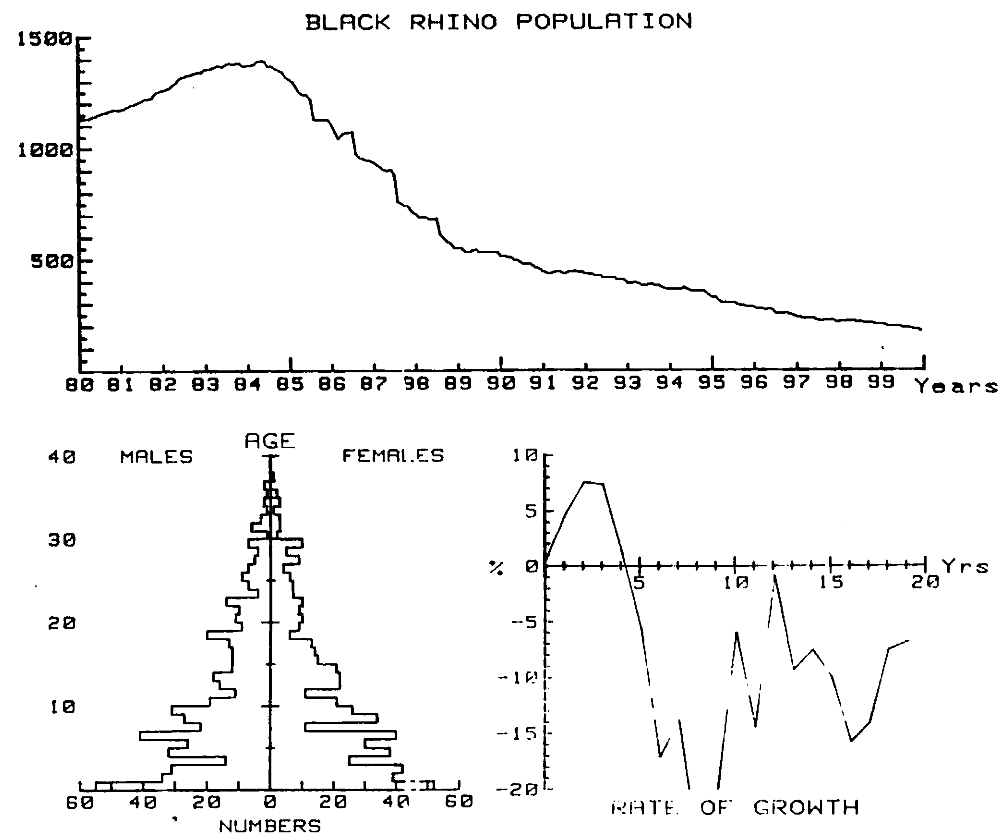

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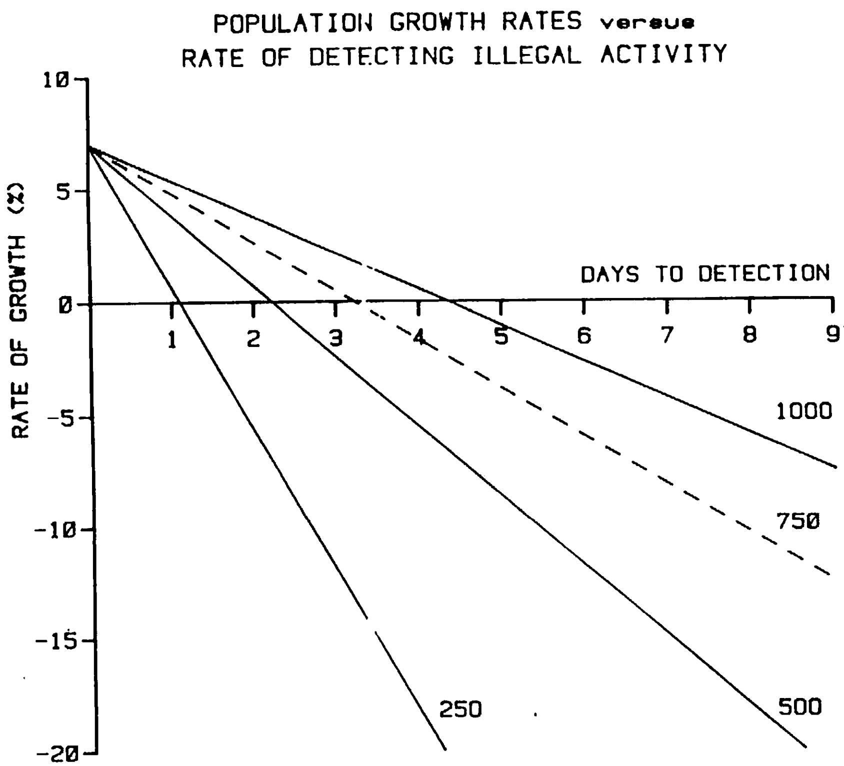

Figure 13

REQUIRED ANNUAL RECURRENT EXPENDITURE: 1 man / 20 sq.km

Total Parks Estate area: 44,000

A. SALARIES	Staff required	COST/SQKM Z$	TOTALS	PERCENT
Management:				
Scouts	2,347	233.02		
General Hands	1,100	79.80		
Officers	264	86.04		
Directorate	5	3.69	402.55	60.3
Administration				
Typists	89	17.25		
Clerks	135	22.17		
Executive Officers	23	7.84	47.26	7.1
	----	------		
(TOTAL STAFF)	3963	449.81		
B. TRANSPORT & SUBSISTENCE				
Vehicles		50.16		
Aircraft		3.64		
Subsistence		19.13	72.93	10.9
C. INCIDENTAL EXPENSES				
Uniforms		18.01		
Office maintenance		2.05		
Communications (PTC)		6.31		
Printing & stationery		0.85		
Water, light etc.		10.23	37.45	5.6
D. MANAGEMENT CONSERVATION				
Consumable stores		14.86		
Game Products		12.15		
Casual labour		6.94		
Maintenance: equipment		25.76		
Game water supplies		13.97		
Roads		29.63		
Soil & Water		4.38	107.69	16.1

TOTAL COST / SQUARE KILOMETRE		.... Z$	667.88	
		.... US$	307.22	

Figure 14

REQUIRED ANNUAL RECURRENT EXPENDITURE: 1 man / 50 sq.km

Total Parks Estate area: 44,000

	Staff required	COST/SQKM Z$	TOTALS	PERCENT
A. SALARIES				
Management:				
Scouts	939	93.21		
General Hands	440	31.92		
Officers	112	37.79		
Directorate	5	3.69	166.61	52.1
Administration				
Typists	37	7.32		
Clerks	54	8.89		
Executive Officers	15	5.17	21.38	6.7
(TOTAL STAFF)	1602	187.99		
B. TRANSPORT & SUBSISTENCE				
Vehicles		50.16		
Aircraft		3.64		
Subsistence		7.70	61.5	19.2
C. INCIDENTAL EXPENSES				
Uniforms		7.28		
Office maintenance		2.05		
Communications (PTC)		6.31		
Printing & stationery		0.85		
Water,light etc.		10.23	26.72	8.4
D. MANAGEMENT CONSERVATION				
Consumable stores		6.01		
Game Products		4.91		
Casual labour		2.81		
Maintenance: equipment		10.41		
Game water supplies		5.65		
Roads		11.98		
Soil & Water		1.77	43.54	13.6
TOTAL COST / SQUARE KILOMETRE		Z$	319.75	
		.... US$	147.09	

Figure 15