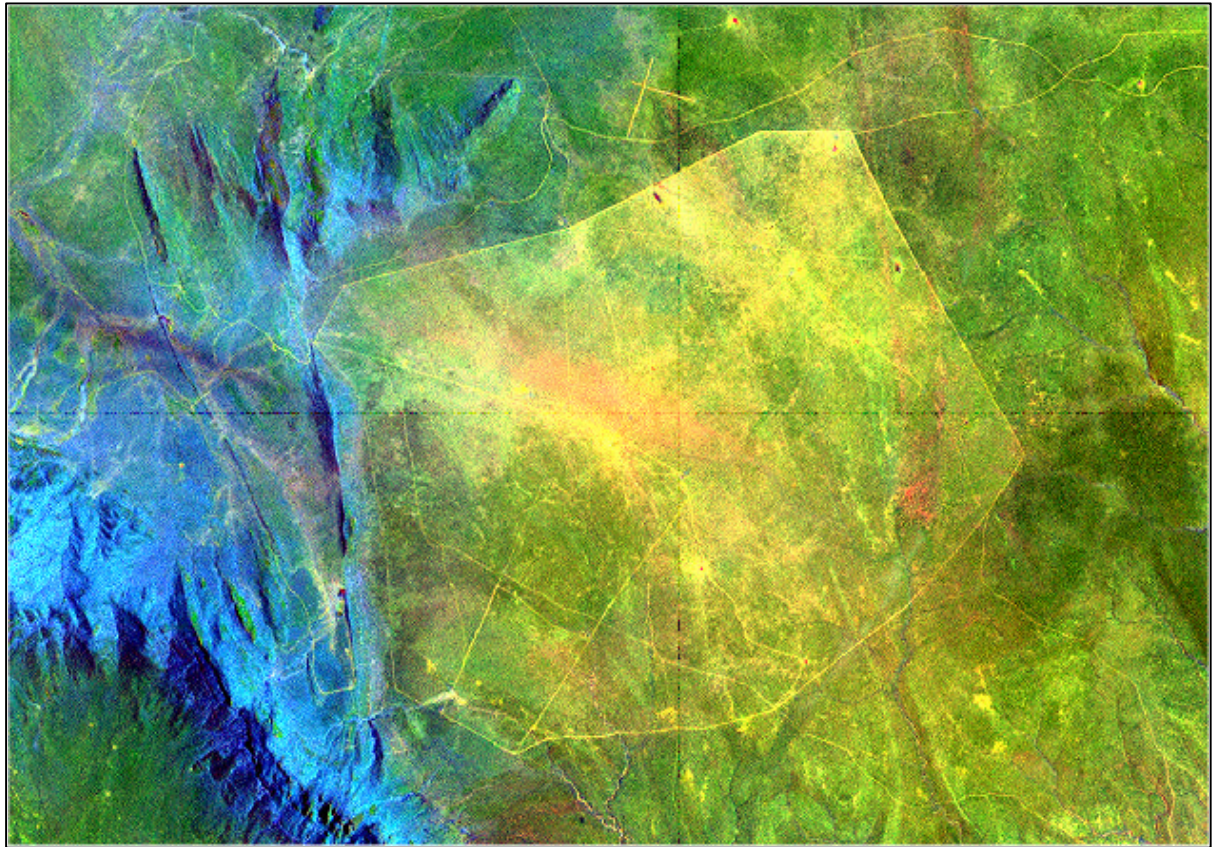


**Population Performance of Black Rhinoceros
(*Diceros bicornis michaeli*) in Six Kenyan Rhino Sanctuaries**



BENSON OKITA OUMA

SEPTEMBER 2004

Population performance of black rhinoceros (*Diceros bicornis michaeli*) in six
Kenyan rhino sanctuaries

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(*Diceros bicornis michaeli*) in six Kenyan rhino sanctuaries**



By

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Dissertation submitted in partial fulfilment of the requirements for the degree of
Master of Science in Conservation Biology

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About the cover

The satellite image on the cover is of Ngulia rhino sanctuary in Tsavo West National Park taken in 2001, showing extent of vegetation degradation due to high density of browser species. The image (courtesy of Keryn Adcock) was obtained as apart of the 2003-2007 DEFRA Darwin Initiative for the Survival of Species project in Kenya.

Other images and logos

The rhino photograph on cover page and page (ii) is a flehming¹ male black rhino called "Observation" in Ngulia rhino sanctuary. Photograph was taken in 2003 by Joseph Muia, a rhino monitoring staff. The logos are in recognition of all organisations and institutions that directly supported this study and my stay in England.

Number of pages and words, and size of fonts

The dissertation contains xix + 112 pages. The number of words are 14,844, excluding tables, figures, references and appendices. Section headings are font size "**thirteen-13**"; other headings and subheadings are font size "**eleven-11**"; the main body's texts are font size "ten-10"; all tables' and figures' annotations are font size "nine-9"; while footnotes are font size "eight-8". Paragraphs have been spaced at 1.5.

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¹ Flehming is a common and conspicuous component of olfactory investigation in both domestic and wild mammals. The grimace or "lip curl" by the black rhino characterizes flehmen and facilitates the transport of non-volatile, excreted compounds to the vomeronasal organ, enabling males to evaluate the reproductive status of females. A frequent context is sampling the urine of females. It is exhibited predominantly by males in most species (Estes 1972).

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ACRONYMS

AfRSG – IUCN SSC African Rhino Specialist Group

ANOVA – Analysis of Variance

APLRS – Association of Private Land Rhino Sanctuaries

AWF – African Wildlife Foundation

BUGS – Biodiversity Underpinning Global Survival

CBSG – Captive Breeding Specialist Group

CITES – Convention of International Trade in Endangered Species and Wild Fauna and Flora

DEFRA – UK-Department for Environment, Food and Rural Affairs

DICE – Durrell Institute of Conservation and Ecology

EKZNW – Ezemvelo Kwa-Zulu Natal Wildlife

GIS – Geographical Information System

IFAW – International Fund for Animal Welfare

IPZ – Intensive Protection Zone

IUCN – World Conservation Union

KWS – Kenya Wildlife Service

NGO – Non-Governmental Organisation

NMC – Rhino National Management Committee

REC – Rhino Executive Committee

RMG – Rhino Management Group

RTC – Rhino Technical Committee

SADC - Southern African Development Community

SPSS – Statistical Package for Social Sciences

SRC – Save the Rhino Committee

SRI – Save the Rhino International

SSC – Species Survival Commission

TRAFFIC – Trade Records Analysis on Flora and Fauna in Commerce

USAID – United States Agency for International Development

US-Fish and Wildlife RTCF – United States Fish and Wildlife Service, Rhinoceros and Tiger Conservation Fund.

WWF – World Wide Fund for Nature

WWW – World Wide Web

ZSL – Zoological Society of London

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Last but not least, LONG LIVE RHINOS.

SUMMARY

Monitoring and demographic data for the eastern black rhinoceros (*Diceros bicornis michaeli*) in six Kenyan rhino sanctuaries were analysed for the period 1992 to 2003, to assess the performance and population dynamics, and to begin the process of meta-population status reporting for informed biological management decision making. Rhino densities, sex ratios and rainfall amounts were related against standard population performance indicators through appropriate statistical analyses. Procedures for collecting and storing rhino data were also assessed. All populations have in the past or are currently exhibiting signs of sub-optimal performance in one or more of the performance indicators because either skewed sex ratio towards males, and/or high densities of both rhino and competing browsers limited rhino growth rate. Nakuru, Nairobi and in particular Ngulia, require urgent management intervention to lower the density of rhino and/or other competing browsers. In Ngulia, the high density of competing browsers is having a severe impact on the habitat and has resulted in a significant reduction in the ecological carrying capacity from approximately 1-1.5 to 0.6 rhino/km². Other populations including Nakuru, Nairobi, and Ol Jogi require readjustment towards female biased sex ratios through translocations and removals.

All populations as outlined in the Kenya Black rhino conservation strategy should be maintained at or below maximum sustained yield by harvesting a set proportion of the population annually to maintain at least 5% annual growth rate as seen in Nairobi N.P. This strategy will require accurate estimates of population numbers and carrying capacities. Population estimates need to be improved in Nakuru N.P., Nairobi N.P. and Ngulia reserve, which have an increasing proportion of “clean” animals, through the implementation of ear notching exercises, improved monitoring and the use of RHINO v.2 population estimation tool. Initial crude carrying capacity estimates were obtained for some of the populations using information on population performance and dynamics. Better carrying capacity estimates can be determined by assessing a range of determinants such as monthly and annual rainfall distributions, browse availability and suitability, temperature regimes and soil fertility.

It was shown that field data collection, validation, storage and reporting procedures have not been followed to the required standards hence significant amount of time was spent validating and cleaning past data, which would otherwise have compromised the analyses. The joint ZSL/KWS/AfRSG UK government funded Darwin Initiative project currently underway is addressing this situation through rigorous training and implementation of procedural mechanisms such as master rhino identification files.

This project provides the basis for: 1) producing standardised annual park status reports and 2) synthesising National status report which interprets the status, performance and dynamics of all Kenya's black rhino populations. This information is necessary for making informed biological management decisions to help achieve and maintain rapid meta-population growth (=5% as outlined in the Kenyan Black Rhino Conservation Policy). Increased rhino numbers will also enable Kenya to play a key role in assisting neighbouring countries (Tanzania, Uganda, Rwanda) in building up their black rhino numbers.

Key words: *black rhino, population performance, meta-population, status report, sanctuaries, carrying capacity.*

1 INTRODUCTION AND LITERATURE REVIEW

1.1 Problem statement

Black rhinoceros (*Diceros bicornis*) - (hereinafter, rhinoceros referred to as rhino) - are uncommon outside protected areas today because severe levels of poaching have reduced many unprotected populations (Brooks 1993; Gakahu 1993; Berger 1994; Rachlow *et al.* 1999). Rhino Conservation Areas, Rhino Conservancies, Rhino Sanctuaries and Intensive Protection Zones (IPZs) (Brett 1990; Nduku and Martin 1993; Emslie 1994; Leader-Williams *et al.* 1997; Emslie and Brooks 1999) have been the main focus of recent *in-situ* rhino conservation work. Even though a number of research into black rhino population biology and ecology has been conducted in Kenya when large numbers of free-ranging rhinos existed (e.g. Goddard 1966, 1967, 1970; Schenkel and Schenkel-Hullinger 1969), and in confined Kenyan sanctuaries (e.g. Waweru 1991; Oloo *et al.* 1994; Tatman *et al.* 2000; Brett and Adcock 2002; Birkett 2002), continuous research is still required in the confined areas to guide their management and rhino demography and behaviour (Rachlow and Berger 1998).

In Kenya, under intensive protection, black rhino and other herbivore densities have continued to increase within the sanctuaries, to approaching or exceeding ECC in some areas, possibly with negative consequences for black rhino performance. Kenya Wildlife Service (KWS), the State body bestowed with the responsibility of managing black rhinos in Kenya, has in the past tended to focus on the overall "averaged out" performance of the Kenyan meta-population. As a result, poorer performing populations have perhaps not had as much attention as they should have.

While the Low growth rate of Kenyan meta-population could be explained by writing off of outliers, in part it may be due to sub-optimal breeding performance in some areas. The SADC RMG workshop on black rhino biological management in 2001 (SADC-RMG 2001), highlighted many case histories in a number of range states where following a build up in rhino densities, their underlying growth rates dropped below the minimum target of 5% highlighting the critical importance of biological management. Sound biological management requires the collection and analysis of quality monitoring data to provide performance indicators which can be used to contrast the performance of different populations and contribute to making more informed decisions with a view to increasing overall meta-population growth rates (Emslie and Brooks 1999; SADC-RMG 2001).

Kenya has in the past not fully incorporated the element of biological management and annual standardised status reporting making it difficult to identify populations which are already exhibiting or might in the near future exhibit (in the absence of biological management intervention) sub-optimal performance. This dissertation examines whether this has been the case in six of the Kenyan rhino sanctuaries.

Several authorities have suggested translocations², sanctuary expansions, and control of numbers of competing browsers as key technical strategies for improving and maintaining black rhino population growth (Emslie and Brooks 1993; SADC-RMG 2001; Birkett 2002; Brett and Adcock 2002). In Kenya biological management decisions have generally been influenced by considerations of stocking rates (of rhinos and other competing browsers) in relation to dynamic ecological carrying capacities (ECC) (Brett 1989a and Foose *et al.* 1993), which need occasional reviews.

The process of using annual status reporting to monitor and contrast the population performance of black rhino reserves in a meta-population has proved to be very beneficial in South Africa and Namibia (where this has been underway since 1989). Apart from the production of annual summaries of population numbers and translocations by KWS rhino programme, and some limited calculations of growth rates and preliminary documentation of some other reproductive indicators (Adcock *et al.* 1998) a more in depth quantification and comparison of the relative performance of Kenyan black rhino populations has not yet been undertaken.

This situation is set to change with a major effort underway (in part as a collaborative UK Darwin Initiative with KWS's rhino programme) to improve the quality and quantity of monitoring data being collected, and introduce a system of detailed annual status reporting in Kenya, as outlined in the current Kenya's black rhino management policy document. This thesis represents a start of the process of detailed comparative analyses of the performance of Kenya's rhino populations, and seeks to examine and contrast the performance of six of Kenya's rhino populations for which there is better quality data.

1.2 Study objectives

The main objectives of the study are as follows:

1. To contribute towards meeting the objectives of the 2000-2005 Kenya's rhino conservation management policy by providing decision-makers³ with improved information on which to base biological management decisions (whilst also providing feedback to those monitoring rhino on the ground). This is achieved by analysing the monitoring data in the KWS rhino information management system KIFARU[®] and producing population status report which interprets the status, performance and dynamics of Kenya's black rhino populations. The production of individual population status report also allows field managers to assess progress as part of the national conservation strategy.
2. To comment on the quantity and quality of data collected for each population and to recommend improvements in the field data collection, quality control and storage protocols.

² Movements of individual rhinos from one area to another either to improve chances of survival, to establish new populations, to keep established populations productive, or to introduce new blood into a population. Rhinos may be translocated to other areas of suitable habitat and to where they may be better protected from poachers (Emslie and Brooks 1999).

³ The decision makers in the Kenya Rhino Programme include; NMC, RTC, REC, and APLRS.

1.3 Literature review of the study species (*Diceros bicornis*)

1.3.1 Extant rhino species and conservation status

Five species of rhino exist in the world: three in Asia and two in Africa. The two African species are the black rhino (*Diceros bicornis*) and the white rhino (*Ceratotherium simum*). Description of the behaviour, habitats and biology of the two African species can be found in Skinner and Smithers (1990), Estes (1991), and Mills and Hes (1997).

There are four recognised subspecies/ecotypes of black rhino (Emslie and Brooks 1999): the Eastern (*D. b. michaeli*); Western (*D. b. longipes*); South-western (*D. b. bicornis*); and South-central (*D. b. minor*). The distribution of the four black rhino subspecies in 1999 is shown in Fig. 1.1. All populations of black rhino are listed in Appendix I of the Convention on International Trade in Endangered Species and Wild Fauna and Flora (CITES)⁴ (www.cites.org).

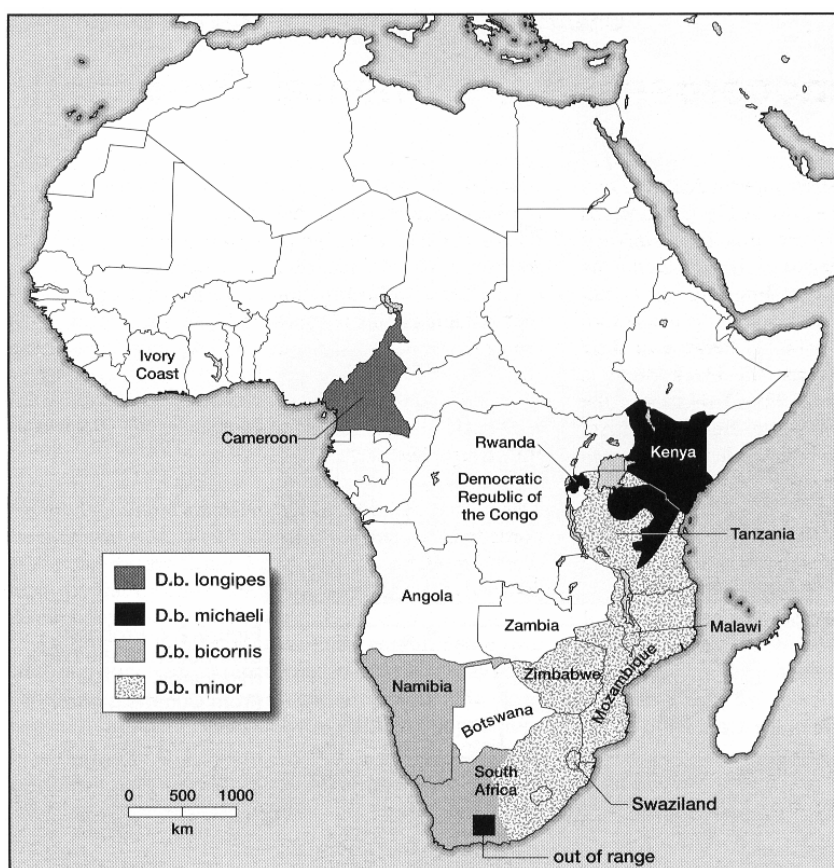


Fig. 1.1: Distribution of the four black rhino subspecies in 1999, Adapted from Emslie and Brooks (1999).

This study focuses on the eastern subspecies of black rhino, *D. b. michaeli*, which the 2003 IUCN Red List of Threatened Animals lists as *Critically Endangered*⁵ (IUCN 2003). Kenya is the stronghold of this subspecies conserving an estimated 84% of the population in the wild in 2003 (AfRSG 2004). The eastern subspecies has longer, more slender and more curved horns than the

⁴ CITES prohibits international commercial trade in the species listed in this appendix.

⁵ A taxon is Critically Endangered when the best available evidence indicates that it is considered to be facing an extremely high risk of extinction in the wild (IUCN 2003).

two southern subspecies of black rhino and is reputedly more aggressive. Some have very distinctive skin ridges on their sides giving them a corrugated appearance (Fig. 1.2).



Fig. 1.2: A picture of *D. b. michaeli* showing the slender curved horn and distinctive skin ridges that gives it a corrugated appearance on its sides. The photograph also shows a suckling calf.

1.3.2 Historical and current distribution

Historically this subspecies ranged from southern Sudan, Ethiopia, and Somalia through Uganda, Rwanda, Kenya and into north-central Tanzania (Emslie and Brooks 1999), but currently it is not found in Uganda, Sudan or Somalia and there is only one rhino remaining in Rwanda. A further small out of range population has also built up in South Africa.

Local adaptations of the eastern subspecies of black rhino in Kenya have developed depending upon their exposure to the disease trypanosomiasis which is carried by tsetse flies (Mihok *et al.* 1992). Rhino living in lowland habitats such as in the Tsavos have been exposed to several species of tsetse fly and trypanosome, while those from highland areas like the Aberdares come from areas where tsetse flies are absent (Foose *et al.* 1992). Care and special procedures therefore need to be followed if translocating rhinos from a highland area to a lowland area with trypanosomiasis.

Patterns and amounts of rainfall is another important bio-geographical consideration affecting rhino distribution (Foose *et al.* 1992; Anon. 1993). Rhino range over a huge rainfall gradient, for example, they live in the arid Kunene, Namibia where annual rainfall range from 150mm to 30mm (Hearn 2003). In contrast to Southern Africa which has a more pronounced long dry season, rainfall patterns in Kenya vary from bi-modal to less seasonal, with amounts varying from 400-1000mm per year. The dual rainy season and rich volcanic soils in many areas allow long periods of vegetation growth, and possibly high densities of rhino (Goddard 1967; Leader-Williams *et al.* 1993).

1.3.3 Historical and current population numbers and trends in Kenya

Historically, like all black rhino, *D. b michaeli* declined throughout its range in the 1970s and 1980s as a result of illegal killing to supply international demand in rhino horn mainly in Asia and Middle East (Martin and Martin 1982; Martin 1983; Leader-Williams 1992; Nowell *et al.* 1992; Mills 1997) and clearing land and nuisance animals for settlement and agriculture (Anon. 1993). Western (1982), Leader-Williams (1988), and Milliken *et al.* (1993) estimated that by the 1980s the *D. b michaeli* that existed in the 1960s had declined by about 95%. Similar conclusions were reached by Emslie and Brooks (1999) for the period between 1970 and 1992. This sharp decline was perpetuated by eras of economic, political instability and internal corruption in a number of range states, which presented organised poachers with a virtually free hand to kill rhinos with little likelihood of apprehension (Emslie and Brooks 1999; Smith *et al.* 2003).

The situation was eased in African rhino range states in the late 1980s through implementation of different management strategies, mainly to protect rhinos in order to scale down poaching and increase rhinos to genetically viable populations. For its part, Kenya managed to turn around the situation by adopting effective conservation initiatives (Anon. 1993). The main guiding policy in Kenya in the late 1980s and 1990s was protection, and thus a combination of approaches were implemented; including the establishment of sanctuaries (Ritchie 1963; Leader-Williams *et al.* 1993), collaboration between KWS and the private and community sectors, increased law enforcement (Dublin and Wilson 1998), improved staff densities and capacities, revision of staff remuneration, and drastic managerial changes within the National Parks. The decline was halted and numbers increased from 380^a in 1987 (Emslie and Brooks 1999) to 458^b in 2003 (Mulama and Okita 2004). Similar turns of events were also evident in other range states (Emslie and Brooks 1999) and Africa's black rhino populations have since then shown an overall increase (Fig. 1.3).

^a The figure includes guesstimates, i.e. poorest quality of population estimate which are either guesses or based on little or no information, or where an existing population estimate is now out of date (i.e. it has been four years since it was updated)

^b The estimates are based on recent census/up to date monitoring data, i.e. all the rhinos sighted within the previous 2 years.

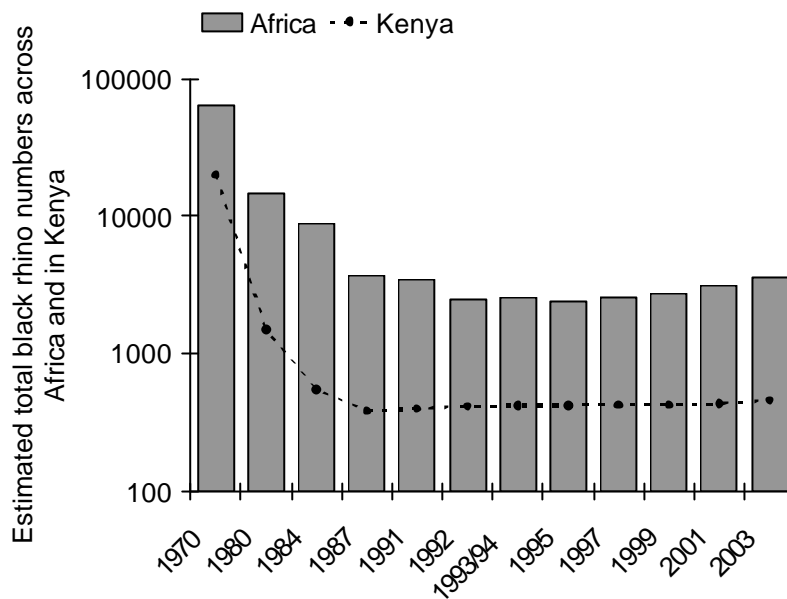


Fig. 1.3: Black rhino trend across Africa and in Kenya from 1970-2003 in a logarithmic scale, showing the sharp decline and slow recovery. Data from Anon. (1993), Foose *et al.* (1992), Emslie and Brooks (1999), Brooks (2002), and Mulama and Okita (2004).

Currently, c.540 and c.170 *D. b. michaeli* are found *in-situ* and *ex-situ*, respectively (AfRSG 2004). Kenya is the stronghold of *D. b. michaeli*, with 458 rhinos as at end of 2003, mostly within protected areas, within sanctuaries in both protected areas and on private land, and in a free-ranging population on county council land. Tanzania has an estimated 42 *D. b. michaeli*, mostly in free-ranging populations in unfenced protected areas, and a few in one sanctuary. Rwanda and Ethiopia hold a relict population of 1 or 2-4 animals each in a protected area and community land, respectively. South Africa as at 2003 had an estimated 36 *D. b. michaeli* of predominantly Kenyan origin out of range on private land. The c. 170 *D. b. michaeli ex-situ* are in different zoos worldwide (Fig. 1.4).

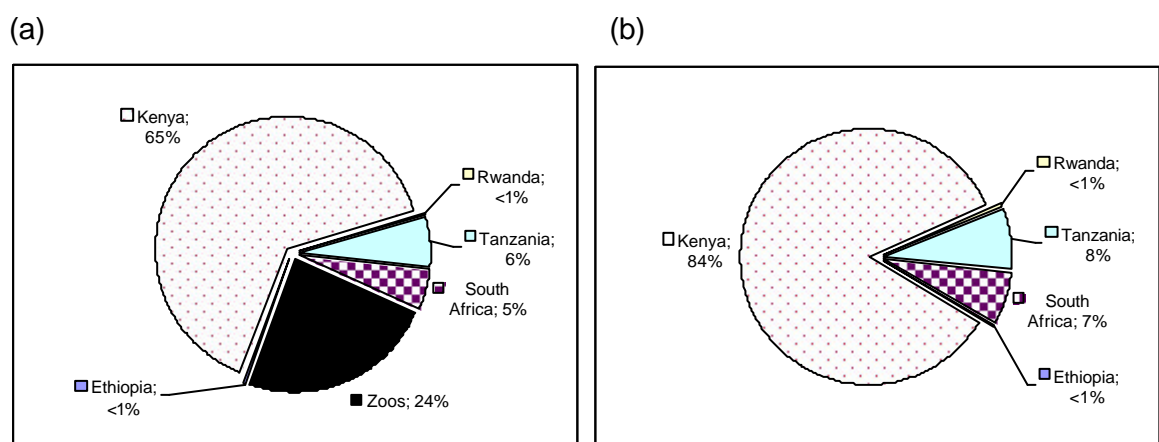


Fig. 1.4: The distributions of *D. b. michaeli in-situ* and *ex-situ*, (a) showing distribution of *D. b. michaeli* both *in-situ* and *ex-situ*, and (b) showing distribution of *D. b. michaeli in situ* as at end of 2003. Data from AfRSG (2004).

Even though Kenya is the stronghold of *D. b michaeli* worldwide, and rhino numbers are increasing, meta-population growth rates have fallen below the minimum target level of 5% per annum (Anon 1993; Anon. 2003a). For this reason, Kenya has increased the emphasis on improved biological and security monitoring in all its populations to ensure that poaching does not recur and population growth can be enhanced and in so doing meet recovery targets and maintain long term demographic and genetic viability.

Strategies to achieve the National goal of a minimum of 5% growth rate per annum are outlined in the Conservation and Management Strategy for the Black Rhino in Kenya 2001-2005 (Anon. 2003a). This policy document has given the highest priority to biological management, and it is hoped that meta-population growth rates of at least 5% per annum can be achieved through specific training and capacity building in rhino monitoring, standardised data collection, recording of good quality data, analysis and status reporting. Assessing black rhino habitat ECC to assist in developing new viable populations and to manage existing rhino sanctuaries is also a key component. This study will form an integral part of the strategy to assess progress towards these goals as well as providing valuable biological data to guide decision-making aimed at boosting meta-population growth rates.

1.3.4 Rhino conservation policies in Kenya

Legally, all black rhinos in Kenya have always remained the property of the State, irrespective of the land tenure system. Changes in wildlife administrations and in status of rhinos (Appendix 1) have witnessed the adoption of many different policies and structures to oversee rhino conservation in Kenya (Leader-Williams *et al.* 1993).

The latest policy guidelines for conserving rhinos were formulated in 2000, revised in March 2003, when they were officially ratified by the government. These were built around the earlier plans of 1979, 1983, 1985 and 1993 that saw the rhino numbers stabilise initially, and then slowly increase (Fig. 1.5).

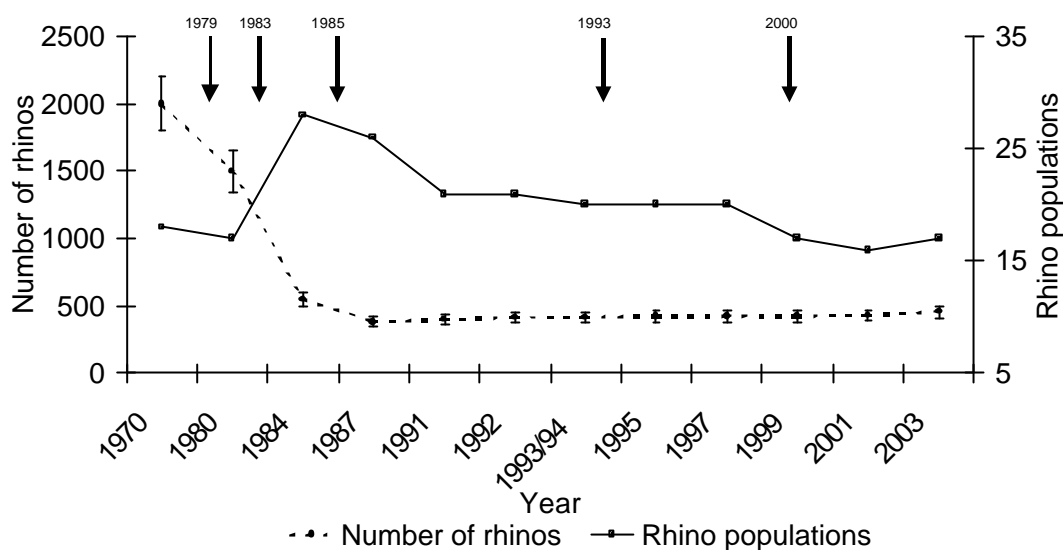


Fig. 1.5: Trends in rhino numbers and populations from 1970-2002. The solid line represents the number of rhino populations. The dotted line with 10% error bars indicates numbers of rhinos. The arrows point to the times different rhino management strategies were formulated. The increase in the number of populations in the early 1980s arose from increased fragmentation into smaller populations. The decrease in the number of rhinos between 1984 and 1991 resulted from the loss of outlier populations. The effect of the rhino policies is shown by the steady increases in rhino numbers from 1993.

Kenya's present policy on rhino conservation has the overall vision of conserving 2000 *D. b. michaeli in-situ*, with an overall goal of increasing the numbers by at least 5% per annum, to reach 500 rhinos by 2005, 650 by 2010 and 1000 by 2020, by six strategic objectives.

This study will directly contribute to three objectives of this policy, namely:

- 1) **Biological management** – to maintain an overall biological growth rate of at least 5% per annum with a total population of 500 in 2005.
- 2) **Monitoring for management** – to develop an integrated standard monitoring system.
- 3) **Capacity** – to sustainably and collaboratively allocate resources necessary for the effective and efficient management of designated rhino areas.

1.4 Population dynamics and performance

1.4.1 Dynamics of herbivore population abundance and composition

Populations grow if births exceed deaths and if emigration is less than immigration. This simple logic underlies the principles of population dynamics. The population growth rate that could potentially be maintained in an ideal environment can be calculated from basic demographic parameters collected over time (Sinclair *et al.* 1985; Mills *et al.* 1995; Runyoro *et al.* 1995; Campbell and Borner 1995; Broten and Said 1995; Prins and Douglas-Hamilton 1990). Owen-Smith (1988) and Emslie (1999) have both estimated the long term r_{max} for rhino at 99.4% per annum, although young growing populations with very low adult mortality rates or ones with skewed sex ratios in favour of females may grow faster. Estimates of population numbers,

distribution, natality, mortality, and age and sex structures, breeding performance, and translocations are amongst the most common data collected for management of wildlife populations. When analysed, these statistics can be used to guide biological management decision making (Downing *et al.* 1977; Gilbert 1978; McCullough *et al.* 1994; Adcock 2000).

If collection of these data is not standardised, for example, by age classes, or body condition (Adcock and Emslie 2000), then biases in demographic estimates may not be comparable since errors will not be systematic (McCullough *et al.* 1994). That is, if biases are not reduced by standardising surveys or monitoring in studies that monitor long term trends of demographic variables, then the differences obtained may not necessarily represent real changes in composition and abundance of populations (Le Resche and Rausch 1974; Caughley 1976).

For these reasons, Kenya began to standardise monitoring and surveying of its rhino populations as soon as the sanctuaries were established and has been part of continental efforts to use standardised ageing and condition assessment categories promoted by the AfRSG. Monitoring based on the AfRSG's ID training course and using the AfRSG recommended standardised age classes and condition assessment scales is currently being promoted in Kenya through training courses and follow up in the field as part of a joint AfRSG-ZSL-KWS-Darwin Initiative project funded by the UK's DEFRA (Amin *et al.* 2004).

1.4.2 Population dynamics and its associated problems

The large scale decline of black rhino numbers and fragmentation of its habitat have created a number of discrete small populations (Leader-Williams *et al.* 1993; Hanski *et al.* 1996; McCullough 1996; Hanski and Simberloff 1997), making these populations vulnerable to random fluctuations in size and eventual extinction unless actively managed as a meta-population.

Biologists have observed that small populations have a greater tendency to go extinct than large populations for three reasons: loss of genetic variability and related problems of inbreeding depression and genetic drift (Loeschcke *et al.* 1994; Avise and Harmrick 1996; Woodruff 2001); demographic fluctuations (Menges 1992; Lacy and Lindenmayer 1995; Morales *et al.* 1997); and environmental variations or natural catastrophes (Menges 1992). Experience with captive animals has led to some tentative rules that isolated wild populations should have 50 to 500 individuals to maintain genetic variability, although protecting 5000 individuals or more is preferable (Primack 2002). Combinations of these effects on small populations create an extinction vortex that tends to accelerate the drive to extinction (Gilpin and Soulé 1986).

To conserve a population, it is essential to determine the effective population size, which is an estimate of the number of individuals that are actually producing offspring (Kimura and Crow 1963; Lande and Barrowclough 1987) and is based on the number of genes in the population that can be passed on to the next generation. This is assigned the symbol (N_e). Factors which have an impact on N_e are unequal sex ratio, fluctuations in the number of individuals in the group and a non-random distribution of offspring (Nunney and Elam 1994).

The reason that effective population size is of such great importance to conservation genetics studies is because it is involved in the rate of heterozygosity loss per generation from the group. The formula for this process is as follows:

The proportion of genetic variation remaining in the population per generation is:

$$(1 - 1/2N_e),$$

where N_e is the effective population size.

It is possible to see from this equation that if N_e is very large, the term subtracted from one will be very small and most of the genetic variability will be maintained each generation. However, if the effective population size is very small, the subtracted term becomes significant resulting in more heterozygosity being removed from the group each generation. N_e is calculated as follows:

$$N_e = 4N_mN_f / (N_m + N_f),$$

where N_e = effective population size; N_f = number of females; and N_m = number of males.

The conditions that would result in a population having the highest possible effective population size would be parity sex ratio and if the population size remained high and constant over time and if every individual in the group produced an equal number of offspring.

Most black rhino range states manage their meta-populations with a view to maintaining the long term genetic health of rhino populations (Emslie and Brooks 1999). Apart from translocations to introduce new blood every generation or two, and recommended minimum founder numbers, a key component of conservation of heterozygosity is to achieve rapid meta-population growth rates.

1.4.3 Animal densities and population dynamics

Populations cannot continue to expand indefinitely and rhinos are no exception (SADC-RMG 2001). The finite resources supporting animals become divided amongst the increasing numbers of individuals, predation losses may increase, disease can spread more easily, and high densities may promote aggression, fatal injuries and both inter- and intra-specific competition (Ogutu 1999; Gotelli 2001; Huxel and Polis 2001; Owen-Smith 2001; Ricklefs 2001). The outcome is that birth rates decline, mortality rate and emigration increases, as the population density rises. Such density dependence in vital rates eventually leads to a situation where births just balance deaths, and net population growth equals zero. This is conventionally termed K-carrying capacity, also Ecological Carrying Capacity (ECC) (Primack 2002).

In the case of long lived K-selected⁶ large herbivores like rhino, rather than level off at ECC, they appear more inclined to overshoot carrying capacity in numeric terms before then, as they may continue to breed while calves remain small and are not yet exerting much impact on the habitat (Emslie 2001a and 2001b). However in time as these younger animals grow up into adults their biomass and hence impact on habitat would increase. There may also be time lags in the impact of a given density on the habitat (Adcock 2001). Never the less, this a real problem which can lead

⁶ K-selected species are slower in development, excellent competitors, larger in body size, poor dispersers, longer lived, and slower in reproduction. They are also adapted to exist at or near ECC in relatively stable habitats, and have S-shaped growth curve.

to an overall lowering of ECC through the elimination or reduction in favoured food plants and is more likely to overshoot and suffer decline before population adjusts (Hitchins 1968; Emslie 1999; Emslie 2001c).

1.4.4 Adult sex ratio and population dynamics

Sex ratio alteration influences the population dynamics of a species and thus has important implications for large herbivore welfare and management (Verme and Ozoga 1981; Adcock 2000; Milner-Gulland *et al.* 2001; Saltz 2001). Skewed sex ratios (<1:1 or >1:1) may be indicative of chance demographics and/or differential survival between females and males, and may limit the reproductive potential of a population (Taylor 1984). For black rhinos in Kenya, where migration is achieved through translocations, careful selection of animals to translocate is critical to avoid skewing sex ratio.

1.4.5 Rainfall and population dynamics

Many studies (e.g. Coe *et al.* 1976; Sinclair 1979; East 1984; Owen-Smith 1990), have widely regarded rainfall as a critical variable driving ecosystem function and the dynamics of the African savannah ecosystems, and hence the food production for large mammalian herbivores. Depending on the coefficient of variation (>30% of mean) in rainfall, populations tend towards some saturation density during wet season. In Africa, coefficients of variation in rainfall only exceed 30% when mean annual rainfall is less than 400mm. Over the typical rainfall range for savannah vegetation of 400-800mm, the coefficient of variation of rainfall is typically $\pm 25\%$, which is just under the critical threshold (McNaughton 1979, 1985; Owen-Smith 2001). However, El Niño⁷ events may raise this coefficient of variation above the $\pm 25\%$ (Karanja and Mutua 2000), suggesting the possibility of populations attaining their ceiling density, yet remaining well below ceiling densities at other times.

Although rainfall has been shown to be a reliable predictor of animal densities in savannah ecosystems (Rosenzweig 1968; Philipson 1975; Sinclair 1977), it is an indirect measurement of population dynamics and at best gives only an indication of range condition (Mills *et al.* 1995)

1.4.6 Black rhino demographic and reproductive indicators

Population performance for a K-selected species such as black rhino would attain its maximum sustainable yield (MSY) around 75% of ECC (Caughley 1985; McCullough 1992; Kirkwood *et al.* 1994; Robinson 2000). To achieve a growth rate of >5%, rhino numbers should be kept at the

⁷ "El Niño" is the term used to refer to an oceanographic phenomenon in which there is extensive warming of the upper ocean in the tropical eastern Pacific lasting three or more seasons accompanied by changes in the atmospheric pressure over the western and central regions of the Pacific Ocean. An El Niño event results from interaction between the surface layers of the ocean and the overlying atmosphere in the tropical Pacific. Several El Niño events have been recorded in the past. Whilst these events share some similar characteristics, each is somewhat different in magnitude, duration, and the resulting global climatic impacts. El Niño events effectively disrupt normal seasonal patterns. Wetter than normal conditions are usually observed during warm episodes, while drier than normal conditions are experienced during cold episodes. A recent strong El Niño event relevant to this study is that of 1997/1998.

MSY or ensure an annual off-take of 5%+ (Goodman 2001). These principles guide the current Kenya rhino conservation strategy (Anon. 2003a).

In order to assess and detect any local variations in performance of black rhino populations; a number of indicators are considered (du Toit *et al.* 2001). Some of these indicators are interrelated, allowing the same information to be viewed in slightly different but informative ways (Knight 2001). Although debates have revolved around the adequacy of such indicators on the basis that rhino reserves differ in climate, geology, habitat and altitude (Knight and Adcock 2000), they still provide the best available measures of performance.

This study therefore assesses the following demographic and reproductive indicators in six rhino sanctuaries in Kenya from 1992-2003:

- 1) Average annual growth rates: this remains one of the best indicators of population performance, and numerical predictions of numbers are possible and meaningful to a wide range of users. By virtue of their large body size and concomitantly low reproductive rate, black rhinos have a maximum intrinsic rate of increase of about 9%, according to allometric relationships (Caughley and Krebs 1983; Owen-Smith 2001). The greatest drawbacks to using annual growth rates are that it requires good knowledge of the population estimates, which are difficult to obtain in difficult-to-monitor populations. Secondly, it is sensitive to sex ratio (but can be corrected, Appendix 8), and thirdly, it becomes less meaningful with small population where 1 birth or death can make a significant difference.
- 2) Rhino densities: this relative to ECC is correlated with growth rate at higher densities. It is a good measure especially if compared with historical densities of the same area when rhinos used to thrive. High densities imply greater competition and may impact negatively on the demography and behaviour of a K-selected species (Rachlow *et al.* 1999).
- 3) Average percentage mortality rate: this is a sensitive indicator, as it is a true reflection of a problem and sends a strong message to management. However, it requires accurate monitoring over three-year "windows".
- 4) Adult sex ratios: this has been noted to have considerable influence on the rates of increase of rhino populations (Knight 2001). Populations with close to two females to an adult male, in "good habitat" should have a good population growth rate, indicative of social constraints placed upon the population with sex ratios close to parity.
- 5) Inter-calving intervals (ICIs) and proportion of adult females calving per year: these two measures can be directly correlated and are good for dealing with sub-population variability as they are independent of sex ratio. They are relatively sensitive if births or neonatal deaths are not detected. However, they do not deal with success of recruitment of sub-adults and require a sample size of at least 5 cows.
- 6) Age at first calving: this is a sensitive measure at a population level and is useful in small or sub-populations, but must consider individual variation among cows. However, it requires detailed and continuous monitoring of individual cows, including accurate dates of birth.

- 7) Proportion of calves in the population: this indicator is useful in single population samples and could be used in large, infrequently monitored populations. It helps to track recruitment and is a true reflection of population structure to help interpret other parameters. However, it could require lumping of data that would obscure sub-population variability. It is difficult to use in small or sex-biased populations. Deciding if a rhino has crossed from a calf of 3.4 years to a sub-adult of 3.5 years is difficult without accurate knowledge of individual birth dates.

1.4.7 Black rhino status reporting

Status reports are prepared with the aim of analysing and interpreting population performance indicators, security and management issues at both sanctuary and meta-population levels with the intention of providing managers with information relevant to the assessment of the overall progress made towards the conservation goals of rhino. This study will contribute demographic and population performance information to start the process of Kenya Black rhino status reporting.

2 METHODOLOGIES

2.1 Study areas

The study was conducted in six rhino sanctuaries in Kenya (Fig. 2.1). A combination of the following reasons led to their selection for the study; 1) some e.g. Ngulia have high numbers of competing herbivores to see density dependence feedbacks, 2) some e.g. Nairobi have removed many rhinos to examine response of population to harvesting, 3) they have better quality data and monitoring has been reliable and consistent, 4) their State and private land tenure systems, where three are on state land and the other three on private lands, 5) their ranges in rainfall, where some are in low rainfall while some in high rainfall zones, and 6) the time limits for an MSc dissertation.

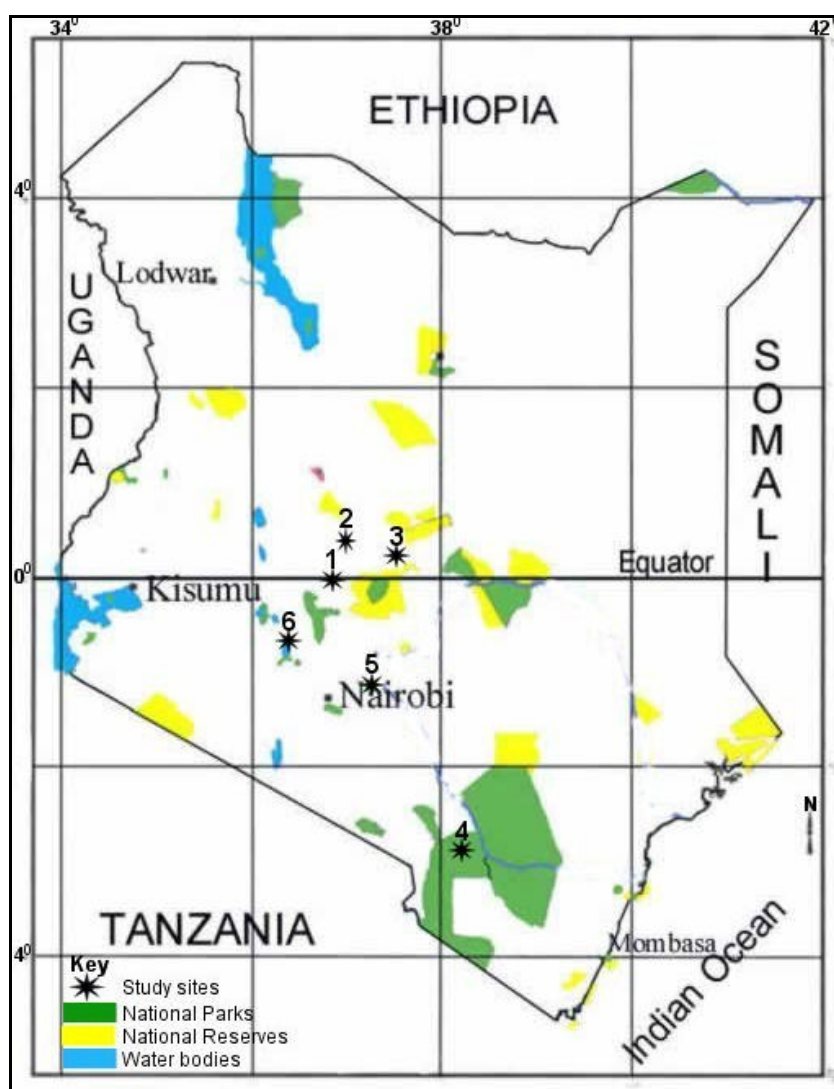


Fig. 2.1: A map of Kenya showing the approximate locations of the six study sites; 1=Ol Pejeta Game Reserve, 2=Ol Jogi Game Reserve, 3=Lewa Downs Conservancy, 4=Ngulia Rhino Sanctuary, 5=Nairobi National Park, 6=Lake Nakuru National Park. Adapted and edited from (www.kws.org).

2.1.1 OI Pejeta Game Reserve

This is a completely fenced 93km² reserve on private land, located in central Kenya between 0°00'N to 0°05'N, and 36°53'E to 37°00'E. The terrain is generally undulating between 1770m and 1820m altitude. Rainfall averages 850mm per year. The vegetation is a mosaic of grassland, *Acacia* woodland, *Euclea* shrub and riverine woodland grassland. Further descriptions can be found in Tatman *et al.* (2000) and Birkett (2002).

2.1.2 OI Jogi Game Reserve

This is a completely fenced 50km² reserve on private land size located in central Kenya between 0°15'N to 0°20'N, and 37°00'E to 37°05'E. The terrain undulates between 1800m and 1920m altitude. Rainfall averages 460mm per year. The vegetation is a mosaic of grassland, *Acacia* woodland and shrubs (Mizutani 1999).

2.1.3 Lewa Downs Conservancy

This conservancy is completely fenced with an area of 247km², on private land, located in central Kenya between 0°10'N to 0°15'N, and 37°15'E to 37°20'E. The terrain is rugged with occasional sharp slopes between 1750m and 1950m altitude. Rainfall averages 550mm per year. The vegetation is dominated with *Stipa dregeana* forest, *Acacia- Commiphora* woodland plains and open grasslands. Further descriptions are provided in Anon. (1993) and Botha (1999).

2.1.4 Ngulia Rhino Sanctuary

Ngulia sanctuary is located within the central part of Tsavo West National Park. It was conceived as a way or re-establishing a large free-ranging populations within the park. It is completely fenced with an area of 62km², located in southern Kenya between 3°01'S to 3°06' S and 38°06'E to 38°10'E. Altitude Ranges from 600m of low lands to 1800m of craggy hills, with average annual rainfall of 600mm. The vegetation is thickly wooded by *Commiphora-Acacia* woodland, dotted with baobab trees. For further description see Leader-Williams *et al.* (1993), Anon. (1993), and Brett and Adcock (2002).

2.1.5 Nairobi National Park

Nairobi National Park was the first national park to be established in East Africa. It is partially fenced, covering an area of 117km² and leaving approximately 20km perimeter on its southern boundary for animal migration. It is situated 10km from Nairobi city centre between 2°18'S to 2°20'S and 36°23'E to 36°28'E. The national park presents gently undulating elevations from high altitudes of 1790m around woodland areas in the north-west of 1790m to mosaic grasslands of lowland plains in the south-east at lower altitudes of 1508m. Mean annual rainfall is 800mm. Major vegetation communities comprise deciduous forest, riverine thorn forests, shrubs and grasslands. Further detailed descriptions are available (Smith and Verdicourt 1962; Hurxthal 1979; Muya and Oguge 2000).

2.1.6 Lake Nakuru National Park

This National Park is completely fenced covering an area of 188km², of which 44km² lies in the shallow highly alkaline soda lake in the central rift valley. It is located 4km from Nakuru town centre between 0°50'S to 1°00'S and 36°20'E to 36°25'E. The relatively flat lowlands around the lake are 1200m altitude and are surrounded by hills and gentle cliffs of up to 1750m altitude. The mean annual rainfall is 850mm. The vegetation is a mixture of open grassland *Acacia*, *Tarchonanthus* bush land, deciduous and *Euphobia* forests and riverine bush land (Kutilek 1974; Waweru 1991; Mwasi 2002; Anon. 2003b).

2.2 Data Collection

2.2.1 Collation of rhino monitoring data

Monitoring of the rhino populations by special dedicated staff have taken place in these six rhino populations since their establishment. Individual rhinos were recognised by a combination of features (ear notches, distinctive body marks, horn shapes, age, and sex) as have been used widely (Klingel and Klingel 1966; Hitchins 1970; Hamilton and King 1969; Western and Sindiyo 1972; Makacha *et al.* 1979; Adcock and Emslie 2000). Those that could not be recognised by a combination these features were considered “clean” rhinos (see Appendix 3 for further description of “clean” rhino). Rhinos were sexed and aged using the standardised A-F AfRSG age categories (Appendix 2). For each sighting, the information of individual(s) encountered and general area of sighting was recorded using a standardised field recording forms (Appendix 4a&b). Mortality information was collected using standard mortality form (Appendix 4c), which also incorporated information on carcass of other larger (Impala and above) herbivores. These standard data collection forms have been through several modifications and improvements but have still collected the basic data required for assessing population performance. The data was then verified by accredited observers following the standard protocols in some areas (Mulama *et al.* 2004) (Appendix 3), before they were finally entered into the Kenya Black Rhino Information Management System⁸ (KIFARU[®]) (Amin *et al.* 2001) at the sanctuary level.

Data in KIFARU[®] were checked and verified on-site between April and July 2004 using original paper-based data forms and enlisting experienced rhino staff including the retirees or those who were transferred to other departments but had valuable historical information. Automatic retrieval of the data for analysis was done through computer scripting in MS-Access[®]™ version 97 and XP[®] and Matlab[®]™ version R12 software (e.g. Appendix 5). These were also counter-checked by a few random manual calculations.

2.2.2 Collation of translocations and other historical information

⁸ This is a decision support infrastructure implemented in eleven Kenyan rhino reserves/areas with the financial and technical support from USAID and ZSL, respectively. It is based upon a management system whose framework is built around two software packages providing the necessary database and GIS functionality. The information system is composed of three categories of databases: The central database which is controlled by KWS headquarters and contains general information on rhinos; the sanctuary database which is controlled by the respective sanctuary and stores daily information on patrols and rhino sightings; and the management database which contains extensive range of forms, queries and graphs for data entry, retrieval and display.

These were retrieved from KIFARU[®], KWS's and respective sanctuary files, records and reports. Personal communications and referencing to previous published and unpublished studies augmented this exercise. Data was then summarised for each sanctuary (Appendix 6) and detailed population history tables produced (e.g. Appendix 7⁹)

2.2.3 Collation of rainfall data

Rainfall data for the period 1992-2003, collected from various weather stations within the sanctuaries, were supplied by the respective sanctuary scientists. Annual averages were then calculated based on the monthly average rainfall and number of weather stations.

2.3 Calculations for comparative analysis

Apart from calculation of average age at first calving and average inter-calving interval which considered a periods since establishment of rhino population to 2003, all other calculations for comparative analysis were performed for the period 1992 to 2003.

A black rhino's gestation period is 16 months (Skinner and Smithers 1990) and in part due to lag effects, birth rates can vary substantially from year to year (Adcock 1999); In order to better examine underlying trends and reduce the impact of year to year variation in the data 3year moving averages were used in calculations (Emslie 2001a).

2.3.1 Biological growth rate

This is the natural net increase in a population's size from births and mortalities expressed as a percentage of the population size at the start of a year (Emslie and Brooks 1999). Biological growth rate herein after referred to as "underlying growth rate" or intrinsic rate of growth " r_{max} ", was calculated for the sum total of confirmed¹⁰ and the probable¹¹ categories of population estimate (the official rhino numbers). Guesstimates were excluded from the growth rate calculations but included in population estimate graphs. Rhinos were classified under these categories based on their last date of sighting. Translocations (removals and introductions) were incorporated and calculated over 3-year window periods for a least squares error minimisation and best fit value of r_{max} as follows:

Population at the end of year $t = [(population\ at\ end\ of\ year\ t-1) - removals\ in\ year\ t] \times multiplier + introduction\ in\ year\ t$.

The **multiplier** represented the $(r/100+1)$ in the standard intrinsic growth rate equation:

$$N_t = N_0(r/100 + 1)^t,$$

⁹ For confidentiality reasons, only one example of population history table has been presented, some information has also been deliberately disguised. Similar tables for other populations can be obtained with the permission of KWS.

¹⁰ 'Confirmed' refers to rhinos which were sighted within the year (Year y)

¹¹ 'Probable' refers to rhinos which were sighted within the previous two years (Year $y-2$)

Where N_t = cumulative population at end of year t including man induced deaths¹²; N_0 = cumulative base population including man induced deaths; t = time in years; and r = intrinsic rate of growth.

2.3.2 Mortalities and mortality rate

Only mortalities that occurred between 1992 and 2003 were considered. These were categorised into age classes A-B, C-D, E, and F (see Appendix 2 for descriptions) by causes, which included disease, fighting, nutrition, predation, other natural, poaching, and other unnatural. Total numbers dying in each age class and by each cause were then tabulated.

Mortality rate was calculated using the following formula:

$$\% \text{ mortality} = [M_t / (M_t + N_t)] \times 100,$$

where M_t = Mortalities in year t ; N_t = Population at the end of year t .

2.3.3 Rhino densities

Rhino densities are expressed in numbers of rhinos per km². Unless for obvious cases, the entire land area within each sanctuary was assumed to be the effective area for use by rhinos. The Lake (44km²) in Nakuru National Park was excluded from the estimate of the area of available rhino habitat.

2.3.4 Population structure and reproductive indicators

Due to the long continuous period of monitoring, it was possible to age all rhinos within a confidence range of within 1 week to within 5 years, by reference to their month of birth if known. Individuals were classified into two sex and three age class categories of males or females; calf <3.5 years old, sub-adult =3.5 to <7 years old, and adult =7 years old (Adcock and Emslie 2000).

Population structure and reproductive indicators were calculated as follows:

Adult sex ratios were derived by dividing the number of adult females by the number of adult males alive at the end of year t . **Average inter-calving interval** referred to the average period from the birth of one calf to the birth of the next, but calculations excluded births recorded after 31st December 2003. Calculations were done in MS-Excel[®]™ version XP[®] spreadsheet using the following formula:

$$\text{Inter-calving Interval in years} = [(LC_{db} - M_{db} - (365*7)) / C_n - 1] / 365,$$

where LC_{db} = last calf's date of birth; M_{db} = mother's date of birth; C_n = number of known calves to the mother; **365** = number of days assumed to make any year, and **7** = the assumed breeding age in years for a female rhino, for comparative purposes, and to include females >7yrs only.

Percentage of adult females calving per year was derived by dividing the number of calves born in year t by the number of adult females alive at the end of year t , and then expressed as a percentage. For comparison purposes, females that calved at <7 years were excluded, but their calves included. **Age at first calving** was calculated in years by determining the difference

¹² Man induced deaths include poaching and capture related deaths.

between the dates of birth of the mother and of its known first calf. **Proportion of calves in the population** was calculated by dividing the sum of all calves by the sum total of confirmed and probable rhino estimates at the end of a given year t , and then expressed as a percentage.

2.4 Statistical analysis

The broad aims of the statistical analysis were four-fold: **a)** to assess whether populations, based on the above indicators, were in fact performing well; **b)** to investigate the correlations between demographic and breeding indicators; **c)** to investigate the hypothesis that adult sex ratio and rhino densities significantly affected variation in underlying population growth rate; and **d)** to establish the lag effect of rainfall on underlying growth rate.

Appropriate statistical tests including descriptive statistics, ANOVA, linear regression, multiple comparison tests, correlation tests and lag effect cross correlations at 95% confidence limits, were used.

Statistical analytical components of SPSS[®]™ version 12.0.1, MS-Excel[®]™ version XP[®] and Matlab[®]™ version R12 were used for all analyses and generation of graphs. Zar (1984) and Dytham (2003) guided the use of appropriate statistical tools and interpretation of the derived results.

2.5 Caveats and limitation of the study

Caveats and limitations to the study could be categorised as follows:

- 1) Monitoring limitations:** Accuracy of monitoring varied greatly between sanctuaries, and therefore it was assumed that the data were reasonable reflection of actual numbers over time. The private sanctuaries had their rhinos sighted very frequently, and accurately identified, whilst the KWS sanctuaries, had the accuracy of its monitoring vary from good to poor, with many cases of using territory and behaviour to identify rhinos. This meant there were possibilities of overestimation or underestimation of population numbers (Demers 2002).
- 2) Rhino identification problems:** Rhino identification master files were not used in some areas, or where they were used, it was not a routine exercise as it should be. This implied data control and quality check was not to the stipulated standards (Mulama *et al.* 2004).
- 3) Gaps in and conflicting records:** There were some gaps in rainfall data and inconsistency in some weather stations because of broken down weather equipment. Averages from the next nearest station were used to fill the gaps. In a few cases some information in different records that referred to the same thing could conflict, and this consumed substantial time in trying to reconcile.
- 4) Time and number of words limitations:** Effective 8-weeks of data collection and verification and management of such a voluminous data and by virtue that such a study was being done comprehensively for the first time, made it very laborious and quite challenging. Therefore more detailed analyses and comparisons could not be performed, for example, underlying growth rates were not corrected to sex ratio, and inter-calving intervals not corrected to exclude dead calves (Appendix 8).

5) Statistical limitations: Most of the adult breeding females had $>\pm 3$ years birth date accuracies, which meant they were excluded in some analysis, for example, age at first calving. This left very small sample sizes for statistical conclusions. However, where such females were included, for example in the calculations of inter-calving intervals, one or two old or infertile ones could significantly skew results. Linear equations were used to project growth patterns, with the assumption that rhino populations had not attained the ramp shape production curve (McCullough 1992), thus highlighting the problem with using a linear test for what is likely to be a non-linear process. Since there were several parameters to compare, the multiple comparison “problem” could have easily occurred leading to possible wrong classification of 1 in 20 tests at 95% confidence limits (Zar 1984).

3 RESULTS

3.1 Kenya rhino meta-population and translocations

3.1.1 Rhino meta-population in Kenya

There were 17 rhino populations at the end of 2003, one of which was newly established in 2002, and another one, was re-established in 2003. Each population had =75 rhinos, which totalled 458 confirmed rhinos. Some 61% of these rhinos were in the nine populations on state lands, 32% were in the five populations on private lands, 6% were in two populations under county council lands, while <1% were from the one population under communal land (Table 3.1).

Table 3.1: Summary statistics for the Kenya black rhino meta-population as at 31st December 2003

Rhino population	Area (Km ²)	Land tenure	Rhino Nos.	Est.
Oi Pejeta Game Ranch [†]	93	P	37	1988
Oi Jogi Game Ranch [†]	50	P	22	1979
Lewa Downs Conservancy [†]	247	P	37	1983
Laikipia (Oi Ari Nyiro) Ranch	397	P	10*	1987
Solio Ranch	72	P	50*	1970
Ngulia sanctuary [†]	62	S	58	1985
Nairobi Nat. Park [†]	117	S	75	1963
Lake Nakuru Nat. Park [†]	144	S	69	1986
Tsavo East Nat. Park	1800	S	55*	1993
Aberdares Nat. Park (Salient)	100	S	25*	1988
Aberdares Nat. Park (North)	767	S	1	1983
Chyulu Nat. Park	471	S	10*	1983
Mt. Kenya Nat. Park	715	S	2	1993
Meru Nat. Park	870	S	1	1988 ^a , 2003 ^b
Mara-triangle (Transmara)	<50	M	2	1999
Masai Mara Nat. Reserve	1510	M	25*	1958
IL Ngwesi Community Ranch	<170	C	1	2002

[†]Study sites.

* Figures rounded off to the nearest 5.

^a First establishment but abandoned in 1990 due to inadequate security (Anon. 1993);

^b Second establishment.

S=State; P=Private; M=Municipal or County Council; C=Communal; Est.=year of establishment of rhino population; Nat.=National

3.1.2 Rhino translocations in Kenya from 1992 to 2003

Translocation history of black rhinos in Kenya prior to 1992 can be found in Anon. (1993). A total of 96 black rhinos were translocated between 1992 and 2003. Tsavo East National Park and Ngulia rhino sanctuary were the main recipients of 48 and 14 rhinos, respectively. Nairobi National Park and Solio Ranch were the main donors of 41 and 33 rhinos, respectively. Lewa Downs

donated 2 rhinos that established the new IL Ngwesi Community Ranch population in 2002, and re-established Meru National Park population in 2003. No translocations took place into or from Lake Nakuru, Chyulu and Mt. Kenya National Parks, and Masai Mara National Reserve (Fig. 3.1).

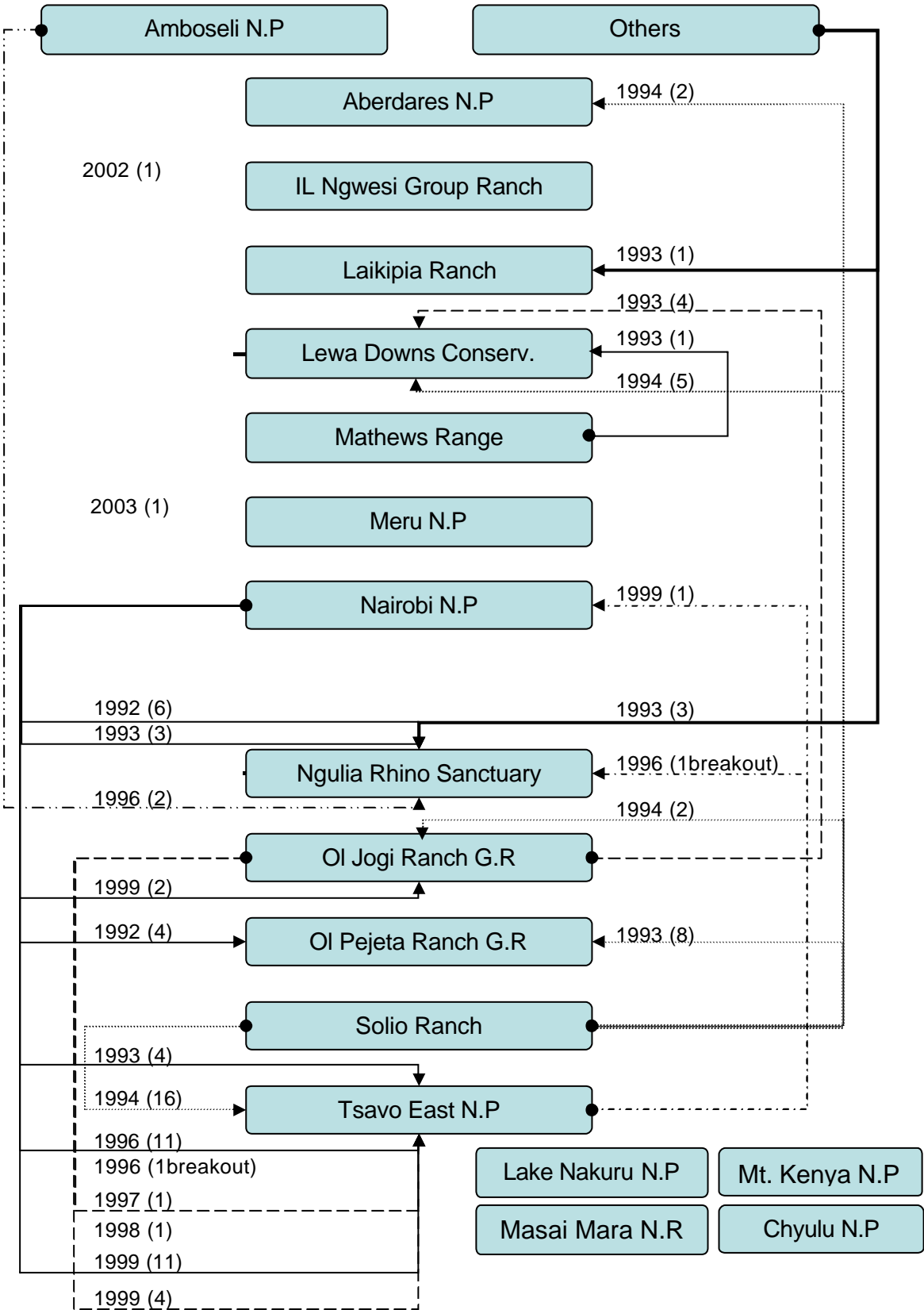


Fig. 3.1: Translocation history of *D. b. michaeli* in Kenya (1992-2003). The figures in brackets indicate the number of rhinos translocated in a given year. The arrows originate from source population and point to the recipient population. Data from Anon. (1993); Oloo and Okita (2000); and Mulama and Okita (2004).

3.2 Population demography and reproduction within the sanctuaries

This section contains analyses results of demography and reproductive performance indicators within the six rhino sanctuaries where the study was conducted. Averages are based on 3-year moving “windows” for a least squares error minimisation to find the best fit value of r_{\max} (underlying growth)

3.2.1 OI Pejeta Game Reserve

3.2.1.1 Population estimates and growth

All rhinos comprised confirmed estimates for the period 1992 to 2003, apart from 1998 when one rhino was categorised as a probable estimate (Fig. 3.2). 8 rhinos were ear-notched in 2003. No rhinos were translocated out, so no cumulative off-take was calculated, but a total of 12 rhinos were introduced in 1992 and 1993 (Fig. 3.3). The confirmed population increased from 11 rhinos in 1992 to 37 rhinos in 2003. Fig. 3.3 also shows a period when 56 elephants were removed from the reserve. Density increased steadily within the 93km² reserve (Fig. 3.5) from an average of 0.19 rhinos km⁻² in 1992/95 to 0.36 rhinos km⁻² in 2000/2003 ($y=0.02x+0.16$; $R^2=0.96$).

Rhino numbers gradually increased from 11 rhinos in 1992 to 40 rhinos in 2003. A sharp increase in growth rate occurred, from 7.5% in 1997/2000 to 10.5% in 1998/2001 (Fig. 3.4). This was maintained for a while but began to decline in 2000/2003 to an average annual growth rate of 8.9% from 1992-2002 ($y=0.68x+4.87$; $R^2=0.72$).

Fig. 3.4 also shows that the average annual mortality rate was as high as 10.4% in 1992/1995 but steadily decreased to 0.9% in 1998/2001 ($y=-1.30x+0.1$; $R^2=0.91$). Ten rhinos died over the study period. Two rhinos died in each of age classes A-B and C-D, while 1 and 5 rhinos, died in age classes E and F, respectively. Natural causes killed 5 rhinos, of which 3 were from fighting, while 1 of the other 5 that died from unnatural causes was poached (Table 3.2).

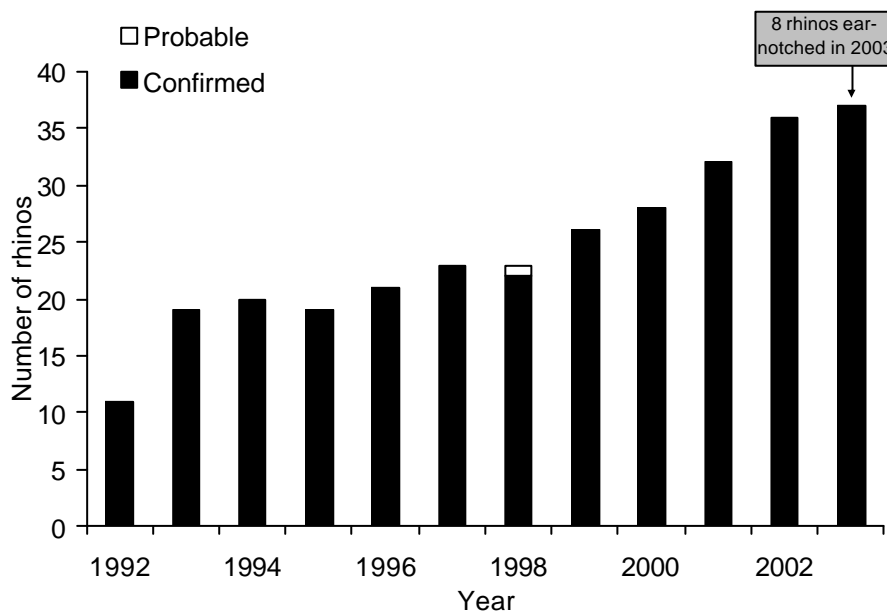


Fig. 3.2: Annual population estimates for OI Pejeta from 1992-2003, classified in the standard categories, showing number of rhinos ear-notched in 2003 to improve individual rhino identification.

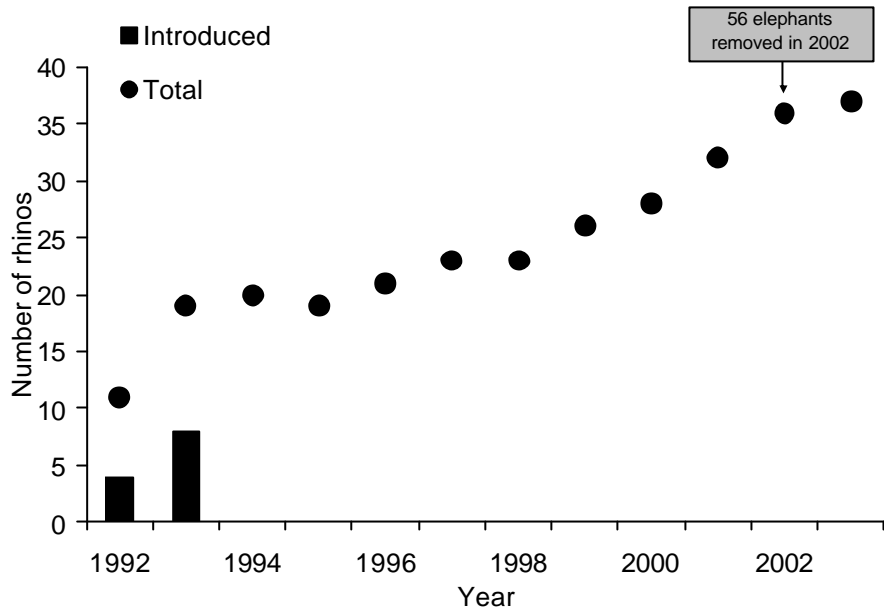


Fig. 3.3: Changes in the numbers of black rhinos in OI Pejeta from 1992-2003, showing the numbers and timings of translocations. The introduced rhinos were a mixture of sub-adult and adult males and females. There were no removals from 1992-2003. 'Total' refers to the sum total of 'confirmed' and 'probable'

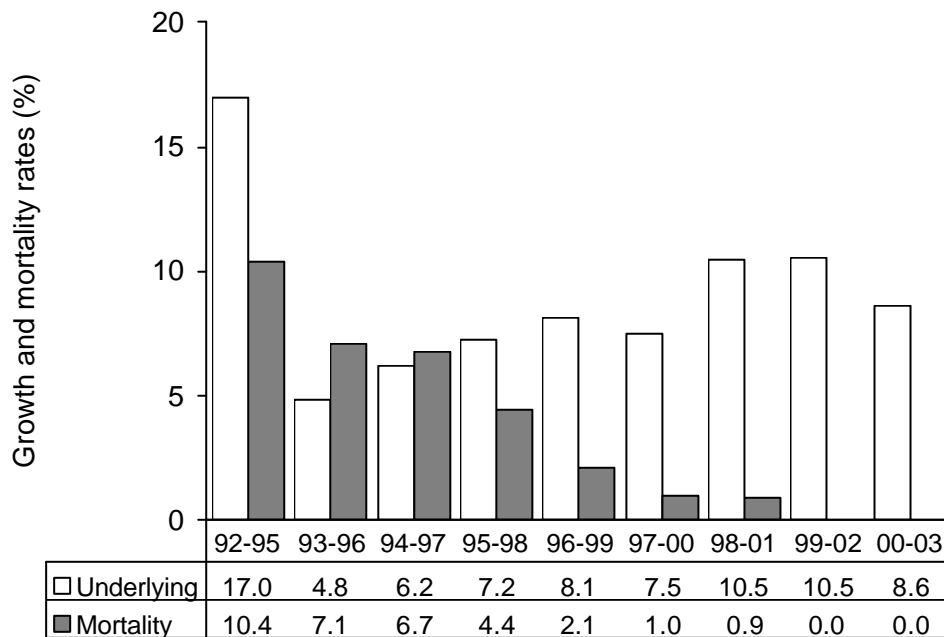


Fig. 3.4: 3-year moving averages of underlying growth and mortality rates in OI Pejeta from 1992-2003. The figure also shows an inverse relationship between growth and mortality rates.

Table 3.2: Summary of mortalities in OI Pejeta by cause and age class from 1992-2003.

Age Class \ Cause	<1.0 yr (A-B)	=1.0 < 3.5 yr (C-D)	=3.5 < 7.0 yr (E)	>7.0 yr (F)	Total
Disease	0	0	0	0	0
Fighting	0	1	0	2	3
Nutrition	0	0	0	0	0
Predation	0	0	0	0	0
Other Natural	2	1	1	0	4
Poaching	0	0	0	1	1
Other Unnatural	0	0	0	2	2
Total	2	2	1	5	10

3.2.1.2 Population structure and reproduction

The 3 year average adult sex ratio showed a decreasing trend from 1.13F:1M in 1992/95 to 1.06F:1M in 2000/2003. The average inter-calving interval (ICI) was 3.16 yrs ($n=8$) (Fig. 3.6). Average percentage of females calving per year ranged between 24% and 42%, averaging 31.4% from 1992-2003 (Fig. 3.7). The average age at first calving was 6.24 yrs ($n=3$). The proportion of calves in age classes A-D increased gradually from 13.5% in 1992/95 to 27.2% in 1996/99, with an average of 23.2% from 1992-2003 (Fig. 3.8). Figures 3.5, 3.7 and 3.8 all show improved performance although sex ratio declined in 2000/2003. However this can not go on infinitely as population density continues to rise.

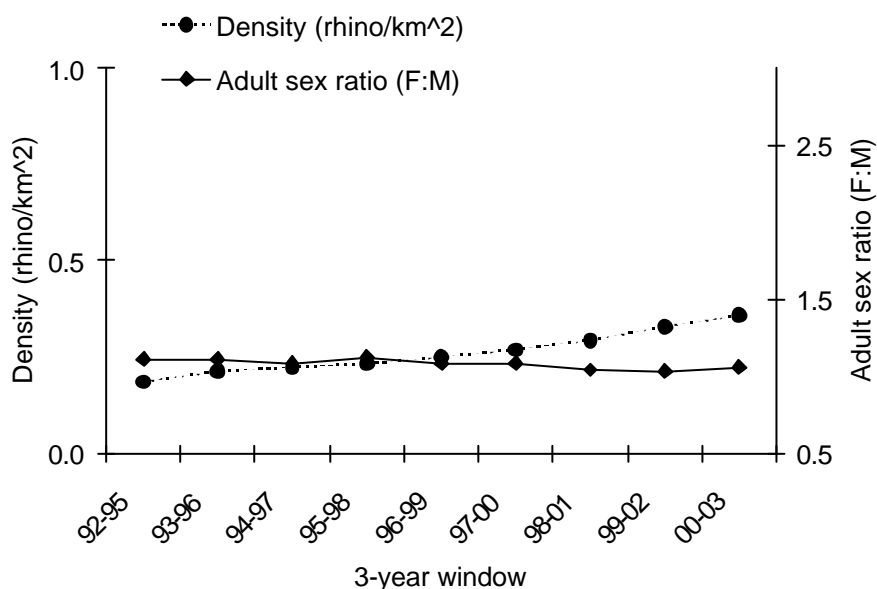


Fig. 3.5: Trends in density and adult sex ratio in OI Pejeta from 1992-2003, showing and increasing density and a declining sex ratio.

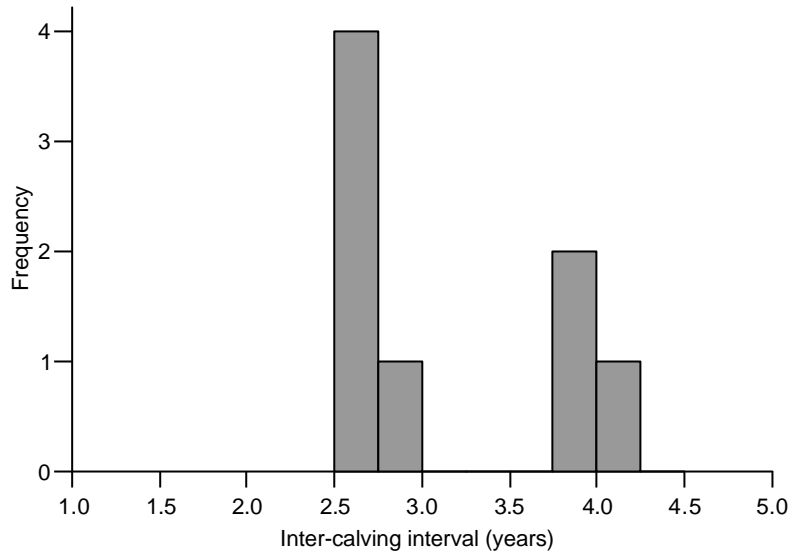


Fig. 3.6: Frequency distribution of inter-calving intervals in OI Pejeta as at 2003.

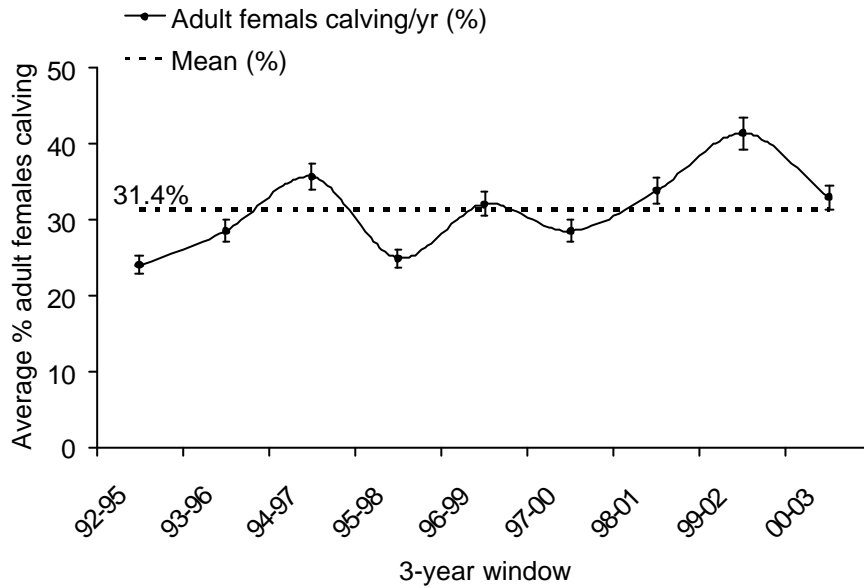


Fig. 3.7: Proportions of adult females calving per year in OI Pejeta from 1992-2003, also showing 5% SE error bars. The dotted horizontal line shows the mean across 1992-2003.

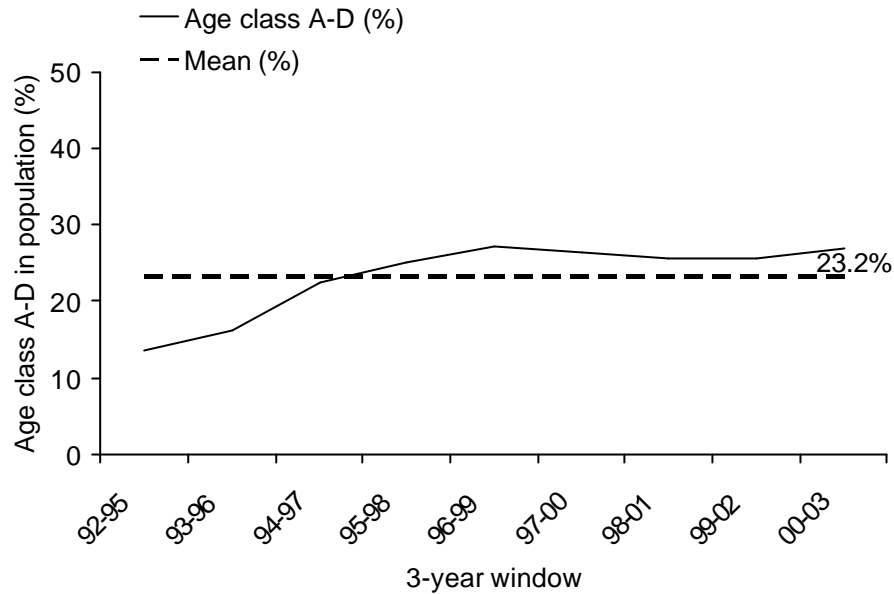


Fig. 3.8: Trends in the proportion of calves (Age class AD) in OI Pejeta from 1992-2003. The dotted horizontal line shows the mean across the period 1992-2003.

3.2.1.3 Demographic parameters, and reproductive indicators

Correlations at 95% confidence limits (Table 3.3) produced a significant negative correlation between sex ratio and percentage of females calving per year ($r=-0.86$; $P<0.01$). However, there was no significant linear relationship between sex ratio and underlying growth rate ($R^2=0.01$; $P=0.805$). There was also no significant linear relationship between density and underlying growth rate ($R^2=0.01$; $P=0.829$).

Table 3.3: Correlations between and within demographic, and reproductive parameters in OI Pejeta based on 3-year moving averages from 1992-2003.

	SexRatio		Calves		FemaleCalv		UndLGrowth	
	r	P*	r	P*	r	P*	r	P*
Density	-0.78	(*)	0.72	(*)	0.63	(NS)	-0.05	(NS)
SexRatio			-0.54	(NS)	-0.86	(**)	-0.11	(NS)
Calves					0.49	(NS)	-0.36	(NS)
FemaleCalv							-0.20	(NS)

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Density = Rhinos km²; *SexRatio* = Adult sex ratio (F:M); *Calves* = Proportion of A-D age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

3.2.1.4 Rainfall with demographic and reproductive parameters

The mean annual rainfall in OI Pejeta was 702.01 ± 28.03 mm from 1992 to 2003. The highest amount of 835mm fell in 1995/98. There was an 18.9% coefficient of rainfall variation as a result of the 1997/98 El Niño events. The relationship between this rainfall variation and population growth rates was evident 3 years later in 1998/2001 when underlying growth significantly increased to 10.5% from 7.5% in the preceding 1997/2000 ($F_{1,2}=35.79$; $P=0.027$) (Fig. 3.4 & Fig. 3.9). However, a cross correlation plot (Fig. 3.10) did not reveal an overall rainfall lag effect over 1992-2003. All other correlations between rainfall and other demographic and reproductive parameters were not significant ($P>0.05$).

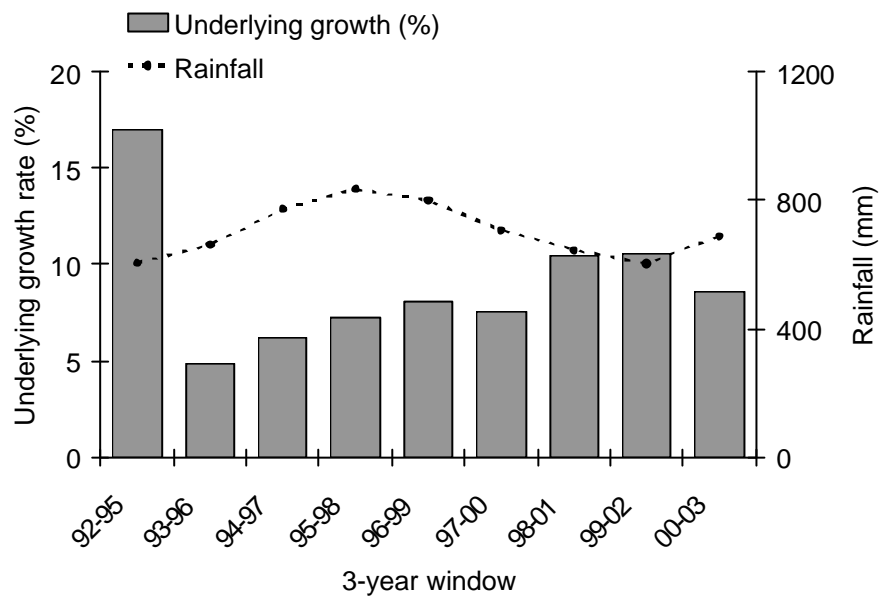


Fig. 3.9: The relationship between rainfall patterns and underlying growth rate in OI Pejeta from 1992-2003.

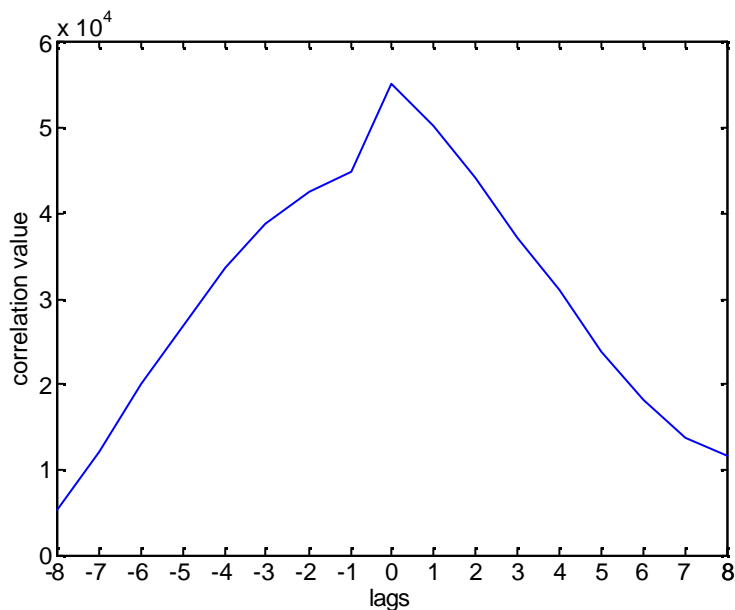


Fig. 3.10: Cross-correlation plot of rainfall and underlying growth rate in OI Pejeta from 1992-2003. The distinct peak at $x=0$ lags indicate no lag effect of rainfall on underlying growth rate.

3.2.2 OI Jogi Game Reserve

3.2.2.1 Population estimates and growth

All rhinos comprised confirmed estimates for the period 1992 to 2003. Rhino numbers steadily increased from 12 in 1992 to 15 rhinos in 1996, then stabilised for 3 years, and then further increased to 22 rhinos in 2003 (Fig. 3.11). A total of 4 removals took place from 1993-1999. Density increased steadily within the 50km² reserve (Fig. 3.13) from 0.23 rhinos km⁻² in 1992/95 to 0.38 rhinos km⁻² in 2000/2003 ($y=0.02x+0.21$; $R^2=0.96$).

There was a rapid increase of underlying growth rate from 3.7% in 1995/98 to 10.6% in 1998/2001 (Fig. 3.12), which then declined to 7.7% in 2000/2003 with an average growth rate of 8.3% ($y=1.85x+10.17$; $R^2=0.97$) from 1992-2003.

Fig 3.12 also shows that mortality increased from 2.0% in 1993/96 to 3.3% in 1996/99, then declined in 2000/2003 with an overall average rate of 2.1% ($y=0.19x+1.17$; ($R^2=0.24$)). A total of three rhinos died over the study period. Two were of age class A-B and the other one was of age class F. Two died from fighting and one from poor nutrition (Table 3.4).

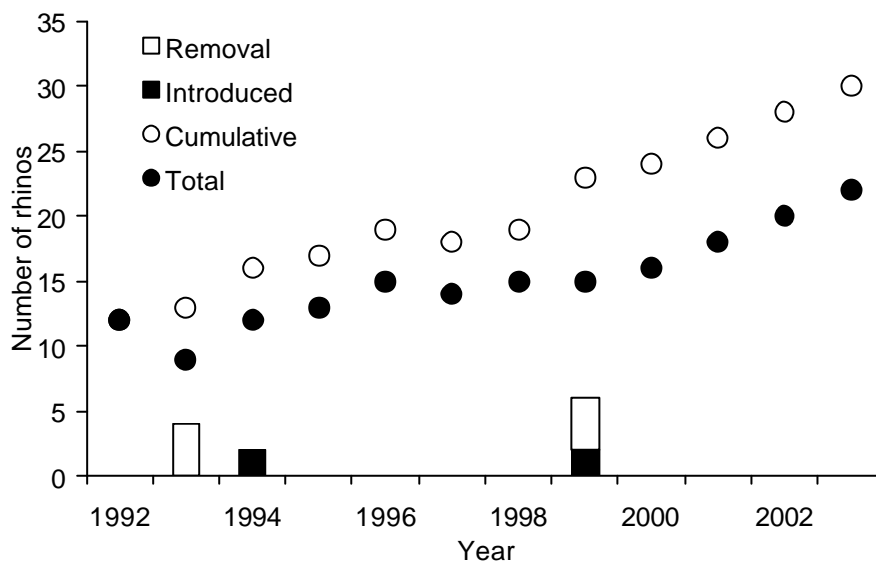


Fig. 3.11: Changes in the numbers of black rhinos in OI Jogi from 1992-2003 showing the numbers and timings of translocations.

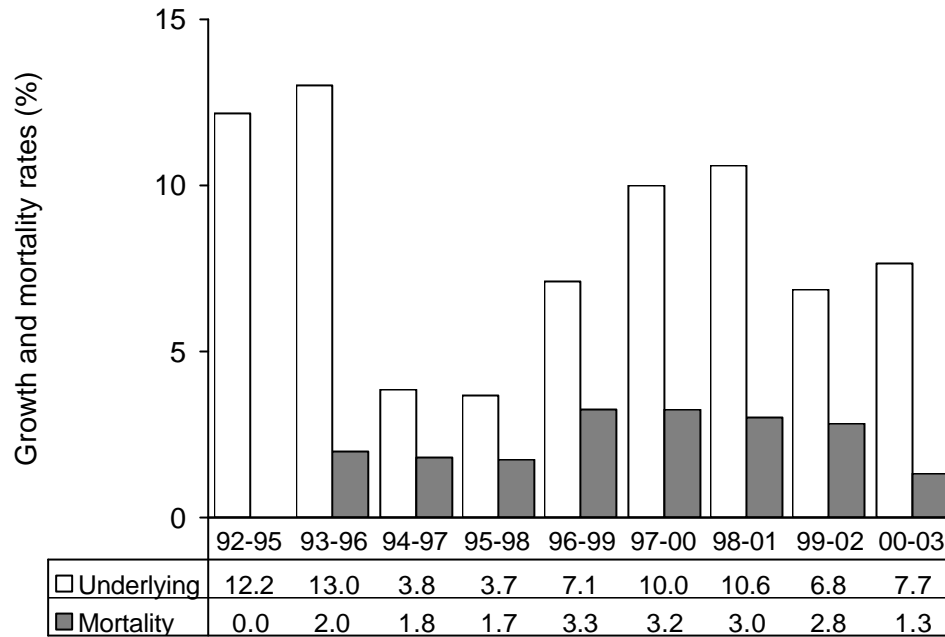


Fig. 3.12: 3-year moving averages of underlying growth and mortality rates in OI Jogi from 1992-2003.

Table 3.4: Summary of mortalities in OI Jogi by cause and age class from 1992-2003.

Cause \ AgeClass	<1.0 yr	=1.0 < 3.5 yr	=3.5 < 7.0 yr	>7.0 yr	Total
	(A-B)	(C-D)	(E)	(F)	
Disease	0	0	0	0	0
Fighting	1*	0	0	1	2
Nutrition	1	0	0	0	1
Predation	0	0	0	0	0
Other Natural	0	0	0	0	0
Poaching	0	0	0	0	0
Other Unnatural	0	0	0	0	0
Total	2	0	0	1	3

* was caught up in fight between its mother and an adult bull

3.2.2.2 Population structure and reproduction

Adult sex ratio remained strongly in favour of females from a low of 1.96F:1M to a high of 2.83F:1M (Fig. 3.13). The average inter-calving interval (ICI) was 2.75 yrs ($n=6$) (Fig. 3.14). Average percentage of females calving per year was 30.4% (Fig. 3.15). The average age at first calving was 7.98 yrs ($n=4$). The proportion of calves in age class A-D averaged 31.0% (Fig. 3.16).

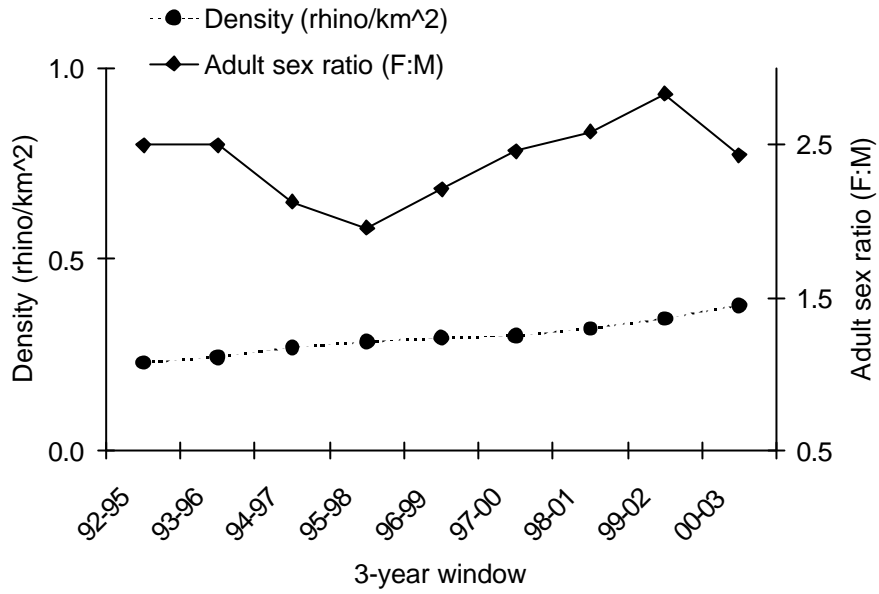


Fig. 3.13: Trends in density and adult sex ratio in OI Jogi as at 2003, showing an increasing density and skewed sex ratio in favour of females.

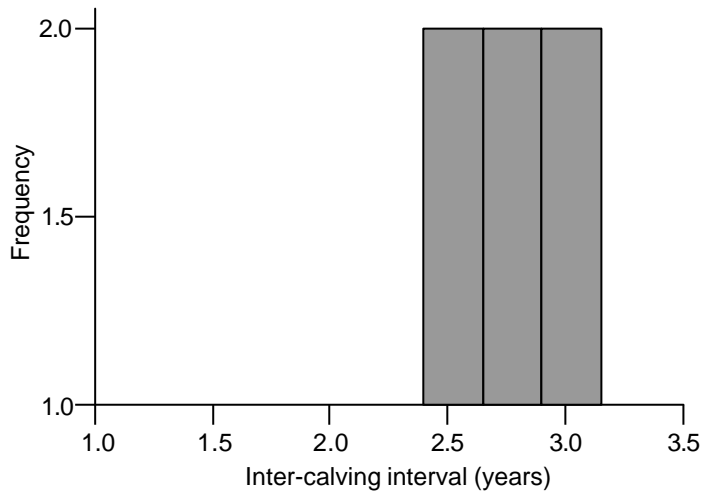


Fig. 3.14: Frequency distribution of inter-calving intervals in OI Jogi as at 2003.

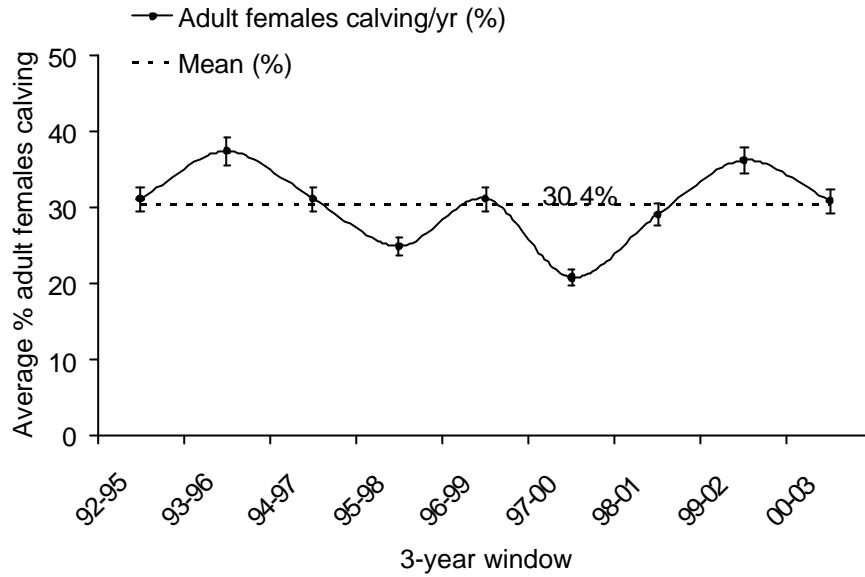


Fig. 3.15: Proportions of adult females calving per year in OI Jogi from 1992-2003, also showing 5% SE error bars. The dotted horizontal line shows the mean across 1992-2003.

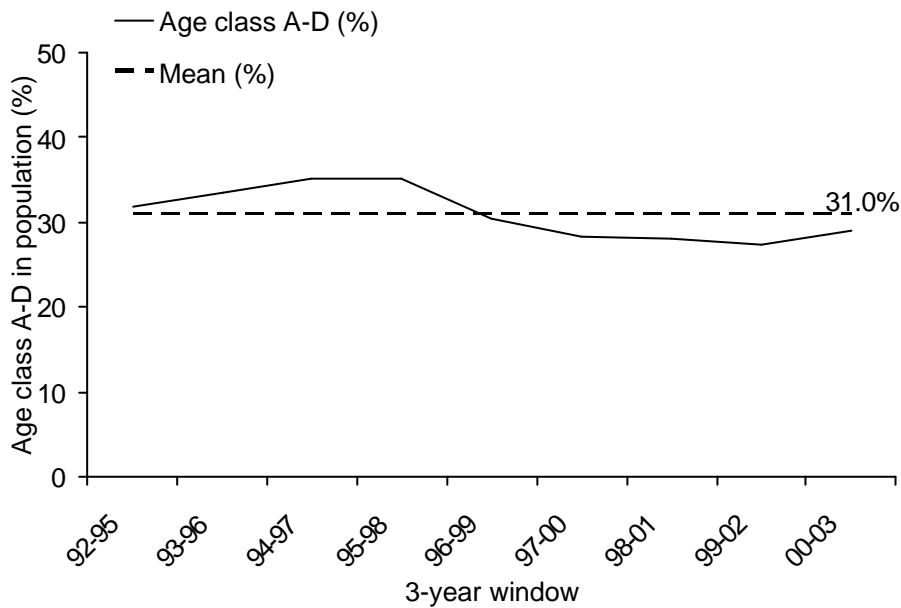


Fig. 3.16: Trends in the proportion of calves (Age class A-D) in OI Jogi from 1992-2003. The dotted horizontal line shows the mean across 1992-2003.

3.2.2.3 Demographic parameters and reproductive indicators

Correlations at 95% confidence limits (Table 3.5) showed a significant negative correlation between sex ratio and proportion of calves in the population ($r=-0.76$; $P<0.05$). However, there was no significant linear relationship between sex ratio and underlying growth rate ($R^2=0.35$; $P=0.091$). Relationship between density and underlying growth rate was also not significant ($R^2=0.10$; $P=0.419$).

Table 3.5: Correlations between and within demographic, and reproductive parameters in Ol Jogi, based on 3-year moving averages from 1992-2003.

Pearson correlation at 95% confidence limits, N=9

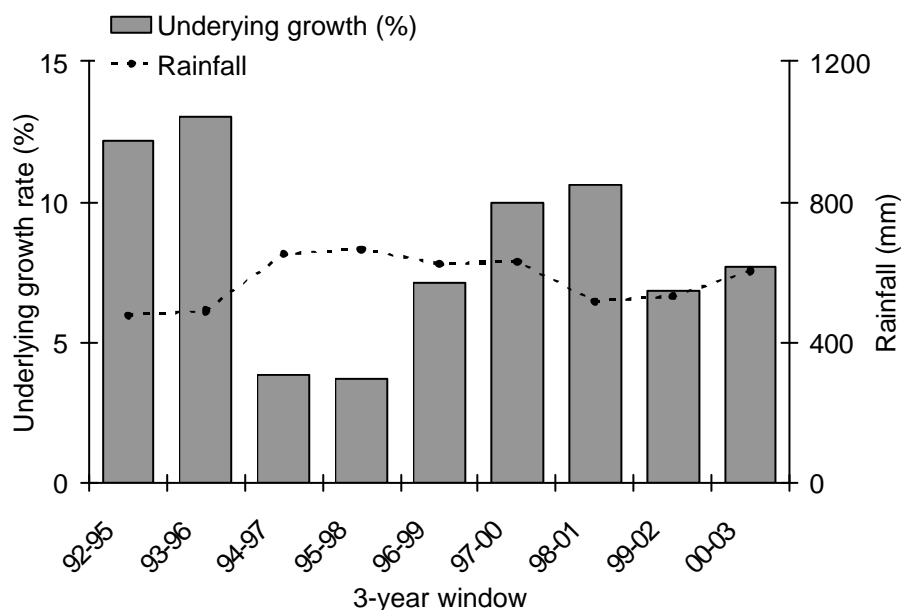
	SexRatio		Calves		FemaleCalv		UndLGrowth	
	r	P*	r	P*	r	P*	r	P*
Density	0.29	(NS)	-0.65	(NS)	-0.05	(NS)	-0.32	(NS)
SexRatio			-0.76	(*)	0.42	(NS)	0.60	(NS)
Calves					0.06	(NS)	-0.32	(NS)
FemaleCalv							0.23	(NS)

* Correlation is significant at the 0.05 level (2-tailed).

Density = Rhinos per km²; *SexRatio* = Adult sex ratio (F:M); *Calves* = Proportion of A-D age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

3.2.2.4 Rainfall with demographic and reproductive parameters

The mean annual rainfall in Ol Jogi was 576.33 ±24.24mm from 1992 to 2003. The highest average of 665mm fell in 1995/98. There was a 15.8% coefficient of rainfall variation as a result of the 1997/98 El Niño events. The relationship between this rainfall variation and population growth rate was evident 2 years later in 1997/2000 when underlying growth rate increased to 10.0% from 7.1% in the preceding 1996/99 (Fig. 3.12 & Fig. 3.17). The difference in growth between these two successive periods was not significant ($F_{1,2}=11.02$; $P=0.080$). A cross-correlation plot (Fig. 3.18) also did not show a clear lag effect of rainfall on underlying growth rate. However, Pearson correlation produced a significant but negative correlation between rainfall and underlying growth rate ($r=-0.81$; $P<0.01$) (Table 3.6). Other correlations between rainfall and other demographic and reproductive parameters were not significant ($P>0.05$).

**Fig. 3.17:** The relationship between rainfall patterns and underlying growth rate in Ol Jogi from 1992-2003.

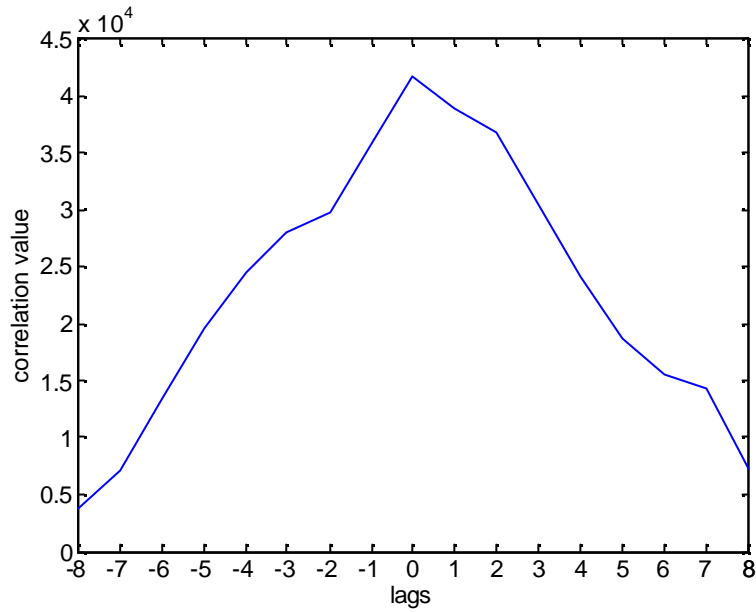


Fig. 3.18: Cross-correlation plot of rainfall and underlying growth rate in OI Jogi from 1992-2003. The two peaks at $x=0$ and $3 < x < 2$ lags show very weak sign of lag effect.

Table 3.6: Correlation between rainfall and demographic and reproductive parameters in OI Jogi based on 3-year moving averages from 1992-2003.

Reproductive and demographic parameters; N=9								
	Density		Calves		FemaleCalv		UndLGrowth	
	r	P*	r	P*	R	P*	r	P*
Rainfall	0.25	(NS)	0.28	(NS)	-0.60	(NS)	-0.81	(**)

** Correlation is significant at the 0.01 level (2-tailed).

Density = Rhinos per km²; *Calves* = Proportion of AD age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

3.2.3 Lewa Downs Conservancy

3.2.3.1 Population estimates and growth

All rhinos comprised confirmed estimates for the period 1992 to 2003, apart from 1998 when one rhino was categorised as a probable estimate (Fig. 3.19). Both confirmed and cumulative numbers did not increase from 1992 until 1997, when a rapid increase was recorded. A total of 3 rhinos were removed from 1996 to 2003. The confirmed rhino totals increased from 20 rhinos in 1992 to 37 rhinos in 2003 (Fig. 3.20). Densities increased in the 247km² conservancy (Fig. 3.22) from 0.08 rhinos km⁻² in 1992/95 to 0.13 rhinos km⁻² in 2000/2003 ($y=0.01x+0.06$; $R^2=0.89$).

Sharp increases in underlying growth rate occurred in 1995/98, and 1997/2000, and was followed by a sharp decline in 1998/2001 with an average rate of 7.0% ($y=1.02x+1.95$; $R^2=0.43$) over 1992-2003 (Fig. 3.21).

Fig. 3.21 also depicts that average annual mortality rate increased from 7.0% in 1992/95 to 10.6% in 1994/97 and then gradually declined to 0.7% in 2000/2003 with an average of 4.6% ($y=-1.06x+9.95$; $R^2=0.75$) over 1992-2003. This period of high mortality also corresponded with the period of the lowest underlying growth rates. A total of 12 rhinos died, across all age classes. Age classes A-B, C-D, E and F had 4, 2, 2, and 4 mortalities, respectively. Natural causes killed 11 rhinos while one rhino died from unnatural cause (Table 3.7).

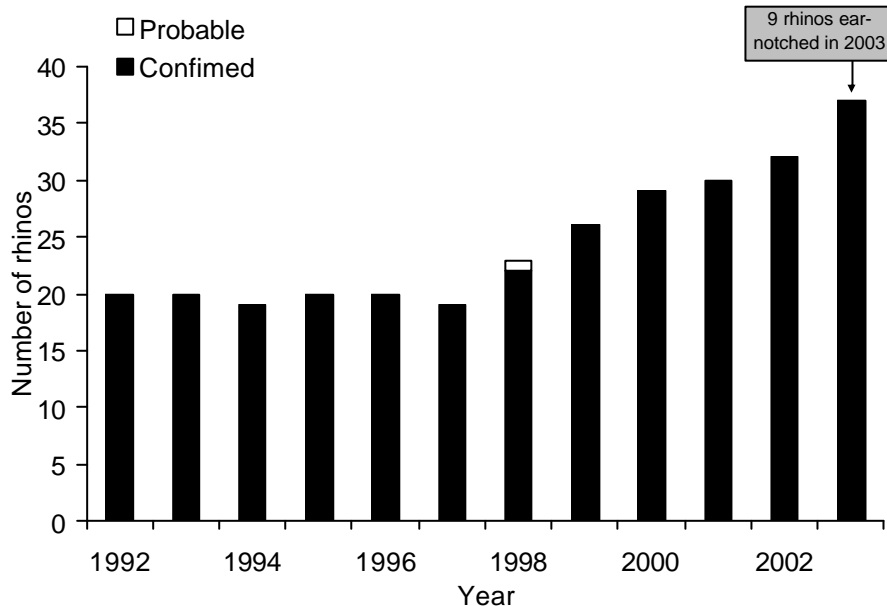


Fig. 3.19: Annual population estimates for Lewa Downs classified in the standard categories from 1992-2003, showing number of rhinos ear-notched in 2003 to improve individual rhino identification.

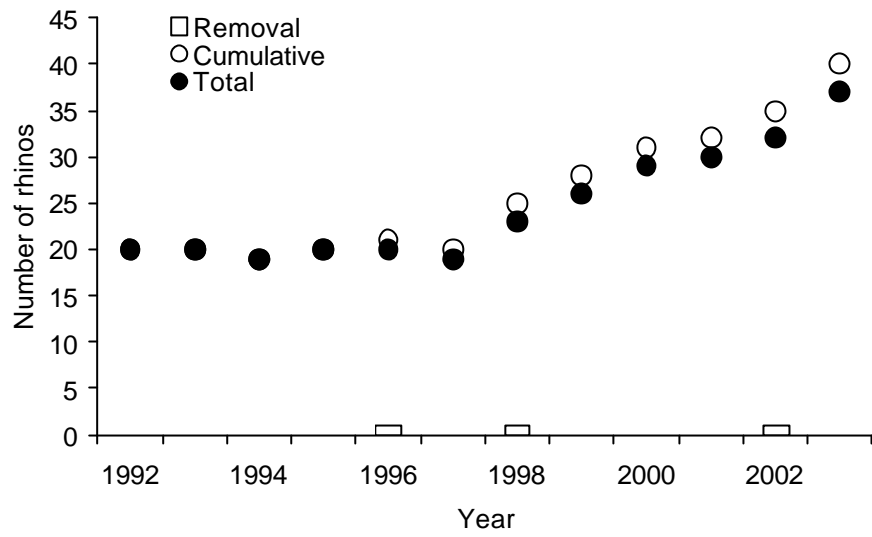


Fig. 3.20: Changes in the numbers of black rhinos in Lewa Downs from 1992-2003 showing the numbers and timings of translocations. There were no introductions from 1992-2003

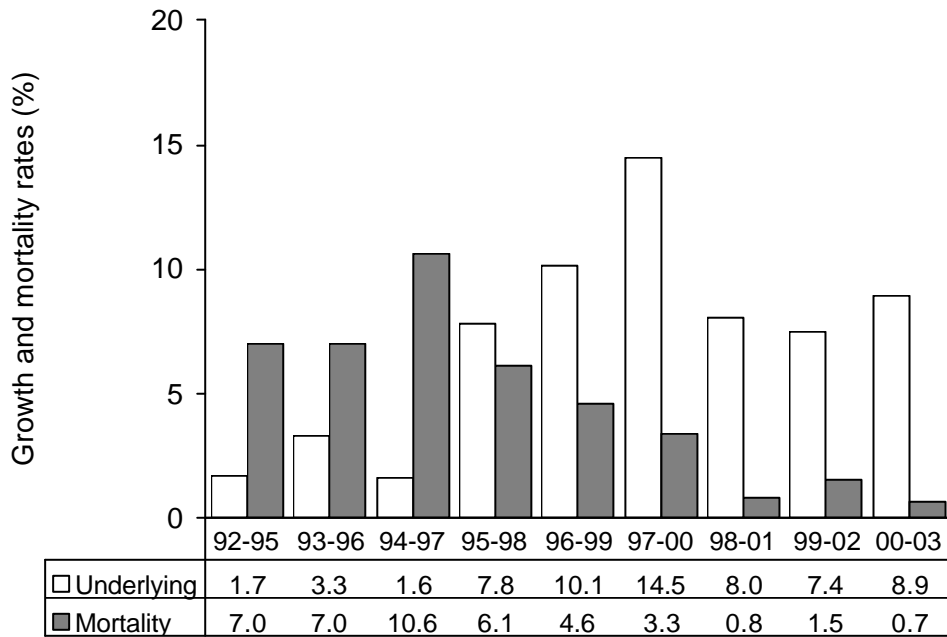


Fig. 3.21: 3-year moving averages of underlying growth and mortality rates in Lewa Downs from 1992-2003. The figure also shows an inverse relationship between growth and mortality rates, a similar trend to Fig. 3.4.

Table 3.7: Summary of mortalities in Lewa Downs by cause and age class from 1992-2003.

Age Class \ Cause	<1.0 yr (A-B)	=1.0 < 3.5 yr (C-D)	=3.5 < 7.0 yr (E)	> 7.0 yr (F)	Total
Disease	1	0	0	1	2
Fighting	0	1	0	1	2
Nutrition	0	0	0	1	1
Predation	2	0	0	0	2
Other Natural	1	1	1	1	4
Poaching	0	0	0	0	0
Other Unnatural	0	0	1	0	1
Total	4	2	2	4	12

3.2.3.2 Population structure and reproduction

Adult sex ratios increased steadily in favour of females (Fig. 3.22) from 0.81F:1M in 1992/95 to 1.61F:1M in 2000/2003. The average inter-calving interval was 3.47 yrs ($n=11$) (Fig. 3.23). Average percentage of females calving per year was 38.3% (Fig. 3.24). The average age at first calving was 7.52 yrs ($n=5$). The proportion of calves in age class A-D increased gradually from 17.7% in 1992/95 to 32.5% in 1998/2001, then declined to 29.3% in 2000/2003 with an average of 25.3% over 1992-2003 (Fig. 3.25).

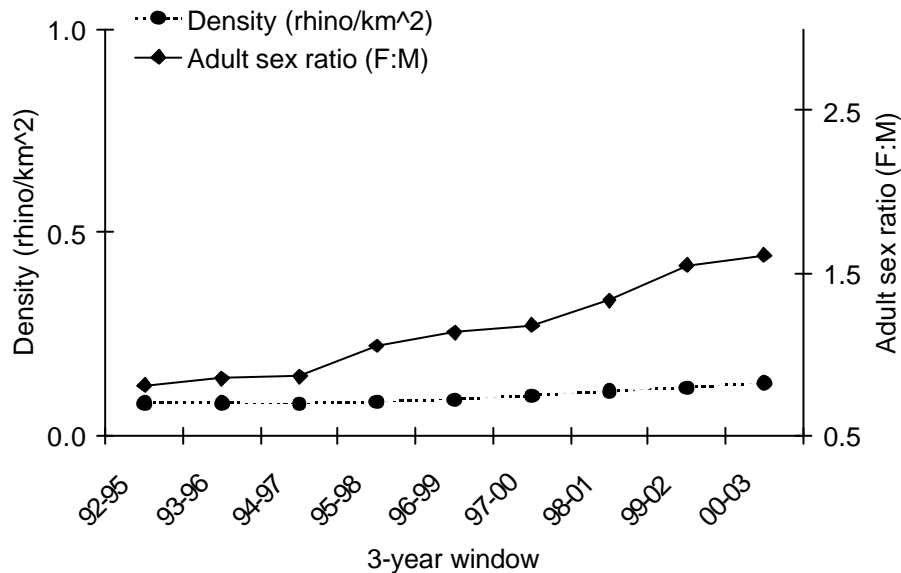


Fig. 3.22: Trends in density and adult sex ratio in Lewa Downs from 1992-2003, showing increasing density and sex ratios.

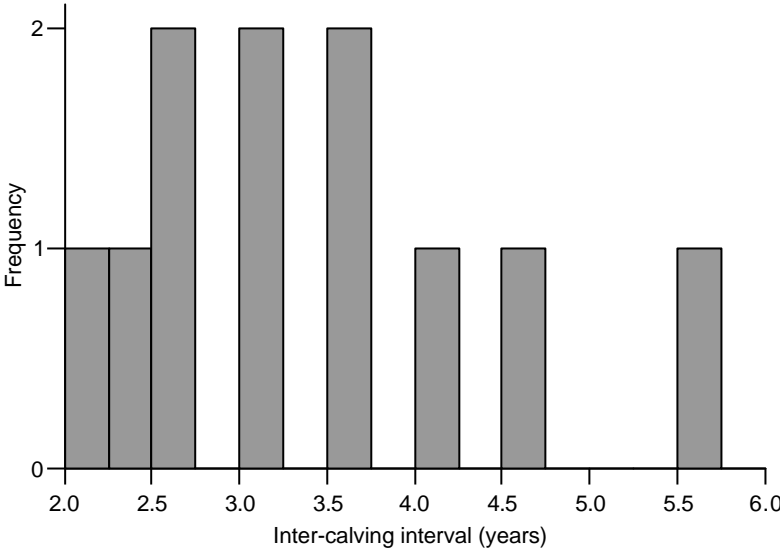


Fig. 3.23: Frequency distribution of inter-calving intervals in Lewa Downs as at 2003.

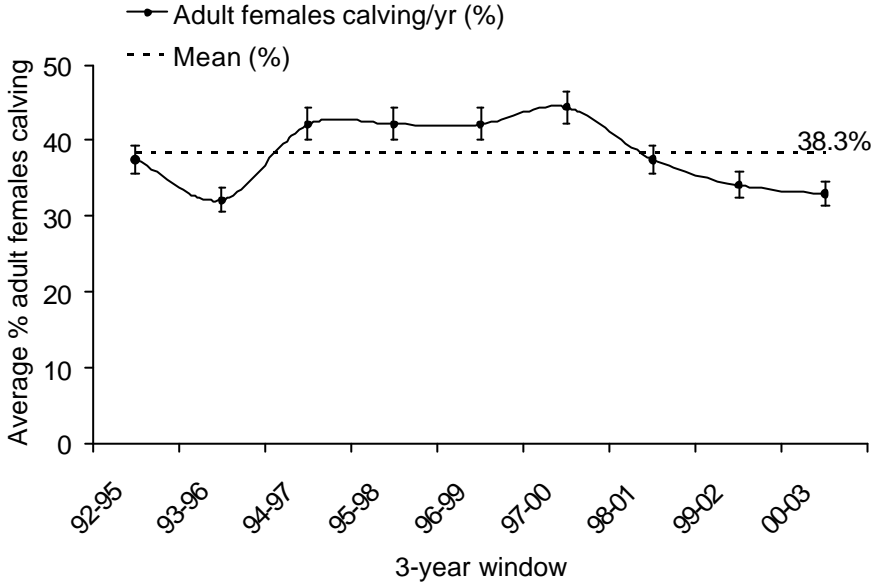


Fig. 3.24: Proportions of adult females calving per year in Lewa Downs from 1992-2003, also showing 5% SE error bars. The dotted horizontal line shows the mean across 1992-2003.

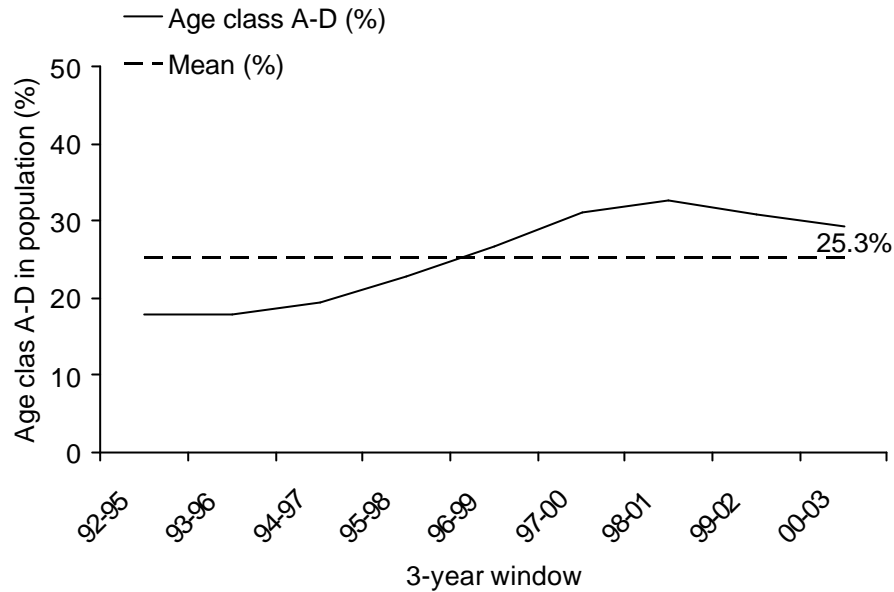


Fig. 3.25: Trends in the proportion of calves (Age class A-D) in Lewa Downs from 1992-2003. The dotted horizontal line shows the mean across 1992-2003.

3.2.3.3 Demographic parameters and reproductive indicators

Correlations at 95% confidence limits (Table 3.8) showed that density was significantly correlated with proportion of calves in the population ($r=0.82$; $P<0.01$). The proportion of calves in the population was also positively correlated with underlying growth ($r=0.80$; $P<0.01$). Sex ratio and proportion of calves were also significantly correlated ($r=0.86$; $P<0.01$). There was no significant linear relationship between sex ratio and underlying growth rate ($R^2=0.83$; $P=0.101$), or between density and underlying growth rate ($R^2=0.24$; $P=0.184$).

Table 3.8: Correlations between and within demographic, and reproductive parameters in Lewa Downs, based on 3-year moving averages from 1992-2003.

Pearson correlation at 95% confidence limits, $N=9$

	SexRatio		Calves		FemaleCalv		UndLGrowth	
	r	P^*	r	P^*	r	P^*	r	P^*
Density	0.97	(**)	0.82	(**)	-0.43	(NS)	0.49	(NS)
SexRatio			0.86	(**)	-0.33	(NS)	0.58	(NS)
Calves					0.04	(NS)	0.80	(**)
FemaleCalv							0.33	(NS)

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Density = Rhinos per km^2 ; *SexRatio* = Adult sex ratio (F:M); *Calves* = Proportion of A-D age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

3.2.3.4 Rainfall with demographic and reproductive parameters

The mean annual rainfall in Lewa Downs was 570.44 ± 39.39 mm from 1992 to 2003. The highest peak of 721mm fell in 1995/98. There was a 26.4% coefficient of rainfall variation due to the 1997/98 El Niño events. The relationship between this rainfall variation and growth rate was evident 2 years later in 1997/2000 when underlying growth rate increased to 14.5% from 10.1% in the preceding 1996/99 (Fig. 3.21 & Fig. 3.26). Although the difference in growth rate between these successive periods was not significant ($F_{1,2}=10.22$; $P=0.085$), a cross correlation plot (Fig. 3.27) depicted a -3.5 (negative!) years lag effect of rainfall on growth. Rainfall was positively correlated with percentage of females calving per year ($r=0.84$, $P<0.01$) (Table 3.9).

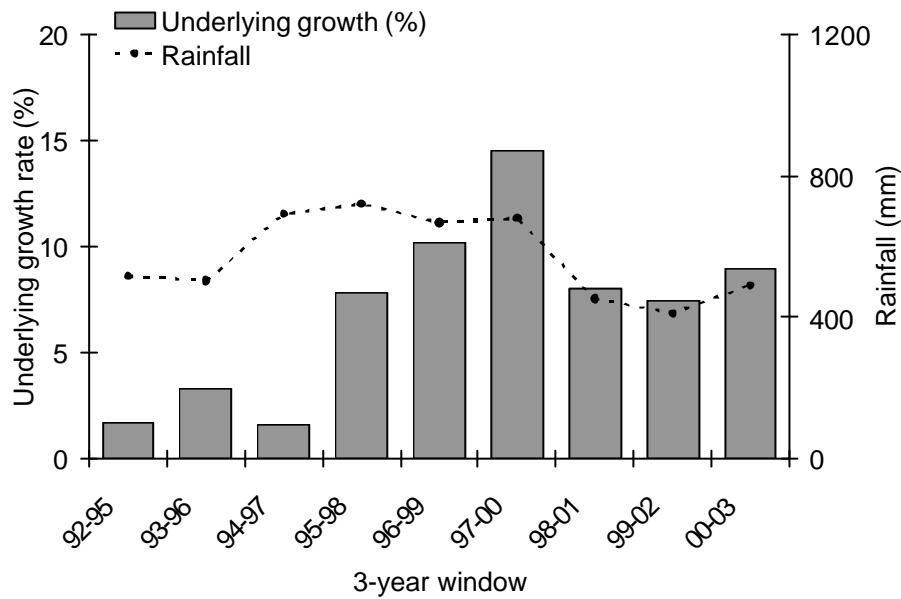


Fig. 3.26: The relationship between rainfall patterns and underlying growth rate in Lewa Downs from 1992-2003.

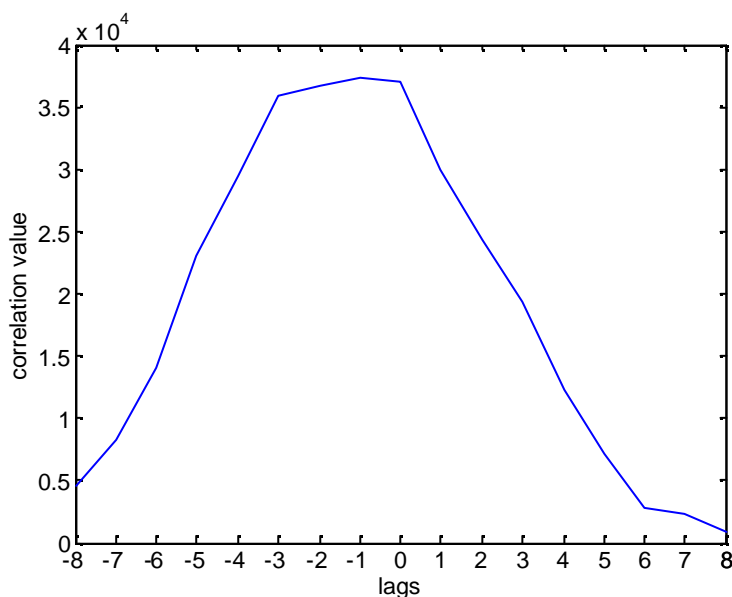


Fig. 3.27: Cross-correlation plot of rainfall and underlying growth rate in Lewa Downs from 1992-2003. The two peaks at $x=0$ and $-2 < x < -3.5$ lags show signs -3.5 to 0 years lag effect of rainfall on underlying growth. Ideally the lag effect should be displayed to the positive side, but this was on the negative!

Table 3.9: Correlation between rainfall and demographic and reproductive parameters in Lewa Downs, based on 3-year moving averages from 1992-2003.

	Density		Calves		FemaleCalv		UndLGrowth	
	r	P*	r	P*	R	P*	r	P*
Rainfall	-0.56	(NS)	-0.26	(NS)	0.84	(**)	0.20	(NS)

** Correlation is significant at the 0.01 level (2-tailed).

Density = Rhinos per km²; *Calves* = Proportion of A-D age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

3.2.4 Ngulia Rhino Sanctuary (in Tsavo West National Park)

3.2.4.1 Population estimates and growth

Probable estimates were first recorded in 1998 when the total number of rhinos had increased slightly to above 40 animals. All of these were confirmed in 1999 and 2001, but numbers of probables increased rapidly to constitute 47% of the population in 2003 (Fig. 3.28). A total of 14 rhinos were introduced between 1992 and 1996, which resulted in an increase in confirmed numbers from 16 rhinos in 1992 to a total of 58 rhinos in 2003 (Fig. 3.29). Densities also increased steadily within the 62km² sanctuary (Fig. 3.31) from 0.38 rhinos km⁻² in 1992/95 to 0.86 rhinos km⁻² in 2000/2003 ($y=0.06x+0.33$; $R^2=0.99$).

Underlying growth rate decreased steadily (Fig. 3.30) up to 1997/2000 when it stabilised, but continued to decline in 1998/2001 with an overall annual average growth rate of 11.5% ($y=-1.74x+20.16$; $R^2=0.88$) across 1992-2003.

Fig. 3.30 also shows that mortality increased slightly from 0.7% in 1995/98 to 1.1% in 1998/2001 then decreased to 0.5% in 2000/2003, with an average rate of 0.5% ($y=0.10x+0.01$; $R^2=0.38$) across 1992-2003. The two rhinos that died (Table 3.10) were both of age class F and were caused by poor nutrition and poaching.

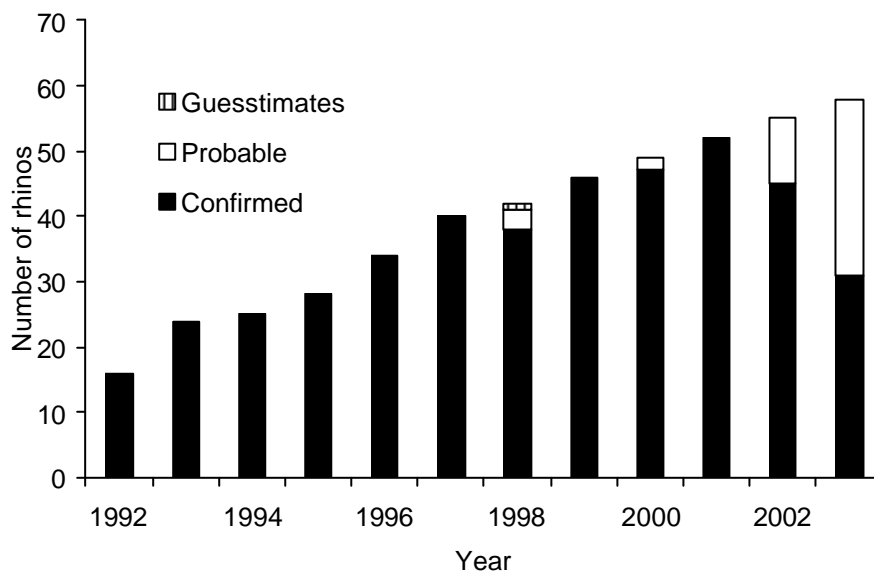


Fig. 3.28: Annual population estimates for Ngulia classified in the standard categories from 1992-2003.

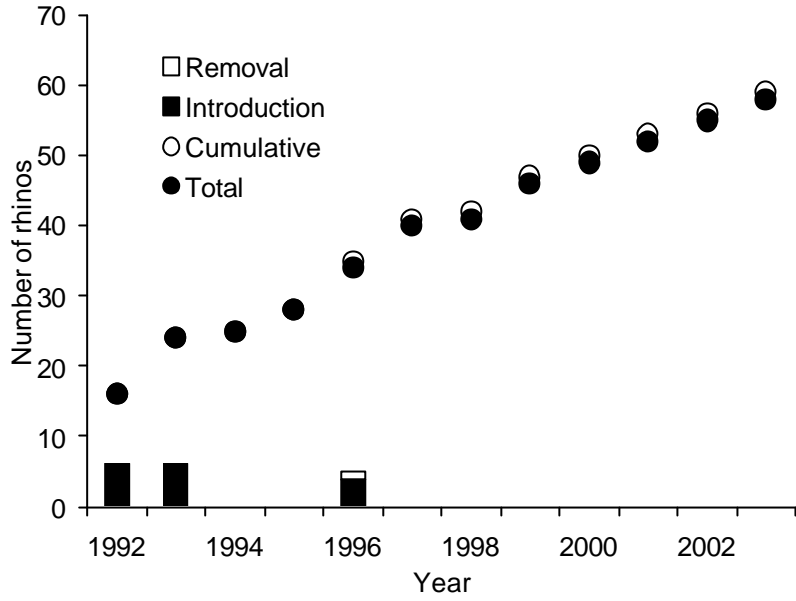


Fig. 3.29: Changes in the estimated numbers of black rhinos in Ngulia from 1992-2003 showing the numbers and timings of translocations. The introduced rhinos were a mixture of sub-adult and adult males and females. 'Total' refers to the sum total of 'confirmed' and 'probable'.

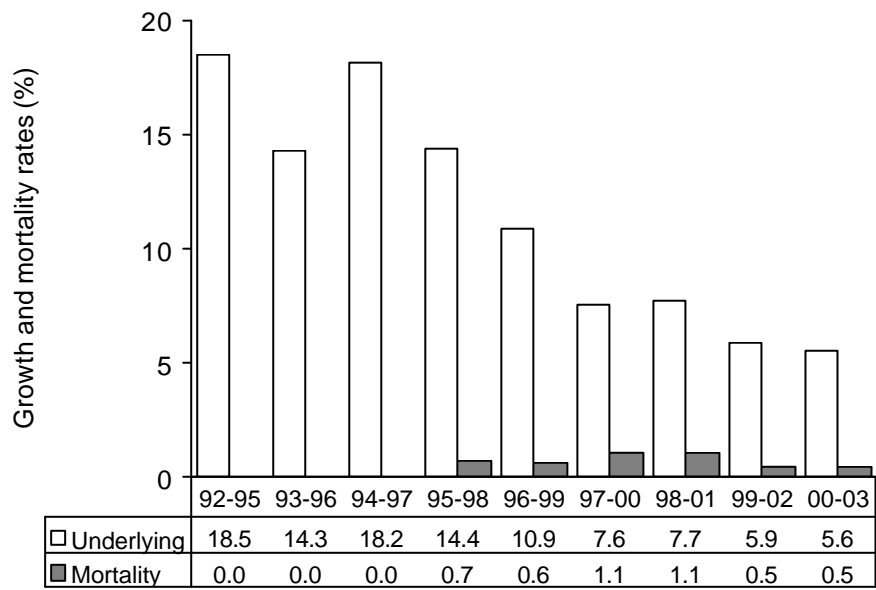


Fig. 3.30: 3-year moving averages of underlying growth and mortality rates in Ngulia from 1992-2003 showing a steadily declining growth rate.

Table 3.10: Summary of mortalities in Ngulia by cause and age class from 1992-2003.

Cause	Age Class				Total
	<1.0 yr (A-B)	=1.0 < 3.5 yr (C-D)	=3.5 < 7.0 yr (E)	> 7.0 yr (F)	
Disease	0	0	0	0	0
Fighting	0	0	0	1	1
Nutrition	0	0	0	0	0
Predation	0	0	0	0	0
Other Natural	0	0	0	0	0
Poaching	0	0	0	1	1
Other Unnatural	0	0	0	0	0
Total	0	0	0	2	2

3.2.4.2 Population structure and reproduction

Adult sex ratio remained biased to females (Fig. 3.31), increasing from 1.05F:1M in 1992/95 to 1.81F:1M in 1996/99 when it slightly decreased to 1.67F:1M in 2000/2003. The average inter-calving interval (ICI) was 4.48yrs ($n=11$). The ICI's mean was skewed by the >50% of breeding females with considerably longer ICI (Fig. 3.32). Average percentage of females calving per year increased steadily from 17% in 1992/95 to 29% in 1997/2000, and then declined to 23% in 2000/2003 with an average of 24.2% (Fig. 3.33). The average age at first calving averaged 8.06 yrs ($n=10$). Proportions of calves in age class A-D increased steadily from 9.6% in 1992/95 to a peak of 30.9% in 1997/2000, when it steadily declined to 19.5% in 2000/2003 with an average of 22.1% (Fig. 3.34)

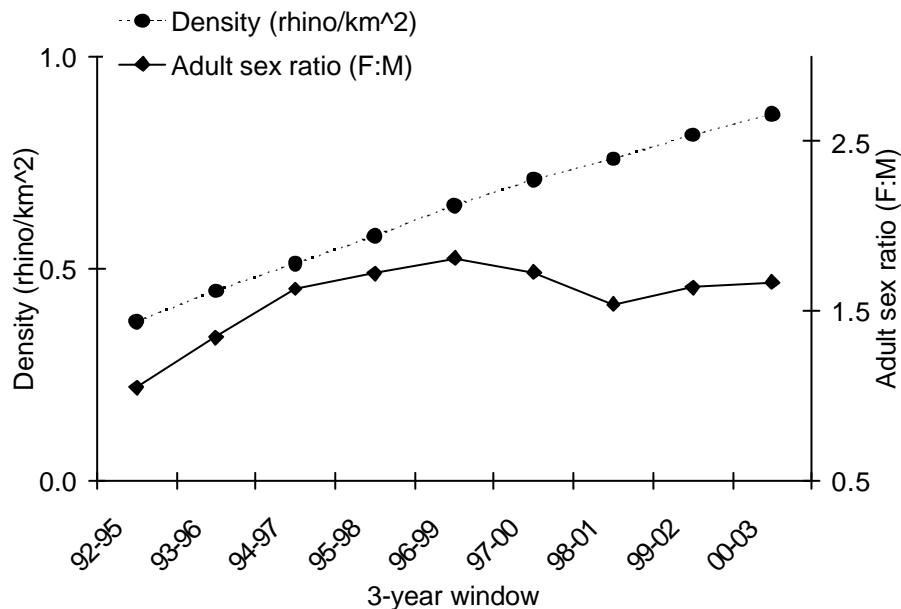


Fig. 3.31: Trends in density and adult sex ratio in Ngulia from 1992-2003, showing increasing density and skewed sex ratio in favour of females.

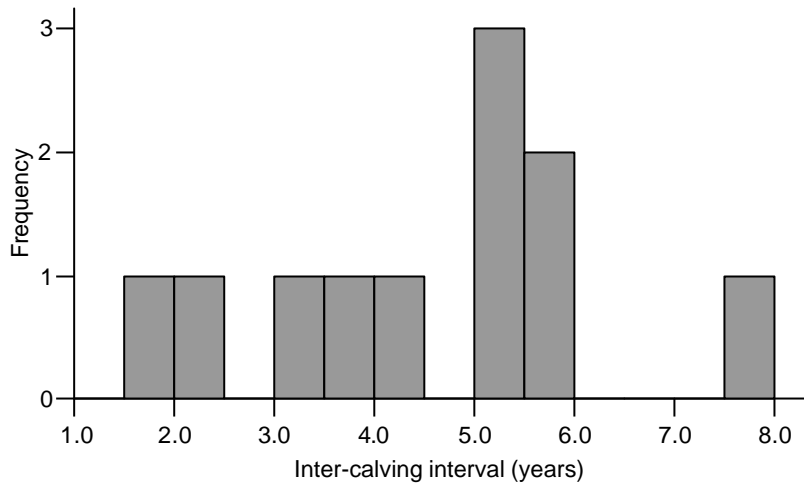


Fig. 3.32: Frequency distribution of inter-calving intervals in Ngulia as at 2003.

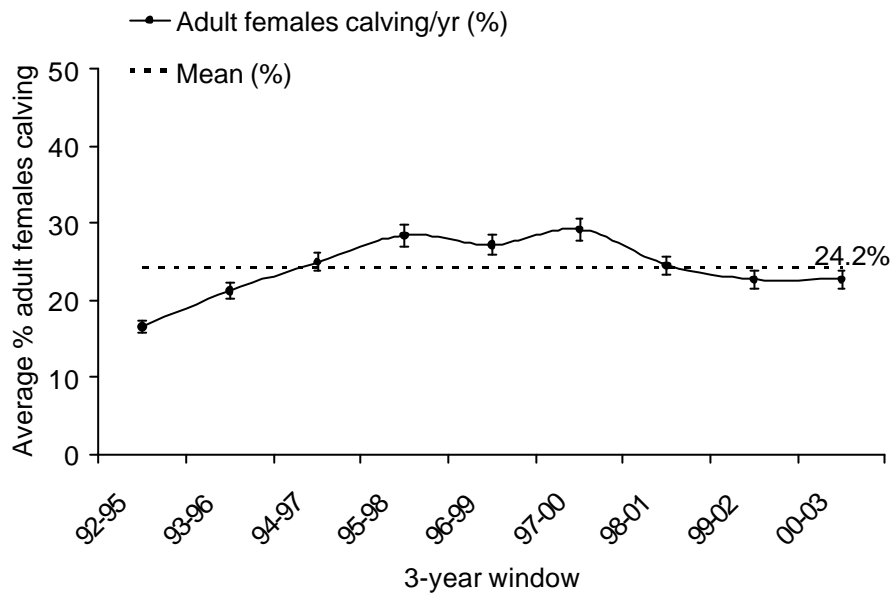


Fig. 3.33: Proportions of adult females calving per year in Ngulia from 1992-2003, also showing 5% SE error bars. The dotted horizontal line shows the mean across 1992-2003.



Fig. 3.34: Trends in the proportion of calves (Age class A-D) in Ngulia from 1992-2003. The dotted horizontal line shows the mean across 1992-2003.

3.2.4.3 Demographic parameters and reproductive indicators

Density was negatively correlated with underlying growth ($r=-0.95$; $P<0.01$). Sex ratio was positively correlated with proportion of calves ($r=0.86$; $P<0.01$) and with percentage of females calving per year ($r=0.89$; $P<0.01$). The linear relationship between sex ratio and underlying growth rate was not significant ($R^2=0.29$; $P=0.148$). However, the linear relationship between density and underlying growth rate was highly significant ($R^2=0.89$; $P=0.000$) (Fig. 3.35).

Table 3.11: Correlations between and within demographic, and reproductive parameters in Ngulia, based on 3-year moving averages from 1992-2003.

	SexRatio		Calves		FemaleCalv		UndLGrowth	
	r	P*	r	P*	r	P*	r	P*
Density	0.66	(NS)	0.60	(NS)	0.43	(NS)	-0.95	(**)
SexRatio			0.86	(**)	0.89	(**)	-0.50	(NS)
Calves					0.94	(**)	-0.54	(NS)
FemaleCalv							-0.34	(NS)

** Correlation is significant at the 0.01 level (2-tailed).

Density = Rhinos per km²; *SexRatio* = Adult sex ratio (F:M); *Calves* = Proportion of A-D age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

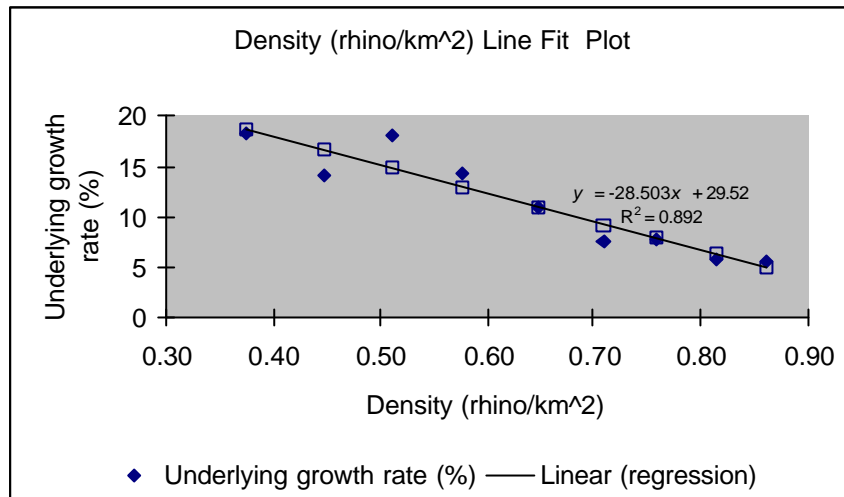


Fig. 3.35: Linear relationship between density and underlying growth rate in Ngulia from 1992-2003. The graph shows that $-28.50 \times \text{density} + 29.52$ significantly explained 89.2% of the variations in the underlying growth rate ($F_{1,7}=57.88$; $P=0.000$).

3.2.4.4 Rainfall with demographic and reproductive parameters

The mean annual rainfall in Ngulia was $701.99 \pm 77.12\text{mm}$ from 1992 to 2003. The highest mean of 1003mm fell in 1996/99. There was 42.7% coefficient of rainfall variation as a result of the 1997/98 El Niño events. The relationship between this rainfall variation and growth rate was evident 2 years later when the declining underlying growth rate stabilised from 7.6% in 1997/2000 to 7.7% in 1998/2001 (Fig. 3.30 & Fig. 3.36). A cross correlation plot (Fig. 3.37) showed a 2 to 3 years lag effect of rainfall on underlying growth rate. Even though rainfall was not significantly correlated with underlying growth rate ($r=0.30$; $P>0.05$), it was significantly correlated with percentage of females calving per year ($r=0.71$; $P<0.05$) (Table 3.12).

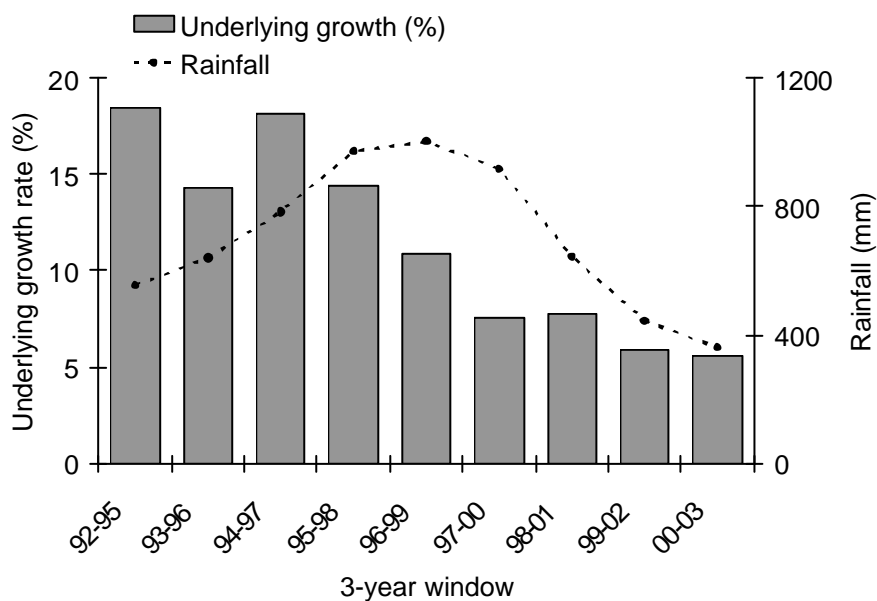


Fig. 3.36: The relationship between rainfall patterns and underlying growth rate in Ngulia from 1992-2003.

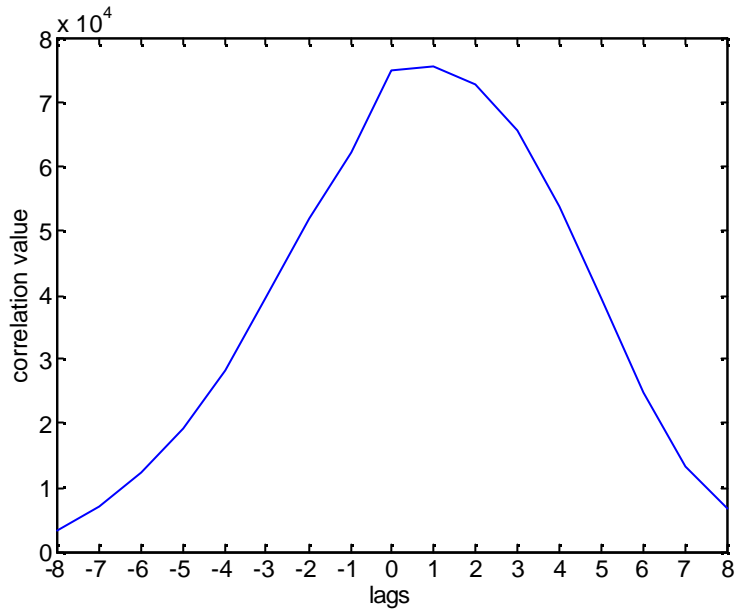


Fig. 3.37: Cross-correlation plot of rainfall and underlying growth rate in Ngulia from 1992-2003. The two peaks at $x=0$ and $3 < x < 2$ lags show signs of a 2 to 3 years lag effect of rainfall on underlying growth rate.

Table 3.12: Correlation between rainfall and demographic and reproductive parameters in Ngulia, based on 3-year moving averages from 1992-2003.

Reproductive and demographic parameters; N=9								
	Density		Calves		FemaleCalv	UndLGrowth		
	r	P*	r	P*	R	r	P*	
	P*							
Rainfall	-0.27	(NS)	0.58	(NS)	0.71	(*)	0.30	(NS)

* Correlation is significant at the 0.05 level (2-tailed).

Density = Rhinos per km²; *Calves* = Proportion of A&D age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

3.2.5 Nairobi National Park

3.2.5.1 Population estimates and growth

Probable estimates were first recorded in 1996 when the total number of rhinos was above 55 animals. Numbers of probables increased gradually as did number of guesstimates. However, the sum total of both probable and guesstimates remained fairly constant despite the increase in the total numbers of rhinos (Fig. 3.38). The estimated total population of 80 rhinos in 2003 comprised 91.2% confirmed, 2.5% probable and 6.3% guesstimates. A total of 41 rhinos were removed, and 1 introduced between 1992 and 1999 which resulted in the sum of confirmed and probable increasing from 52 rhinos in 1992 to 75 rhinos in 2003 (Fig. 3.39), and thus made Nairobi park the biggest donor population. Rhino densities within the partially fenced 117km² national park increased from 0.50 rhinos km⁻² in 1992/95 to 0.60 rhinos km⁻² in 2000/2003 ($y=0.01x+0.49$; $R^2=0.88$) (Fig. 3.41).

Notable increases in underlying growth rate occurred from 5.6% to 6.1% between 1993/96 and 1994/97 and from 4.3% to 5.1% between 1998/2001 and 1999/2002, while notable decreases in growth rate occurred from 9.5% to 5.6% between 1992/95 and 1993/96, and from 5.1% to 3.6% between 1999/2002 and 2000/2003 (Fig. 3.40). Average annual underlying growth rate decreased gradually with an overall average of 5.5% ($y=-0.48x+7.91$; $R^2=0.63$) across 1992-2003.

Fig. 3.40 also shows that average annual mortality rate increased from 1.3% in 1992/95 to 2.1% in 2000/2003 ($y=0.09x+0.75$; $R^2=0.21$). Eleven rhinos died, eight were from age class F, one from age class E, and two from age classes C-D. All were by natural causes, 4 of which were disease (Table 3.13).

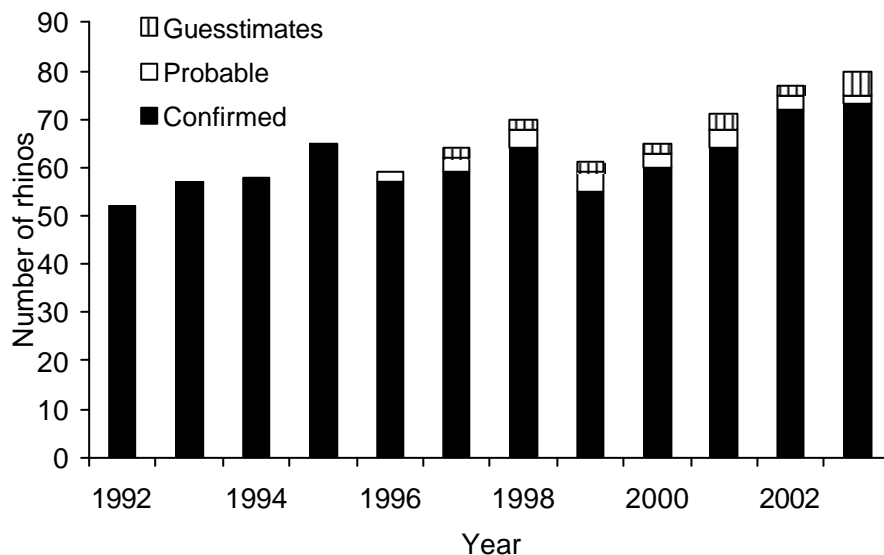


Fig. 3.38: Annual population estimates for Nairobi National Park classified in the standard categories from 1992-2003.

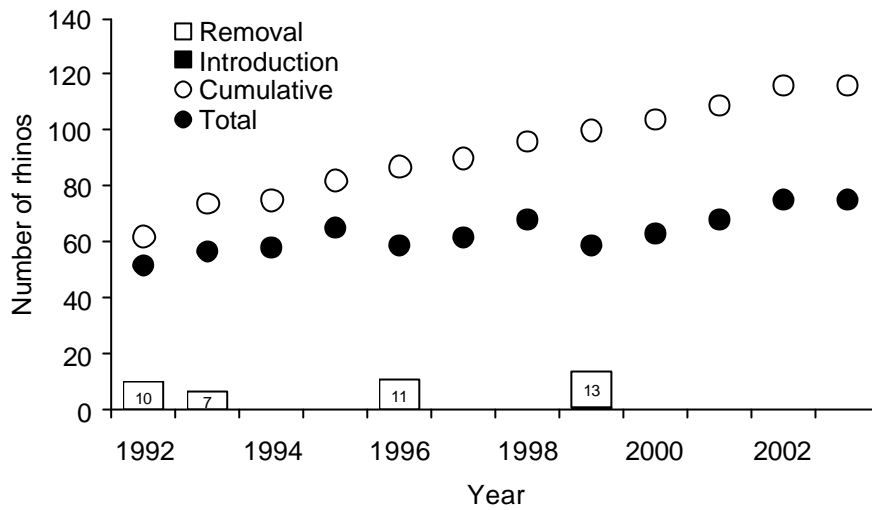


Fig. 3.39: Changes in the numbers of black rhinos in Nairobi National Park showing the numbers and timings of translocations from 1992-2003. The figures in the “removal” bars indicate the numbers that were translocated. The translocated rhinos were a mixture of sub-adult and adult males and females. The figures in the bar graphs indicate the rhino numbers that were removed. ‘Total’ refers to the sum total of ‘confirmed’ and ‘probable’.

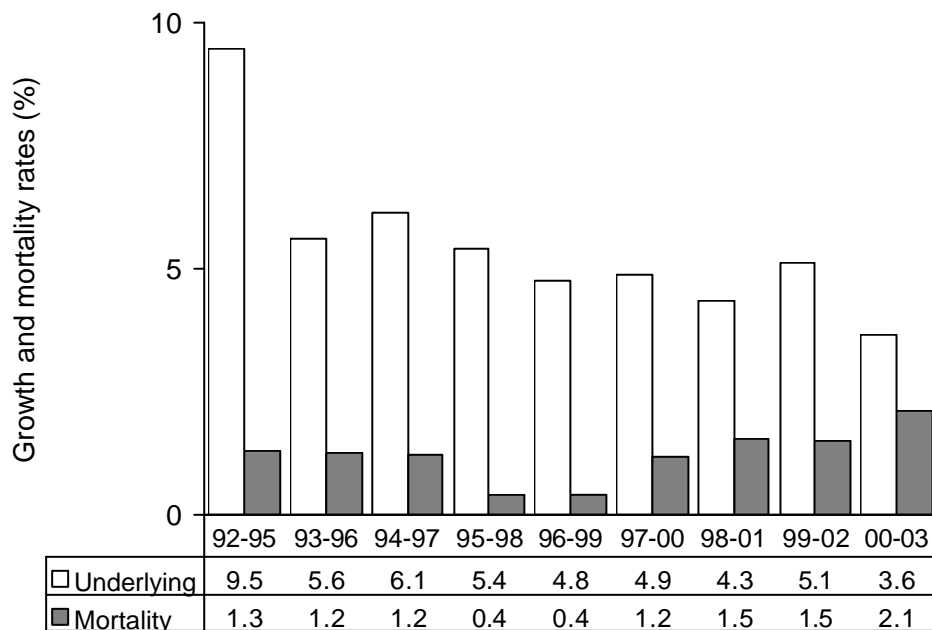


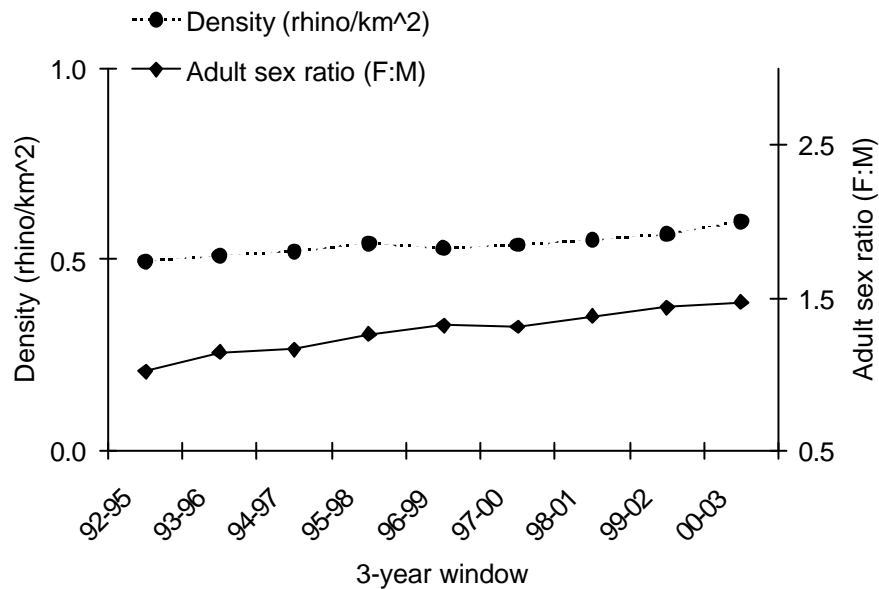
Fig. 3.40: 3-year moving averages of underlying growth and mortality rates in Nairobi National Park from 1992-2003.

Table 3.13: Summary of mortalities in Nairobi National Park by cause and age class from 1992-2003.

Cause	Age Class				Total
	<1.0 yr (A-B)	=1.0 < 3.5 yr (C-D)	=3.5 < 7.0 yr (E)	> 7.0 yr (F)	
Disease	0	0	1	3	4
Fighting	0	0	0	0	0
Nutrition	0	0	0	0	0
Predation	0	0	0	0	0
Other Natural	0	2	0	5	7
Poaching	0	0	0	0	0
Other Unnatural	0	0	0	0	0
Total	0	2	1	8	11

3.2.5.2 Population structure and reproduction

Adult sex ratio increased gradually in favour of females (Fig. 3.41) from 1.02F:1M in 1992/95 to 1.47F:1M in 2000/2003. The average inter-calving interval was 3.67 yrs ($n=18$), but this figure was slightly skewed by four females with considerably longer inter-calving intervals (Fig. 3.42). Average percentage of females calving per was 33.9% (Fig. 3.43). The average age at first calving was 7.47 yrs ($n=8$). Proportion of calves in age class A-D decreased gradually from 30.8% in 1992/95 to 25.7% in 2000/2003 with an overall average of 28.4% across 1992-2003 (Fig. 3.44).

**Fig. 3.41:** Trends in density and adult sex ratio in Nairobi National Park from 1992-2003.

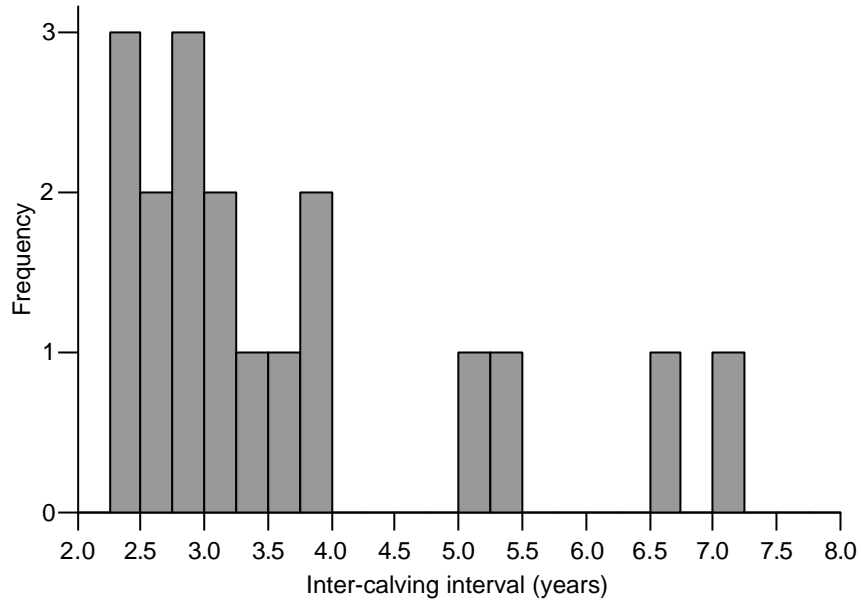


Fig. 3.42: Frequency distribution of inter-calving intervals in Nairobi National Park as at 2003.

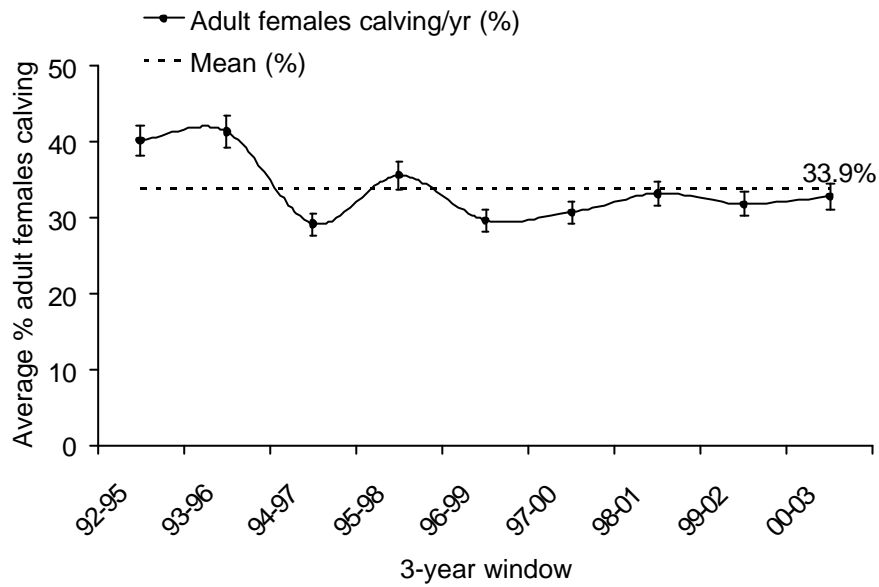


Fig. 3.43: Proportions of adult females calving per year in Nairobi National Park from 1992-2003, also showing 5% SE error bars. The dotted horizontal line shows the mean across 1992-2003.

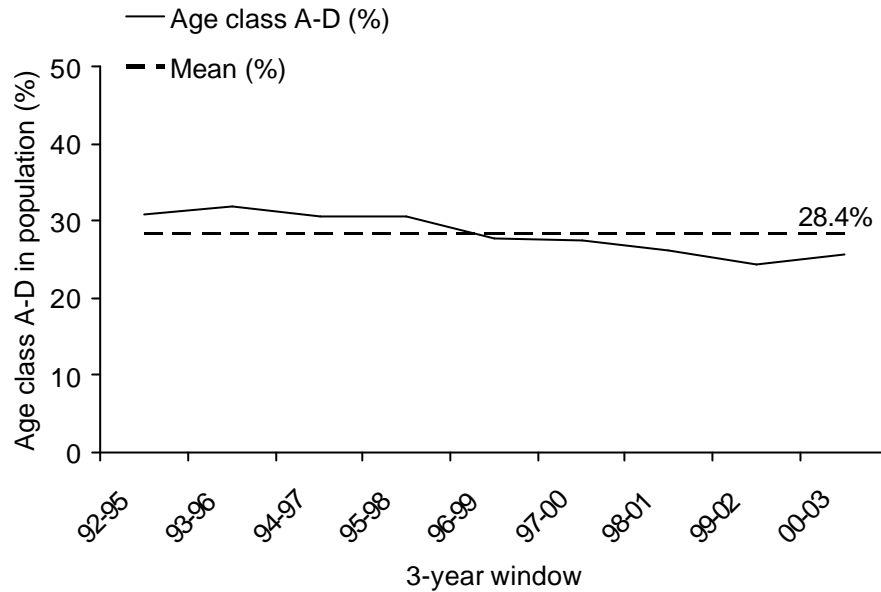


Fig. 3.44: Trends in the proportion of calves (Age class A-D) in Nairobi National Park from 1992-2003. The dotted horizontal line shows the mean across 1992-2003.

3.2.5.3 Demographic parameters and reproductive indicators

Density was negatively correlated with both the proportion of calves ($r=-0.82$; $P<0.01$) and underlying growth rate ($r=-0.74$; $P<0.05$). Sex ratio was negatively correlated with the proportion of calves ($r=-0.90$; $P<0.01$) and underlying growth ($r=-0.87$; $P<0.01$) (Table 3.14). There were significant linear relationships between underlying growth rate and sex ratio ($R^2=0.76$; $P=0.002$), and between density and underlying growth rate ($R^2=0.59$; $P=0.015$) (Fig. 3.45).

Table 3.14: Correlations between and within demographic, and reproductive parameters in Nairobi National Park, based on 3-year moving averages from 1992-2003.

Pearson correlation at 95% confidence limits, $N=9$

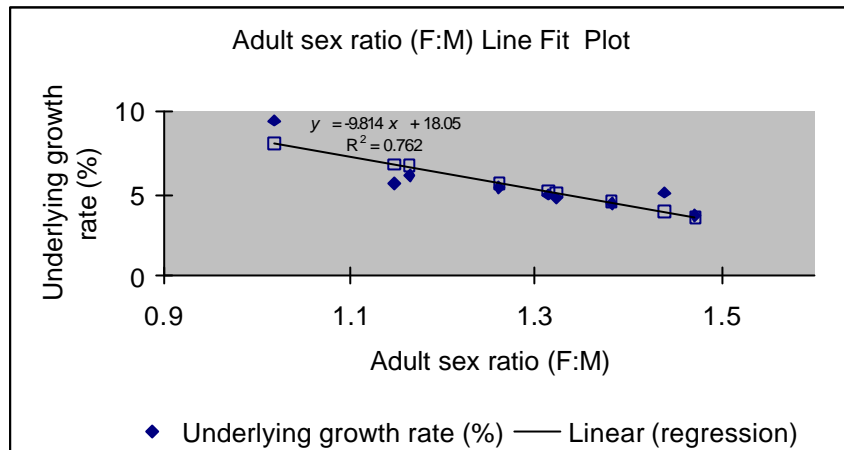
	SexRatio		Calves		FemaleCalv		UndLGrowth	
	r	P*	r	P*	r	P*	r	P*
Density	0.92	(**)	-0.82	(**)	-0.42	(NS)	-0.74	(*)
SexRatio			-0.90	(**)	-0.55	(NS)	-0.87	(**)
Calves					0.55	(NS)	0.61	(NS)
FemaleCalv							0.53	(NS)

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Density = Rhinos per km²; *SexRatio* = Adult sex ratio (F:M); *Calves* = Proportion of A-D age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

(a)



(b)

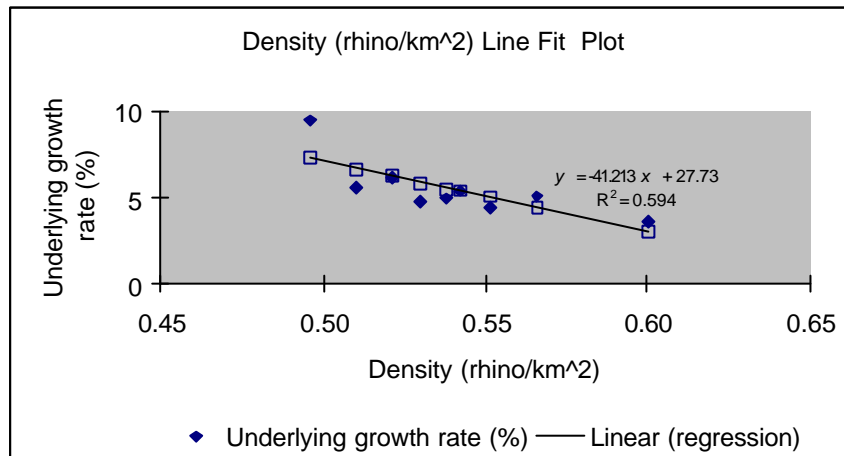


Fig. 3.45: Linear relationships between sex ratio and underlying growth rate, and between density and underlying growth rate in Nairobi National Park from 1992-2003. (a) shows that $-9.81x \text{ sex ratio} + 18.05$ significantly explained 76.2% of the variations in the underlying growth rate ($F_{1,7}=22.45$; $P=0.002$), while (b) shows that $-41.21x \text{ density} + 27.73$ significantly explained 59.4% of the variations in the underlying growth rate ($F_{1,7}=10.26$; $P=0.015$).

3.2.5.4 Rainfall with demographic and reproductive parameters

The mean annual rainfall in Nairobi National Park was $932.04 \pm 22.86\text{mm}$. The highest average of 1049mm fell in 1995/98. There was a 12.5% coefficient of rainfall variation as a result of the 1997/98 El Niño events. The relationship between this rainfall variation and growth rate was probably evident 4 years later when underlying growth increased slightly from 4.3% in 1998/2001 to 5.1% in 1999/2002 (Fig. 3.40 & Fig. 3.46). This increase in growth rate was not significant ($F_{1,2}=0.36$; $P=0.609$), and a cross correlation plot (Fig. 3.47) did not show any sign of lag effect of rainfall on underlying growth rate. There were no other significant correlations between rainfall and other demographic and reproductive parameters ($P>0.05$).

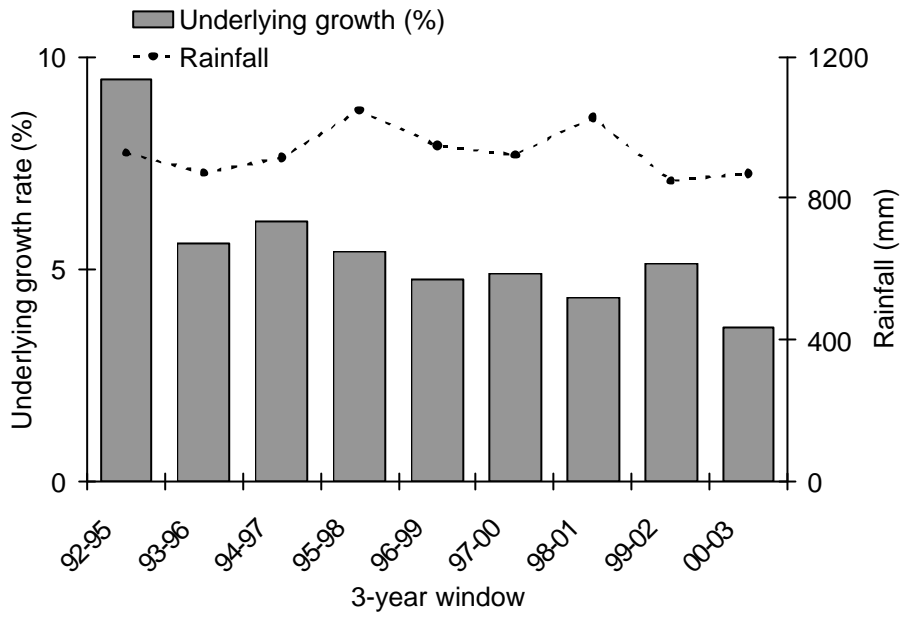


Fig. 3.46: The relationship between rainfall patterns and underlying growth rate in Nairobi National Park from 1992-2003.

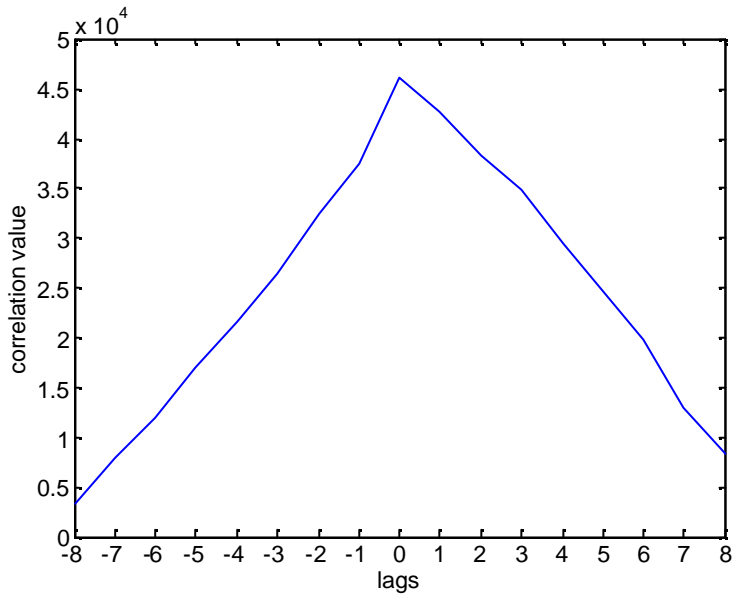


Fig. 3.47: Cross-correlation plot of rainfall and underlying growth rate in Nairobi National Park from 1992-2003. The distinct peak at $x=0$ lag show no lag effect of rainfall on underlying growth rate.

3.2.6 Lake Nakuru National Park

3.2.6.1 Population estimates and growth

Probable estimates were first recorded in 1996 when the total number of rhinos was slightly above 40 animals. Intriguingly, there were more guesstimates in 1998 than the probables of the preceding year! (probables turn to guesstimates). During this period, the most experienced rhino observer, and also the head of the monitoring team was ill to actively monitor rhinos. Probables increased from 1.85% of the population in 1996 to 10.0% in 2003. Guesstimates decreased from 8.3% of the population in 2001 to 1.4% in 2003, leaving 88.6% of the population as confirmed (Fig. 3.48). However, despite the increase in total numbers of rhinos, the sum total of probables and guesstimates remained fairly constant. No translocation took place during the period 1992 to 2003 and therefore cumulative total was not calculated. Density increased steadily within the 144km² area, assumed as the effective for the rhinos from 0.25 rhinos km⁻² in 1992/95 to 0.44 rhinos km⁻² in 2000/2003 ($y=0.02x+0.21$; $R^2=0.96$) (Fig. 3.50).

The average underlying annual growth rate fluctuated between a low of 1.6% in 1995/98 and a high of 14.1% in 1998/2001 with an overall average annual growth rate of 7.9% ($y=0.54x+5.17$; $R^2=0.17$) across 1992-2003 (Fig. 3.49).

Fig. 3.49 also shows that mortality increased from 0.6% in 1994/97 to 2.3% in 2000/2003 ($y=0.23x+0.22$; $R^2=0.69$). A total of eight rhinos died, six were from age class F (4 identifiable, 2 "clean"), and one each from age classes A-B and C-D. Five and three deaths were caused by natural causes and unnatural causes, respectively. Two of the unnatural causes were poaching of 2 "clean" rhinos.

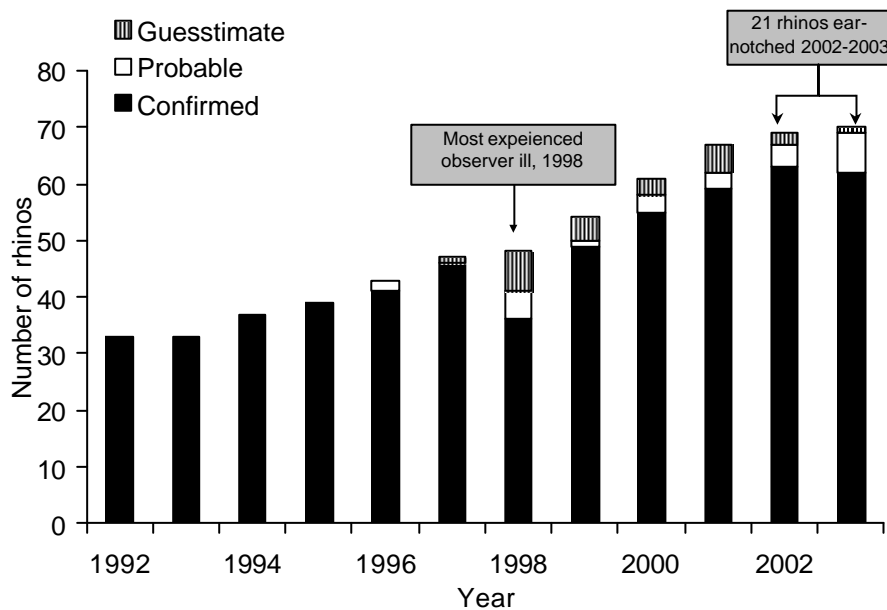


Fig. 3.48: Annual population estimates for Lake Nakuru National Park classified in the standard categories from 1992-2003, showing a period when most experienced observer was ill, and number of rhinos ear-notched in 2002-2003 to improve individual rhino identification.

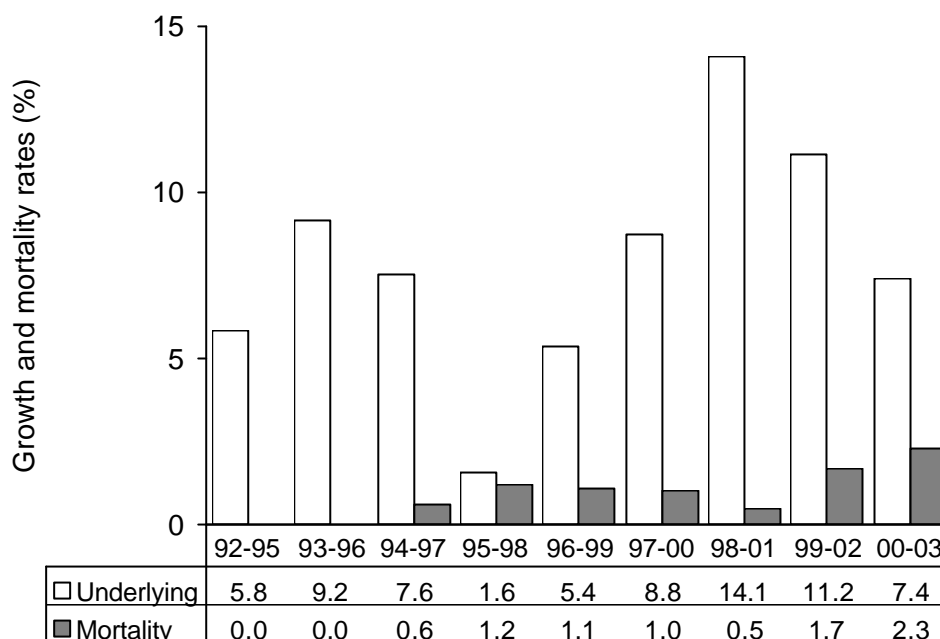


Fig. 3.49: 3-year moving averages of underlying growth and mortality rates in Lake Nakuru National Park from 1992-2003.

Table 3.15: Summary of mortalities in Lake Nakuru National Park by cause and age classes from 1992-2003.

Cause \ Age Class	<1.0 yr	=1.0 < 3.5 yr	=3.5 < 7.0 yr	> 7.0 yr	Total
	(A-B)	(C-D)	(E)	(F)	
Disease	0	0	0	2	2
Fighting	0	0	0	1	1
Nutrition	0	0	0	0	0
Predation	1	0	0	0	1
Other Natural	0	0	0	1	1
Poaching	0	0	0	2	2
Other Unnatural	0	1	0	0	1
Total	1	1	0	6	8

3.2.6.2 Population structure and reproduction

Adult sex ratio remained in favour of males, fluctuating between 0.70F:1M and 0.82F:1M (Fig. 3.50). The average inter-calving interval was 3.41 yrs ($n=16$), but this figure was slightly skewed by one female with considerably longer inter-calving interval (Fig. 3.51). Average percentage of females calving per year showed a general increasing trend with an average of 36.4% (Fig. 3.52). The average age at first calving averaged as low as 5.50yrs ($n=10$). Proportion of calves in age class A-D in the population increased gradually from 18.3% in 1992/95 to 27.8% in 2000/2003 with an average of 23.7% across 1992-2003 (Fig. 3.53).

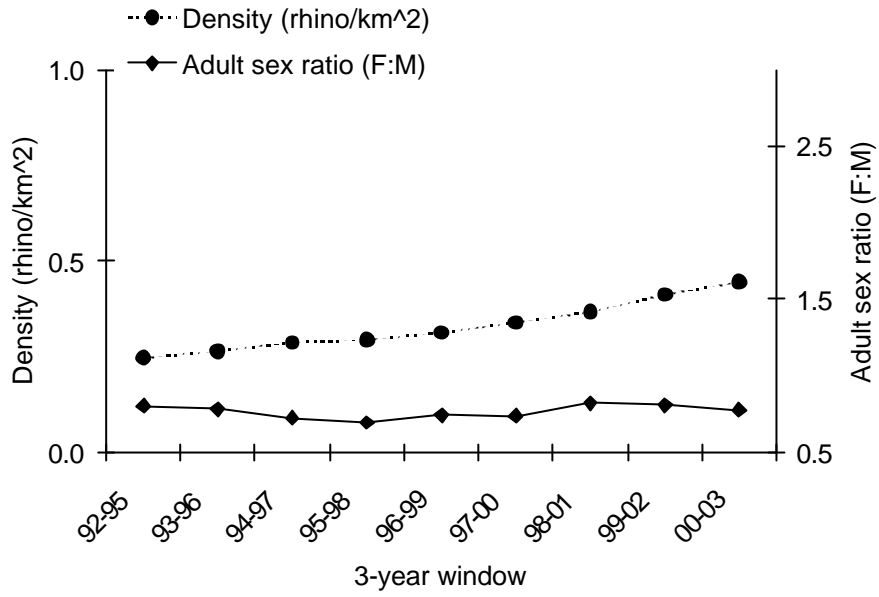


Fig. 3.50: Trends in density and adult sex ratio in Lake Nakuru National Park from 1992-2003, showing unfavourable sex ratio (biased to males) throughout the period while densities increased.

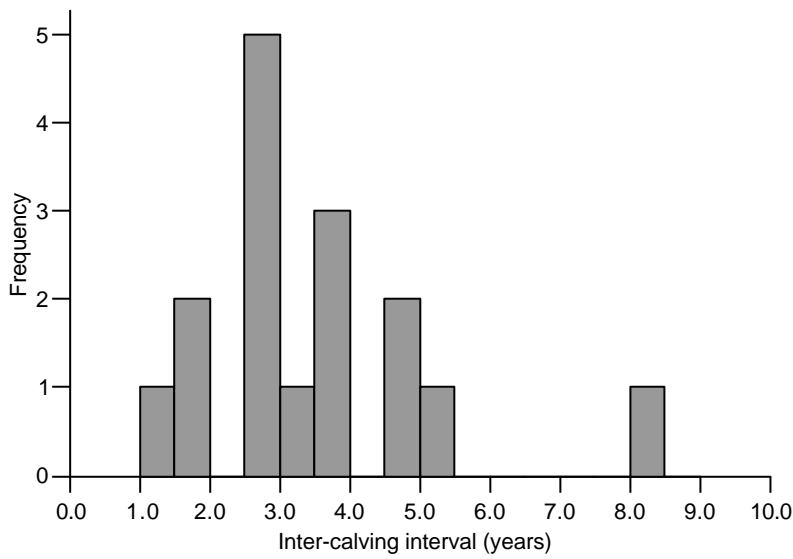


Fig. 3.51: Frequency distribution of inter-calving intervals in Lake Nakuru National Park as at 2003.

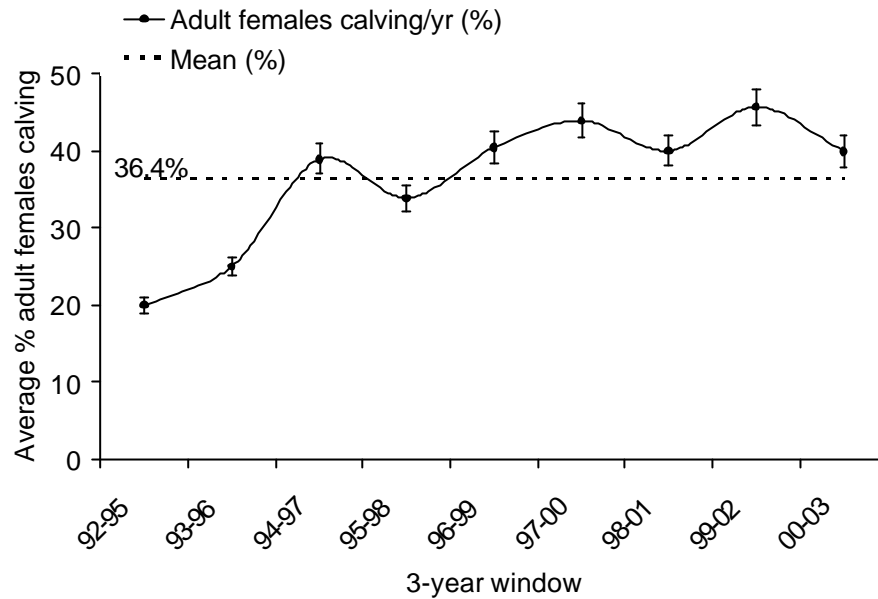


Fig. 3.52: Proportions of adult females calving per year in Lake Nakuru National Park from 1992-2003, also showing 5% SE error bars. The dotted horizontal line shows the mean across 1992-2003.

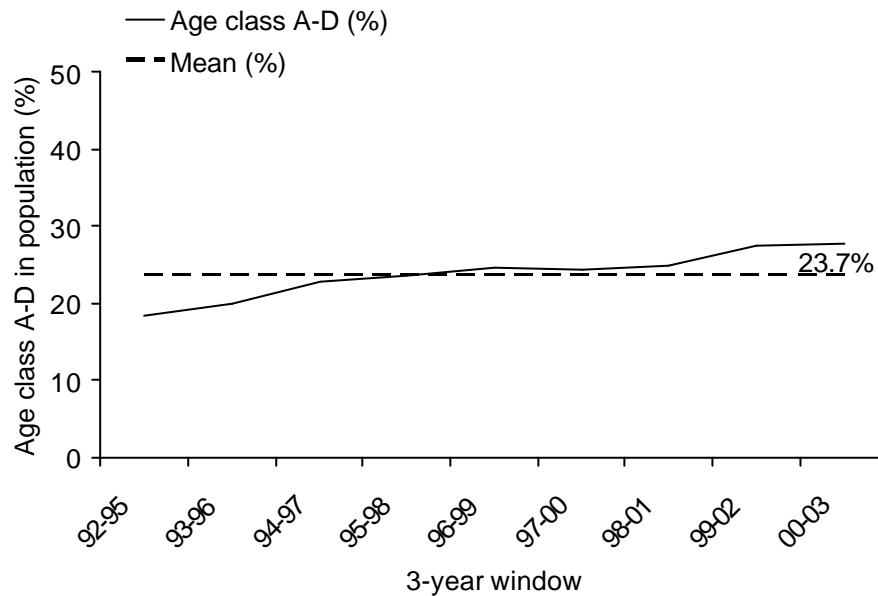


Fig. 3.53: Trends in the proportion of calves (Age class A-D) in Lake Nakuru National Park from 1992-2003. The dotted horizontal line shows the mean across 1992-2003.

3.2.6.3 Demographic parameters and reproductive indicators

Density was positively correlated with proportion of calves ($r=0.93$; $P<0.01$) and females calving per year ($r=0.74$; $P<0.05$). Sex ratio was positively correlated with underlying growth rate ($r=0.74$; $P<0.05$). Proportion of calves in the population was positively correlated with percentage of females calving per year ($r=0.89$; $P<0.01$) (Table 3.16). There was a significant linear relationship between sex ratio and underlying growth rate ($R^2=0.56$; $P=0.020$) (Fig. 3.54) but no significant linear relationship was evident between density and underlying growth rate ($R^2=0.18$; $P=0.251$).

Table 3.16: Correlations between reproductive indicators and demographic parameters in Lake Nakuru National Park based on 3-year moving averages from 1992-2003.

Pearson correlation at 95% confidence limits, N=9

	SexRatio		Calves		FemaleCalv		UndLGrowth	
	r	P*	r	P*	r	P*	r	P*
Density	0.36	(NS)	0.93	(**)	0.74	(*)	0.45	(NS)
SexRatio			0.05	(NS)	-0.11	(NS)	0.74	(*)
Calves					0.89	(**)	0.27	(NS)
ObsGrowth					0.26	(NS)	0.99	(**)
FemaleCalv							0.34	(NS)

* Correlation is significant at the 0.05 level (2-tailed).

** Correlation is significant at the 0.01 level (2-tailed).

Density = Rhinos per km²; *SexRatio* = Adult sex ratio (F:M); *Calves* = Proportion of A-D age class calves in the population; *FemaleCalv* = Percentage of females calving per year; *UndLGrowth* = Underlying growth rate.

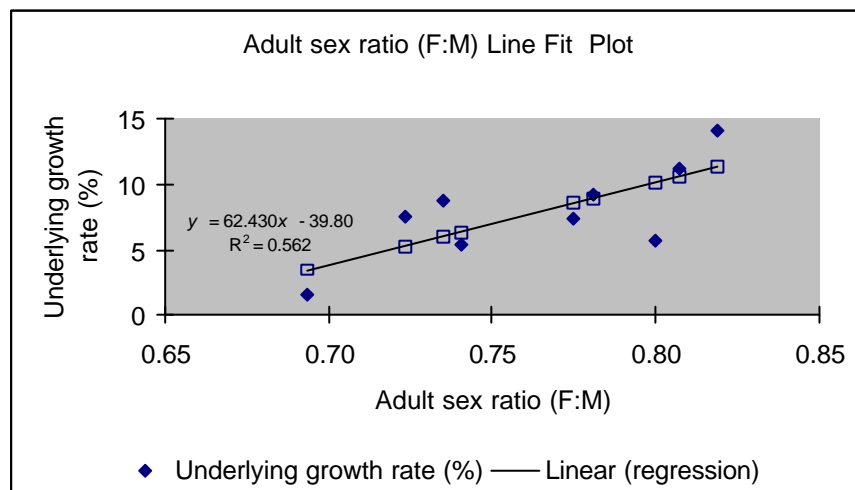


Fig. 3.54: Linear relationship between sex ratio and underlying growth rate in Lake Nakuru National Park from 1992-2003, showing that $62.43 \times \text{sex ratio} - 39.80$ significantly explained 56.2% of the variations in the underlying growth rate ($F_{1,7}=8.97$; $P=0.020$).

3.2.6.4 Rainfall with demographic and reproductive parameters

The average annual rainfall in Lake Nakuru was 835.54 ± 14.16 mm. The highest mean of 926mm fell in 1996/99 following the 1997/98 El Niño events. There was a 10.8% coefficient of rainfall variation. The relationship between this rainfall variation and underlying growth rate was evident 2 years later when underlying growth rate increased significantly from 8.8% in 1997/2000 to 14.1% in 1998/2001 ($F_{1,2}=129.57$; $P=0.008$) (Fig. 3.49 & Fig. 3.55). However, a cross correlation plot (Fig. 3.56) did not show any sign of lag effect of rainfall on underlying growth rate. Correlations between rainfall and other demographic and reproductive parameters were also not significant ($P>0.05$).

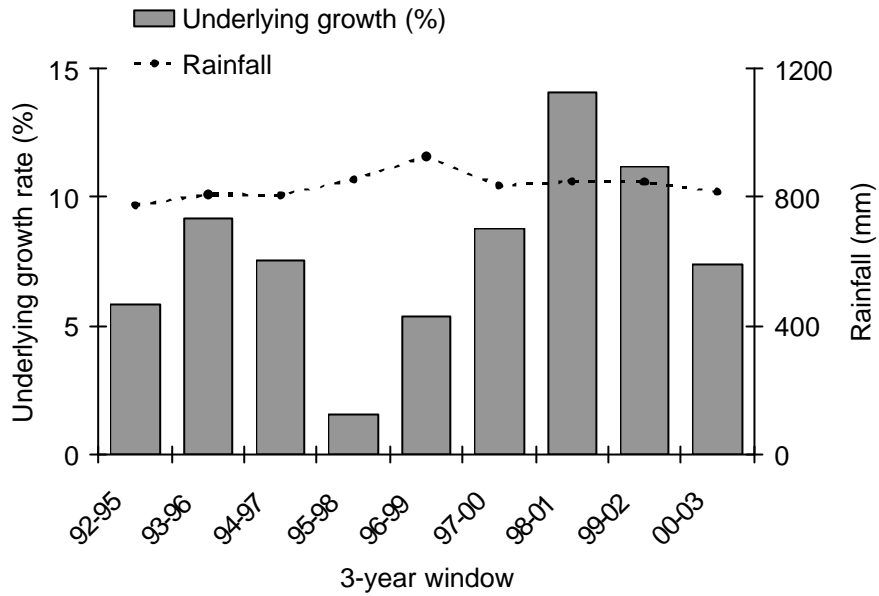


Fig. 3.55: The relationship between rainfall patterns and underlying growth rate in Lake Nakuru from 1992-2003.

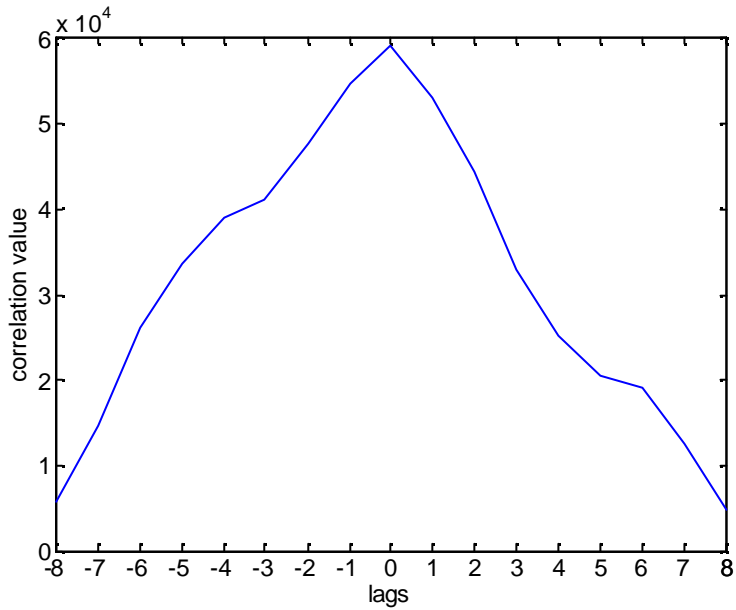


Fig. 3.56: Cross-correlation plot of rainfall and underlying growth rate in Lake Nakuru National Park from 1992-2003. The distinct peak at $x=0$ lags indicate no lag effect of rainfall on underlying growth.

3.3 Population demography and reproduction across the sanctuaries

This section of population performance across sanctuaries compares the standard measures. The order of comparison has been changed to a descending order of the calculated average underlying growth rate for each sanctuary for the period 1992-2003 as follows: *NGL*=Ngulia sanctuary; *OPS*=Ol Pejeta sanctuary; *OJS*=Ol Jogi sanctuary; *LNP*=Lake Nakuru National Park; *LDS*=Lewa Downs sanctuary; and *NNP*=Nairobi National Park. This new order allows better visual comparisons of other demographic and reproductive parameters with underlying growth rate. Some of the figures and tables may not have been referred to in the text, as they have sufficient captions, or may have been displayed in earlier graphs and tables of respective sanctuaries, and are intended for visual overview of performance across sanctuaries, and in relation to standard measures for particular performance indicators.

3.3.1 Population estimates and growth across sanctuaries

3.3.1.1 Average population estimates

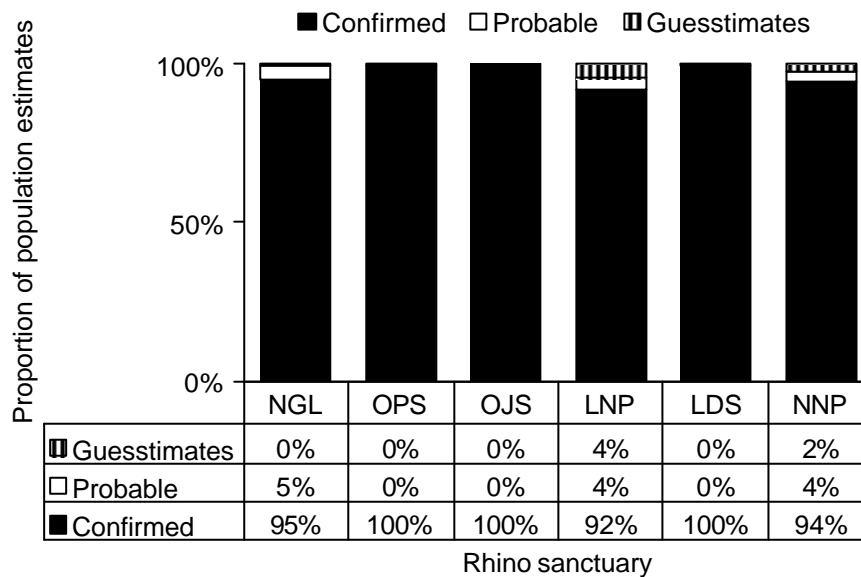


Fig. 3.57: Comparison of rhino population estimates across sanctuaries from 1992-2003. As mentioned in the caveats of the study of possible double counts, this figure should be interpreted as an indicator of the need for population estimation.

3.3.1.2 Average annual underlying growth rate and mortality rate.

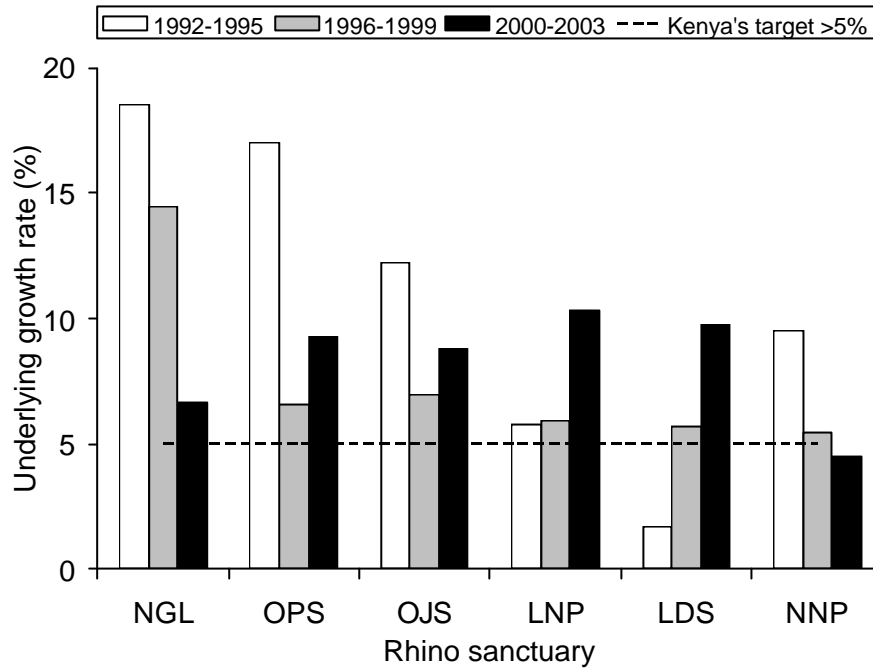


Fig. 3.58: Comparison of average underlying growth rates across sanctuaries from 1992 to 2003, over successive 4-year periods. The horizontal line indicates the Kenya's meta-population underlying growth target. Some populations (OPS and OJS) phases of high growth rates at the beginning due to effect of small population size then stabilised as number increased, and eventually increased, thus typical of what would be expected. Some (LNP and LDS) had their growth rates increase gradually over the three phases. Others (NGL and NNP) had their growth rates decline across the three phases, with NNP performing below the Kenya's 5% target in the 2000-2003 phase.

3.3.1.3 Average rhino densities

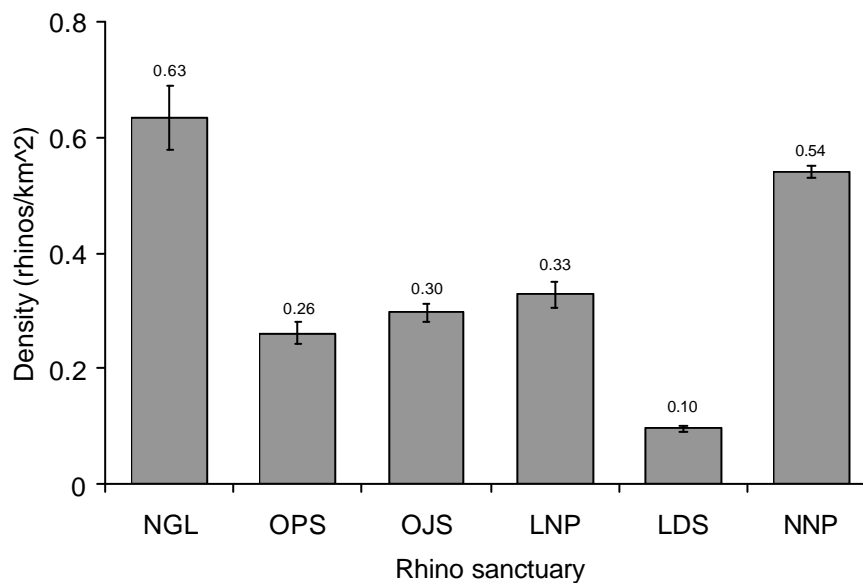


Fig. 3.59: Comparison of average rhino densities across sanctuaries from 1992 to 2003 showing SE error bars and average densities above the bars. Current estimates are listed in Table 3.18.

3.3.2 Population structure and reproduction across sanctuaries

3.3.2.1 Average adult sex ratios

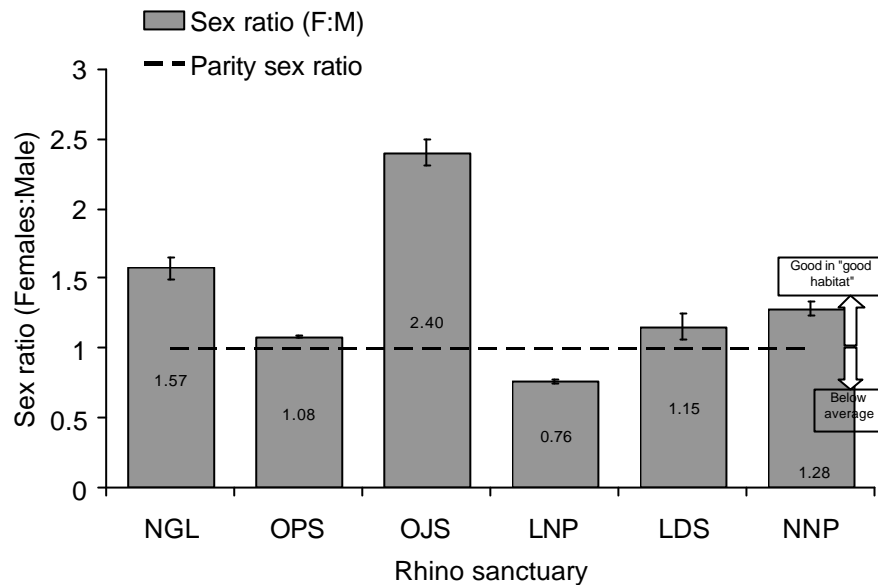


Fig. 3.60: Comparison of average adult sex ratios across sanctuaries from 1992 to 2003 showing SE bars and average sex ratios figures within the bars. The horizontal line indicates parity sex ratio (1F:1M). Sex ratio above parity is good in “good habitat” while that below parity is below average for an optimum population performance. Current estimates are listed in Table 3.18.

3.3.2.2 Average inter-calving interval

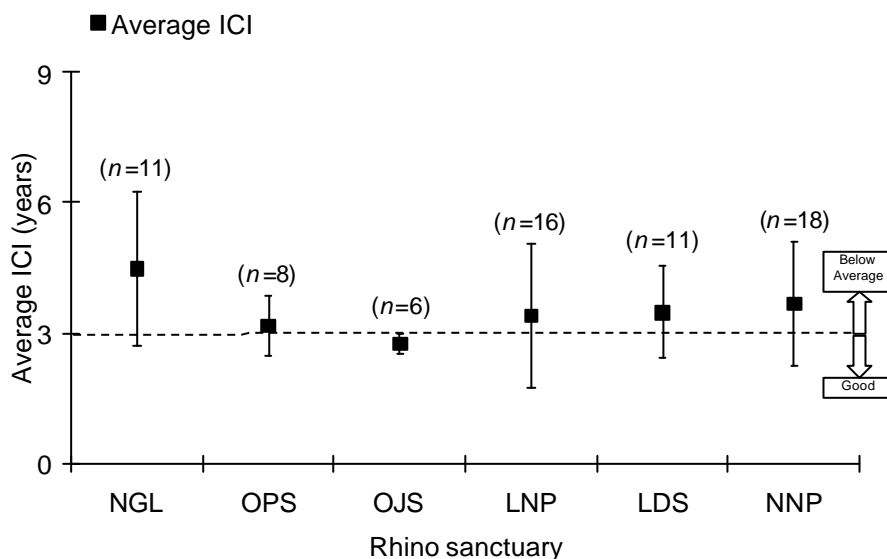


Fig. 3.61: Comparison of average inter-calving Intervals (ICI) across rhino sanctuaries as at 2003, showing SD error bars and sample sizes above the bars. The horizontal dotted line shows the optimum ICI of 3 years. ICIs <3yrs indicate good performance, while ICIs >3yrs indicate sub-optimal performance.

3.3.2.3 Average percentage of females calving per year

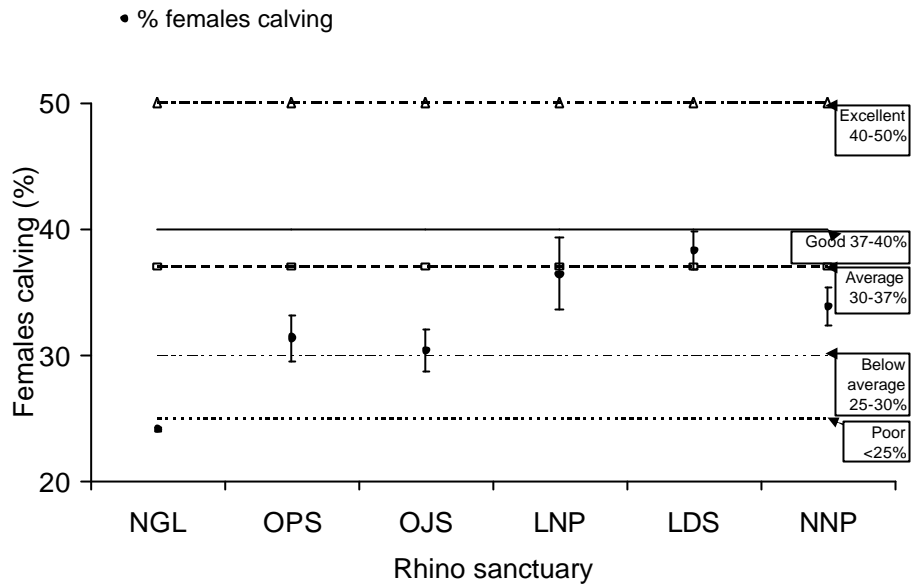


Fig. 3.62: Comparison of average percentage of females calving per year across rhino sanctuaries from 1992 to 2003 with SE bars. The graph also shows the levels of rating this performance indicator, from poor to excellent. Current estimates are listed in Table 3.18.

3.3.2.4 Average ages at first calving

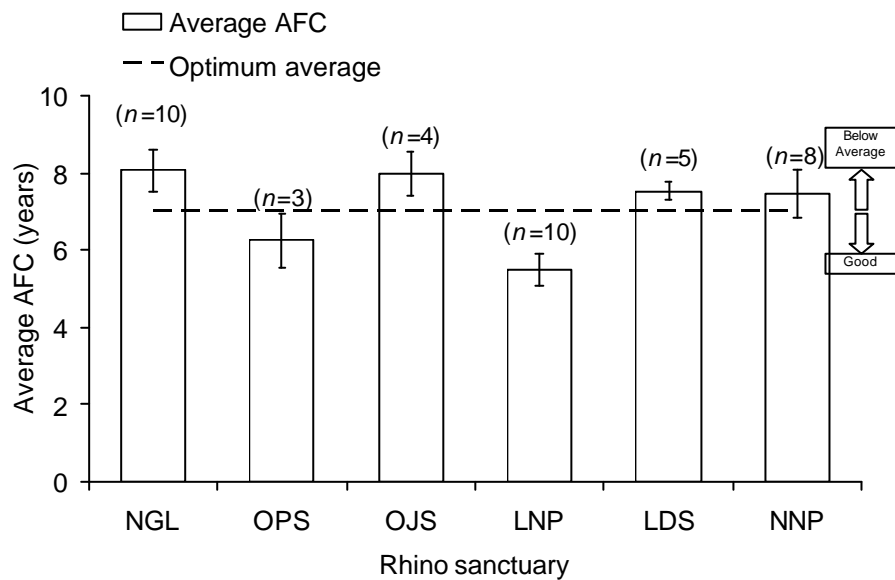


Fig. 3.63: Comparison of average ages at first calving across rhino sanctuaries as at 2003, showing SE bars and sample size (*n*) above the bars. The horizontal dotted indicates the least average AFC of =7 years. Averages =7years indicate good population performance, while those >7years indicate sub-optimal population performance. This is the source figure of all AFCs reported for respective sanctuaries, though not cited in the main text.

3.3.2.5 Proportion of calves in the population

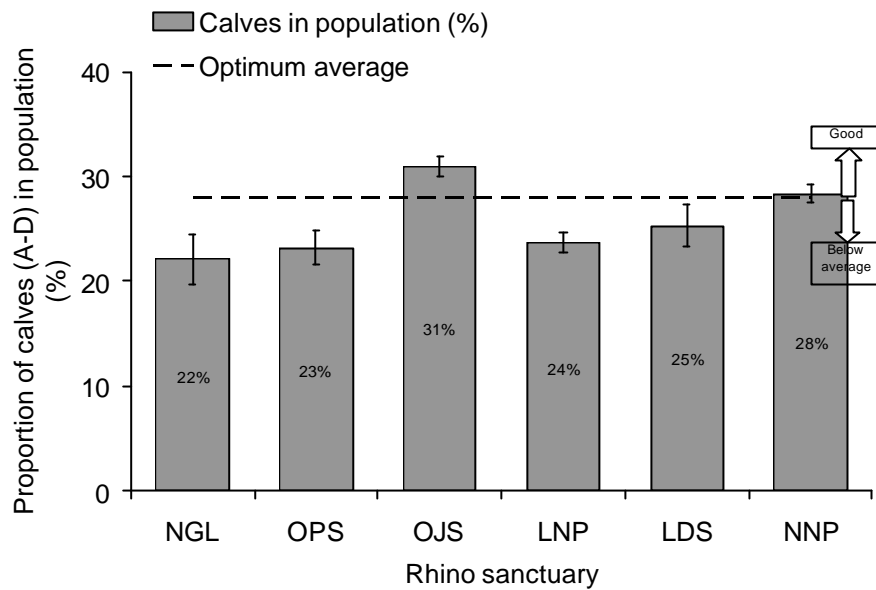
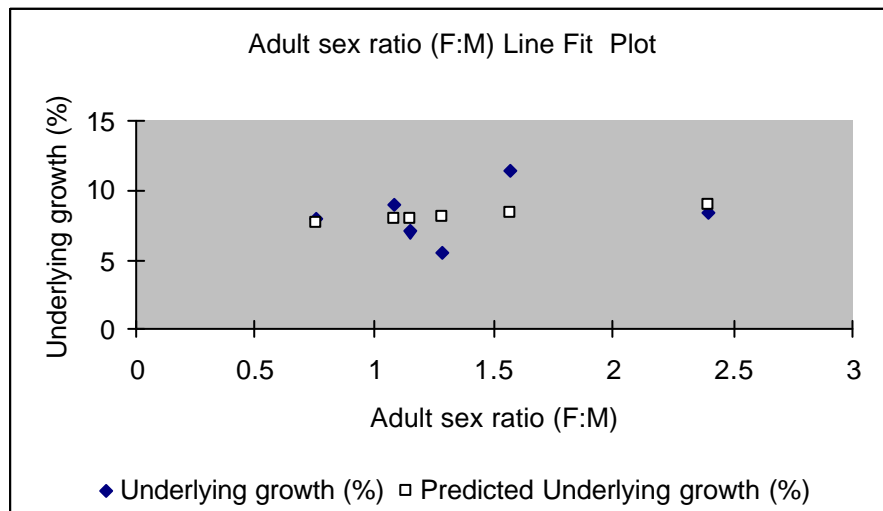


Fig. 3.64: Comparison of average proportion of calves (age classes A-D) in the population across sanctuaries from 1992-2003, showing with SE bars and the averages for each sanctuary in its respective bar. The dotted horizontal line at 28% indicates the minimum average for an optimum performing population. Averages >28% indicates good performance, while <28% indicate suboptimal population performance. Current estimates are listed in Table 3.18.

3.3.3 Demographic parameters and reproductive indicators across sanctuaries

Pearson correlations at 95% confidence limits (2-tailed) produced only one significant negative correlation between density and mortality rate from 1992-2003 ($r=-0.859$; $P=0.029$). There were no significant linear relationships between sex ratio and underlying growth ($R^2=0.51$; $P=0.526$), and between density and underlying growth ($R^2=0.11$; $P=0.13$) (Fig. 3.65).

(a)



(b)

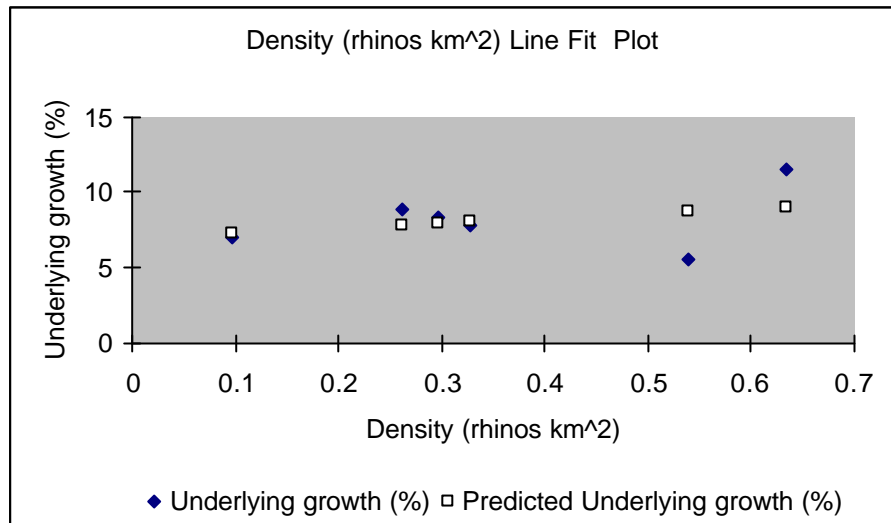


Fig. 3.65: Linear relationships between sex ratio and density, and underlying growth rate across sanctuaries from 1992-2003. (a) shows that $0.79 \times \text{sex ratio} + 7.09$ explained 5.1% of the variations in the underlying growth and was not significant ($F_{1,4}=0.22$; $P=0.526$), while (b) shows that $3.34 \times \text{density} + 6.98$ explained the 10.8% of the variations in the underlying growth and was not significant ($F_{1,4}=0.48$; $P=0.13$). Comparison of these parameters across sanctuaries highlights that “averaging out” performance mask individual population performance, as sanctuaries differ in a number of environmental, ecological and demographic factors.

3.3.4 Rainfall with demographic and reproductive parameters across sanctuaries

The differences in rainfall amounts between sanctuaries were highly significant ANOVA ($F_{5,48}=12.74$; $P<0.001$). Least Significance Differences test (LSD) (Table 3.17) showed that sanctuaries could be grouped as follows based on their mean annual rainfall from 1992-2003:

LDS	OJS	LNP	OPS	NGL	NNP
570.5mm	576.6mm	701.9mm	702.0mm	835.6mm	932.1mm

The underlined were **not** significantly different ($P>0.05$).

Table 3.17: Multiple comparison of rainfall amounts across sanctuaries from 1992-2003. (a.k.a Fisher Least Significant Difference - LSD test)

	OJS	<i>P</i> *	LDS	<i>P</i> *	NGL	<i>P</i> *	LNP	<i>P</i> *	NNP	<i>P</i> *
OPS	0.03	(*)	0.02	(*)	0.02	(*)	1.00	(NS)	0.00	(***)
OJS			0.91	(NS)	0.00	(***)	0.03	(*)	0.00	(***)
LDS					0.00	(***)	0.02	(*)	0.00	(***)
NGL							0.02	(*)	0.09	(NS)
LNP									0.00	(***)

*** Difference in the rainfall means is significant at 0.001 level

** Difference in the rainfall means is significant at 0.01 level

* Difference in the rainfall means is significant at 0.05 level

However, when underlying growth rates were grouped by rainfall, there were no significant linear relationship between rainfall and underlying growth rate (ANOVA: $F_{2,51}=0.21$; $P=0,815$), again highlighted the problems of “averaging out” meta-population performance

3.4 Summary of current (2000/2003) population performance across sanctuaries

Table 3.18: Summary of current (2000/2003) population performance across sanctuaries

	Pop.E	UnL.G	Mot.R	Den.	SR	ICI	%FC	AFC	%CP
NGL	95%	✓(5.6%)	✓(0.5%)	×(0.86)	✓(1.67)	×(4.48)	×(23%)	×(8.06)	×(20%)
OPS	100%	✓(8.6%)	✓(0.0%)	✓(0.36)	✓(1.06)	×(3.17)	×(33%)	✓(6.24)	×(27%)
OJS	100%	✓(7.7%)	✓(1.3%)	✓(0.38)	✓(2.43)	✓(2.75)	×(31%)	×(7.98)	✓(29%)
LNP	92%	✓(7.4%)	✓(2.3%)	✓(0.44)	×(0.78)	×(3.41)	✓(40%)	✓(5.49)	✓(28%)
LDS	100%	✓(8.9%)	✓(0.7%)	✓(0.13)	✓(1.61)	×(3.47)	×(33%)	×(7.53)	✓(29%)
NNP	94%	×(3.6%)	✓(2.1%)	×(0.60)	×*(1.47)	×(3.67)	×(33%)	×(7.47)	×(26%)

✓ = “Good”; indicative of optimal population performance

× = “Below average”; indicative of sub-optimal population performance

* was >1F:1M, but marked ‘×’ because it significantly limited underlying growth rate (Fig. 3.45a).

The degree of “Good” and “Below average” differ (Adcock 1999; du Toit 2001; du Toit *et al.* 2001) (Appendix 8). Comparisons on this table are based on the “moderate to good” levels of each performance indicator, as follows: Pop. E=‘Confirmed’ population estimate; UnL.G=Underlying growth rate (5% level); Mot.R=Mortality rate (4% level); Den.=Rhino density (relationship with underlying growth); SR=Sex ratio (1F:1M level); ICI=Average inter-calving interval (3yrs level); %FC=Percentage of females calving per year (37% level); AFC=Age at first calving (7yrs level); and %CP=Proportion of calves (class A-D) in the population (28% level).

4 DISCUSSIONS AND RECOMMENDATIONS

4.1 Kenya meta-population and translocations

Recognising that *D. b. michaeli* remains the least well recovered of the three other subspecies of black rhinos in Africa, achieving co-operative planning and management of *D. b. michaeli* with a primary focus on local and regional co-operation would be an appropriate strategy to enhancing its recovery (AfRSG 2004). As was seen in the partnerships between private, community and state lands owners in establishing new rhino populations in Kenya, it is possible to broaden such co-operations to regional levels to achieve the long term recovery of the subspecies. The underpinning factor is the source for rhinos, but as data on translocation history (Fig. 3.1) has shown, Nairobi National Park and Solio Ranch have great potentials to provide substantial continuous surplus of rhinos for re-stocking if carefully managed (Anon. 1993; Anon 2003a). Based on the analyses, other areas such as Lake Nakuru, Ol Jogi and Ol Pejeta also showed potentials for providing surplus rhinos. It is therefore feasible to meet demands for rhinos within Kenya and by other countries from the region, if constraints including rhino insecurity, exorbitant costs, non explicit policies, and less preferred demographic structures of sex and age of rhinos are overcome (AfRSG 2004).

4.2 Population demography and reproduction within sanctuaries

4.2.1 Population estimates and growth within sanctuaries

4.2.1.1 OL Pejeta Game Reserve

Factors that affect quality of rhino monitoring including numbers of skilled staff, monitoring effort, monitoring equipment, numbers of rhinos, vegetation cover and terrain, all seemed favourable to ensure that all rhinos were categorised as confirmed across 1992 to 2003. In addition, the timely ear notching exercise in 2003 funded by US-Fish and Wildlife RTCF that saw 8 rhinos ear-notched in Ol Pejeta and 9 in Lewa Downs in 2003 contributed to maintaining all rhinos in the confirmed category.

The decline in underlying growth rate from 2001 when rhino numbers reached levels of 25-30 suggested that rhinos may have reached their Maximum Sustained Yield (MSY). Based on the MSY at 75% ECC, the initial best guessed ECC estimate of 93 rhinos (Brett 1989; Foose *et al.* 1992) had therefore reduced by about 54% (ECC of 40 rhinos). In his study, Birkett (2002) attributed this phenomenon to high inter-specific competition, where elephants, giraffes and rhinos significantly impacted habitat. A total of 56 elephants were therefore removed from the sanctuary in 2002, and recommendations to reduce densities of other competing browsers particularly giraffes were made with a postulation of attaining an ECC of 50 rhinos, which would be an increase of about 25% of this study's calculations, thus highlighting the fact that ECC are ever dynamic. It may be too early for this study to determine how this management intervention of reducing the elephant numbers has affected underlying growth rate, because it still decreased in 2000/2003, and therefore still require monitoring.

The high mortalities in 1992/95 which then reduced to 0.9% well below the acceptable <4% (Adcock 1999; du Toit *et al.* 2001), may be attributed to acclimatisation and settling down (du Toit 2001) following translocation. This is because 4 out of 5 deaths in age classes E and F were caused by drowning, fighting and capture.

4.2.1.2 Ol Jogi Game Reserve

All rhinos remained in the confirmed category mainly because their numbers were relatively fewer (≈ 12 to ≈ 22) in a relatively small reserve (50km^2). These two factors in addition to those discussed under Ol Pejeta may have led to ease in individual rhino identification, and to effective monitoring and deployment of patrols.

The higher underlying growth rates than the average 9.4% observed in relatively large rhino populations with near parity sex ratio, approximately 2.5yrs of inter-calving interval, and 1-2% mortality rates (Owen-Smith 1988; Emslie 1999; Primack 2002), was because of the small population size, where if for instance 2 females calved in a population of 5 animals, r_{max} would be 40%! However, population numbers gradually increased despite being lower than the recommended founder populations (≈ 20 animals) (Anon 1993; Brett *et al.* 2001). Thus underlying growth rate increased but only up to 1998/2001 when it declined as rhino numbers stabilised around 18-20 animals until translocation were done in 1999. Assuming this was the time the rhinos attained ECC, its MSY was therefore 15 rhinos (Brett 1989; Foose *et al.* 1992).

The 1999 translocation was an attempt to ease territorial fights and inject “new blood” into the population for genetic variability, by reducing and swapping adult males. Reasons for this translocation were not fully achieved since a fatal fight of a newly introduced male rhino occurred in 2000. This scenario was a classic example that reinforced the suggestions by Brett *et al.* (2001) that effecting new male breeding contributions in small populations is likely to be successful only if dominant male or all males are removed and replaced to minimise the risks attached to succession.

The high mortality rates, like r_{max} , between 1996 and 2001 were due to the small population size. However, their causes (fighting and nutrition), suggested that the relatively small reserve could not socially accommodate more than two dominant male rhinos, and secondly, the habitat may have been performing sub-optimally at that point in time (Adcock 1999). This calls for a home range study of the dominant bulls and habitat suitability assessment.

4.2.1.3 Lewa Downs Conservancy

Even though Lewa Downs Conservancy had all its rhinos in the confirmed category, like in Ol Pejeta Game Reserve, it had one rhino under probable category in 1998. This suggested emergence of “clean” rhinos in the population when the rhino numbers increased slightly above 20 animals. Ear-notching of 9 rhinos ear-notched in 2003, augmented the monitoring factors

discussed earlier hence improved population estimates through more credible individual rhino identification.

The initial low underlying growth rates could be attributed to the high mortalities during the same period and effects of small populations (<50 animals), because this later improved to average above the Kenya's annual meta-population growth rate target of =5% (Fig. 3.58) as number of mortalities reduced (Anon. 1993, Anon. 2003). Though density did not have significant relationship with underlying growth rate, it was positively correlated with proportion of calves in the population, implying the reserve could still hold greater numbers of rhinos, but would first require assessment of habitat quality.

The initial high mortalities were spread across different age classes mainly caused by accidents, fighting and capture. Given the small sample size in each cause of mortality, a prevalent cause could not be diagnosed for curbing. In spite of the lack of management intervention, mortalities decreased to acceptable levels. From these reasons, it could be concluded that the high mortalities were a manifestation of settling down period after translocation (du Toit 2001).

4.2.1.4 Ngulia Rhino Sanctuary

The probable estimates were first recorded in 2000 when rhino numbers were above 35 rhinos, implying proportions of "clean" rhinos increased. As seen in OI Pejeta and Lewa Downs, individual rhino identification became difficult because the proportion of "clean" rhinos increased as rhino numbers increased. Majority of rhinos in the 47% probable category in 2003 were "clean" sub-adult rhinos that separated from their ID mothers, which were being used to identify them, that is, mother-calf identification. In addition to the "clean" issue, the situation was also accelerated by two other factors which both translated to less search effort in individual rhino identification. These included: **a)** Over reliance on <10 full moon nights per year spread over four dry season months, at three artificial water holes, because normal day-time monitoring is limited by difficult-to-see through shrubs that also put the lives of monitoring staff at higher risks. **b)** Lack of reliable modern night monitoring equipment (www.nightoptics.com) and unpredictable clear skies (Nur *pers. comm.* 2004). In Etosha Namibia, for example, use of Generation II night vision equipment has been tried but rejected for not giving image of sufficient detail for reliable rhino identification work. It therefore meant that if an animal was not sighted within these few nights, it was unlikely the animal could be positively identified until the following year, hence "clean" rhinos and subsequently the numbers in the probable category increased rapidly, unless this was an effect of the ongoing DEFRA Darwin training of rhino officers in rhino monitoring, which then made them become more rigorous in rhino identification and classification of estimates from 2003.

The following conclusions can be draw from the results: **a)** there are chances that rhino numbers at Ngulia have been underestimated or overestimated, **b)** It is very likely neo-natal mortalities occurred and remained un-detected by day-time monitoring staff, **c)** it is postulated that the population would have similar proportion of guesstimates in 2004 as there were probables in 2002,

unless an urgent ear-notching exercise is implemented, and **d)** given a, b and c, the use of rhino population performance indicators would be less meaningful because >20% rhinos breeding history would have been lost by 2004.

While the population numbers steadily increased, the underlying growth rate steadily decreased. Basing calculations on the linear slope of underlying growth rate ($y = -1.74x + 20.16$; $R^2 = 0.88$) over 1992-2003 (Fig. 3.30), it was projected that the 2001/04 underlying growth rate would be 2.6% per annum (not considering ramp shape curve of K-selected species, McCullough 1992), a figure that would be well below Kenya's meta-population target of $\approx 5\%$ per annum. This inverse relationship between underlying growth rate and rhino numbers from 1992 to 2003 (Fig. 2.9 and Fig. 3.30) depicted a marked density dependence as was also observed in Mkhuzi black rhino population in South Africa (Emslie 2001b), thus showed an overdue off-take or translocation.

Lowering of rhino densities to improve underlying growth rate were underpinned by the rapidly decreasing trends in growth rates and highly significant linear relationship and negative correlations between rhino density and underlying growth rate. Calculations based on the linear equation (Fig. 3.35) showed that to maintain the average underlying growth rate of about 8% recorded for the period 1992-2003 (Fig. 3.58), rhino densities would be maintained at 0.63 rhinos/km². This translated to an ECC of 39 rhinos within the 62km² sanctuary, that is, an MSY of 30 rhinos (75% of ECC), which implied the ECC of 62 rhinos estimated by Brett (1989) and Foose *et al.* (1992) had reduced by 62.9%. Brett and Adcock (2002) came to similar conclusions, which they attributed to the deteriorating habitat condition caused by impact of inter-specific competitors mainly the high density of elephants (Fig. 4.1).

Urgent management interventions are therefore required for Ngulia rhino sanctuary: **a)** reduction of herbivore densities within the sanctuary to avoid similar situations as occurred in northern Hluhluwe population in South Africa in 1961, when 46 black rhinos died mysteriously at a time when rhinos were >1.03 rhinos/km² and the area had extensive selective clearing of black rhino food (Hitchins 1968; Emslie 1999; Emslie 2001c). **b)** Implementation of recommendations by Brett and Adcock (2002), which included sanctuary expansion, significantly reducing herbivore densities, census of the animals in the sanctuary, and eventual establishment of rhinos into Ngulia valley (IPZ), should be expedited. **c)** An ear-notching exercise is crucial to improve rhino identification and tracking of their breeding history. **d)** Analysis of sighting and re-sighting data and improvement of night census techniques are needed to improve population estimate.

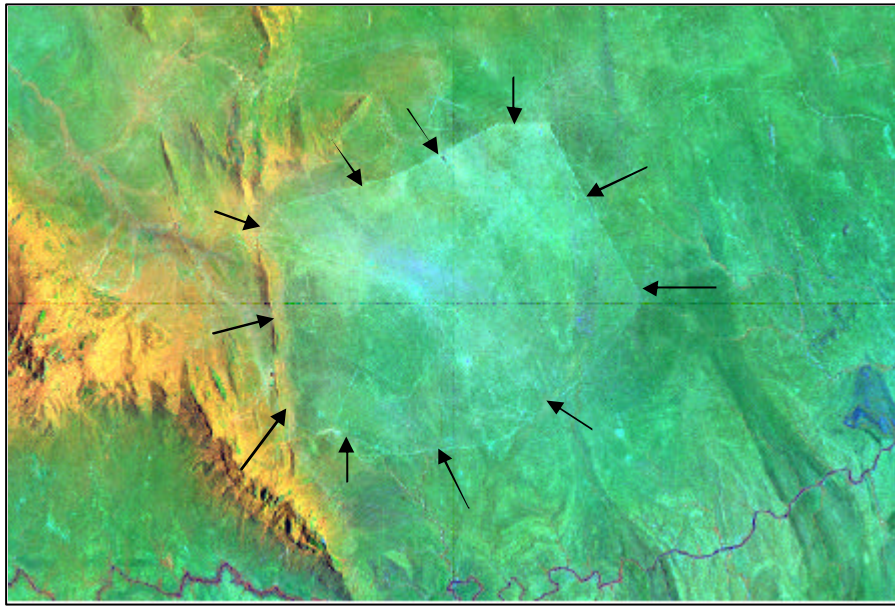


Fig. 4.1: A satellite image taken in 2001, of Ngulia rhino sanctuary showing extent of vegetation degradation due to high density of browser species. The arrows point to the fence boundary of the sanctuary. Image courtesy of Keryn Adcock through DEFRA Darwin Initiative funding.

4.2.1.5 Nairobi National Park

Difficulties in identifying individual rhinos became evident when numbers exceeded 50 animals. Probables turned into guesstimates, but their sum total remained fairly constant despite the increase in the total rhino numbers. This suggested that either **a)** the rhinos in these categories were double counted when a figure of 50 rhinos was attained or, **b)** the guesstimates were elusive animals that reside in difficult-to-monitor areas of the park, e.g. within the park's forest or, **c)** some of these rhinos were recognised by subtle features which were lost when experienced observers were transferred or retired. The third reason highlights the importance of keeping good quality and using rhino master files instead of relying on individual people for rhino identification. This is currently being improved through a DEFRA Darwin project in Kenya (Amin *et al.* 2004).

Underlying growth rate gradually decreased despite increase in numbers and translocating 41 rhinos out of the park, implying these translocations may not have fully achieved the primary objective of improving underlying growth rate of donor population. However, it may have maintained a 5% odd growth rate with 2000/2003 declining due to increasing densities (Fig. 3.45b). This was evident by the significant negative linear relationship between underlying growth rate and rhino density, and significant negative correlations between density and proportion of calves in the population. To maintain Nairobi's average growth rate of 5.5% recorded over 1992-2003 (Fig. 3.58), a figure that was also marginally above the Kenya's meta-population target of =5% per annum, rhino densities should be kept at 0.54 rhinos/km² (Fig. 3.45b) from the current 0.60 rhinos/km² or remove 5% per annum on average (Goodman 2001). This translated to an ECC of 63 rhinos within the 117km² national park which an meant MSY of 47 rhinos (75% of ECC) as was also calculated by Brett (1989) and Foose *et al.* (1992).

Interestingly annual growth rate from 1993 to 2003 was pretty consistent at around 5% (Fig. 3.40). Average removal over this period also came to around 5% (i.e. average of 70 with 41 = 3.42 per year or 4.9% odd). Thus the 5% growth following 5% removals is exactly what one would expect given set percentage harvesting theory (Goodman 2001). This graph supports KWS's policy of removals, and highlights the need to continue at 5%+ removals to maintain at least 5% growth.

A careful monitoring of mortality trends and investigation of the prevalent cause would be necessary since mortalities gradually approached the maximum =4% per annum. Secondly, the densities of other competitors and habitat quality should be assessed, as these could be possible factors in addition to rhino densities that limited growth rate.

4.2.1.6 Lake Nakuru National Park

Over reliance on experienced observers and lack of keeping individual rhino identification records could potentially deteriorate quality of rhino information. This was evident in Lake Nakuru National Park when data showed higher guesstimates in 1998 than the probable of 1997 because the most experienced observer and also the head of the monitoring team became ill (Fig. 3.48). Like in Nairobi National Park, the sum total of probable and guesstimates remained fairly constant except for the period 1997-1998 despite increase in total rhino numbers which meant that; **a)** track history of some animals were lost when the most experienced observer became ill in 1998, **b)** the guesstimates could be elusive animals that reside in difficult-to-monitor bushes, and **c)** indeed rhinos turned "clean". Loss of history of some animals was evident in two occasions in 2003 when two adult rhinos were poached but to date have not been identified (Mulama and Okita 2004). Animals turning "clean" were also evident in 2002-2003 during an ear-notching exercise of 21 rhinos, when a "clean" rhino of age class E with a "clean" mother was notched. These incidences implied the park could be holding more rhinos than are actually estimated and hence the need to classify data properly and use RHINO v.2 (Emslie and Amin 2001) to estimate population numbers. However, the immediate important strategy would be to alleviate over reliance on experienced observers by setting up master files with clear identification details that include even the subtle features.

The gradual increase in underlying growth rate between 1996/99 and 1998/2001, which decreased in 2000/2003 could be an indication that the park was close to ECC in 2002 when the total sum of confirmed and probable reached 67 rhinos. A figure exactly equal to Brett (1989) and Foose *et al.* (1992) ECC estimate. However, given the significant positive correlations between density and proportion of calves, and percentage of females calving per year, it may be postulated that the park could hold higher black rhino densities. However, bush encroachment of *Tarchonanthus camphoratus*, an invasive non-palatable rhino browse accelerated by >2500 buffaloes, c.45 white rhinos and hundreds of other grazers (Roques *et al.* 2001; Mwasi 2002; Anon. 2003b) may reduce ECC. Similar situation of encroachment of invasive non-palatable species was also observed in Nairobi park, where *Lantana spp.* is spreading fast. Only bush encroachment of palatable rhino browse would improve ECC, as was observed in Umfolozi Park in South Africa when black rhino

densities increased significantly from 0.29rhinos/km² in 1991 to 0.46rhinos/km² in 1994 (Adcock 2001).

Even though mortality rates were within the acceptable =4% per annum, predation of one rhino calf by lions and one rhino fatal fight, both in 2002, were indications of the potential risks of rhino calves to high predator densities and social carrying capacity situations, respectively. The former was controlled in 2003 when KWS removed about 30 lions, some of which had turned man-eaters (Anon. 2003b; Kahihia *pers. comm.* 2003). The latter was evidenced by the skewed sex ratio (<1F:1M) (Fig. 3.53), as is discussed in section 4.2.3. Despite the low sample sizes, these causes of mortalities would still require continuous monitoring.

4.2.2 Population structure and reproduction within sanctuaries

4.2.2.1 OL Pejeta Game Reserve

Generally, the reproductive performance indicators in OL Pejeta would be rated “average”. However, given the small sample size, continuous monitoring would still be required.

4.2.2.2 OL Jogi Game Reserve

The negative significant correlation between skewed sex ratio (>1F:1M) with proportion of calves in the population meant sex ratio was not favourable to natality, in spite of the small population size and birth lags¹³. Calculations based on the 31% proportion of calves (Fig. 3.16), 24% proportion of sub adults (Appendix 6), the minimum adult sex ratio of 2.43F:1M (Fig. 3.13), and the range of 12-30 cumulative rhino numbers (Fig. 3.11); showed that 1.57 to 3.94 adult males constituted effective breeding population between 1992 and 2003. The fact that there was a dominant bull during this period (Kimani-Kuria *pers. comm.* 2004), meant that N_e (effective population size) was 6 to 8, which was indeed lower than the actual population size, and thus inbreeding could not be ruled out unless investigated.

It is therefore recommended that alongside a genetic variability study, males should also be exchanged per generation, but noting the risks observed that were attached to succession and fatal fights between potential successors.

4.2.2.3 Lewa Downs Conservancy

The increase in sex ratio from <1F:1M to approximately 1F:1M favoured the underlying growth rate since adult sex was significantly correlated with proportion of calves in the population, which was positively correlated with underlying growth rate. This underscored the fact that parity or higher sex ratio may be optimum for optimum underlying growth rate in K-selected population (Tylor 1983) under favourable conditions of good habitat and prime breeding ages. Thus, calls for careful monitoring of the current population and regulation if necessary.

¹³ If a bunch of females have calves in year t , because of the long conception period (16 months), they can not have calves again in year $t+1$ even if habitat is suitable or precipitation is high. Chances of synchronized breeding are also high in small populations (Adcock 1999).

4.2.2.4 Ngulia Rhino Sanctuary

The positive correlations between sex ratio and proportion of calves in the population and with percentage of females calving per year underscored observations made in Fig. 3.31 that more females than males were recruited to the population. This was evident in the no significant linear relationship between sex ratio and underlying growth rate, which further highlighted problem of declining performance.

Other reproductive performance indicators were generally poor, signalling sub optimally performing habitat (Brett and Adcock 2002). Interesting to note was the excellent age at first calving but very poor inter-calving interval, which suggested possibilities of neonatal deaths or predation that went unnoticed by monitoring team. Given these circumstances, abortion could also not be ruled out (Adcock 1999). The relatively high growth rates even in the recent years, 2000-2003 (Fig. 3.58) and the increases in population numbers have therefore for sometime hoodwinked managers to think population performance was optimum yet in reality it was declining as evident in other performance indicators. This scenario highlighted the benefits of status reporting that would give an overall picture of performance as well as highlight areas to concentrate efforts on, for example refining confidence in population estimate.

4.2.2.5 Nairobi National Park

Like in Ol Jogi, and Lewa, it was again evident that skewed sex ratio can limit the reproductive potential of a K-selected species, when in Nairobi a significant linear relationship was observed between sex ratio and underlying growth rate (Fig. 3.45a). Basing calculations on this linear relationship and that between densities and underlying growth, a parity sex ratio would yield an annual underlying growth rate of 8.24% in a density of 0.47rhinos/km² (ECC of 55 rhinos in the 117km²). Average of the two ECCs by sex ratio and rhino density (as discussed separately in section 4.2.1.5) would yield an ECC of 59 rhinos, a figure that again was marginally close to the ECC estimate of 60 rhinos (Brett 1989; Foose *et al.* 1992).

While at Ngulia where >1F:1M sex ratio was **positively** correlated with proportions of calves and the percentage of females calving per year, Nairobi National Park which had similar skew, had its sex ratio **negatively** correlated with proportions of calves in the population and underlying growth rate. An explanation for this difference was evident in the selection criteria of the 41 rhinos translocated over the period (Fig. 3.1) where majority of the translocated rhinos were of age classes E and in early age class F (Oloo and Okita 2000). This meant the donor population was left with older females and very old males and very young males which contrary to the expectations at the time of translocation could not breed at their full potential. Mulama and Okita (2004) estimated >70% of breeding age females in Nairobi National Park to be >25years old - a relatively old age for optimum breeding (Adcock 1999). To avoid skewing sex ratio and age structure by translocation while at the same time improving genetic variability, the best strategy would be to

translocate mother and calves >2yrs old, as was observed successful in Malilangwe, Zimbabwe (Brett *et al.* 2001)

4.2.2.6 Lake Nakuru National Park

The positive correlation between sex ratio and underlying growth rate further emphasised the importance of female biased sex ratio, because the closer the sex ratio approached 1F:1M, the higher was the underlying growth rate. Sex ratio remained biased to males which meant more males than females were recruited into adult population. This phenomenon has also been observed in some enclosed black rhino populations in South Africa (Adcock *pers. comm.* 2000) and could probably be due to unexplained phenotypic or genotypic factors or chance. Nevertheless, male-skewed progeny sex ratio among prime-aged females (Saltz and Rubenstein 1995) influenced recruitments of more males than females as Saltz *et al.* (2000) observed in the re-introduced Asiatic wild ass (*Equus hemionus*) in Negev Desert, Israel. If this explanation holds for black rhinos, then it would be imperative to remove excess males to improve female recruitment and subsequently underlying growth rate.

4.2.3 Rainfall with demographic and reproductive parameters within sanctuaries

4.2.3.1 OL Pejeta Game Reserve

There were no signs of lag effect of rainfall on underlying growth rate, and therefore the significant increase in underlying growth rate that occurred three years after the El Niño events could have been by chance, or by other factors other than rainfall. In addition, the 18.9% co-efficient of rainfall variation, underscored the fact that over the typical rainfall range for savannah vegetation of 400-800mm, the coefficient of variation of rainfall is typically $\pm 25\%$, which is also just under the critical threshold of $>30\%$ for a significant effect on animal biomasses (McNaughton 1979, 1985; Owen-Smith 2001).

4.2.3.2 OI Jogi Game Reserve

Rainfall did not seem to have significant relationship with demographic and reproductive parameters. The significant negative correlation between rainfall and underlying growth rate could have been caused by the small population size, skewed sex ratio, and birth lags but not rainfall.

4.2.3.3 Lewa Downs Conservancy

The significant positive correlations between rainfall and percentage of females calving per year, which was also correlated with the underlying growth rate and the observed lag effect of rainfall, though to an unanticipated negative side, implied that Lewa Downs had the potential to hold greater numbers of rhinos in a higher precipitation and better habitat. By inference, this meant it would be critical to assess Lewa Downs' habitat suitability and rhino body conditions (Adcock 1999).

4.2.3.4 Ngulia Rhino Sanctuary

Despite coefficient of rainfall variation (42.7%) due to El Niño events being higher than the critical threshold of >30% (Coe *et al.* 1976; East 1994; Owen-Smith 1990), it did not show any significant relationship with underlying growth. Rainfall however was positively correlated with percentage of females calving per year, and at the same time showed signs of 2 to 2.5yrs of lag effect of rainfall on underlying growth rate. These may have suggested that indeed, habitat has been severely impacted by high densities of herbivores (Brett and Adcock 2002) that despite high coefficient of rainfall variation, the vegetation could not recover to significantly improve underlying growth rates.

4.2.3.5 Nairobi and Lake Nakuru National Parks

The very little signs of rainfall's lag effect on underlying growth further underscored that fact that coefficient of rainfall variations below the critical threshold of >30% in a typical savannah with 400-800mm rainfall may not significantly affect underlying growth rate. The slight increases in underlying growth rates particularly in Nairobi park that coincided with the expected time to observe lag effects of rainfall could have therefore been due to reasons other than rainfall, for example, the 1999 rhino removals or chance.

4.3 Population demography and reproduction across sanctuaries

"Averaging out" population performances can mask individual population performance in meta-population management (Emslie 2001a). This was evident when only mortality rate was significantly correlated with density, yet individual populations had significant relationships between reproductive and demographic parameters. Secondly as was seen in individual populations, some exhibited significant linear relationships between sex ratio and underlying growth rate and between density and underlying growth rates. These were not evident when "averaged out".

Similar conclusions were reached at when sanctuaries were grouped by their similarity rainfall amounts, and thus further reinforced the importance of status reporting that highlights particular issues in within populations independently (e.g. table 3.18).

4.4 Comment on the quality and quantity of rhino monitoring data

The current system of data recording in rhino areas is relatively sound, and provides the core information needed to determine the status of Kenya's rhino. However this study has importantly highlighted the poor quality of some past data. Significant time was therefore spent during the project validating, cleaning and updating this historical data which otherwise would have comprised the accurate assessment of population performance and dynamics in several areas. The following elements and recommendations will therefore help to ensure the quality of data necessary to undertake such future comprehensive analyses of the entire Kenyan rhino populations.

4.4.1 Rhino monitoring training

Under the Darwin Initiative, 20 rhino officers from the rhino reserves have been trained as accredited rhino monitoring instructors (based on the AfRSG course Adcock and Emslie 2000).

The instructors have conducted initial basic training of park staff with support from the project officers. It is the responsibility of these instructors to ensure that all the rhino monitoring field staff in their reserve are properly trained and tested. The training needs to be undertaken on a regular basis to ensure that the monitoring standards are maintained at a high level and that new staff are also adequately trained quickly. An up-to-date training chart should also be displayed on the rhino office wall so that all staff can review their progress. This should also be included as part of the monthly report to enable KWS rhino programme office gauge progress. Regular auditing in the field and providing support will ensure that staff are being adequately trained and evaluated.

4.4.2 Updating rhino master identification files (identikits)

The Darwin Initiative project has set-up master rhino identification files in each reserve. The ID files are to be used to quality control rhino sighting data recorded in field sighting forms and correctly classify the sightings into **a)** first class ID sighting with ID number assigned; **b)** first class clean sighting and **c)** incomplete sighting. The files will also help to capture and transfer the knowledge/skills of the highly experienced key observers which otherwise would be lost during transfers or retirements. The photographic sequences kept in the files will enable changes in the animals to be tracked over time and allow Kenya to develop guidelines on horn and body size appearance with rhino age thus improving the accuracy of ageing of animals in future. It is therefore essential that the information in the files is accurate and kept up-to-date by the data controllers (key accredited observers) who have been trained to maintain these files. This needs to be improved in several areas. It is important that all rhinos are classified and filed according to the following categories: **1)** Identifiable always by all rangers (clear ID features, ear notches mainly); **2)** Identifiable based on more subtle features (but defensible features, not location or behaviour) by key observers, it is essential evidence or really good drawings or photos are kept in the file; **3)** Possibly identifiable but insufficient evidence on file to justify ID; and **4)** Definite clean animals. It will also be useful to store duplicate files at headquarters in case of fire or damage.

4.4.3 Filling field sighting forms and data quality control process

The process of completing and validating field sighting forms is being improved in all reserves through the Darwin Initiative and field part of the work undertaken in this study. The rhino monitoring instructors must ensure that the rangers are adequately trained in completing sighting forms correctly. Many of rangers require a lot of practice in drawing ID features. The use of high-resolution digital cameras will help in improving this process.

Quality control procedures have been set up in most reserves by the Darwin Project. The data quality control process is now being improved through field support visits and monthly reports. To ensure a high data quality standard is maintained, regular field visits by HQ rhino scientists are essential and it is recommended that the Rhino Programme gives the highest priority to this activity.

4.4.4 Dealing with “clean” rhinos

In the past, the field rangers have concentrated on the ID animals and often neglected collecting information on the clean animals. The validation of rhino sightings was also inadequate and the less experienced rangers were often incorrectly identifying animals with subtle ID features even sometimes basing their decisions on unreliable features such as territory and behaviour. This was amplified due to high staff turn over and the loss of vital knowledge of experienced observers. This has been problematic as there is a risk of inflating reserve totals with duplicate “clean” rhinos which have been given different names.

On-going training, accurate filling of sighting forms and the use of up-to-date master ID files for validation will significantly improve this situation. It is recommended that ear-notching programmes are conducted on a regular basis in enclosed populations and if possible entrenched into the KWS rhino policy. Having clearly identifiable rhinos makes monitoring easier, more transparent, and in the long run allows quality information to be maintained for decision making. Notching events also boost interest and motivate rhino monitoring staff.

4.4.5 Estimating population sizes

The use of mark-recapture methods would provide better population estimates (with confidence intervals) in areas where there are “clean” rhinos and where known rhinos are not all seen within a year. The population estimation software, RHINO v.2 (Emslie *et al.* 1993; Emslie and Amin 2001), is already being successfully used in a number of parks in Southern African rhino range states (AfRSG 2004). The rhino senior scientist and the author have been trained in the use of this software (undertaken during this MSc project) and will be applied to sighting data from several reserves such as Lake Nakuru N. Park, Nairobi N. Park, during the production of national status report following this MSc study. This work will also help in refining some of its assumptions, e.g. equal sampling effort.

4.4.6 Population history and performance table

Each area should have a complete population history table (e.g. Appendix 7), and put in the main rhino office at the sanctuary and headquarters. These can be updated whenever births, deaths, or translocations occur, and summarised at the end of each year. These tables would allow rhino monitoring staff, wardens, visiting dignitaries, and donors to get a rapid overview of the past and present rhino status in an area.

4.4.7 Patrol/Surveillance effectiveness

Field rangers on patrols are meant to regularly log their position using a GPS receiver. These are then entered in to the KIFARU[®] database system and plotted on the park GIS map. This information along with individual rhino sighting positions, information on illegal activities such as snares, indirect rhino sightings¹⁴ is very useful for planning daily patrols. It is therefore very important that this information is collected and effectively used in each reserve.

¹⁴ Indirect sightings such as dung, spoor etc. particularly in areas such as Aberdares N.P. where rhinos are very difficult to

4.4.8 Kenya black rhino information management system (database) KIFARU[®]

This is an excellent system, user friendly and quite elaborate. However, to make KIFARU[®] more credible and avoid “GIGO” (Garbage In Garbage Out), it is critical to augment it with the seven issues highlighted above. Besides these, training in use of computers and monitoring equipment, regular updates of computer hardware and software, and safe archiving of information are mandatory.

Thanks to all different donors, institutions and individuals who are currently assisting to improve these processes.

observe due to the thick vegetation and difficult terrain.

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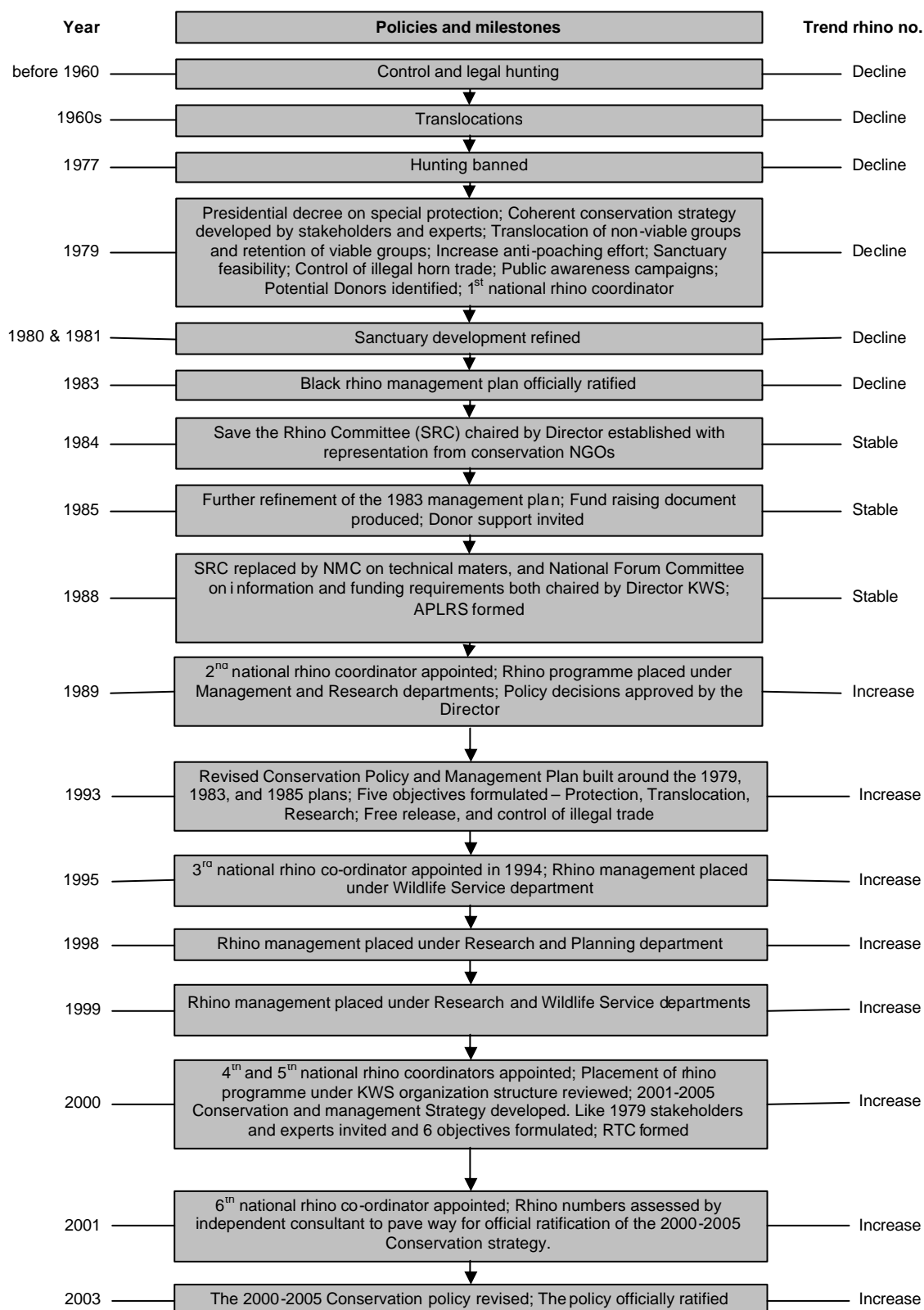
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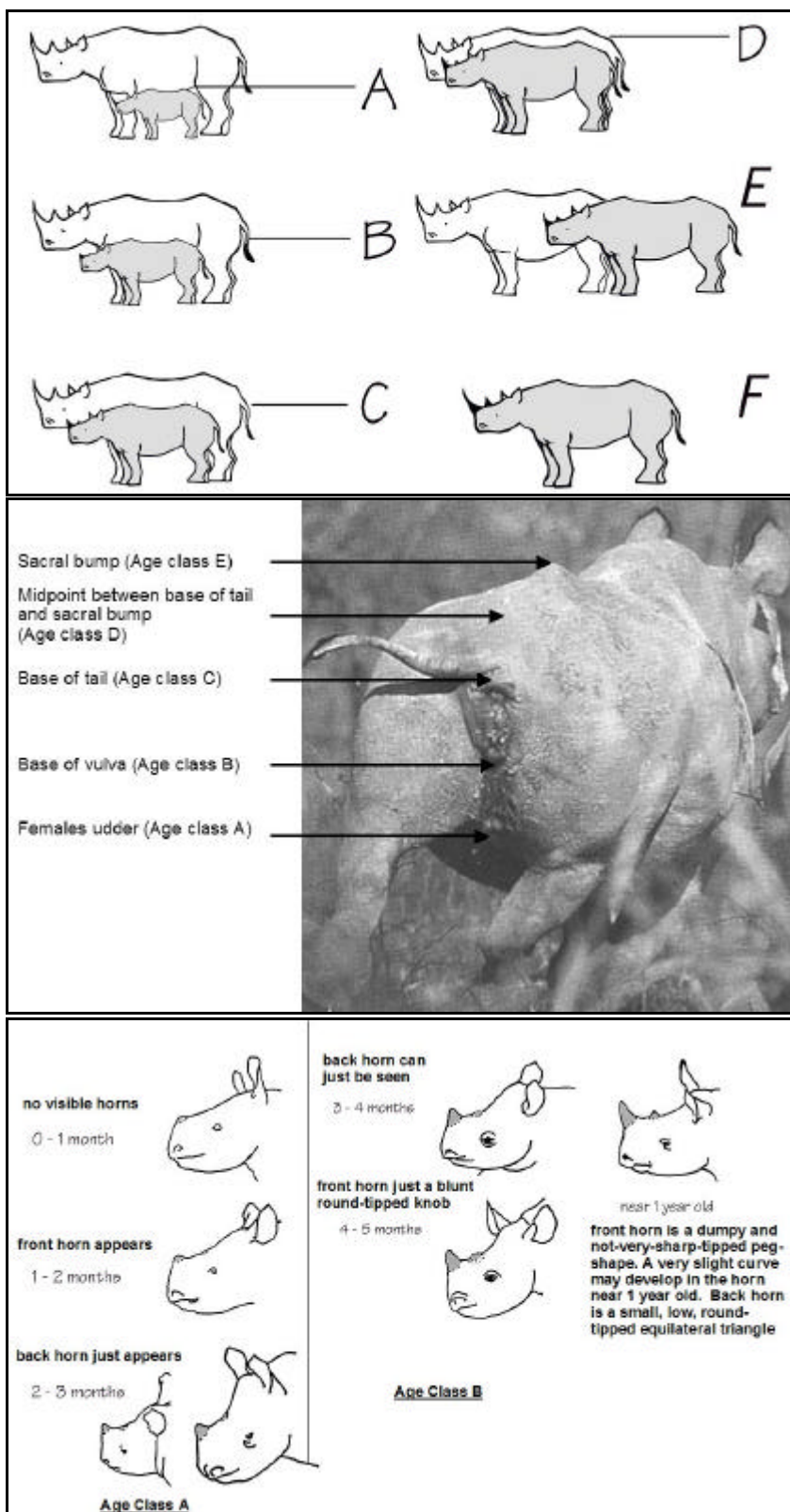
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Appendix 1: Summary of the policies and milestones in rhino management in Kenya, 1960-2003 summarised from Leader-Williams *et al.* (1993).



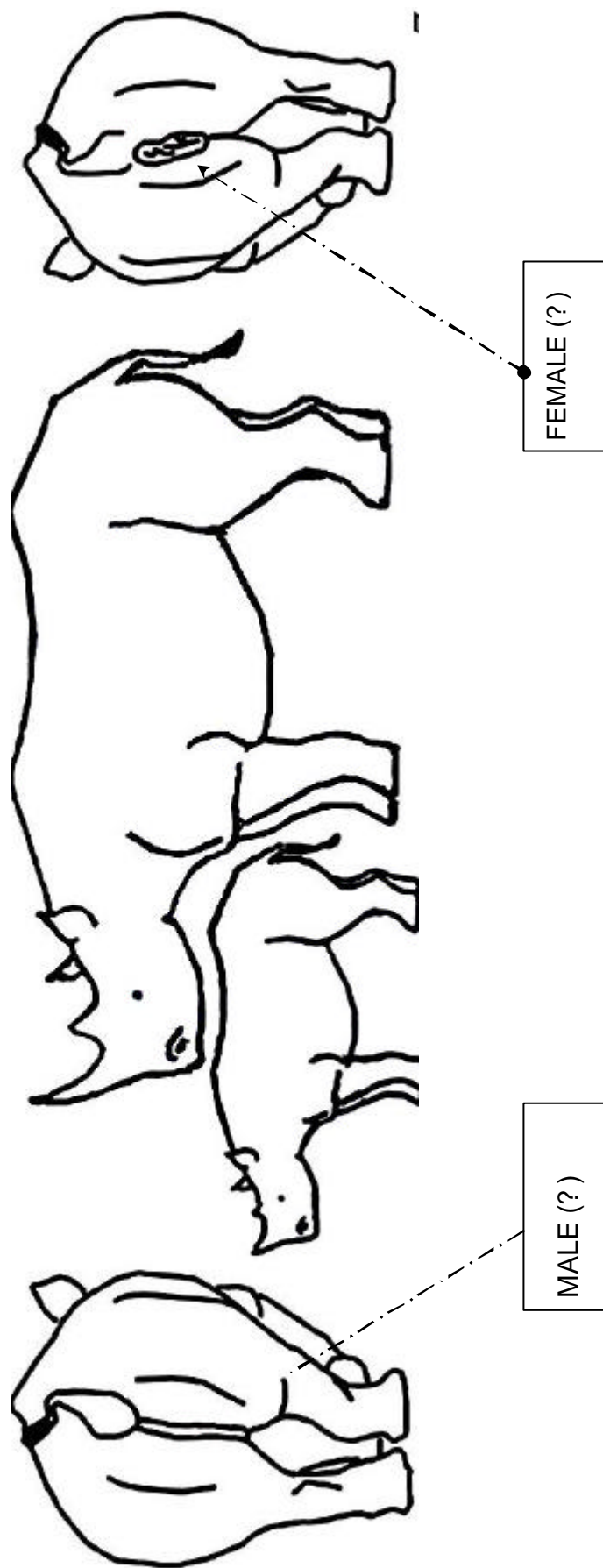
Appendix 2: Ageing and sexing black rhino. An extract from Adcock and Emslie (2000)

(i) Ageing black rhino



N/B: Calf may not always be next to its mother so that their relative sizes can be compared. A sub-adult may have left its mother and be seen on its own, or with other sub-adults. **With experience and paying proper attention, such animals can be aged approximately.**

(ii) Sexing black rhino



Appendix 3: Black rhino data collection and handling protocols. Summarized from Mulama *et al.* (2003).

The aim of rhino monitoring is to obtain information to manage rhino populations wisely. This information is aimed at increasing overall rhino numbers as fast as possible, to meet the goals of national conservation plan. Specifically, monitoring data collected by the individual identification approach, provides estimates of population size, population age and sex structures, calving rates (female breeding performance), and age / sex specific mortality rates; as well as rhino distribution and movements. It is therefore essential that the monitoring programme has properly skilled and motivated observers and a system of strict control of data quality.

A) Data collection protocols

The following basic guidelines MUST be followed by all monitoring staff.

1) Preparation

Here all equipment necessary for monitoring are put in place following a checklist.

2) Patrol and tracking

Standard procedures for patrol and tracking are followed to locate rhinos (Adcock and Emslie 2000).

3) Recording of indirect rhino sightings

Upon sighting of a rhino sign (indirect sightings such as spoor, midden, dung scrap, browsed vegetation) details including location (GPS, map grid cell or block) especially in areas where visual body sighting is difficult i.e. Aberdares National Park and Tsavo East National Park are recorded. This information is then written in the patrol and sighting field notebook.

4) Recording of direct (visual) rhino sightings

Complete details on how to fill in the sighting form (Appendix 4a) can be found in (Adcock and Emslie 2000). However some important rules include:

- a) Sighting of ID¹⁵ animals: Details of ID animals are accurately completed in field sighting form approximately once a month. For all other animals the sighting form is always completed. Very experienced (Key) observers who can recognize clean animals by subtle differences in their features complete in a good accurate sighting form of the animals once a month.
- b) Sighting of CLEAN¹⁶ rhinos: Always a sighting form for these animals is completed, and equal attention as for the ID animals is given to them.

¹⁵ An animal which has clear individual identification features such as unique horns, easily seen unique body marks, tail missing or ear notches/tears etc and is recognized by all observers.

¹⁶ An animal that lacks distinctive identification feature(s) on the body that can be used by any observer to identify it. It is the opposite of ID animal, but may occasionally be recognised by very experienced observers using subtle features.

- c) Sighting of calves: Calves up to 1 year in most cases are clean and are recognized by presence of mother so for these calves it is not necessary to fill in a separate sighting form.
- d) Sighting of group of rhinos: If more than one rhino is seen in a group then a set sequence (e.g. left to right) is followed. Also if there is more than one observer then each observer concentrates on a separate animal to maximize the chance of collecting all the information on the animals.
- e) Taking photos: Where possible several good photos of the animal showing distinguishing features are taken.
- f) Observing rhinos: Binoculars are used to avoid getting too close therefore disturbing the animal(s).

5) Recording of animal carcass sightings

Information on any carcasses of large animals (impala or above) observed during patrol are recorded. This information includes time, location (GPS or grid cell), type of animal and approximately how long it has been dead; and any specific notes. Analyses of this information help to make patrols more effective.

6) Recording of patrol information

Patrol movements: For foot patrols, GPS or grid location approximately every kilometer or half an hour traveled is recorded. For vehicle patrols, GPS or grid location approximately every 15-20 minutes traveled.

Other information: number of rangers on patrol, start time, end time and date, patrol method (operational, fixed etc.) and type (foot, vehicle etc.) and areas patrolled are also recorded.

7) Looking after and submitting field data

All the information collected is submitted on return to base or at the earliest opportunity, for quality control checking and entry into KIFARU[®].

B) Data quality control protocols

These procedures are very important for ensuring that the data from the field is of the highest quality. The basic steps are as follows:

Step 1: Field recording forms handed in and checked

- a) Field sighting forms and log books are formally handed to the assigned rhino data controller.
- b) The data controller carefully checks all information including sighting forms where completed. The rhino IDENTIKIT¹⁷ is used in this verification process.
- c) A debriefing session is then undertaken by the data quality controller / Officer-In-Charge to clarify and correct any mistakes. (Note that where necessary refresher

¹⁷ A set of individual rhino identification and history details put together in the form of descriptions, sketches and photographs. Summary of the rhino's sighting details are also included.

training MUST be undertaken at the earliest opportunity. It is important to ensure all rhino staff are at the same level of understanding with regards to data collection. Rangers should also be encouraged to become key observers).

Step 2: Rhino data controller classifies sightings

Based on the debriefing of rangers and examination of the field recording forms and log books, the sightings in the field forms are classified into incomplete, 1st-class (complete) ID or 1st class CLEAN sightings. (The ranger's own classification of a sighting may be re-classified in some cases). The Rhino data controller enters the ID number where applicable and initializes the record (and dated) in the Rhino Sighting Logbook (Appendix 4b) and where completed on the field rhino sighting form.

Step 3: Data is then stored

- a) All rhino sightings are correctly entered into the rhino logbook and this information is then entered into KIFARU[®].
- b) The sighting number automatically generated by the KIFARU[®] is written in the rhino logbook record and completed onto each field sighting form for that sighting.
- c) For calves seen with the mother, the same computer sighting number is written on both the mother and calf(s) sighting forms.
- d) 1st-class field sighting forms are then stored in the field sighting file under the ID rhino's ID number/name, or under the CLEAN rhino section of the file for future reference.
- e) Incomplete sightings which contain partial information on potentially important ID features can also be stored under the "incomplete" section of the file. Where desired, incomplete sightings with little / no useful identifying information are logged and then discarded (neither ears nor body nor horns seen /drawn well).
- f) An Individual Identikit page is opened up for any new identifiable rhino (e.g. a previously clean rhino with a newly torn ear).


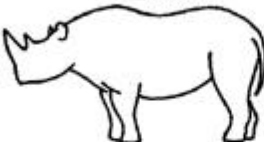

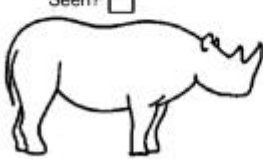

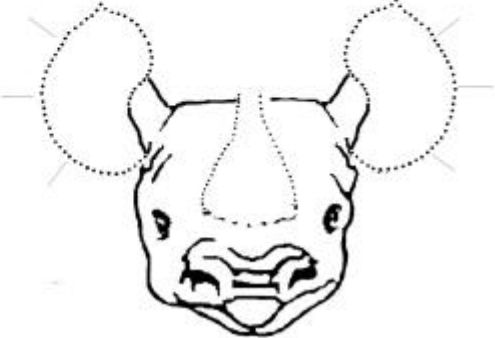
Patrol information (including movements) and any carcass sightings are also correctly entered into the KIFARU[®] by the data quality controller / system operator.

The Rhino logbooks are securely kept as they contain confidential information.


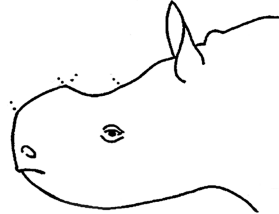
Appendix 4a: The rhino sighting form and example of identification diagrams

i) Sighting form*

Front page

<div style="display: flex; justify-content: space-around;"> <div style="text-align: center;"> <input type="checkbox"/> Seen?  </div> <div style="text-align: center;"> <input type="checkbox"/> Seen?  </div> </div> <div style="display: flex; justify-content: space-around; margin-top: 20px;"> <div style="text-align: center;"> <input type="checkbox"/> Seen?  </div> <div style="text-align: center;"> <input type="checkbox"/> Seen?  </div> </div>	<div style="text-align: right; font-size: small;">  BLACK RHINO IDENTIFICATION FORM KENYA WILDLIFE SERVICE </div> <div style="text-align: right; font-size: x-small;"> dd mm yy Rhino area _____ Date ____/____/20____ Observers _____ Time (24hrs) _____ Location (Area/Block No.) _____ GPS Location: UTM Eastings: <table border="1" style="display: inline-table; border-collapse: collapse;"><tr><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td></tr></table> UTM Northings: <table border="1" style="display: inline-table; border-collapse: collapse;"><tr><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td><td style="width: 20px; height: 15px;"></td></tr></table> </div> <div style="display: flex; justify-content: space-between; margin-top: 10px;"> Seen? <input type="checkbox"/> Seen? <input type="checkbox"/> </div> <div style="text-align: center; margin-top: 20px;">  </div>												




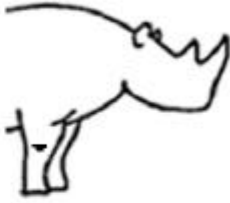
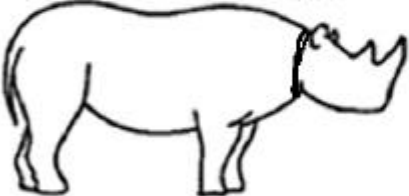




Back page

<table border="1" style="width: 100%; border-collapse: collapse; font-size: x-small;"> <tr> <td style="width: 10%;">Total :</td> <td style="width: 10%;"></td> <td style="width: 10%;">A (age)</td> <td style="width: 10%;">B (age)</td> <td style="width: 10%;">C</td> <td style="width: 10%;">D</td> <td style="width: 10%;">E</td> <td style="width: 10%;">F</td> </tr> <tr> <td>Male</td> <td style="text-align: center;">♂</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Female</td> <td style="text-align: center;">♀</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Unknown</td> <td style="text-align: center;">?</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> </tr> </table> <p>Notes: _____ _____ _____</p>	Total :		A (age)	B (age)	C	D	E	F	Male	♂							Female	♀							Unknown	?							<div style="margin-bottom: 10px;"> Sex: (if seen) <input type="checkbox"/> ♂ <input type="checkbox"/> ♀ <input type="checkbox"/> ? UNKNOWN </div> <div style="margin-bottom: 10px;"> Age: <table border="1" style="display: inline-table; border-collapse: collapse; font-size: x-small;"> <tr> <td style="width: 20px; height: 15px; text-align: center;">A</td> <td style="width: 20px; height: 15px; text-align: center;">B</td> <td style="width: 20px; height: 15px; text-align: center;">C</td> <td style="width: 20px; height: 15px; text-align: center;">D</td> <td style="width: 20px; height: 15px; text-align: center;">E</td> <td style="width: 20px; height: 15px; text-align: center;">F</td> </tr> </table> </div> <div style="margin-bottom: 10px;"> Period observed: _____ (min.) Distance: _____ (m) </div> <div style="margin-bottom: 10px;"> Binocs?: Y/N Disturbed?: Y/N </div> <div style="margin-bottom: 10px;"> Lighting: _____ </div> <div style="margin-bottom: 10px;"> Body Condition Score 1 _ 2 _ 3 _ 4 _ 5 (1 to 5 incl. 1/2 scores) </div> <div style="display: flex; justify-content: space-around; margin-top: 20px;"> <div style="text-align: center;">  <p>Black Rhino</p> </div> <div style="text-align: center;">  <p>Black Rhino</p> </div> </div>	A	B	C	D	E	F
Total :		A (age)	B (age)	C	D	E	F																																
Male	♂																																						
Female	♀																																						
Unknown	?																																						
A	B	C	D	E	F																																		

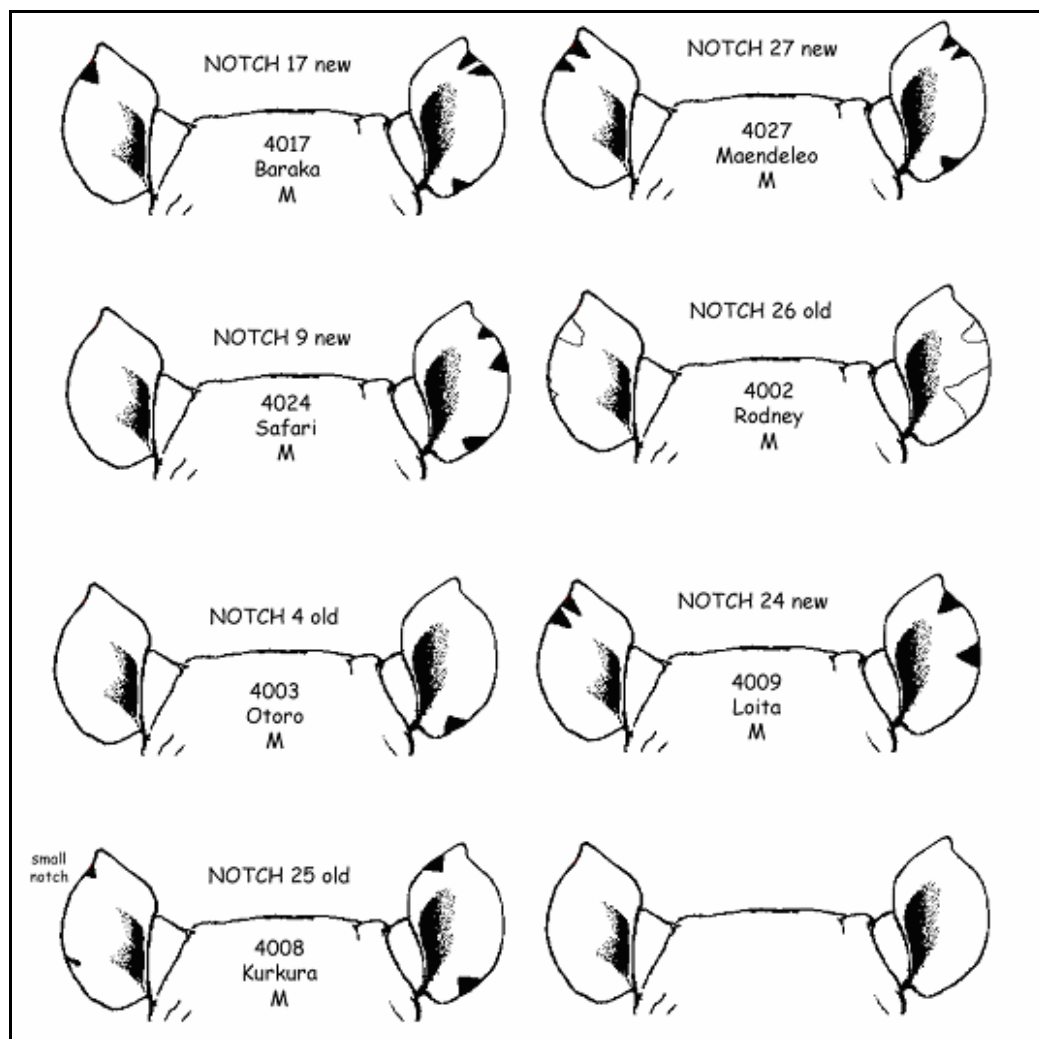
*Note: The actual size of this form is a folded A5 sheets, stapled together to form a booklet that fits into the side-pockets of the monitoring staff. A completed form is plucked out of the booklet and submitted for data control and quality check.

ii) Examples of identification diagrams

ABERDARES NATIONAL PARK - TAIL AND BODY FEATURES - FEMALES (1)

 <p>1024 Ark F (CLEAN EARS)</p> <p>tail : 1/2 to 2/3 missing</p> 	 <p>1070 Mora F (CLEAN EARS)</p> <p>wart on right front leg ("knee")</p> 
<p>1085 Shingo F (ears not seen)</p> <p>snare removed from neck, 13/6/03</p> 	 <p>1029 Tumbo F (JAGGED NOTCH LOW ON HER RIGHT EAR)</p>  <p>Large scabery scar on left back leg</p>
 <p>1008 Mukia F (SQUARE NOTCH OUT OF HER EAR AT LOWER LEFT)</p> <p>2/3 of tail missing</p> 	

iii) Examples of ear notch diagrams



Appendix 4c: Rhino Mortality Form: An extract from KIFARU® showing types of information collected and how the form is linked to two other forms.

Individual Rhino Mortality Information

KENYA WILDLIFE SERVICE Lewa Downs P.S. Rhino Mortality information

Mortality Information

Officer In Charge: [] Rhino ID Number: 2511

Estimated Death Date: 28/07/1990 Death Date Accuracy: Estimate likely to be within 1 week

Carcass Date: 30/07/1990 Cause of Death: Fighting

How Was Carcass Found: Ground Carcass Found By: Sanctuary/Park Staff

Carcass Location: Sanctuary GPS UTM Position Eastings: 8000 Northings: 8000 Sanctuary Area: []

Absent Horn Reasons: Front Horn [] Back Horn []

Notes: General Notes: By Dr. Rottcher injuries were noticed on this Syr animal around 22nd of July. The animal was running with its mother. She was in season at the Official Post-Mortem Notes: By Dr. Dieter Rottcher The Rhino had been horned twice in the perianal tissue. One wound involved skin and

Record: 1 of 21 Find New Delete Edit Cancel Close

Individual Rhino General Information

KENYA WILDLIFE SERVICE Lewa Downs P.S. Rhino General Information

General Rhino Information

Registration Date: 31-Jul-86 Rhino ID Number: 2511 Name: BAHATI

Birth Date: 22-Jul-86 Birth Date Accuracy: Estimate likely to be within 1 week

Birth Place: Lewa Downs G.S. Gender: Male

Mother ID Number: 2504 Father ID Number: []

Current Location: Lewa Downs G.S. Notes: Father Sole animal

Notches? NONE

Current Age: 64 (months) Breeding Age: No Current Age Class: SubAdult (E) Introduced? No Current Status: dead

Close

Individual Rhino General Information

KENYA WILDLIFE SERVICE Lewa Downs P.S. Rhino Relationship

ID: 2511 Location: Lewa Downs G.S. Sex: Male Age: 234 months Status: Dead

Mother: STUMPY (2504) Father: "Unknown"

Identified Siblings

ID	Name	Sex	Age (Months)	Local
2517	BYOTA	Female	155	LDS
2529	STELLA	Male	185	LDS
2533	BASHAM	Female	75	LDS
2542	TANA	Female	48	LDS

(Double click an item to obtain thero relationship)

Reproductive Details

Age at First Call: N/A
Avg Calving Interval: N/A
Next Call Expected: N/A

Identified Offsprings

ID	Name	Sex	Age (Months)
----	------	-----	--------------

(Double click an item to obtain thero relationship)

Close

NOTES: The form at the top shows the types of rhino mortality information collected; the form in the middle shows general information on the same rhino; while the form at the bottom shows the family tree of the same rhino. The curved arrows originated from the buttons that link the forms.

Appendix 5: Matlab[®]™ R12 script used in the automatic generation of growth rates

The example below is for Nairobi National Park. The script is based on the underlying growth rate formulae in the results section 2.3.1. It generates 3-year moving average annual growth rate by considering translocations.

```
clear

%      Numbers      Ins,  Outs
Nairobi  x =  [52      0      10
              57      0      7
              58      0      0
              65      0      0
              59      0      11
              62      0      0
              68      0      0
              59      1      13
              63      0      0
              68      0      0
              75      0      0
              75      0      0];

R = zeros(1,length(x));
for i = 4:length(x)
    index = 1;
    for r = 0: 0.0001: 2
        p1 = ((x(i-3,1) - x(i-2,3)) * r) + x(i-2,2);
        p2 = ((p1 - x(i-1,3)) * r) + x(i-1,2);
        p3 = ((p2 - x(i,3)) * r) + x(i,2);
        error(index,1) = r;
        error(index,2) = p3 - x(i,1);
        index = index + 1;
    end
    [temp,I] = min(abs(error(:,2)));
    R(i) = error(I,1);
    i
end
```

Appendix 6: Summaries of Sanctuaries Black Rhino Statistics 1992-2003

Ol Pejeta's black population summary statistics 1992-2003																												
CONFIRMED														PR	SG													
Year	Male				Female				Unknown sex							Management				Breeding						Trans		
	AD	SA	CF	ST	AD	SA	CF	ST	AD	SA	CF	ST	cST	pST	sgST	TOT	A	D	K	ML	S	SR	%CC	%C	+	-	In	Out
1992	4	1	1	6	4	0	1	5	0	0	0	0	11	0	0	11	93	0.12	93	69.75	-59	1	25	18.2	1	3	4	0
1993	7	2	0	9	9	0	1	10	0	0	0	0	19	0	0	19	93	0.2	93	69.75	-51	1.3	0	5.26	0	0	8	0
1994	7	2	2	11	7	0	2	9	0	0	0	0	20	0	0	20	93	0.22	93	69.75	-50	1	57.1	20	4	3	0	0
1995	6	3	0	9	7	1	1	9	0	0	1	1	19	0	0	19	93	0.2	93	69.75	-51	1.2	14.3	10.5	1	2	0	0
1996	7	0	2	9	7	1	2	10	0	0	2	2	21	0	0	21	93	0.23	93	69.75	-49	1	42.9	28.6	3	1	0	0
1997	6	1	5	12	7	2	2	11	0	0	0	0	23	0	0	23	93	0.25	93	69.75	-47	1.2	28.6	30.4	2	0	0	0
1998	6	1	3	10	7	1	2	10	0	0	2	2	22	1	0	23	93	0.25	93	69.75	-47	1.2	14.3	30.4	1	1	0	0
1999	7	2	3	12	7	5	0	12	0	0	2	2	26	0	0	26	93	0.28	93	69.75	-44	1	42.9	19.2	3	0	0	0
2000	7	3	3	13	7	4	3	14	0	0	1	1	28	0	0	28	93	0.3	93	69.75	-42	1	28.6	25	2	0	0	0
2001	8	3	2	13	8	4	2	14	0	0	5	5	32	0	0	32	93	0.34	93	69.75	-38	1	50	28.1	4	0	0	0
2002	8	4	3	15	9	4	2	15	0	0	6	6	36	0	0	36	93	0.39	93	69.75	-34	1.1	44.4	30.6	4	0	0	0
2003	10	3	0	13	11	3	0	14	0	1	9	10	37	0	0	37	93	0.4	93	69.75	-33	1.1	9.09	24.3	1	0	0	0

KEY		
AD = Adults (=7 yrs)	TOT = Population total	SR = Known Adult sex ratio (AD Female:AD Males)
SA = Sub-adults (=3.5 to <7.0 yrs)	ST = Subtotal	%CC = % Females calving that year
CF = Calves (<3.5 yrs)	cST = Confirmed sub-total	%C = Percentage of Calves in population
A = Area of rhino reserve (sq km)	pST = Probable sub-total	+ = Total No. of Births for stated period
D = Density (rhinos/sq km)	sgST = Speculative guesstimate sub-total	- = Total No. of Deaths for stated period
K = ECC Estimate (Brett 1989a; Foose <i>et al.</i> 1993)	PR = Probable numbers	ML = Management Level (75%K)
S = Surplus rhinos available for translocation (cST+pST-ML)	In = rhino translocated in	Out = rhino translocated out

Lewa's black rhino population summary statistics 1992-2003																												
CONFIRMED													PR	SG														
Year	Male				Female				Unknown sex							Management				Breeding						Trans		
	AD	SA	CF	ST	AD	SA	CF	ST	AD	SA	CF	ST	cST	pST	sgST	TOT	A	D	K	ML	S	SR	%CC	%C	+	-	In	Out
1992	4	4	1	9	4	4	3	11	0	0	0	0	20	0	0	20	247	0.08	100	75	-55	1	50	20	2	1	0	0
1993	6	3	1	10	4	4	2	10	0	0	0	0	20	0	0	20	247	0.08	100	75	-55	0.7	0	15	0	0	0	0
1994	7	1	2	10	4	3	2	9	0	0	0	0	19	0	0	19	247	0.08	100	75	-56	0.6	50	21.1	2	3	0	0
1995	6	1	2	9	6	4	1	11	0	0	0	0	20	0	0	20	247	0.08	100	75	-55	1	50	15	3	2	0	0
1996	6	1	2	9	7	2	2	11	0	0	0	0	20	0	0	20	247	0.08	100	75	-55	1.2	28.6	20	2	1	0	1
1997	7	0	1	8	5	3	3	11	0	0	0	0	19	0	0	19	247	0.08	100	75	-56	0.7	40	21.1	2	3	0	0
1998	6	0	2	8	8	0	3	11	0	0	3	3	22	1	0	23	247	0.09	100	75	-52	1.3	50	34.8	4	0	0	1
1999	6	1	3	10	8	3	3	14	0	0	2	2	26	0	0	26	247	0.11	100	75	-49	1.3	50	30.8	4	1	0	0
2000	6	1	5	12	8	3	6	17	0	0	0	0	29	0	0	29	247	0.12	100	75	-46	1.3	37.5	37.9	3	0	0	0
2001	6	2	4	12	8	6	2	16	0	0	2	2	30	0	0	30	247	0.12	100	75	-45	1.3	12.5	26.7	1	0	0	0
2002	5	3	3	11	11	4	2	17	0	0	4	4	32	0	0	32	247	0.13	100	75	-43	2.2	36.4	28.1	4	1	0	1
2003	7	4	1	12	11	5	1	17	0	1	7	8	37	0	0	37	247	0.15	100	75	-38	1.6	45.5	24.3	5	0	0	0

KEY

AD = Adults (=7 yrs)	TOT = Population total	SR = Known Adult sex ratio (AD Female:AD Males)
SA = Sub-adults (=3.5 to <7.0 yrs)	ST = Subtotal	%CC = % Females calving that year
CF = Calves (<3.5 yrs)	cST = Confirmed sub-total	%C = Percentage of Calves in population
A = Area of rhino reserve (sq km)	pST = Probable sub-total	+ = Total No. of Births for stated period
D = Density (rhinos/sq km)	sgST = Speculative guesstimate sub-total	- = Total No. of Deaths for stated period
K = ECC Estimate (Brett 1989a; Foose <i>et al.</i> 1993)	PR = Probable numbers	ML = Management Level (75%K)
S = Surplus rhinos available for translocation (cST+pST-ML)	In = rhino translocated in	Out = rhino translocated out

Nairobi's black rhino population summary statistics 1992-2003																												
Year		CONFIRMED												PR	SG													
Male		Female				Unknown sex								Management				Breeding				Trans						
AD	SA	CF	ST	AD	SA	CF	ST	AD	SA	CF	ST	cST	pST	sgST	TOT	A	D	K	ML	S	SR	%CC	%C	+	-	In	Out	
1992	16	4	7	27	15	5	5	25	0	0	0	0	52	0	0	52	117	0.44	60	45	7	0.9	26.7	23.08	4	0	0	10
1993	14	4	11	29	15	4	9	28	0	0	0	0	57	0	0	57	117	0.49	60	45	12	1.1	80	35.09	12	0	0	7
1994	15	4	11	30	15	5	8	28	0	0	0	0	58	0	0	58	117	0.5	60	45	13	1	13.3	32.76	2	3	0	0
1995	16	6	10	32	17	5	11	33	0	0	0	0	65	0	0	65	117	0.56	60	45	20	1.1	41.2	32.31	7	0	0	0
1996	11	9	5	25	16	5	8	29	0	0	3	3	57	2	0	59	117	0.5	60	45	14	1.5	31.3	27.12	5	0	0	11
1997	14	6	7	27	16	4	9	29	0	0	3	3	59	3	2	64	117	0.53	60	45	17	1.1	31.3	30.65	5	0	0	0
1998	13	5	9	27	18	3	8	29	0	3	5	8	64	4	2	70	117	0.58	60	45	23	1.4	38.9	32.35	7	1	0	0
1999	13	5	6	24	17	8	4	29	0	0	2	2	55	4	2	61	117	0.5	60	45	14	1.3	17.6	20.34	3	0	1	13
2000	12	5	9	26	17	7	6	30	0	2	2	4	60	3	2	65	117	0.54	60	45	18	1.4	35.3	26.98	6	2	0	0
2001	12	9	6	27	17	8	6	31	0	1	5	6	64	4	3	71	117	0.58	60	45	23	1.4	41.2	25	7	1	0	0
2002	13	10	8	31	21	7	6	34	0	2	5	7	72	3	2	77	117	0.64	60	45	30	1.6	33.3	25.33	7	1	0	0
2003	16	8	2	26	23	5	5	33	0	2	12	14	73	2	5	80	117	0.64	60	45	30	1.4	21.7	25.33	5	2	0	0

KEY

AD = Adults (=7 yrs)	TOT = Population total	SR = Known Adult sex ratio (AD Female:AD Males)
SA = Sub-adults (=3.5 to <7.0 yrs)	ST = Subtotal	%CC = % Females calving that year
CF = Calves (<3.5 yrs)	cST = Confirmed sub-total	%C = Percentage of Calves in population
A = Area of rhino reserve (sq km)	pST = Probable sub-total	+ = Total No. of Births for stated period
D = Density (rhinos/sq km)	scST = Speculative guesstimate sub-total	- = Total No. of Deaths for stated period
K = ECC Estimate (Brett 1989a; Foose <i>et al.</i> 1993)	PR = Probable numbers	ML = Management Level (75%K)
S = Surplus rhinos available for translocation (cST+pST-ML)	In = rhino translocated in	Out = rhino translocated out

Lake Nakuru's black rhino population summary statistics 1992-2003																												
CONFIRMED												PR	SG															
Year	Male				Female				Unknown sex							Management				Breeding						Trans		
	AD	SA	CF	ST	AD	SA	CF	ST	AD	SA	CF	ST	cST	pST	sgST	TOT	A	D	K	ML	S	SR	%CC	%C	+	-	In	Out
1992	11	5	3	19	10	0	4	14	0	0	0	0	33	0	0	33	144	0.23	67	50.25	-17	0.9	20	21.2	2	0	0	0
1993	12	5	2	19	10	1	3	14	0	0	0	0	33	0	0	33	144	0.23	67	50.25	-17	0.8	0	15.2	0	0	0	0
1994	12	5	4	21	10	3	3	16	0	0	0	0	37	0	0	37	144	0.26	67	50.25	-13	0.8	40	18.9	4	0	0	0
1995	16	2	5	23	10	4	2	16	0	0	0	0	39	0	0	39	144	0.27	67	50.25	-11	0.6	20	17.9	2	0	0	0
1996	12	4	5	21	10	3	5	18	0	0	2	2	41	2	0	43	144	0.3	67	50.25	-7	0.8	40	27.9	4	0	0	0
1997	15	4	6	25	9	6	4	19	0	0	2	2	46	0	1	47	144	0.32	67	50.25	-4	0.6	55.6	26.1	5	1	0	0
1998	14	2	4	20	10	1	3	14	0	0	2	2	36	5	7	48	144	0.28	67	50.25	-9	0.7	20	22	2	1	0	0
1999	16	6	5	27	13	3	4	20	0	0	2	2	49	1	4	54	144	0.35	67	50.25	-0	0.8	46.2	22	6	0	0	0
2000	16	8	5	29	13	2	10	25	0	0	1	1	55	3	3	61	144	0.4	67	50.25	8	0.8	53.8	27.6	7	0	0	0
2001	16	6	9	31	15	5	6	26	0	0	2	2	59	3	5	67	144	0.43	67	50.25	12	0.9	40	27.4	6	0	0	0
2002	21	3	10	34	14	3	7	24	0	0	5	5	63	4	2	69	144	0.47	67	50.25	17	0.7	42.9	32.8	6	4	0	0
2003	19	10	4	33	13	4	9	26	0	0	3	3	62	7	1	70	144	0.48	67	50.25	19	0.7	23.1	23.2	3	2	0	0

KEY

AD = Adults (=7 yrs)	TOT = Population total	SR = Known Adult sex ratio (AD Female:AD Males)
SA = Sub-adults (=3.5 to <7.0 yrs)	ST = Subtotal	%CC = % Females calving that year
CF = Calves (<3.5 yrs)	cST = Confirmed sub-total	%C = Percentage of Calves in population
A = Area of rhino reserve (sq km)	pST = Probable sub-total	+ = Total No. of Births for stated period
D = Density (rhinos/sq km)	sgST = Speculative guesstimate sub-total	- = Total No. of Deaths for stated period
K = ECC Estimate (Brett 1989a; Foose <i>et al.</i> 1993)	PR = Probable numbers	ML = Management Level (75%K)
S = Surplus rhinos available for translocation (cST+pST-ML)	In = rhino translocated in	Out = rhino translocated out

Appendix 7: Example of population history summary table

Females																	
ID no	Name	Sex	Mother	ID	Date born	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
511	Nduku	F			01-Jan-79	ex-Solio		11.0			c-1	15.0			c-1		
506	Mwikali	F			01-Jan-74	ex-Solio	c-9	16.0		c-10		20.0					
508	Jebungei	F			01-Jan-80	ex-Solio		c-12 or 1?				14.0	c-3 or 4?		17.0	c-7	
515	Mama Winnie	F			01-Jan-79	ex-Solio		11.0	c-5		c-12	15.0			18.0		c-5
510	Wangari	F			01-Jan-80	ex-Solio		10.0	c-10			14.0	c-9 or 10?		17.0	c-7	
516	Wanjiku	F			01-Jan-79	ex-Solio		c-5 or 1?				15.0		c-10	18.0		
518	Mwende	F			16-May-74	c-1		15.6				19.6			22.6		D-Disease
523	Suzie	F			01-Jan-79				Ex-Nairobi	c-1		15.0	c-1		18.0	c-3	
522	Judy	F			01-Jan-84				Ex-Nairobi			10.0		c-7 or 9?	13.0	c-3	
520	Jambi	F			01-Jan-85				Ex-Nairobi			9.0	c-2		12.0		
527	Winnie	F	Mama Winnie	515	01-May-90							3.7			c-7		
529	Wambui	F	Wangari	510	01-Oct-90							3.3			6.3		
530	Kvela	F	Suzie	523	01-Jan-91							3.0			6.0	c-12	
532	Zawadi	F	Nduku	511	01-Jan-92							2.0			5.0	c-10	
535	Mimi	F	Suzie	523	01-Jan-94										3.0		
536	Ann	F	Jambi	520	01-Feb-94										2.9		c-10
542	Perfet	F	Mwikali	506	01-Mar-96										0.8		
541	Nelly	F	Nduku	511	15-Jan-96										1.0		
543	Sharon	F	Judy	522	11-Mar-97												
548	Betty	F	Zawadi	532	01-Oct-97												
547	Peris	F	Kvela	530	15-Dec-97												
549	Sophie	F	Mama Winnie	515	09-May-98												
550	Husnah	F	Suzie	523	26-Jun-99												
554	Elisey	F	Mimi	535	01-Sep-99												
555	Helga	F	Kyela	530	01-Dec-99												
559	Denise	F	Nduku	511	01-Mar-04												
560	Lucie	F	Ann	536	15-Apr-00												
562	Moriore	F	Zawadi	532	15-Jun-99												
563	Glenn	F	Jebungei	508	17-Dec-00												
566	Suzie's Calf	F	Suzie	523	14-Feb-02												
569	Muema	F	Nelly	541	15-Jan-01												
570	Winnie's calf	F	Winnie	527	14-Oct-02												
572	Njambi's calf	F	Njambi	520	15-Jan-02												
573	Sharon's calf	F	Sharon	543	20-Jan-02												
574	Njambi's calf2	F	Njambi	520	15-Aug-98												
575	Mary Mayende	F	Mimi	535	11-Jan-01												
576	Carol	F	Jebungei	508	03-Jan-03												
577	Zawadi's Calf	F	Zawadi	532	01-Jan-01												
578	Njeri	F	Moriore	562	31-Oct-03												
579	Judy's calf	F	Judy	522	11-Sep-03												

KEY

c-month =Calving-month of

Ex-Source =Introduction-place of origin

D-Cause =Death-cause

To-Dest'n =Removed-Destination

Males																	
ID no	Name	Sex	Mother	ID	Date born	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
517	Wachira	M			01-Jan-75	ex-Solio		15.0		17.0		19.0		21.0		23.0	
513	Rodney	M			01-Jan-78	ex-Solio		12.0		14.0		16.0		18.0		20.0	
514	Sindano	M			01-Jan-78	ex-Solio		12.0		14.0		16.0		18.0		20.0	
512	Nyahururu	M			01-Jan-82	ex-Solio		8.0		10.0		12.0		14.0		16.0	
505	Nderit	M			01-Jan-76	ex-Solio		14.0		16.0		18.0		20.0		22.0	
509	Major Mwangi	M			01-Jan-81	ex-Solio		9.0		D-Accident							
503	Tatu	M			01-Jan-79	ex-Solio		11.0		13.0		15.0		17.0		19.0	
504	Ridgeback	M			01-Jan-82	ex-Solio		8.0		10.0		12.0		14.0		16.0	
501	Amboni	M			01-Jan-70	ex-Solio?		20.0		22.0		24.0		26.0		28.0	
502	Kiseriani	M			01-Jan-74				Ex-Nairobi	18.0		20.0		22.0		24.0	
524	Sihoho	M			01-Jan-82				Ex-Nairobi	10.0		12.0		14.0		16.0	
519	Kisee	M			01-Jan-79			11.0		13.0		15.0		17.0		19.0	
525	Nj'and'a	M	Mwende	518	01-Jan-87			3.0		5.0		7.0		9.0		11.0	
521	Kagiri	M	Mwikali	506	01-Sep-88			1.3		3.3		5.3		7.3		9.3	
526	Prince Bernard	M	Jebungei	508	01-Jan-89			1.0		3.0		5.0		7.0		9.0	
528	Kariuki	M	Wanjiku	516	01-Jan-89			1.0		3.0		5.0		7.0		9.0	
531	Mburugu	M	Mwikali	506	06-Oct-91					0.2		2.2		4.2		6.2	
533	Muya	M	Mama Winnie	515	21-Dec-92							1.0		3.0		5.0	
537	Leaky	M	Jebungei	508	01-Mar-94									1.8		3.8	
538	John Wambua	M	Wangari	510	01-Sep-94									1.3		3.3	
539	Rajan	M	Judy	522	01-Jul-95									0.5		2.5	
540	Franz	M	Wanjiku	516	15-Oct-95									0.2		2.2	
542	Perfet	M	Mwikali	506	01-Jan-96											2.0	
544	Olindo	M	Suzie	523	28-Mar-97											0.8	
545	Okita	M	Jebungei	508	05-Jul-97											0.5	
546	Detlev	M	Winnie	527	22-Jul-97											0.4	
551	Ochien'g	M	Wambui	529	01-May-99												
552	Gathua	M	Mwikali	506	24-Oct-99												
553	Bor	M	Ann	536	01-Oct-98												
556	Paul	M	Judy	522	10-Apr-00												
557	Rafiki	M	Njambi	520	01-Feb-00												
558	Kervern	M	Winnie	527	11-Jun-00												
561	Bernharded	M	Mama Winnie	515	24-Jan-01												
565	Mampuli	M	Wanjiku	516	01-Jul-99												
564	Strolch	M	Wangari	510	15-May-00												
567	Laban	M	Kyela	530	01-Dec-97											0.1	
568	Ngeno	M	Wambui	529	15-Jan-02												
571	Mwanzia	M	Beth	548	02-Nov-04												
580	Okuku	M	Zawadi	532	01-Dec-03												
Clean					??												
Clean					??												

KEY

c-month =Calving-month of

Ex-Source =Introduction-place of origin

D-Cause =Death-cause

To-Dest'n =Removed-Destination

Appendix 8: Benchmarks for rhino population performance in the wild and correction factors summarised from Adcock (1999); du Toit (2001); and du Toit *et al.* (2001).

1) Benchmarks for rhino population performance

Table 8.1: Benchmarks for good, average and poor breeding success

Population performance*	Very poor-Poor	Poor-Moderate	Moderate-Good	Good-Excellent
UnL.G	<2.5%	2.5 – 5.0%	5.0 – 7.5%	>7.0%
Mot.R	>4%	-	-	-
SR	<1F:1M	<1F:1M	1F:1M	>1F:1M ^a
ICI	>3.5 yrs	3.5 – 3.0 yrs	3.0 – 2.5 yrs	<2.5 yrs
%FC	<29%	29 – 33%	33 – 40%	>40%
AFC	>7.5 yrs	7.5 – 7.0 yrs	7.0 – 6.5 yrs	<6.5 yrs
%CP	-	<28%	=28%	-

^a Good-Excellent in “good habitat”

^b Calves of age classes A to D.

UnL.G=Underlying growth rate; Mot.R=Mortality rate; SR=Sex ratio; ICI=Average inter-calving interval; %FC=Percentage of females calving per year; AFC=Age at first calving; and %CP=Proportion of calves (age classes A-D) in the population.

2) Correction factors

Calculated growth rates may sometimes be misleading for small populations because of skewed age or sex ratios, chance synchrony in the calving by several females, etc.). Also populations have recently been established through translocation into a new range, will according to RMG experience; generally show a time lag of years rather than months before settling into a consistent breeding pattern, so their growth rates can not be readily established with those of established populations.

For a fair comparison, for small populations, sex ratios may have to be balanced by adding or subtracting arbitrary number of males to equal number of females. In recently established populations, inter-calving intervals may have to be calculated as the number of “cow breeding months per calf born”, to allow for settling in. Calculations of inter-calving interval should be based on the surviving calves. For established populations, graphing performance parameters and comparing means at different quartiles would give a better benchmark (du Toit 2001).