THE DEMOGRAPHY AND POPULATION DYNAMICS OF A RE-INTRODUCED BLACK RHINOCEROS POPULATION ON THE GREAT FISH RIVER RESERVE, EASTERN CAPE PROVINCE

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ABSTRACT

The re-introduction of black rhinoceros onto the Great Fish River Reserve in the Eastern Cape, following the species absence for over a century, created an opportunity to study this species in the thicket biome, and in particular the succulent thicket of the Great Fish River valley. The thicket biome is quite different from the habitats in which other extant populations of these animals are found and where studies of their demography have been undertaken. Data collection occurred from May 1986, with the arrival of the first four animals to December 2008, when the population was estimated to be 144 individuals. A variety of monitoring techniques were used including direct ground observations, aerial helicopter census, aerial monitoring by microlight aircraft, camera traps and opportunistic observations, each with its own advantages and disadvantages. The combination of methods and effort has resulted in the population being recognized as completely known with up to 97% of the animals being located at least once per year with a mean frequency of sightings of 11.5 per animal per year.

In 2008, the population was about 20% juvenile, 36% sub-adult and 44% adult with a female biased sex ratio of 1.3 females per male. Mean age at first birth was about 80 months and this increased significantly with increasing density of black rhinoceroses. Mean intercalf interval was about 28 months and 41% of adult females gave birth each year. Mortality rates were low for juveniles, higher for sub-adults and higher for males than females. There was a weak but significant positive effect of density on male mortality. Population growth rate was about 10% and was not significantly affected by density.

These results suggest that this population is beginning to show the first indications of density dependant constraints and that harvesting should be implemented in order to maintain the productive tempo. A secondary goal of the Management Plan will then be realized as the population functions as a donor to establish founder populations elsewhere within the *Diceros bicornis minor* range.

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PREFACE

This thesis is structured as follows:

CHAPTER 1 is a general introduction that broadly sets the scene. It reviews the conservation status of the black rhinoceros. It does not however introduce the major research chapters as these have their own introductions and results.

CHAPTER 2 is a detailed description of the study site particularly for readers who are not familiar with the region.

CHAPTER 3 details the monitoring methods used between 1986 and 2008 and analyses and compares the efficacy of the various methods.

CHAPTER 4 addresses the changing population dynamics and compares the demography and performance against expected minimum criteria of the RMG.

CHAPTER 5 is a final discussion and presents some management implications derived from the study.

REFERENCES are synthesized and presented in one listing for all chapters.

APPENDIX 2A, 2B, 2C & 2D: Rainfall data from weather stations.

APPENDIX 2E: Scientific names of all indigenous mammals on the study site.

APPENDIX 3A: Monitoring methods used in other conservation areas.

CHAPTER 1

GENERAL INTRODUCTION

OVERVIEW

The black rhinoceros (*Diceros bicornis*, Linnaeus 1758), belongs to the Superorder Paraxonia, Order Perissodactyla and Family Rhinocerotidae (Skinner & Chimimba 2005). It is one of the five species of rhinoceros that exist globally and one of the two that occur in Africa along with the larger white rhinoceros (*Ceratotherium simum*).

The three Asian species are the Indian (*Rhinoceros unicornis)*, Javan (*Rhinoceros sondaicus*) and Sumatran rhinoceros (*Dicerorhinus sumatrensis*). The status of the three Asian species of rhinoceros is precarious; there are only about 50 wild surviving individuals of the Javan species, and an estimated wild population of 300 Sumatran rhinoceroses (van Strien & Maskey 2006). The greater one horned Indian rhino (*Rhinoceros unicornis*) numbered approximately 2800 in 2009 (Milliken *et al.* 2009).

The white rhinoceros was historically distributed in the form of two discrete populations, namely, the southern subspecies (*C.s. simum*) in Southern Africa, and the northern subspecies (*C.s. cottoni*) which occurred to the west of the Nile river in southern Sudan, north-western Uganda, Central African Republic and north-eastern parts of the Democratic Republic of Congo (Owen-Smith 1988; Estes 1991; Emslie & Brooks 1999). The southern white rhinoceros subspecies is the most secure of the African rhinoceros species increasing from a small relict population of between 20 to 50 animals in the Imfolozi Game Reserve at the beginning of the twentieth century (Emslie & Brooks 2002; Skinner & Chimimba

2005) to an estimated 17500 by December 2007 (Emslie 2008; IUCN 2010a). In contrast the northern white rhinoceros is probably extinct in the wild and the latest initiative is the translocation of four potential breeding animals from a zoo in the Czech Republic to Kenya and intercrossing these northern animals with southern white rhino with the intention of returning the progeny to the former distribution range of the northern white rhino (Brooks 2009). In Africa, four subspecies of black rhinoceros are recognized by the International Union for the Conservation of Nature and Natural Resources (IUCN) Species Survival Commission's African Rhinoceros Specialist Group (Cumming *et al.* 1990). These are defined by locality as the north-western black rhinoceros (*Diceros bicornis longipes*); eastern (*Diceros bicornis michaeli*); south-western (*Diceros bicornis bicornis*); and southern-central black rhinoceros (*Diceros bicornis minor*). These definitions were agreed to at the African Rhino Workshop in Cincinnati, U.S.A. in 1986 in order to standardize classification (du Toit *et al.* 1987). Only the south-western arid adapted *D.b.bicornis* and southern-central *D.b.minor* are indigenous to the Southern African Subregion (Smithers 1983; Skinner & Chimimba 2005; Emslie 2006).

Based on a likely historical distribution of the black rhinoceros in sub-Saharan Africa (Figure 1.1), the species occurred in a variety of habitats and elevations indicating a high level of adaptability. Occupied habitats include forest, savanna woodland and scrub vegetation from sea-level to an elevation of 1500m above sea level (asl) in the Southern African subregion, and up to 2700m asl in East Africa (Kingdon 1979). The distribution range of the black rhinoceros has been steadily reduced beginning in the 19th century and continuing into the latter half of the 20th century (Emslie & Brooks 1999). The cause of the decline is a combination of habitat destruction and incompatibility with human settlement, and in the latter three decades of the 20th century, syndicated poaching (Emslie & Brooks 1999).

Figure 1.1: Map of the probable historic distribution of the black rhinoceros, c1700 from Emslie & Brooks (1999) after Cumming *et al.* (1990).

CONSERVATION STATUS OF THE BLACK RHINOCEROS

Despite a steady decline in the numbers of the black rhinoceros throughout Africa since the early colonial period, over a million black rhinoceroses were present at the beginning of the 20th century (Dublin & Wilson 1998). The black rhinoceros was regarded as a worthy quarry by colonial hunters, sportsmen, explorers and collectors of the 19th and early 20th centuries (Roosevelt 1986; Enright 2008) and hunting pressure contributed to the slow decline. In Africa there was no particular value attached to the horn by indigenous peoples, although rhinoceroses may have been hunted for food (Thomson 2006) and this too would have contributed to the decline. However, it is in the last four decades that the black rhinoceros has been brought to the brink of extinction by illegal poaching (Emslie & Brooks 1999). Poaching is fuelled mainly by the perceived value of the horns which are used to fashion handles for cultural daggers, known as *jambiyas* in Yemen, or for their use in traditional Chinese medicine (TCM; Emslie & Brooks 1999). In TCM, rhinoceros horn is believed to function as an antipyretic, however laboratory experiments have shown that there is no scientific evidence supporting this application (Davidson *et al.* 1999). Other contributory threats include political instability, corruption, poverty and ignorance (Dublin & Wilson 1998; Emslie & Brooks 1999) which all facilitate illegal exploitation. Habitat loss and poaching have combined to bring about a catastrophic decline in black rhinoceros numbers and between 1970 and 1993 an estimated 96% of Africa's free-ranging black rhinoceroses were lost to poaching alone (Potter 1994; Emslie & Brookes 1999; Sherriffs 2005a). This has been described as "one of the greatest wildlife tragedies in modern times" (Dublin and Wilson 1998). The Selous Game Reserve in Tanzania was home to one of the largest black rhinoceros population of 3000 animals in 1981, but by 1985 the population had been reduced to a critically low level (Borner & Severre 1986) and by 1999 only 30 to 50 animals remained (Morgan-Davies 2001). In Botswana, although original numbers were not known, an extensive aerial search covering 15000km^2 in 1992 located only seven white rhinoceroses (Anon 1992).

By 1975 the black rhinoceros was recognised as an endangered species by the Convention on International Trade in Endangered Species (CITES), and all trafficking in rhinoceros horns was banned (Thomson 2006). In 1977, all African rhinoceros species were listed on CITES Appendix 1, which prohibited all international commercial trade in rhinoceros and their products (Emslie & Brooks 1999). In spite of these regulations, the number of free-ranging black rhinoceroses declined to the lowest recorded levels between 1992 and 1995 with an estimated total of just over 2,400 individuals (Walker 1994; Emslie 1996). In response to the dramatic decline in the numbers of the black rhinoceros, a number of reactive management interventions were launched to arrest and reverse the decline. A significant step was the formation of the Southern African Development Community (SADC) Rhino Management Group (RMG), and the compilation of the first Southern African Black Rhinoceros Conservation Plan in 1988 (Brooks 1989). The RMG is made up of representatives from South Africa, Namibia, Zimbabwe and Swaziland, although Namibia has now formulated its own plan. Most recently, the SADC RMG has revised and updated the conservation plan (Emslie 2006) and its role as overall co-ordinator of the plan is to evaluate and to assist the formal conservation agencies and private landowners in achieving the stated goals (Brooks & Adcock 1997). The long term vision of the RMG's South African black rhino conservation plan is to develop and maintain viable populations of the southern central *(D.b.minor)* and south-western *(D.b.bicornis)* black rhinoceros in natural habitats throughout their former range both inside South Africa and other range states. The long term goal is to have at least 3000 *D.b.minor* and 500 *D.b.bicornis* in South Africa, with at least three populations of *D.b.minor* exceeding 100 individuals and another 10 populations greater than 50 individuals; and at least one population of

D.b.bicornis greater than 100 animals and another greater than 50 individuals (Emslie 2006).

As a result of the various conservation interventions, the metapopulation number stabilised at approximately 2400 individuals between 1992 and 1995 and then climbed to an estimated 2700 by 1999 and 3100 by 2001 in 86 discreet populations (Emslie 2002). These discrete populations are now managed as metapopulations. By the end of 2005, the estimated number of all free-roaming animals on the African continent had reached 3725 (Emslie *et al.* 2007), and by the end of 2007 the metapopulation, had risen to 4200 individuals, comprising 700 *D.b. michaeli;* 1505 *D.b. bicornis* and 1995 *D.b. minor* (Brooks 2008). A slightly modified overall figure of 4230 is given for December 2007 by the IUCN (Milliken *et al.* 2009). The north-western *D.b. longipes* was not protected in the same way and was declared extinct in July, 2006 (IUCN News Release 2006; Lagrot *et al.* 2007; Enright 2008). In 2009 the IUCN listing for the three extant black rhinoceros subspecies remained "critically endangered" (IUCN 2010b).

The role that South Africa has played in the conservation of the black rhinoceros has been considerable. In the 1930s there were only about 110 wild black rhinoceros (*D.b. minor)* in South Africa (Dublin & Wilson 1998; Enright 2008). This represented less than 0.1% of the world's population (Emslie 2006). By 1980, South Africa conserved 4% of the continent's black rhinoceroses and by the end of 2005 it conserved more black rhinoceroses in the wild than any other range state (1379 = 37% of Africa's total; Emslie 2006).

In common with the large mammalian carnivores, and other megaherbivores such as elephant and hippopotami, rhinoceroses are not compatible with most land-use practices, and, typically, have to be conserved within large game reserves and protected areas. This creates fragmented populations that are often limited by available space. In an attempt to overcome this problem, recent conservation initiatives, particularly in Namibia and KwaZulu-Natal have led to a number of programmes resulting in range expansion with the sanction of landowners and/or rural communities (Sherriffs 2005b).

In spite of these efforts, the status of both the black and white rhinoceros, is not secure due to a marked escalation in poaching in recent years, utilising conventional firearms and sophisticated methods such as helicopters, immobilising drugs, poison and cross-bows. Between 2006 and 2009, 95% of all rhino deaths in Zimbabwe and South Africa were as a result of poaching (Milliken *et al.* 2009). Zimbabwe was particularly hard hit (du Toit 2002). Between January 2006 and September 2009, a minimum of 470 rhinoceroses in seven rhinoceros range states throughout Africa were poached, with black rhinoceroses comprising nearly half of this number (Milliken *et al.* 2009). By December 2010, over 300 animals comprising mainly white rhinoceroses had already been poached during the year in South Africa alone, (Pienaar, J. 2010. Department of Economic Development & Environmental Affairs, Bisho. pers. comm.) evidencing the scope of a new onslaught. Thus, while the efforts of the SADC RMG and other groups have resulted in encouraging increases in populations, the threat from poaching remains real.

HISTORICAL REVIEW: INCIDENCE OF BLACK RHINOCEROS IN THE GREAT FISH RIVER VALLEY AND OTHER LOCALITIES IN THE EASTERN CAPE

The early records of European explorers, settlers and soldiers showed that the black rhinoceros occurred in the region now occupied by the Great Fish River

Reserve (GFRR). One of these records was that of Lieutenant William Paterson in 1779, who recorded buffalo, hippotami, elephant and black rhinoceros in the environs of Trompeters Drift on the Great Fish River (Paterson 1790), about 17 kilometres south of the present GFRR. However approximately 63 years later, in 1842, the black rhinoceros had been locally extirpated from the Great Fish River valley (Skead 2007) with the shooting of the last animal near the Ecca valley. There are varying accounts about the demise of the last remaining animal in the Eastern Cape Province. According to Smithers (1983) the last black rhinoceros in the Eastern Cape Province was shot in 1853 in the vicinity of the Coega river, or Grassridge, near Port Elizabeth (Skead 2007). Skinner and Chimimba (2005), report that the last remaining animal was shot nearly 30 years later in Graaff-Reinet in 1880, while Skead (2007) again reports the last rhinoceros in the Cape Province being shot in the Fort Beaufort area between 1884 and 1886. Assuming that 1886 is correct, the re-introductions to the GFRR began 100 years after the species had been extirpated from the Province.

THE "CORRECT" SUBSPECIES FOR THE EASTERN CAPE PROVINCE

The precise identity of the black rhinoceros that occurred in the Eastern Cape Province is unknown. It was called the Cape black rhinoceros and was larger than the two subspecies now described for South Africa (Rookmaaker & Groves 1978). However, morphological features need not indicate subspecies level difference and, in the absence of comparative DNA material, there is uncertainty as to which of the two South African subspecies should be represented in the Province (O'Ryan *et al.* 1994). There are two contrasting schools of thought regarding the subspecific status of the black rhinoceros in Southern Africa. It has been suggested that intraspecific genetic variation in black rhinoceros may represent clinal variation that reflects adaptation to varying ecological conditions (du Toit 1986) and the subspecies are ecological or conservation units with little mitochondrial DNA diversity between them (O'Ryan *et al.* 1994). Similarly, Swart & Ferguson (1997) compared populations of *D.b.bicornis* and *D.b.minor* and concluded that the populations do not belong to discrete subspecies, but that an east-west cline in genetic characteristics exists. By contrast, support for keeping black rhinoceros subspecies distinct is based on the examination of four isolated populations, where it was concluded that substantial genetic variation exists equating to that expected in outbred natural populations (Swart *et al.* 1994). More recent genetic analyses, based on microsatellite DNA, indicate that *D.b.minor*, *D.b.bicornis*, and *D.b.michaeli* are all sufficiently distinct to support the current subspecies distinction, and that genetic bottlenecks in these populations have had a limited impact on diversity (Harley *et al.* 2005). In summary, the most recent data support the existence of subspecies, and this should be incorporated into conservation planning. Thus the question of which of the subspecies to re-introduce into the Eastern Cape Province remains an important one.

The problems associated with deciding which subspecies to re-introduce to the Eastern Cape Province is illustrated in the following example. During 1961 and 1962, seven *D.b.michaeli* were translocated from south-eastern Kenya to the Addo Elephant Park (Hall-Martin & Penzhorn 1977; Hall-Martin 1979). This was followed in 1977 with the release into the same Park of three *D.b.minor* bulls from KwaZulu-Natal (Hall-Martin 1979). This was controversial as interbreeding of the two subspecies was likely to occur. This situation was rectified when both the *D.b. minor* and the *D.b.michaeli* were removed from Addo (Emslie & Brooks

1999; Adcock 2005). Today the Addo Elephant National Park accommodates only *D.b. bicornis* (Hall-Martin & Knight 1994), and this subspecies has also been introduced into other parks in the former Cape Province (Augrabies National Park; Hall-Martin & Knight 1994; Vaalbos National Park near Kimberley, Raath & Hall-Martin 1989).

Consideration has been given as to which of the two subspecies is the closest ecological replacement for the extirpated Cape black rhinoceros, and for which subspecies the Eastern Cape could have been a natural extension of the known range. The south-western arid adapted *D.b.bicornis* reportedly had a historic distribution through Namibia and into the north-western and south-western regions of what was the Cape Province (Skead 1980). However, it has been suggested that the Namibian and original Cape black rhinoceros populations were not contiguous, and the absence of rivers and shortage of surface water in the area between the Orange River to just north of Clanwilliam in the south, formed a barrier for strongly water dependent mammals (Lloyd 2006). Furthermore, there is no evidence of a contiguous distribution west to east between the South-Western Cape and the Eastern Cape Province. There are no records of black rhinoceroses between the Hottentots Holland mountains in the South-Western Cape and the Uitenhage area in the Eastern Cape, or from the Little Karoo or Langkloof (Skead 1980; Skead 2007). It has been suggested that *D.b.bicornis* would have moved from the north-western regions of the Cape Province south-eastwards into the Eastern Cape Province but there are no records further east than the present towns of Hanover and De Aar in the northern Great Karoo to support this (Skead 2007). Thus, the evidence for the distribution of *D.b.bicornis* including the Eastern Cape Province is poor.

The southern-central *D.b.minor* has a distribution range along the eastern portions of central and southern Africa from lower central Tanzania through Zambia, Malawi, Zimbabwe, Mozambique, Botswana, and Swaziland and into the eastern and central regions of South Africa (Emslie & Brooks 1999). However, distribution records from KwaZulu-Natal and the Great Fish River (Skead 2007) are separated by a gap of 700km representing the coastal belt between the Indian Ocean and the Drakensberg mountains. This region is composed of extensive grasslands and indigenous forest, and is bisected by numerous rivers and gorges. Interestingly, other browsing species from the eastern seaboard, such as impala and giraffe also failed to penetrate the coastal belt. It is has been suggested that the lack of evidences of black rhinoceroses from the coastal belt is more an artifact of inadequate palaentological collecting rather than unsuitable habitat (Lloyd 2006), but this argument could equally be used to explain gaps in the distribution of *D.b.bicornis*. For neither subspecies is there convincing evidence to support a historic range that would have included the Eastern Cape Province.

In the absence of evidence to support one subspecies over the other, decisions have been made (and changed) based in part on re-introductions that had already occurred and in part on ecological considerations. In addition, it was decided to keep the two subspecies apart in the SADC RMG conservation plan (Emslie 2006). The initial proposal was to use the 400 millimeter annual rainfall isohyet as a boundary and to the west of the isohyet, where rainfall is less than 400mm *D.b.bicornis* was allowed, with *D.b.minor* in the wetter East. Thus, *D.b.bicornis* could be re-introduced to the Western Cape Province and across into the Eastern Cape Province to the Greater Addo Elephant National Park, Mountain Zebra National Park and the Baviaanskloof Mega Reserve, all protected areas to which *D.b.bicornis* had been introduced (Peinke *et al.* 2007). East of the 400mm isohyet some re-introductions of *D.b.minor* had already taken place into the GFRR (from 1986), the Shamwari Game Reserve (1993/4) and the Kwandwe Private Game Reserve (2000). Although the 400mm isohyet was an arbitrary boundary, it did locate the arid adapted *D.b.bicornis* in the drier parts of the southern Cape and the more mesic adapted *D.b.minor* in the wetter regions. This decision was changed in 2010 when the policy document: "Black Rhino Management Plan for the Great Fish River Nature Reserve" (Peinke & Fike 2010) was formally accepted, adopting the stance that the Eastern Cape Province be regarded as a *D.b.bicornis* only Province, and the GFRR population of *D.b.minor* will henceforth be considered as an "out population".

STUDY AIMS

In May 1986, when the first consignment of black rhinoceroses was released onto the GFRR, the reserve began to function as a recipient area with the objective of growing a local population as part of the overall objective of increasing the metapopulation of black rhinoceroses (Emslie 2006). This era as a recipient protected area terminated in 2000 when the final 20 animals were released. Since 1986, the population of black rhinoceroses has grown to 144 in 2008 (see Chapter 4 for details), and is now categorised as a Key 1 population. This denotes an internationally important population in excess of 100 individuals with a stable or increasing population, and is viewed as critical for the wider survival of the subspecies (Emslie 2006). The GFRR is one of only three South African populations that currently qualifies for Key 1 status for *D.b.minor* (Adcock

2009). The GFRR made the transition from recipient to donor status in 2006 when the first five animals were translocated to the 15000ha Intensive Protection Zone set up in North Luangwa, Zambia (Kampamba 2003). This translocation marked a significant milestone for the GFRR and the successful establishment of the *D.b.minor* in the Eastern Cape Province. It also marked the realization of the vision for the GFRR (Peinke & Fike 2010) which was to maintain and secure a viable population of the black rhinoceros (*Diceros bicornis minor*) in an optimal productive state in the GFRR. The population will thus become a donor source for the establishment of breeding nuclei of this subspecies (Peinke & Fike 2010).

Throughout the period from first re-introduction to first removal, the black rhinoceroses have been carefully monitored and in this study the information from the monitoring programme has been analysed and is reported. In this thesis only data from 1986 to 2008 are presented but monitoring efforts are ongoing. The first research chapter describes and compares the methods used to monitor black rhinoceroses on the GFRR (Chapter 3). The aim of the chapter is to establish if one or more methods are better or more appropriate than others and the chapter should provide useful information for managers of other populations as they establish monitoring programmes. The second research chapter reports on population demography and looks at the influence of density and climate on certain population parameters. The aims of this chapter are to add to the available knowledge of the basic reproductive parameters that are important in understanding population growth and structure; to describe the demography of the black rhinoceros on the GFRR and to establish if the population growth rate is being inhibited. The final chapter summarises the important results and comments on future management of this *D.b.minor* population.

CHAPTER 2

DESCRIPTION OF THE STUDY AREA AND GENERAL METHODS

INTRODUCTION

This study was carried out on the Great Fish River Reserve (GFRR) in the Eastern Cape Province of South Africa (Figure 2.1). The GFRR is a provincial protected area administered by Eastern Cape Parks and comprises three Nature Reserves (Figure 2.2) which form a contiguous area of approximately 440km^2. The Andries Vosloo Kudu Reserve (AVKR) was the original protected area of 65km^2 established in 1973. The 230km^2 Double Drift Nature Reserve (DDNR) lies to the east of the Kat and Great Fish rivers and was established in the former Ciskei homeland in 1983. It is separated from the AVKR by the Sam Knott (SKNR) properties of 145km^2 bequeathed by the late Mr. M.T. (Sam) Knott to conservation in 1987. The three properties are managed as a single unit (GFRR). The GFRR lies between 32.927°S and 33.146°S in a north to south plane, and 26.622°E to 26.967°E in the west to east plane. Two permanent rivers, the Great Fish River and Kat River, flow for 75.3km and 21.3km respectively, through the GFRR (Figure 2.2). The Keiskamma River forms a section of the north-eastern boundary of the DDNR, but is fenced out of the GFRR.

Although the total size of the GFRR is 440km^2, black rhinoceroses presently have access to about 390km^2. There is no access to the Nyathi Game camp of 35km^2 on the DDNR sector. Infrastructural development for staff accommodation and tourist lodges plus an area presently excluded in an agreement with a local community are also excluded to rhinoceroses and this accounts for an additional 15km^2.

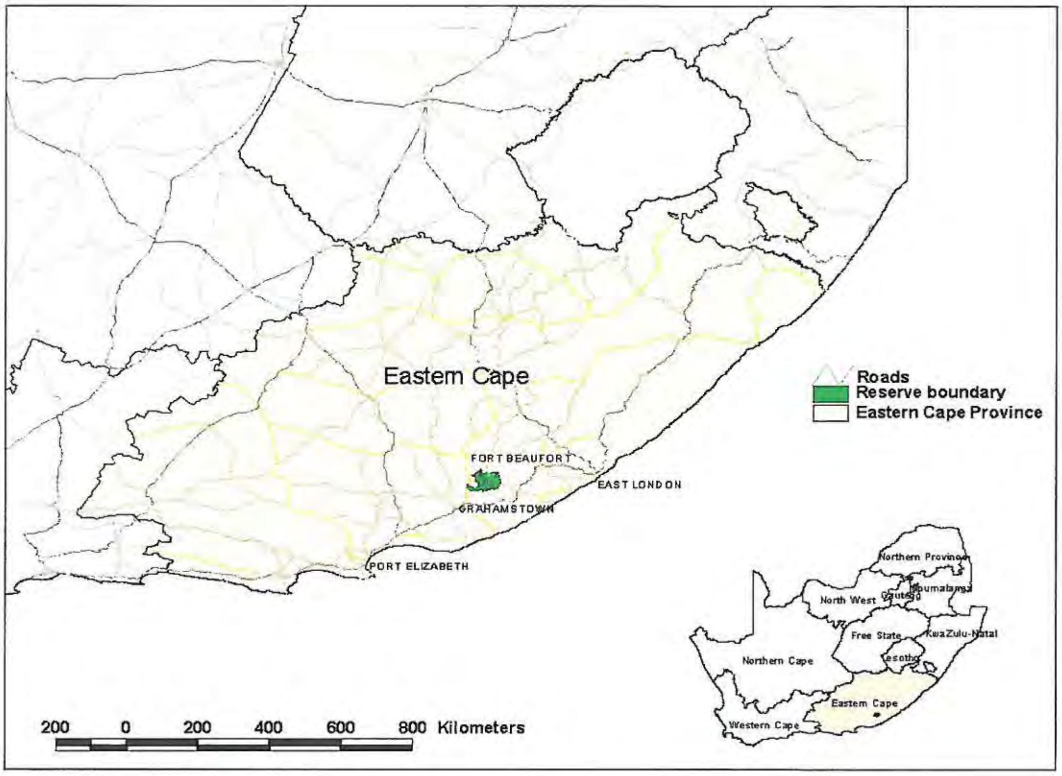


Figure 2.1: Situation of the GFRR within the Eastern Cape Province, Republic of South Africa. (Maps: ArcView 3.3, ArcGIS 9.2 and PlanetGIS).

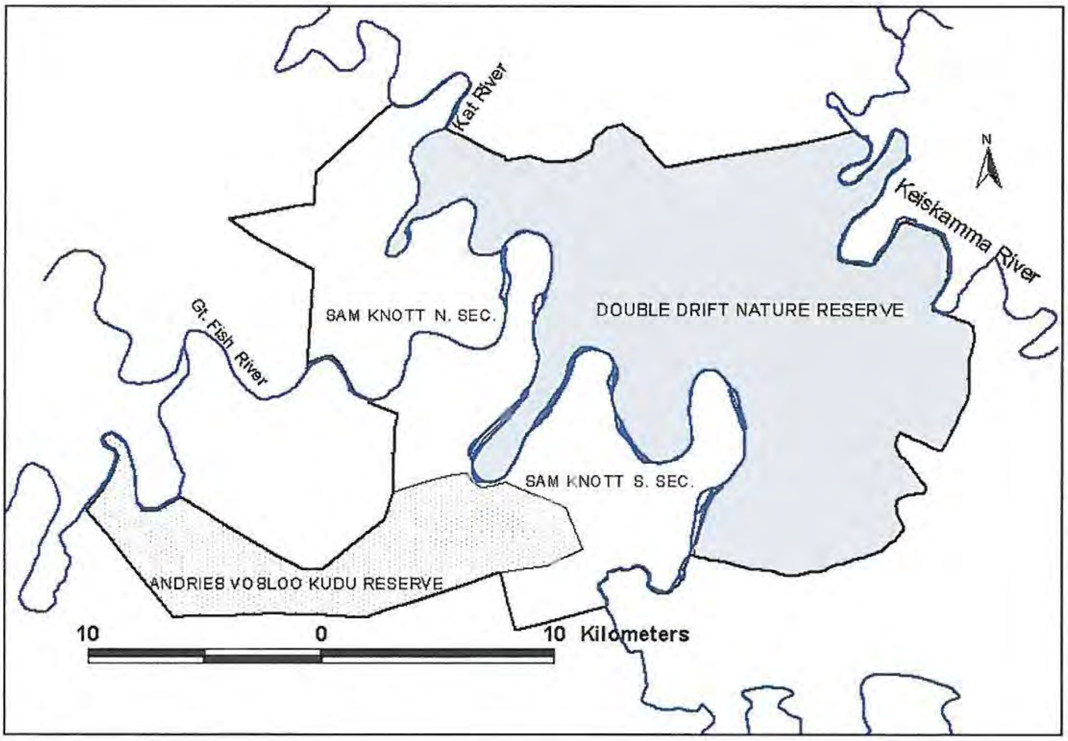


Figure 2.2: The GFRR showing the three contiguous conservation areas and main river systems.

TOPOGRAPHY AND GEOLOGY OF THE GFRR

The landscape consists of steep, incised river valleys with inter-basin ridges. The river valleys contain nutrient rich mudstones, which are susceptible to erosion, whereas the more resistant sandstones occur on the inter-basin ridges. It is likely that steep slopes will act as a barrier to movement of black rhinoceroses and areas with a slope angle in excess of 20° (Figure 2.3) will inhibit movement of black rhinoceroses (pers. obs.). The range of elevation on the GFRR is between 95m above sea level (asl) at the exit of the Great Fish River from the Reserve in the south, to 561m asl in the Nyathi Game Camp in the Double Drift sector.

The main rivers are the Great Fish River and Kat River which have been largely responsible for sculpting the landscape. These two rivers follow highly convoluted courses through the GFRR. Dolerite dykes have been exposed in the river beds, in places forming small waterfalls of up to 4m in height. Tributaries to the main rivers are ephemeral and subject to rapid drainage after heavy rainfall. The Koonap River, which is the third major watercourse in the area, forms a confluence with the Great Fish outside the boundaries of the GFRR. Since the middle 1970's dramatic changes have occurred with respect to the Great Fish River system with the completion of the Orange-Fish interbasin transfer scheme in 1975. The Great Fish River changed, almost overnight, from being a seasonally flowing system to a perennial system. Water flow in the Kat River is controlled by the Kat River Dam at Seymour, and in dry periods is reduced to a series of pools.

The geology of the area comprises two main groups, namely the Ecca and Beaufort Groups, both of which are part of the Karoo Supergroup (Table 2.1). The Beaufort Group is predominantly grey/red mudstone and sandstone of the

Middleton Formation, and grey mudstones, sandstone and shale of the Koonap Formation. Both of these formations are part of the Adelaide subgroup of the Beaufort group, Karoo supergroup (Johnson & Keyser 1976). The second major formation is the Ecca group made up of the shales of the Fort Brown formation, and the sandstone and shales of the Ripon formation (Table 2.1 and Figure 2.4).

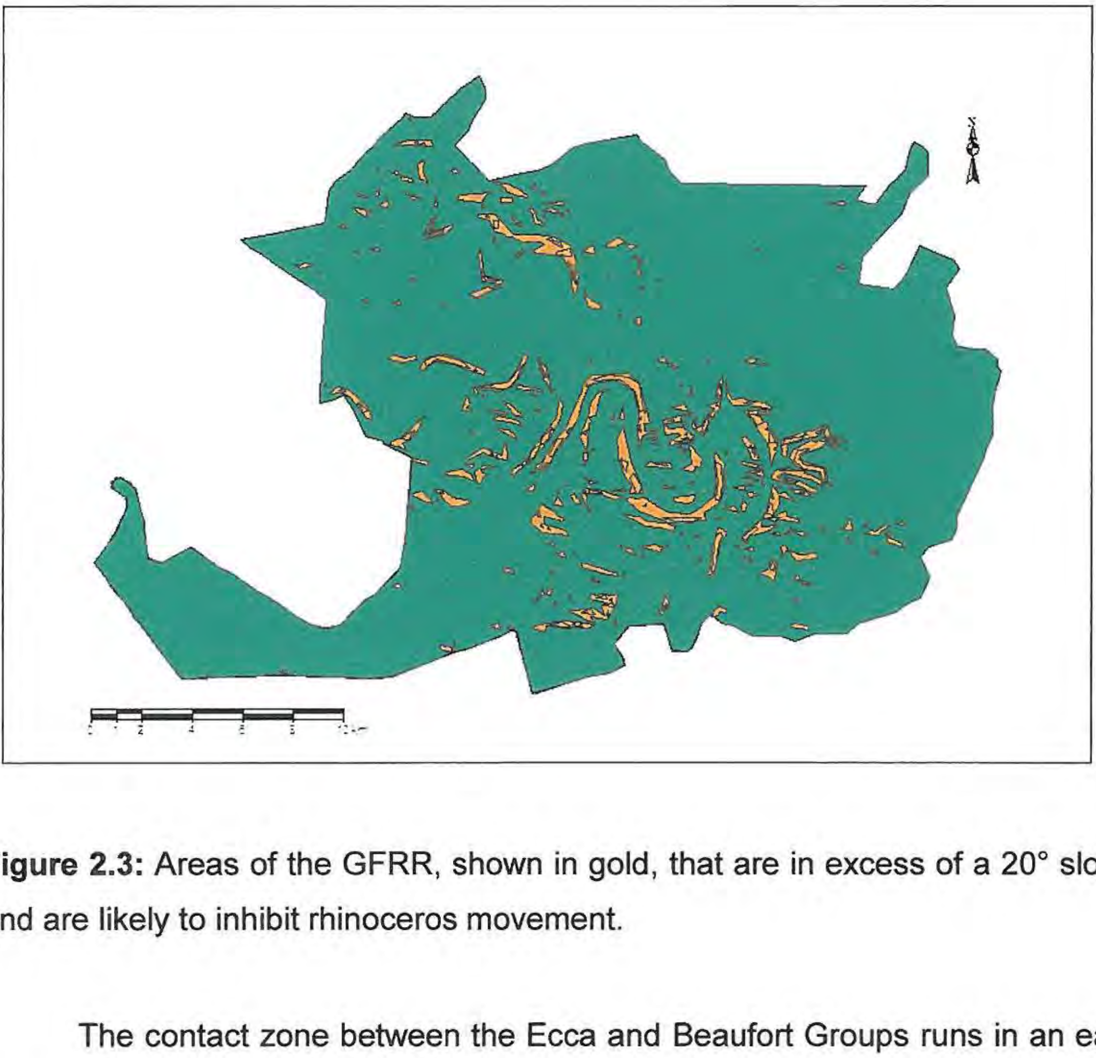


Figure 2.3: Areas of the GFRR, shown in gold, that are in excess of a 20° slope and are likely to inhibit rhinoceros movement.

The contact zone between the Ecca and Beaufort Groups runs in an east to west direction through the southern section of the GFRR (Figure 2.4; Gow & de Klerk 1997). This contact zone is a remnant of the onset of terrestrial conditions in the Karoo basin, which had been part of the large inland sea (Johnson 1976; Jordaan 1981; Rubidge 1988). The geology of the central and the northern sectors of the GFRR is predominantly of homogenous Middleton formation (Pm), and as such the northern areas of the GFRR have been excluded from display on the map in Figure 2.4. The soils in the Eastern Cape Province range from sandy clays and lithosols of the Ecca formations, to deep solonetic soils derived from dolerites of the Beaufort group (Low & Rebelo 1996) (Table 2.1).

Table 2.1: Schematic depiction of the geology of the Great Fish River Reserve from the 1:250 000 Geological Series Map No. 3326 GRAHAMSTOWN, (S.A. Council for Geoscience, 1995).

SUPERGROUP	**KAROO SUPERGROUP**			
GROUP	**BEAUFORT**		**ECCA**	
SUBGROUP	**ADELAIDE**		Contact zone	
FORMATION	**Middleton**	**Koonap**	**Fort Brown**	**Ripon**
LITHOLOGY	**Grey and Red mudstone, sandstone**	**Grey mudstone, sandstone & shale**	**Shale**	**Sandstone, shale**

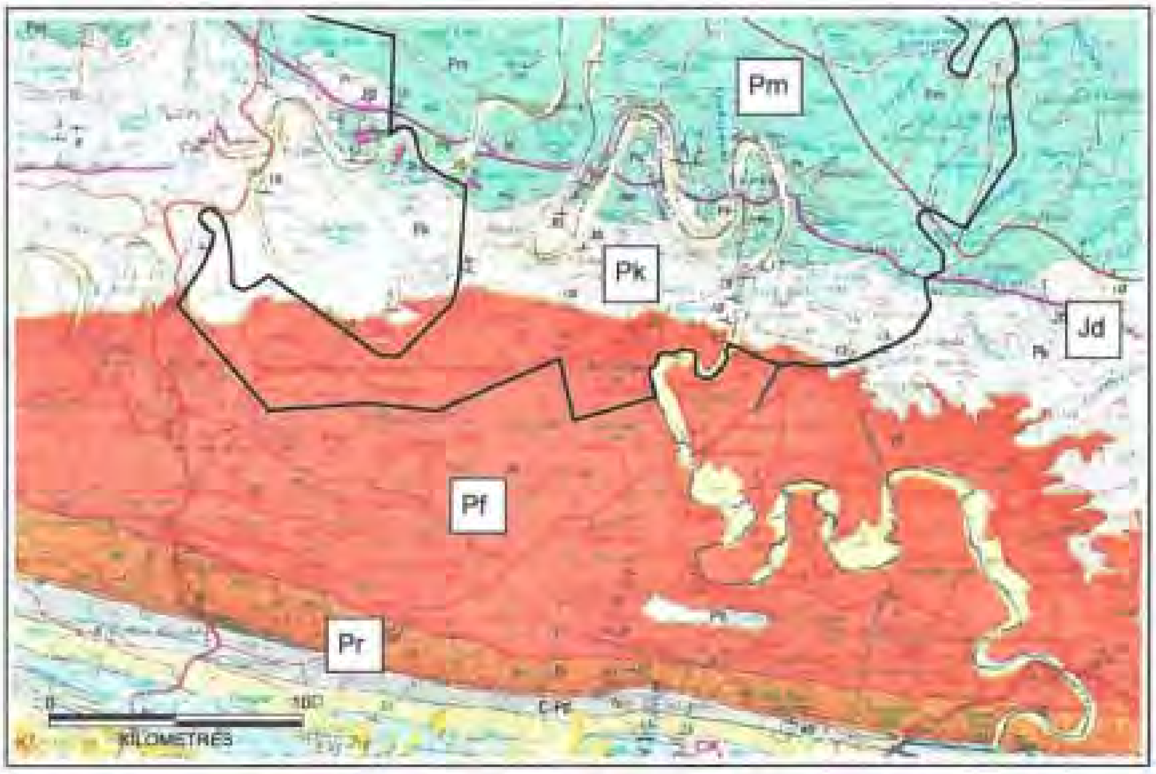


Figure 2.4: The geology of the Great Fish River Reserve and surrounding area. (from the 1:250 000 Geological Series Map No. 3326 GRAHAMSTOWN, S.A. Council for Geoscience, 1995). The contact zone between the Beaufort and Ecca groups is clearly seen running in a West to East direction (Pf – Fort Brown Formation, Pk – Koonap Formation, Pm – Middleton Formation, Pr – Ripon Formation, Jd – Dolerite intrusions.

CLIMATE

Climatological data have been collected from five sites throughout the GFRR (Figure 2.5), and from an additional weather station that has been maintained on a neighbouring farm "Bucklands" since 1967, for varying periods of between 5 and 42 years (Appendix 2A). According to the Köppen classification (Schulze 1947), the climate of the area may be described as *Cfa*, where *C* = warm temperate climate — coldest month 18°C to –3°C; *f* = sufficient precipitation during all months; *a* = maximum temperature over 22°C. Mist, or advective fog, is a frequent phenomenon, especially in the winter months, and this makes a significant contribution to total precipitation (Palmer 1981).

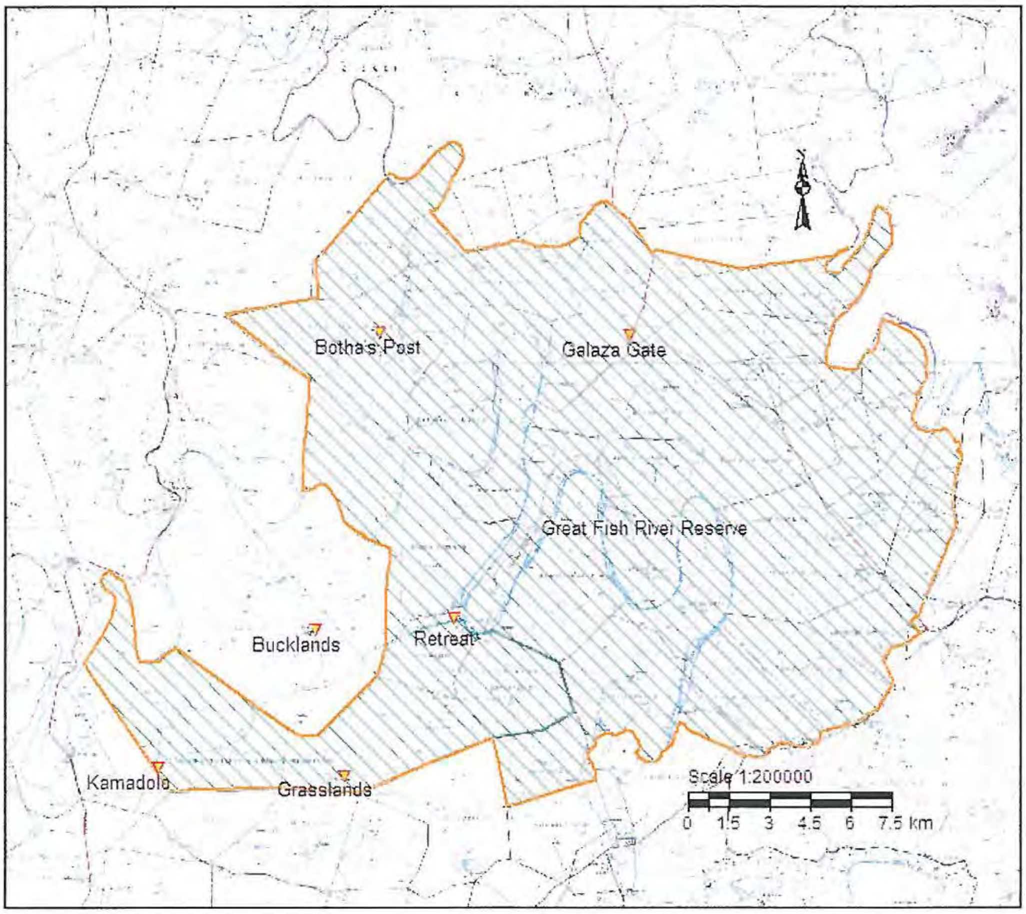


Figure 2.5: Localities of weather recording stations on the GFRR and adjacent property "Bucklands".

Mean annual rainfall varied significantly among the six stations (One-way ANOVA; $F_{5,116} = 3.80$; $P<0.05$; Table 2.2; Appendix 2A) and rainfall at Galaza was significantly greater than at Kamodolo (post hoc test; $P<0.05$). Rainfall varied in both space and time and the annual minimum and maximum rainfall varied at each site by between 300 and 650mm (Table 2.2).

Table 2.2: Summary of annual rainfall at the six weather stations in the GFRR and "Bucklands".

	Annual rainfall (mm)		
Weather Station	mean ± 1sd	min-max	N (years)
Kamadolo	404.3± 112.6	179-732	26
Retreat	483.1± 109.6	251-706	21
Botha's Post	507.9± 94.6	308-632	16
Bucklands	479.5± 137.4	209-779	42
Galaza	644.0± 167.5	427-863	5
Grasslands	532.7 ± 198.8	263-910	12

Mean monthly precipitation at three selected sites (Botha's Post, Retreat and Kamodolo) varied significantly (One-way ANOVA; Botha's Post, $F_{11,180}$ = 4.42; P<0.05; Retreat, $F_{10,241}$ = 6.7, P<0.05; Kamodolo, $F_{11,300}$ = 5.2, P<0.05). At each station, rainfall in winter (May-July) was significantly lower than in early summer (November-December) and late autumn (February-March; post hoc tests, P<0.05 for each pair; Figure 2.6 and Appendices 2B to 2D). The topographical complexity of the GFRR contributed to spatial variability in rainfall, and the lower elevation sites such as Kamadolo, experienced a lower mean annual rainfall, resulting in a semi-arid environment. The higher elevation sites such as Botha's Post, were wetter and were characterised by plant species not found at lower elevations (e.g. *Scutia myrtina, Sideroxylon inerme, Diospyros dichrophylla* and *Hippobromus pauciflorus.*). Aspect and slope resulted in further variation in climate as southern slopes experienced cooler and moister conditions.

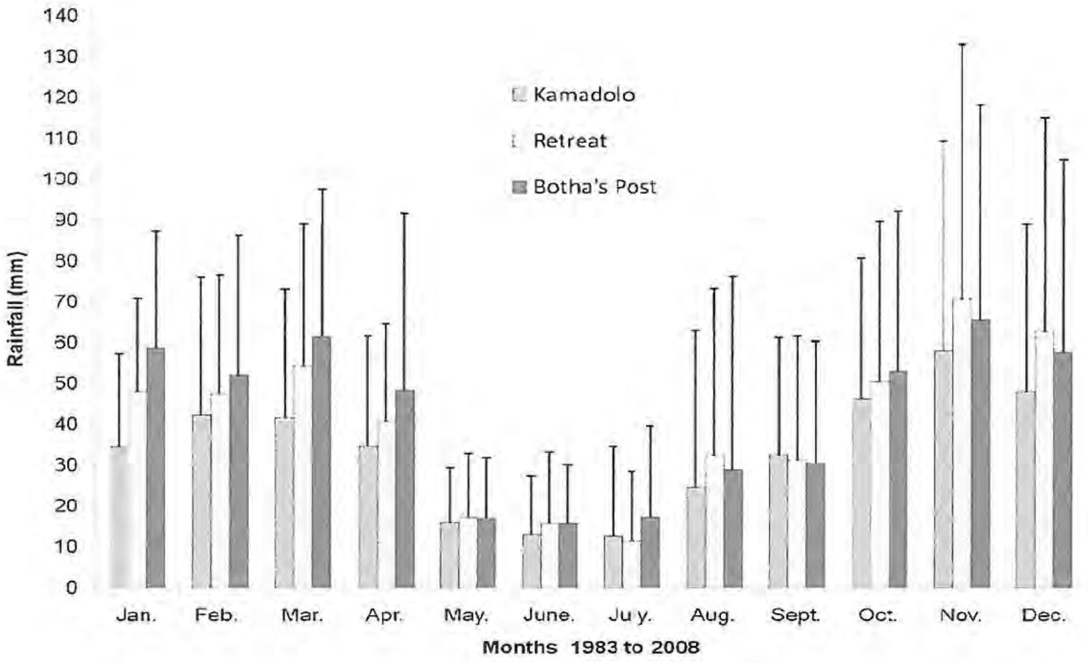


Figure 2.6: Mean monthly rainfall from three sites within the GFRR for the period 1983 to 2008. Data are means ± 1sd.

Mean minimum and maximum monthly temperatures (Figure 2.7) varied significantly (One-way ANOVA; minimum; $F_{10,203}$ =26.6; P<0.05; maximum, $F_{2,202}$ =22.2; P<0.05). In the summer months maximum daily temperatures often exceeded 35^{0}C, whereas in the winter months of June to August, night temperatures dropped below zero. The major river valleys experienced lower minimum temperature with frost. Altitude and aspect affected temperature and the lower elevation sites experienced a greater degree of variability in temperature and frost in winter. The higher elevation sites and southern slopes were cooler in summer but did not experience frost in winter.

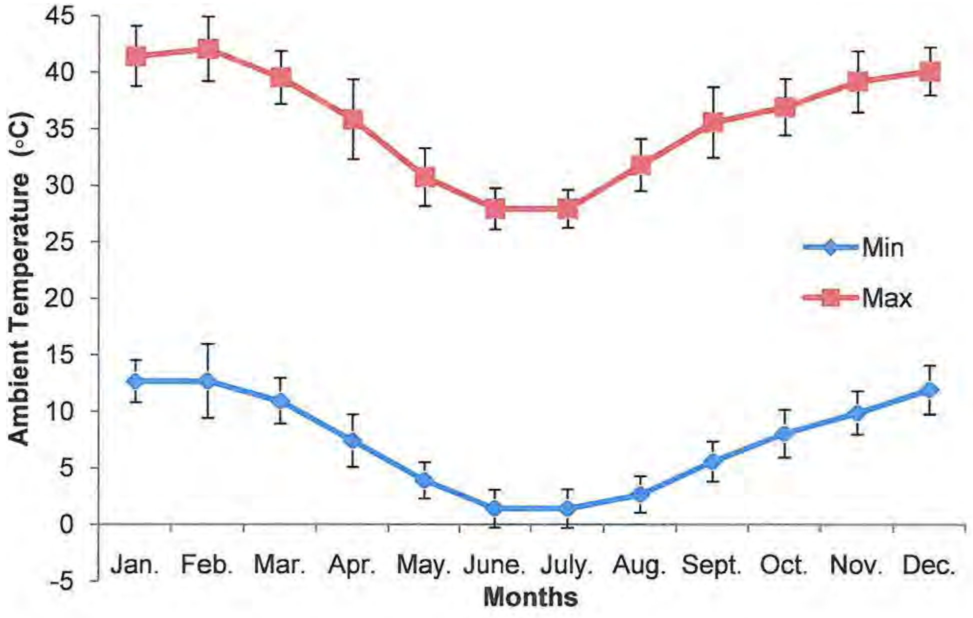
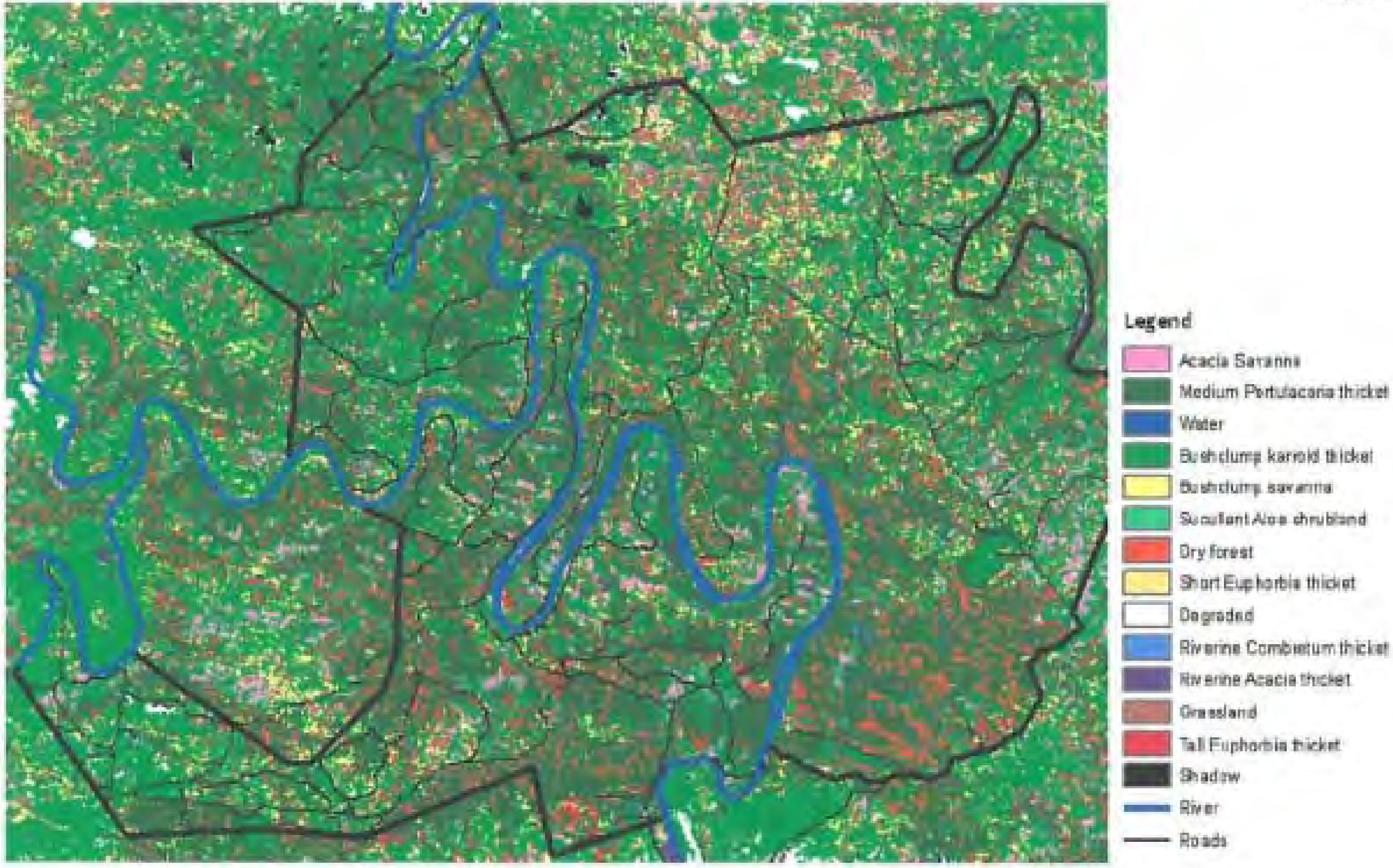


Figure 2.7: Maximum and minimum monthly temperatures from three weather stations on the SKNR sector for the period 1990 to 2008. Data are means ± 1sd.

VEGETATION

Methods

The vegetation map for the GFRR was produced as a key component of the vegetation monitoring programme that was developed in conjunction with the University of Fort Hare (Trollope & Webber 2000; Trollope *et al.* 2004). The vegetation map was developed using remote sensing data from SPOT 5, a satellite Earth Observation System (van den Broeck *et al.* 2008b). To verify the satellite imagery, 79 ground monitoring sites were established in homogeneous vegetation units (HVU's) throughout the GFRR, and these were used to link satellite data to vegetation types. This resulted in eleven distinct vegetation types being recognised. Surveys of these eleven vegetation classes resulted in the development of plant species lists which were compared against the comprehensive plant checklist of Clark (1994). The initial verification of the satellite data was carried out by "Earth Collective" (van den Broeck *et al.* 2008a) and the vegetation map (Figure 2.8) was developed by S. Weel of "Earth Collective" in 2008 (van den Broek *et al.* 2008b).



Scale 1:160,000

Figure 2.8: Distribution of the vegetation types of the Great Fish River Reserve (Vegetation map author S. Weel of Earth Collective - van den Broek *et al.* 2008b)

General Description of the Vegetation

The GFRR falls within the western sector of the Maputaland-Pondoland-Albany biodiversity hotspot which is characterized by a high incidence of endemic plants mostly of succulent and bulb affinity (Low & Rebelo 1996; Knight & Cowling 2006). The vegetation of the GFRR is classified broadly as Sub-Tropical Transitional Thicket (Everard 1987). Acocks (1988) described the vegetation as Valley Bushveld - Fish River Scrub variation. He further described the Fish River Scrub "in its undamaged state, as an extremely dense, semi-succulent thorny scrub about 2m high". Occurring in the wide valley of the Great Fish River, it is adapted to hot and semi-arid conditions. A large portion of the GFRR has been further classified as Xeric Succulent Thicket, due to the preponderance of succulent forms of vegetation, such as *Portulacaria afra*, *Crassula spp.* and *Euphorbia bothae* (Everard 1987; Low & Rebelo 1996). A contemporary description of thicket is given by Cowling *et al.* (2005) as "a dense formation of evergreen and weakly deciduous shrubs and low trees (2-5m), often spiny and festooned with vines". Where over utilisation of the vegetation has occurred, the thicket has been invaded by exotic plant species such as *Opuntia spp.* as well as indigenous karroid elements such as *Euphorbia bothae* (Acocks 1988). Subtropical thicket is extremely sensitive to over utilisation, and once stressed beyond a certain threshold, where microclimates and litter loads are extensively modified, it will not regenerate but it will be replaced by a form of false dwarf karroid veld comprising karroo shrublets (Aucamp & du Toit 1973; Aucamp & Tainton 1984). Once thinned, it does not regenerate or revert to its former state even under an ideal regime (Stuart-Hill & Aucamp 1993; Fabricius *et al.* 1996). *Acacia* savanna occurs mainly in the Nyathi game camp, from which black rhinoceroses are presently excluded, but much of this vegetation type is the result of old cleared areas now in the process of invasion by *Acacia karoo*. Non-succulent thicket, described as Xeric Kaffrarian Thicket by Everard (1987) is found in the vicinity of the Keiskamma River in the eastern areas of the GFRR and in the Nyathi game camp in the north-eastern section of the DDNR, which experience higher annual rainfall.

Initially ten major vegetation classes were identified on the GFRR (Trollope *et al.* 2004), with an additional vegetation class being added by van den Broek *et al.* (2008a) in his revision and finalisation of Trollope's research project. Additionally, a previously existing class, namely "Karroid *Cynadon* Shrubland", which occupied a small localised area in the western sector of the AVKR, but which has been part of the original fixed point vegetation monitoring plots since 1984, was retained, although not included in the vegetation map due to its small area. A description of this vegetation type is nevertheless included at the end of the vegetation type list. The vegetation map (van den Broek *et al.* 2008b) depicts eleven vegetation classes for the GFRR, and these homogeneous vegetation units (HVU's) are described below. The vegetation map also includes areas described as "degraded", but these areas are not limited to any particular vegetation type.

1. Tall *Euphorbia* Thicket (TET) (Figure 2.9)

This vegetation class occurs mainly on slopes with southern, south-eastern or south-western aspects and is dominated by two tree euphorbias, *Euphorbia tetragona* and *Euphorbia triangularis*. Other plant species found include: *Coddia rudis, Ehretia rigida,* *Azima tetracantha, Grewia occidentalis, Grewia robusta, Rhus refracta, Rhus lucida, Asparagus spp., Putterlickia pyracantha, Phyllanthus verrucosus, Capparis sepiara, Rhoicissus spp. Pappea capensis, Ptaeroxylon obliquum and Schotia afra.* Shrubs such as *Tecoma capensis*, *Jatropha capensis* and *Plumbago auriculata* are characteristic low growing plant species. Shade adapted grass species such as *Panicum maximum* and *Panicum deustum* are represented in the understory, especially during wet periods. Brown (2008) found that *P. auriculata, J. capensis*, and the two tree *Euphorbia spp.* contribute to over 50% of the diet of black rhinoceroses in this vegetation class.

Figure 2.9: Tall *Euphorbia* Thicket, characterized by *Euphorbia tetragona* and *Euphorbia triangularis* stands growing on steep slopes

2. Short Euphorbia Thicket (SET) (Figure 2.10)

Short Euphorbia Thicket occurs only in the extreme western area of the AVKR sector near Fort Brown. The dominant species is a stem succulent, *Euphorbia bothae* which is included in Appendix II of the CITES list of protected plants. SET is a xeric vegetation class characterised by a high succulent component, especially when in a degraded state, and occurs in flatter areas on shallow soils overlying mainly Ecca shales. Other plant species are *Rhigozum obovatum*, *Gymnosporia capitata*, *Brachylaena ilicifolia*, *Portulacaria afra*. *Grewia robusta*, *Lycium ferocissimum*, *Asparagus spp.*, *Ehritia rigida*, *Pentzia incana* and *Mesembryanthemum spp.* Larger tree species include *Pappea capensis*, *Schotia afra* and *Boscia oleoides*. Representative grass species include *Cymbopogon marginatus*, *Aristida spp.*, *Digitaria eriantha*, with *Cynadon dactylon* in cleared areas, and *Panicum maximum* in the clumps and drainage lines.

Figure 2.10: Short *Euphorbia* Thicket dominated by stands of *Euphorbia bothae*.

3. Medium *Portulacaria* Thicket (MPT) (Figure 2.11)

The Medium *Portulacaria* Thicket is analogous to the Xeric Succulent Thicket of Low and Rebelo (1996). This vegetation class is dominated by high proportions of succulent shrubs, sclerophyllous trees and shrubs, succulent herbs and forbs. As the name suggests, dense stands of *Portulacaria afra* dominate in the MPT, but this class also includes a great diversity of other species such as: *Euclea undulata, Schotia afra, Grewia robusta, Capparis sepiara, Ptaeroxylon obliquum, Phyllanthus verrucosus, Ozoroa mucronata, Euphorbia bothae, Euphorbia pentagona, Ehretia rigida, Azima tetracantha, Carissa haematocarpa, Asparagus spp, Jasminum angularae, Rhoicissus spp, Brachylaena ilicifolia, Pappea capensis, Cussonia spicata, Crassula spp., Sansevieria hyacinthoides, Protasparagus spp., Strelitzia spp., Gymnosporia capitata, Putterlickia pyracantha* and *Rhigozum obovatum*. The understory is bare with an absence of grass species.

Figure 2.11: Medium *Portulacaria* Thicket showing the dense nature of this class

4. Dry Forest (DF) (Figure 2.12) A high incidence of tree species is supported, frequently in excess of 3m in height. Dry Forest is associated with south facing slopes of uplands, or the valleys draining higher lying areas. Dry Forest also occurs on the south facing scarp on the southern boundary of the AVKR. Slope, which is characteristic of many Dry Forest localities, moderates black rhinoceros utilisation. Browsing is restricted to the lower growing species, or young plants that are accessible. The tall tree species are: *Harpephyllum caffrum, Calodendrum capense, Schotia latifolia* and *Sideroxylon inerme*. Lower growing tree species are *Ptaeroxylon obliquum, Euclea undulata, Buddleja saligna* and *Olea europaea* while *Plumbago auriculata, Scutia myrtina, Brachylaena ilicifolia, Hippobromus pauciflorus, Diospyros dichrophylla, Tetradenia barberae* and *Tecomaria capensis* form a dense understory.

Figure 2.12: Dry Forest on the southern scarp and characterised by dense stands of tree species such as *Harpephylum caffrum* and *Schotia latifolia*.
(Photograph W. Trollope).

5. Bushclump Karroid Thicket (BKT) (Figure 2.13)

Bushclump Karroid Thicket is characterized by bush clumps of approximately 3m in height, with a karroid herbaceous layer. Grass is poorly represented with species such as *Aristida junciformis* and *Digitaria eriantha* being characteristic. Of historically degraded origin and found on the flatter areas, the soil is shallow with the shale understory of the Ecca formation being exposed in some areas. Soils are highly erodable. Plant species include *Rhus longispina, Rhus refracta, Gymnosporia polycantha, Euclea undulate,* isolated *Boscia oleoides,* The most frequently found karroid shrubs are *Pentzia incana* and *Becium burchellianum.*

Figure 2.13: Bushclump Karroid Thicket found on the dryer and flatter landscape in the western section of the AVKR sector.

6. Riverine *Acacia* Thicket (RAT) (Figure 2.14)

This vegetation class is restricted to the riparian corridor that flanks the main river courses and is driven by disturbance through periodic flooding. The riparian areas of the Great Fish River are dominated by *Acacia karroo*, with a very limited occurrence of other species such as *Combretum caffrum*, *Ziziphus mucronata*, *Rhus lancea*, and *Gymnosporia capitata*. In contrast, the Kat River riparian area has dense stands of *Combretum caffrum*, *Ziziphus mucronata* and *Acacia caffra*. The herbaceous layer on both rivers is dominated by the shade-adapted *Panicum maximum* grass growing on the sandy alluvial deposits. Reeds and sedges are located at the water's edge.

Figure 2.14: Riverine *Acacia* Thicket with *Acacia karoo* stands growing on the alluvial sandy soils bordering the Great Fish River (Photograph: D. Brown).

7. Riverine *Combretum* Thicket (RCT) (Figure 2.15)

Riverine *Combretum* Thicket is found in, and flanking, major ephemeral drainage courses. Of linear configuration, the width of these stands is usually less than 100m. Little evidence exists of a continuum between this and adjacent veld types. The drainage beds are composed of shale particles that have eroded from the surrounding area. The dominant tall tree is *Combretum caffrum* which can exceed 9m in height. Other typical plant species are *Olea europaea, Buddleja saligna, Grewia occidentalis, Ziziphus mucronata, Gymnosporia spp., Azima tetracantha,* and *Rhus lancea* in some areas. *Plumbago auriculata and Rhoicissus spp. are* characteristic, with *Panicum maximum* as the dominant grass species. *Acacia karroo* and *Rus refracta* are also found on the defined edge between this, and adjacent vegetation classes.

Figure 2.15: Riverine *Combretum* Thicket with tall *Combretum caffrum* trees growing in the narrow drainage line with pronounced edge effect in the contact zone with adjacent vegetation types.

8. Succulent *Aloe* Shrubland (SAS) (Figure 2.16)

The dominant species is *Aloe ferox*, but some variation in the understory occurs. On the western sector of the AVKR this vegetation type is interspersed among the MPT and SET, and elements of both these vegetation types are evident. Other species include *Euphorbia bothae*, *Pentzia incana*, *Grewia robusta*, *Portulacaria afra*, *Sansevieria hyacinthoides*, *Ehretia rigida*, *Brachylaena ilicifolia* and *Carissa haematocarpa*. The gramminoid components are mainly represented by *Panicum* spp. which occur in dense bush clumps where they are protected from grazing. Black rhinoceroses make extensive use of this vegetation type probably due to proximity to the MPC and SET vegetation types. The area covered by this vegetation type is fragmented throughout the GFRR.

Figure 2.16: Succulent *Aloe* Shrubland showing mature *Aloe ferox* plants but displaying minimal recruitment of *Aloe spp*.

9. Bush Clump Savanna (BCS) (Figure 2.17)

Bush Clump Savanna occurs on the steeper south facing slopes, in shallow valleys, and also on flatter landscapes at a higher altitude, when compared to Bushclump Karroid Thicket (BKT). Tree and shrub species associated with Bush Clump Savanna are: *Cussonia spicata, Oleo europea, Scutia myrtina, Pteroxylon obliquum, Buddleja saligna, Rhus incisa, Tecomaria capensis, Portulacaria afra, Cassine crocea, Schotia afra, Ehretia rigida, Azima tetracantha,* and *Capparis sepiaria.* Grass species include *Digitaria eriantha, Cymbopogon plurinodis,* and *Themeda triandra,*

Figure 2.17: Bush Clump Savanna with isolated clumps found in flatter areas and separated by the grass sward.

10. *Acacia* Savanna (AS) (Figure 2.18)

This vegetation class is found largely on disturbed areas and old agricultural lands which are in the process of being invaded by ligneous pioneer species such as *Acacia karroo*. The largest example of this vegetation type is found in areas of the Nyathi game camp on DDNR to which black rhinoceroses do not presently have access. Graminoid species are mainly *Sporobolus fimbriatus* and *Digitaria eriantha*. For the purpose of this study, this scattered vegetation class is of minor importance despite the extent of occurrence shown on the vegetation map (pers. obs.).

Figure 2.18: *Acacia* Savanna veld dominated by invading *Acacia karoo*.
(Photograph: W. Trollope)

11. Grassland (G) (Figure 2.19)

The natural upland grasslands are found on the tops of hills and ridges. Graminoid species include *Themeda triandra, Sporobolus fimbriatus, Cymbopogon marginatus, Cymbopogon plurinodis, Merxmuellera disticha*, and *Digitaria eriantha*. Trees and shrubs found in association with the upland grassland include mixed stands of *Olea europaea, Cussonia spicata, Sideroxylon inerme, Buddleja saligna, Euclea undulata, Diospyros dichrophylla, Scutia myrtina, Coddia rudis, Grewia occidentalis, Carissa haematocarpa, Hippobromus pauciflorus and Brachylaena ilicifolia.*

Figure 2.19: Upland Grassland with characteristic bush clumps. Rainfall in these areas is typically in excess of 500mm per annum.

12. Karroid *Cynadon* Shrubland (KCS) (Figure 2.20)

This vegetation class is restricted to a relatively small section in the western sector of the AVKR, but is included here as it is a unique vegetation type characterized by short growing karoo shrublets and a soloniferous grass cover of *Cynadon dactylon*. Plant species typically form a karroid herbaceous layer composed of *Cynadon dactylon, Pentzia incana*, and *Mesembryanthemum spp.*, with trees on the periphery such as *Pappea capensis* and *Rhus refracta*. Grass cover, besides *Cynadon*, is sparse, but *Aristida congesta and Digitaria eriantha* are represented. As this vegetation type occupies a very limited physical area which is not represented by the map scale, it is excluded from the vegetation map.


13/06/2007

Figure 2.20: Karroid *Cynadon* Shrubland largely devoid of trees or bush but with *Mesembryanthemum spp.* well represented.

MAMMALIAN FAUNA OF THE GFRR

Besides the black rhinoceros, a rich indigenous mammalian fauna is represented on the GFRR with a number of extralimital species still present (Table 2.3), (Appendix 2E).

Table 2.3: Results of the annual game counts for 2003-2006. Species in italics are extralimital to the Great Fish River area.

Species	2003	2004	2005	2006
Aardvark				1
Aardwolf		2	1	1
Baboon (Troops)	22	42	56	71
Bat-eared Fox	1	3	2	
Blesbok	*101*	*143*	*134*	*111*
Bontebok	*22*	*21*	*13*	*14*
Buffalo	122	193	245	192
Bushbuck	230	332	192	131
Bushpig	12	3		3
Duiker - Grey	46	90	74	65
Eland	509	361	434	443
Elephant	3	3	2	2
Giraffe	*40*	*46*	*31*	*32*
Grysbok	2	1		
Hartebeest - Red	211	294	343	307
Hippo	21	5	14	17
Impala	*280*	*451*	*347*	*344*
Jackal	71	85	52	87
Kudu	1523	1920	1696	2323
Nyala	*18*	*23*	*16*	*10*
Ostrich	187	208	227	230
Reedbuck – Mountain		18	3	9
Rhino – Black	62	44	66	71
Rhino – White	*13*	*17*	*6*	*6*
Springbok	12	10	8	6
Steenbok	10	85	56	61
Warthog	*865*	*865*	*470*	*949*
Waterbuck	*60*	*51*	*45*	*45*
Wildebeest – Blue	*321*	*311*	*16*	*10*
Zebra	*100*	*143*	*133*	*90*

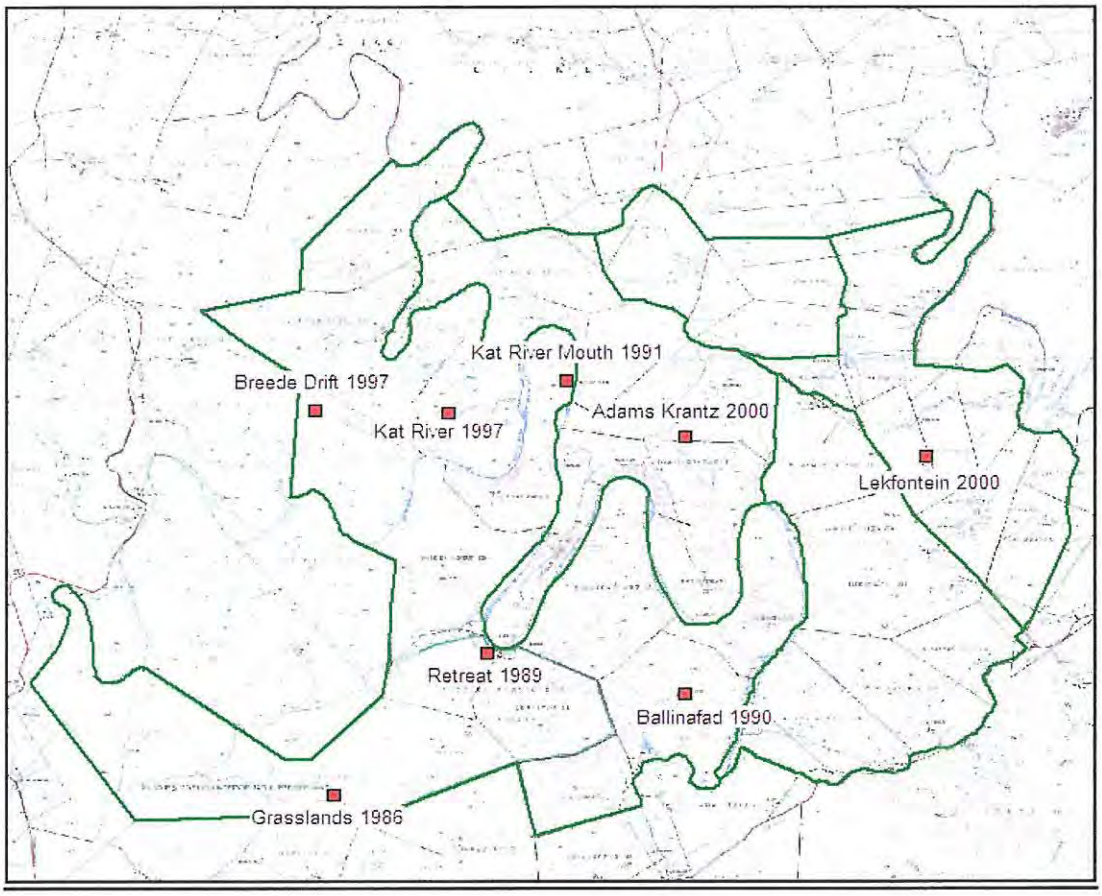


Figure 2.21: Distribution sites and dates of acclimatisation/release bomas on the GFRR.

Re-introduction method

All except two of the black rhinoceroses re-introduced to the GFRR spent at least three weeks in temporary acclimatisation bomas (containment pens) erected in the area of planned release. The bomas were a series of joined pens, each accommodating one rhinoceros. The bomas were $10m^2$, with robust pole walls 2m high incorporating off-loading ramps and release gates. Roofing was of 80% shade cloth, and covered 25% of each boma. Floors had a 300mm layer of sand covering the hard undersurface. Water troughs were incorporated and lucerne was made available *ad lib.* Local vegetation was provided twice a day and hung from the boma walls. All remnants of the previous feeding session were cleared out of the pens before the new fodder was given. While animals were held in the bomas, any wounds were treated. Animals were released singly just after sundown, one each evening, with each pen being closed off after being vacated. The youngest animals were released first, followed by larger females, with any large or mature bulls being held for an additional week before release. This sequential release strategy was adopted in order to allow the more vulnerable younger animals to become acquainted with the area, including knowledge of flight routes in the event of aggression from older animals. Where natural water resources were not located in the immediate vicinity of the release bomas, a temporary water trough was provided close to the bomas for two weeks post-release while animals orientated themselves to the new area.

CHAPTER 3

MONITORING OF BLACK RHINOCEROSES ON THE GFRR: AN ANALYSIS AND COMPARISON OF METHODS

INTRODUCTION

The need for intensive monitoring of populations of the black rhinoceros is justified in a number of ways. The endangered status of the black rhinoceros (Dublin & Wilson 1998; Emslie *et al.* 2007) requires that managers assume responsibility and accountability for the well-being of these populations, necessitating intensive monitoring and regular population performance assessment (Walpole *et al.* 2001). The Southern African Development Community (SADC) Rhino Management Group's (RMG) objectives are to achieve and maintain maximum productivity in all populations and it is therefore imperative that any factors inhibiting this are identified and understood. To meet these objectives, the RMG has emphasised the importance of annual regional monitoring and reporting with particular emphasis on monitoring population growth rate and age structure (Emslie *et al.* 1993). On the GFRR, the black rhinoceros population receives the most intensive monitoring of all mammal species, and the monitoring programme forms the foundation for understanding the dynamics of this population.

A range of different monitoring methods are available and the decision as to which is the most appropriate will depend on what information is required, the behaviour of the species being monitored and the habitat (Bowland & Perrin 1994; Ellis & Bernard 2005). Direct methods, which involve observation and counts of animals which may be individually identifiable, are preferable as they provide demographic data as well as an estimate of abundance. Direct methods are however not appropriate for cryptic and/or nocturnal species, for which a range of indirect methods have been developed. These include counts of sign such as spoor or dung, from which the species abundance may be estimated (Ellis & Bernard 2005; Funston *et al.* 2010). While it may be possible to gain some demographic information from sign such as spoor, the indirect methods typically provide far less information than can be gained from direct observation. Thus, where both a measure of abundance and demographic information are required and the species, and habitat allow, direct observations are preferable (Ellis & Bernard 2005).

In large areas and open habitats, aerial monitoring is often the preferred method for monitoring the black rhinoceros and in Etosha National Park (Namibia) and the Kruger National Park (South Africa), a light fixed-wing aircraft was used to undertake stratified block counts of the black rhinoceroses (du Preez 2004; Hofmeyr 2007). This method is a combination census/monitoring exercise and observations, which include sex and age category (du Preez 2004), provide some of the required demographic information for population monitoring. In the grassland habitats of the Masai Mara (Kenya), observations from hot air balloons give twice the sighting rate compared to ground based vehicle patrols, although with reduced identification accuracy (Walpole 2002). It is unlikely that this method would work in much denser vegetation, such as in the GFRR, where observation would be hindered and there would be very few safe landing sites or vehicle collection points.

An alternative methodology is to focus observations around areas to which rhinoceroses are attracted. In the Etosha National Park, where rhinoceroses need to drink on a regular basis, observations were concentrated around waterholes at night.

Animals that had been immobilized for translocation within Etosha were fitted with colour-coded reflective discs that allowed individual recognition when the animals came to waterholes at night (Hofmeyr 1984). The reflectors had a life span of about six months before they were shed, and this enabled effective monitoring of nine of the ten translocated rhinoceroses (Hofmeyr 1984). Observations may be supplemented by photography, and Cilliers (1989) used cameras to photograph black rhinoceroses visiting waterholes during the dry season. The development of remote camera traps has allowed further refinement of this technique and reduced the need for observers to remain at waterholes or other sites. Camera traps have been successfully used to obtain data for a range of mammal species including cheetah (Marnewick *et al.* 2006; Marnewick *et al.* 2008) and brown hyaena (Thorn *et al.* 2009).

Photography does not have to be concentrated at specific points, and pictures can be taken on a more opportunistic basis. In the arid Damaraland (Namibia), monthly monitoring events were undertaken by small teams tracking on foot, and rhinoceroses were photographed whenever encountered. Identification files were begun in 1982 and by 1988 it was estimated that approximately 100 black rhinoceroses occurred in the area (Britz & Loutit 1989). Similarly, daylight photography has formed the basis of black rhinoceros monitoring in the 68.3km² Solio Game Reserve (Patton *et al.* 2007), and in the Salient of Aberdare National Park in Kenya (Patton & Jones 2007) where both day and night photography over 112 days was undertaken. In the Solio Game Reserve dedicated photographic events lasting 57 days took place in a 13 month period between September 2005 and October 2006. The habitat at Solio is fairly open and the animals were accustomed to vehicles and movement, which favoured this photographic technique. In both Kenyan reserves the objectives were to create master ID files from the photographic records (Patton *et al.* 2007; Patton & Jones 2007). In vegetation types where animals cannot be readily observed, or for secretive species such as the black rhinoceros, a spoor (track) identification technique may be used, although this will not generate as much life history data as observation of the animals (Jewell *et al.* 2001). In Zimbabwe, this technique has been further refined and the age and weight of sub adult black rhinoceroses was estimated based on spoor measurements (Purchase 2007). Spoor measurements were also used in Damaraland as a supplementary method to distinguish between adult and sub-adult animals (Britz & Loutit 1989).

An important component of monitoring is the development of an identikit for each animal (Hansen & Lindemann 1991) which allows the recognition of individual animals and facilitates the conversion of less structured, opportunistic sightings into a measure of absolute abundance. In addition, it allows researchers to track major life events such as age at first pregnancy and birth rate.

Monitoring of the Black Rhinoceroses in the GFRR

The information required for the black rhinoceros population on the GFRR included population size, sex ratio and age structure, the occurrence of deaths through natural causes and poaching, and births. When births occurred, the mother should be identified, the date of birth recorded or estimated, and sex of the calf recorded. In addition, information on the spatial ecology of the rhinoceroses was required. Because the population was closed (the reserve was fully fenced), and emigration and immigration were not possible, changes in population size would be slow. In addition, the reproductive rate for black rhinoceroses is slow with females reaching breeding maturity at approximately 7 years of age and having one calf every 2.5 years, although there is a high degree of variation (Owen-Smith 1988; Bertschinger 1994). It was thus not necessary to monitor as intensively as if the population was open. However, a balance had to be found between monitoring intensity and the likelihood of missing key events such as births, deaths or loss through poaching. The thicket vegetation of the GFRR was quite different from the more open habitats frequented by black rhinoceroses elsewhere in Africa, and this made conventional fixed wing aerial monitoring less feasible. However, the undulating topography allowed the use of direct observation while the aridity of the region and the rocky substrate made the use of spoor impossible. Consequently, a range of direct observational methods was adopted to increase the likelihood of locating each animal on a regular basis and observing key life history events while at the same time working within budgetary and staffing constraints. The aim of this chapter is to compare the methods used on the GFRR in terms of their usefulness and in terms of their costs. Such information may then be used to decide how best to extend the monitoring effort on the GFRR and on other reserves.

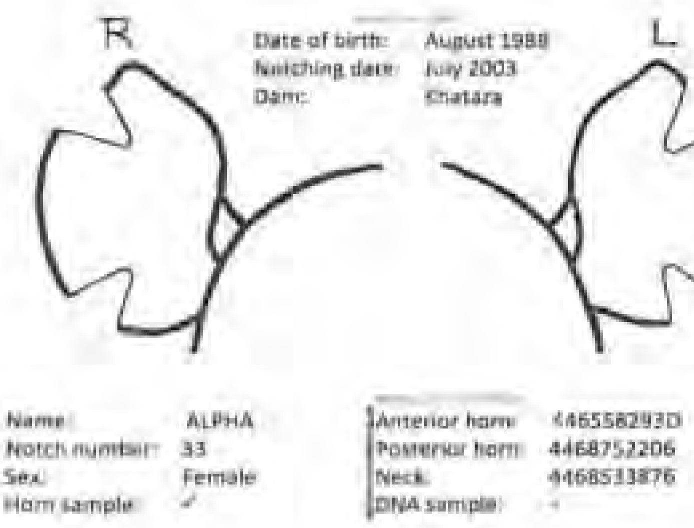
METHODS

Since the basis of monitoring is the repeated location of individually identifiable animals, considerable effort was made to ensure that all black rhinoceroses were identifiable. All introduced individuals since 1989 arrived with ear-notches according to the format adopted by the SADC RMG (Figure 3.1). The only exceptions have been those founder individuals that arrived with ears already damaged in unique identifiable patterns. Beginning in 2001, with annual repeats from 2003 to 2008, specific operations were undertaken to ear-notch unmarked animals that were born on the Reserve and 85 rhinoceroses have been ear-notched. Of this number, 75 were on the GFRR at the end of 2008, with five having been translocated to Zambia in 2006, and five marked animals having died prior to the end of 2008.

Calves between one and two years of age, which were still with their dams and were known due to the association, were selected for ear notching. If this exercise is delayed until after the separation between dam and calf has taken place, accurate identification of the individual calves will be problematic, especially if there are a number of similarly aged unaccompanied sub adults within a particular sector of the reserve.

Figure 3.1: Ear – notch numbering combinations according to the SADC – RMG format which is used on the GFRR (from Brooks 1989).

Based on the ear-notches and other unique marks, an identikit was developed for each known black rhinoceros on the GFRR. This was continually updated, resulting in a comprehensive life history profile for most of the animals. Identikits which included photographs, drawings and descriptions of unique markings, were used to confirm the identification of an animal. Details including date of birth, dam, notching number, microchip numbers with implantation dates were also included (Figure 3.2). Successive photographs were included for monitoring of individual growth patterns and ageing, as well as changes in horn profile. All management interventions such as immobilisations for veterinary treatment of wounds and injuries were photographed and included in the identikit. During immobilization for ear-notching, blood samples, DNA (from the removed ear notches), faecal samples, and external parasites were collected. This material does not form part of the present study and is not reported on in the thesis. Horns were tipped to obtain material for fingerprinting (Amin & Emslie 2002; Emslie & Amin 2002; Lee-Thorp *et al.* 1994) which is a security measure enabling the identification of illegally acquired horns. Microchips were inserted into the horns and the neck both for security reasons as well as enabling the identification of carcasses. In addition to the ear-notches, all animals were given a personal name based on a sequential alphabetical lettering system relative to their birth date. The name of the first calf born into the population began with the letter "A", the second calf's name with "B" and so on, and the alphabetical sequence was repeated after the first 26 calves were named. The Field Rangers in whose area a new birth was noted, were given the opportunity of naming the calf, once the sex of the animal was determined. This served as an incentive to the Field Rangers and resulted in a sense of "ownership" between field staff and the animals.



Date of birth: August 1988
Notching date: July 2003
Dam: Khatara

Name: ALPHA
Notch number: 33
Sex: Female
Horn sample: ✓

Anterior horn: 4465582930
Posterior horn: 4468752206
Neck: 4468533876
DNA sample: -

Figure 3.2: Example of a basic reference sheet in the GFRR master identikit file and in copies held at the Field Ranger bases. (Notch sizes are slightly exaggerated on these reference sheets.)

From the release of the first four animals in 1986, ground based observations by trained Field Rangers formed the backbone of the monitoring programme. Initially, the localities of scrapings at middens (communal latrines) were recorded, but this was discontinued as population size increased and middens could no longer be attributed to a single animal. Observations by Field Rangers were supplemented with observations from a microlight aircraft, the use of camera traps, irregular helicopter based observations and contributions by research staff engaged in various projects on the Reserve. Each method is described in more detail below.

Observations by Field Rangers

Field Ranger units served a dual function by providing security and collecting observational data. Whereas the Reserve boundaries received more attention when the unit carried out security functions such as anti-poaching and fence integrity, actual monitoring of the rhinoceroses covered all areas where the animals were likely to be found. To ensure that data collected were reliable, training was provided (Yule 1992; Hrabar & du Toit 2005) and on the GFRR, periodic workshops were held utilizing "Sandwith's" revised training modules (Adcock & Emslie 2000). All founder animals were kept in holding facilities (bomas) on arrival on the GFRR for a minimum of three weeks prior to release (except for two animals in 1989 that were released directly into the range). The Field Rangers used these periods to become familiar with the ear-notches, age class, size, horn shape, and any other unique scars and marks. Photographs of the confined animals were included in the identikit for each animal.

The relatively short, but dense, vegetation and the hilly topography of most of the GFRR meant that animals could be observed from vantage points such as cliffs, trees or other high lying spots, or across valleys. The Field Rangers made extensive use of the elevated areas to scan the surrounding area with binoculars during the early mornings when rhinoceroses were active. When necessary, other members of the unit were guided into closer proximity to the animals to obtain identifications. Field Rangers recorded their observations in a booklet which contained "blank" template outlines of a rhinoceros head. The Field Rangers inscribed the relevant notches or holes to the ears on these templates and also recorded other important information including sex, age class and presence of a calf or other black rhinoceroses. Observations in the booklets were compared with the identikit files to make a positive identification or to confirm an identification made in the field. These methods were very similar to those used in the Imfolozi/Hluhluwe complex to monitor the black rhinoceros (Yule 1992).

Observations from the Microlight Aircraft

Since 2002, a microlight aircraft, registration ZU-CDH, has been used to supplement observations by the Field Rangers. The benefits of the microlight were that it allowed low level and relatively slow flight and a far greater spatial coverage than achieved by the rangers. When necessary, radio contact between the microlight and the Field Rangers was used to guide ground staff into position to verify the identification of an animal. Although it was a relatively inexpensive form of aerial observation its effective use was weather dependent. Sectors of the GFRR to be surveyed were chosen before commencement of each flight, the aim being to cover the entire reserve on a uniform basis. However, changing weather conditions affected these plans, and the areas closer to the landing strip received more attention. Air speed was between 70 and 80km/hr, although ground speed varied according to wind velocity and direction. Operational height above ground level for rhinoceros monitoring was normally between 10m and 90m, dependent on weather conditions. Commuting between sectors was done at a greater height, while confirmation of a located animal's identity often required multiple low level passes. Optimal times for flying a light aircraft sensitive to air movement and turbulence were the early mornings and late afternoons and this corresponded to periods of rhinoceros activity. The months between December and June were better for the use of the microlight as the weather was more stable, while July to November were the months that experienced greater weather variation with increased wind. One of the greatest benefits of the microlight was that females with newborn calves were located before ground based units became aware of them, giving a more precise birth date. Females moved into very thick vegetation to give birth and these sites were difficult to locate from the ground. In these instances, and in order to limit disturbance, the female's identity as well as the sex of the calf was confirmed at a later date, but the birth was recorded and the area plotted on completion of the flight. The total number of rhinoceroses observed per flight was noted but only those whose identity was confirmed were entered into the data set. While most flights were accomplished alone, a passenger greatly assisted in identification of animals, and sexing of calves. In the final three months of the study, low-level aerial digital photography was incorporated, using SLR digital cameras, with image stabilisation and multiple frame exposure facility (Nikon D90; Nikon Corporation, Chiyoda – ku, Tokyo, and Canon EOS 350D; Canon Inc. Ohta – ku, Tokyo, Japan) equipped with zoom lenses with a focal range of between 55mm and 200mm. Suitable photographs were included in the identikits.

Helicopter Based Observations

Helicopters were used on the GFRR for the game censuses and when it was necessary to immobilise rhinoceroses or buffalo. During these exercises all rhinoceroses that were seen were identified if possible, photographed and localities recorded using a GPS. The helicopter was an ideal platform for photography because it operated at very low levels and was able to match its speed to that of the moving animal. Operating costs were however extremely high and this prevented regular use on the GFRR other than for the game census. During general census operations a four seater helicopter was used with a counter on each side in the rear seats, and the pilot and recorder in the two front seats. GPS generated pre-plotted transects were flown 300m apart, giving each counter a linear strip of 150m on which to focus counting. Flying height was 30m to 50m above ground level and the average ground speed was about 65km/hr. The transect lines were deviated from in order to verify ear-notch patterns for individual rhinoceros identification. Sporadic use of helicopters for census purposes began in the early 1980's but these were limited to the 65km^2 AVKR only, as the SKNR property was only added in 1987, and the DDNR was managed separately under the then Ciskei Homeland Government. The first aerial census that combined the AVKR and the SKNR was flown in 1996 with a repeat in 1998. Both these counts were conducted in small two seat helicopters (Robinson R22). The combined aerial census for the entire GFRR using a four seater helicopter (Bell Jet-Ranger or Robinson R44) became a regular annual event from 2001, with repeat counts until 2006. It was thereafter decided that aerial counts would be conducted over a three year cycle with the next aerial census for the GFRR being scheduled for 2009.

Opportunistic Sightings

All staff on the reserve and visiting researchers involved in other projects were encouraged to report all ground sightings of black rhinoceroses. Visiting researchers were given copies of the booklet provided to the Field Rangers in which they recorded sightings. In addition, some sightings were supported by photographs showing ear notches from which positive identifications were made.

Remote Camera Traps

The most recent addition to the monitoring methods were remote camera traps (Cuddeback Digital, "EXcite" and "EXpert" models; Non Typical; Park Falls, Wisconsin;

U.S.A.). One reason for including camera traps was that observations had suggested that the black rhinoceroses were active at night as well as in the early morning (pers. obs. and Schenkel & Schenkel-Hulliger 1969) and it was hoped that nocturnal monitoring might add to the frequency with which animals were recorded. The number of cameras deployed varied from an initial two units in July 2007, five from the middle of September 2007, and seven from October 2008. Although this slow increase in the number of camera traps was not an ideal design for a monitoring programme, it was determined by the availability of funds. Camera traps were set at waterholes and along frequently used animal paths to increase the chance of photographing a rhinoceros. In particular, more remote sections of the GFRR were selected as sites for the camera traps. Cameras were set facing the expected direction of the animals' approach so as to increase the likelihood of frontal images showing ear-notches. Cameras were set at a height of between 1.5m and 1.7m above ground level and tilted slightly downwards to ensure that the rhinoceroses' heads were captured. Cameras were not mounted lower than 1.5m in order to reduce the likelihood of damage by horns or body rubbing by rhinoceros, buffalo and kudu. Where multiple paths led to a water hole, several cameras were used to increase the likelihood of photographing a black rhinoceros. The length of deployment at a site varied between two and six weeks depending on the expected rhinoceros density in the area. The cameras were serviced (batteries and digital memory cards changed) and the available data downloaded at more frequent intervals. Batteries lasted up to six weeks dependent on the frequency of flash activation. Each photograph was imprinted with the date and time, allowing additional data to be collected on activity patterns and suitable photographs were added to the identikit.

Cost Analysis

This analysis has been done using data for 2003 to 2008 for Field Rangers, microlight and helicopter and for 2008 only for the camera traps. Salaries were calculated as a total cost to company and adjusted to the proportion of time spent by the staff on monitoring. All running costs including fuel, service costs for vehicles, insurance, batteries and helicopter hire were included and were from the GFRR records. The initial costs of purchase of four wheel drive vehicles, microlight and cameras were spread equally over 10 years for the vehicles and microlight, and five years for the camera traps. The initial cost of a four wheel drive vehicle was spread unequally between the Field Rangers, where they were used most regularly, and the camera traps, where they was used less regularly.

RESULTS

At the end of 2008, 137 black rhinoceroses were identifiable either by association with their dam, or as a result of ear-notches or other characteristic features (Table 3.1). A further seven animals were known to be unmarked and independent of their dam and the minimum population size was 144 animals.

Between 1986 and 2001, monitoring relied on Field Rangers with supplementary helicopter game counts in 1996, 1998 and 2001 (Table 3.2). From 2002 to 2007, monitoring was from the microlight, helicopter and Field Rangers and in 2007 and 2008, camera traps were added (Table 3.2). In 2002, observations from the microlight and the helicopter yielded very few records but between 2003 and 2008, the microlight produced on average 22% of all positive sightings, the helicopter 9.3% and Field

Table 3.1: Summary of the numbers of individually identifiable black rhinoceroses on the GFRR in December 2008 (exceptions are the 7 animals that became independent of their dams prior to notching).

Category	**Number**
Founders with notches	25
Founders with natural marks	6
Founders notched after 1986	1
Animals born on GFRR with natural marks	2
Animals notched as calves or subadults on GFRR	74
Un-notched animals independent of dams	7
Un-notched calves with dam	29
Total number of known black rhinoceroses	144

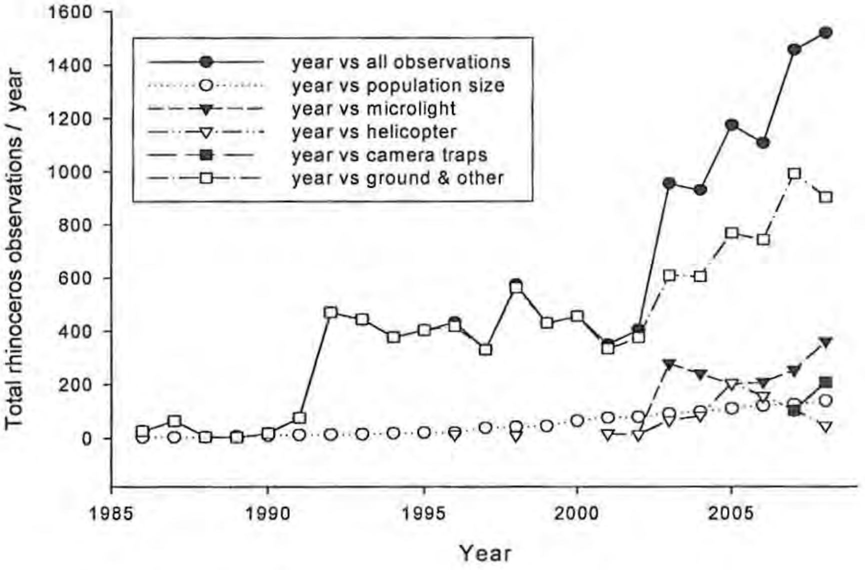


Figure 3.3: The relative contributions of the five monitoring methods to the total number of rhinoceros observations each year. "Ground & other" (open square symbols) are observations made by Field Rangers and visiting researchers.

Rangers 65%. In 2008, when camera traps were first used for a full year, they yielded 13.7% of all positive observations. Thus, in spite of the introduction of additional monitoring methods, the majority of observations were from the Field Rangers (Table 3.2; Figure 3.3).

The proportion of rhinoceroses that were located at least once a year varied through the study. As expected, it was high (100%) in the early years after first re-introductions and with a small population size (Table 3.2). As the population increased and the rhinoceroses occupied more of the reserve so the proportion located declined, and between 1998 and 2001, the population grew from 42 to 76 and the percentage of these that were positively recorded per year dropped from 100% to 68% (Table 3.2). From 2002, and coincident with the introduction of the microlight and annual use of the helicopter, the percentage of the population recorded increased to 82% and it remained between 83% and 97% for the rest of the study (Table 3.2; Figure 3.4). Many of the animals were located more than once each year and the average sightings per rhinoceros per year was 11.5 for the period 1986 to 2008. Between 2001 and 2008, when the populations was larger and occupied a larger area, the average sightings per rhinoceros per year dropped to 8.9.

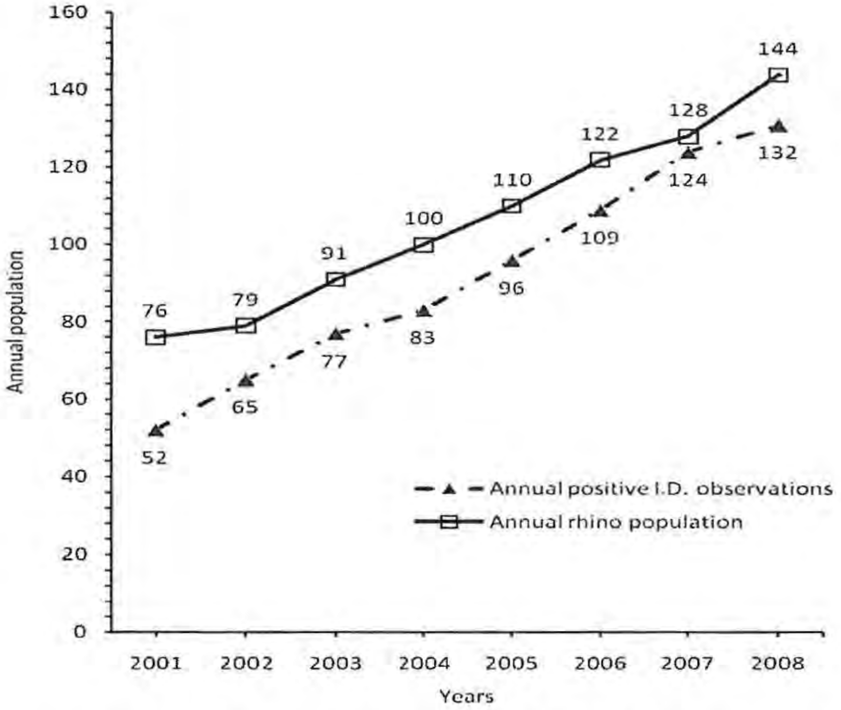


Figure 3.4: Annual changes in population size and the number of animals positively identified at least once in each year between 2001 and 2008.

Table 3.2: Annual records for positively identified animals showing the contribution of each method. Positive observations are the totals for all methods and include repeated sightings of the same animal. The final four columns show the positive observations for each method. Ground observers include Field Rangers and others.

Years	Positive Observations	Estimated Population	positively ID		Average sightings/ rhino	Aerial Observations		Camera Traps	Ground observers
			#	%		Microlight	Helicopter		
1986	27	4	4	100	6.8				27
1987	65	4	4	100	16.3				65
1988	6	4	4	100	1.5				6
1989	4	8	4	50	0.5				4
1990	19	11	6	55	1.7				19
1991	76	13	11	85	5.8				76
1992	471	14	14	100	33.6				471
1993	444	15	15	100	29.6				444
1994	378	19	19	100	19.9				378
1995	404	21	21	100	19.2				404
1996	433	22	22	100	19.7		15		418
1997	330	39	26	67	8.5				330
1998	574	42	42	100	13.7		11		563
1999	430	46	45	98	9.3				430
2000	456	65	47	72	7.0				456
2001	350	76	52	68	4.6		17		333
2002	405	79	65	82	5.1	15	15		375
2003	954	91	77	85	10.5	278	67		609
2004	930	100	83	83	9.3	240	85		605
2005	1173	110	96	87	10.7	201	204		768
2006	1106	122	109	89	9.1	208	156		742
2007	1455	128	124	97	11.4	253	106	104	992
2008	1518	144	132	92	10.5	360	47	208	903
Totals	12008				11.5	1555	723	312	9418

Not all known animals were sighted every year (Table 3.2, Figure 3.4) and rarely an animal was not sighted for several years. In most instances, these were animals that occupied rugged and remote regions where monitoring intensity was low. Routinely, animals that were not sighted for more than two consecutive years were assumed to be dead, however in some cases, animals were relocated after gaps of as much as three years, and in one instance a gap of five years.

The inclusion of monitoring from the microlight resulted in increased overall sightings and improved spatial coverage of the GFRR. Between 2003 and 2008, an average of 665.5 rhinoceros sighting were made from the microlight each year of which, 256 (38%) were identified positively (Table 3.3; Table 3.4). The addition of digital photography from the microlight for the final three months of the study resulted in an increased rate of positive identification. In five flights totaling 7hrs 06mins, 75 rhinoceroses were located of which 50 (66%) were identified from photographs. Flying opportunities in the morning were greater than in the afternoons (Table 3.4), and 79% of flights were made in the morning.

During the 2005 and 2006 helicopter-based censuses, 137 black rhinoceroses were positively identified from a total of 150 observations in 91 hours flying time (Peinke & Venter 2006; Peinke 2010 pers. comm.), representing a 91% positive identification rate during specific census operations (Table 3.3) but excluding other helicopter observations such as during ear notching exercises, etc.. A portion of the observations during the census operations were repeat sightings as counting on an area of 70km^2 was replicated on three different days in order to calculate precision.

In 2008, the camera traps recorded 418 photographs of rhinoceroses of which 208 (50%) were identified (Table 3.3). The photographs from which it was not possible to make an identification were of animals where no marks could be discerned despite good images of both ears being obtained (*n* = 2), animals where both ears could not be clearly seen, animals too close to the lens, and photographs made during early morning mist or during rain, and exposures into the rising or setting sun.

The Field Rangers recorded only positively identified animals in their monthly reports. Animals that could not be positively identified were reported verbally and it was thus not possible to calculate a percentage for positive identification. However, based on the frequency of verbal reports of sightings that could not be positively identified, it was estimated that between 25% and 35% of the sightings made by the Field Rangers were of animals that could not be identified (Table 3.3). These unidentified observations were of animals situated in areas of dense vegetation, animals that had run off before a positive identification could be made, or animals in inaccessible areas where closer approaches could not be undertaken.

Table 3.3: Summary of the results from the different methods, showing the variation in the proportion of all observations that were positively identified.

	Microlight (average per year 2003-2008)	Microlight photography (7hs flying time)	Helicopter (2005 & 2006 census)	Camera traps (2008 only)	Field Rangers & all ground obs. (average per year 2006 to 2008)
Total Obs.	665	75	150	418	unknown
Positive Obs.	256	50	137	208	879
% positive	38%	66%	91%	50%	65-75% est.

Table 3.4: Summary of results of rhinoceros monitoring using the microlight. The averages are for 2003 to 2008 (2002 figures are only for a portion of the year).

Year	Number of flights per year	Annual flying time (hs:mins) per year	% of flights		Number of rhinoceroses observed	Positively identified	
			Morning	Afternoon		Number	%
2002	12	19:36	100	/	54	15	27.8
2003	85	112:18	76	24	755	278	36.8
2004	68	74:30	63	37	681	240	35.2
2005	55	63:06	75	25	611	201	32.9
2006	58	76:48	83	17	546	208	38.1
2007	58	81:00	76	24	675	253	37.5
2008	66	91:18	77	23	725	360	49.7
Totals	402	518:36	/	/	4047	1555	/
Ave.	65	83:16	79	21	665.5	256.7	38.5

Cost/ Benefit Analysis

This analysis only covers the four structured monitoring methods and excludes the records from visiting researchers. The total costs per year for the four methods ranged from R32400 to R765000 (Table 3.5). This was exaggerated further when costs were expressed per hour for which the methods were used and this varied from a minimum for the camera traps of R1.0/hr to a maximum for the helicopter of R4300/hr (Table 3.5). By contrast, the average number of sightings per hour was highest for the microlight and helicopter and much lower for the camera traps (Table 3.5). The most economical method (cost per identifiable sighting) was the camera traps (R156 per sighting) and the least economical the helicopter (approximately R1600 per sighting; Table 3.5).

Table 3.5: Annual cost (Rands) and benefit analysis for the four methods of monitoring. Vehicle running costs are for up to three vehicles utilised on monitoring exercises inclusive of fuel, servicing, repairs, body repairs, tyres, insurance, etc.

Costs	Field Rangers	Microlight	Helicopter	Camera Traps
Salaries	445000	8300	12300	12000
Vehicle purchase	30000	20000	/	5000
Camera trap purchase	/	/	/	5000
Vehicle running costs	290000	/	/	4500
Microlight running costs	/	30500	/	/
Helicopter hire	/	/	164000	/
Batteries	/	/	/	5900
Total costs	**765000**	**58800**	**176300**	**32400**
hrs/ year	3664	83	41	47040
Cost/ hr	209	708	4300	1
Positive sightings/ year	770	257	111	208
Positive sightings / hr	0.2	3.1	2.7	0.004
Cost/ positive sighting	994	229	1588	156

An alternative analysis is to compare the cost per method as a percentage of the total cost, with the returns (number of positive sightings per method as a percentage of all positive sightings). This analysis also showed that camera traps and the microlight were the most economical while the helicopter was the most expensive (Table 3.6). Although the Field Rangers were relatively expensive (their costs represented 74% of the total costs of monitoring the black rhinoceroses, while returns were only 57%; Table 3.6) it was the case that the Field Rangers were responsible for the majority of observations. A final factor that has not been quantified is the coverage achieved by each method. While the helicopter censuses, the Field Rangers and the microlight covered the whole reserve, the camera traps did not. Assuming that the seven camera traps were moved once a month, the camera traps were only able to monitor 84 sample sites per year. By positioning the camera traps on frequented paths or at water holes, the area sampled was much greater than the immediate surrounds of the cameras, but it cannot be quantified.

Table 3.6: Comparison of the relative cost (Rands) of each method with the returns (positive sightings).

Observation method	%observations	Cost	%cost
Rangers	57	765000	74
Microlight	19	58800	6
Helicopter	9	176300	17
Camera traps	15	32400	3
total	100	1032500	100

DISCUSSION

The selection of methods for monitoring the black rhinoceros population on the GFRR was shaped by various factors. The biology of the species (large body size, crepuscular activity and semi secretive behavior; Schenkel & Schenkel-Hulliger 1969; Smithers 1983, Owen-Smith 1988; Stuart & Stuart 1996; Estes 1999; Murray *et al.* 2008), the vegetation (thicket but with open patches), and undulating topography allowed for direct observation. The aridity and rocky substrate made the use of spoor as an indirect measure unviable and the use of communal latrines made dung counts unviable. Conservation areas need a staff of Field Rangers whose responsibilities include anti-poaching patrols, fence patrols and habitat monitoring as well as monitoring the animals. The GFRR has a group of Field Rangers and it is appropriate that they have played a major role in monitoring the black rhinoceroses. In many other studies, direct observations have been made from the air (Walpole 2002; du Preez 2004; Hofmeyr 2007), either from balloon or conventional fixed wing aircraft. Neither was appropriate for thicket vegetation and in the present study, direct aerial observations were made from microlight and helicopter. The GFRR is a large conservation area and some sections were more difficult to reach than others. The development of remote camera traps allowed some of these areas to be sampled more easily than by the Field Rangers. Finally, funding has played a considerable part in the methods used. While the Field Rangers were part of the reserve staff and thus available for monitoring work, and funding was available from the Reserve budget for the annual running costs of the microlight and camera traps, the initial purchases of these items of equipment relied on additional funding being raised. Similarly, while the annual helicopter game census was funded, additional use of the helicopter for notching exercises in 2001, 2007 and

2008 was largely subsidised. For these reasons, the major responsibility for monitoring has fallen on the Field Rangers since the first re-introduction of black rhinoceroses, with additional methods being included when funds allowed.

The current monitoring programme combines five methods of direct observation and has resulted in as many as 97% of the known animals being located at least once per year, and at an average frequency of 11.5 sightings per rhino per year. As a result of this, the population is recognized by SADC RMG as being completely known. A review of the literature (Adcock 2009) revealed reports on rhinoceros monitoring at 20 sites (Appendix 3A) but only two report on the proportion of the population that is identifiable. At Kunene West (Namibia) 61-69% of the population is identifiable and at HIP (South Africa), 96% of the population is known. The methods used to monitor rhinoceros populations range from special monitoring teams and foot patrols, horseback patrols, observations made by game guides on private reserves, aerial observations from balloon, fixed wing plane and helicopter, radio telemetry and camera traps (Adcock 2009). Monitoring effort varies and on small reserves the whole area is monitored, on larger reserves such as Etosha National Park and Kruger National Park, a stratified block count is used (Adcock 2009).

On the GFRR, the majority of black rhinoceros sightings were made by Field Rangers and it may make sense to increase their numbers. The RMG recommend one ranger per 10km^2 (Brooks & Adcock 1997) while Potter (1994) advocates one ranger per 15km^2 with allowance for rotation of staff while ensuring that adequate strength is maintained at all times. A WWF report recommends an optimal coverage of one field ranger per 20km^2 (Dublin & Wilson 1998). On the 220km^2 AVKR and SKNR sectors of the GFRR, where the majority of black rhinoceroses were found, there were seven field rangers (one ranger per 31km^2). An increase in the number of rangers should result in more regular location of a greater percentage of the known animals while at the same time providing additional security. The need for this should be balanced against the additional costs and the fact that the current monitoring programme has produced satisfactory results. The estimated cost per positive sighting by the Field Rangers was the second highest suggesting that it may be more economical to increase the use of camera traps or the microlight.

The introduction of the microlight resulted in increased observations of black rhinoceroses and increased coverage of the reserve. It also allowed rapid response and focused observations in areas that field rangers could not easily or quickly reach. A limiting factor in the effective use of the microlight was its sensitivity to wind and turbulence, whereas very cold temperatures in winter limited the endurance of the pilot and passenger. The possible acquisition of a gyroplane (gyrocopter), which is able to operate in considerably higher wind velocities is being considered. The use of digital photography from the microlight was introduced late in the study and showed great potential and it should be a standard part of the monitoring programme in the future. The cost per positive sighting from the microlight was the second lowest suggesting that this may be a more economical way to increase sightings than by increasing the number of Field Rangers. An important advantage of the microlight as a platform for aerial observation is that, in the case of the GFRR, it is located on the reserve and can be used at short notice to locate specific animals or to search specific areas of the reserve, weather permitting.

Although observations from the helicopter had the highest proportion of positive identifications, the high cost of hire prevented its regular use. Cost per positive sighting was almost an order of magnitude greater than for the microlight or camera traps. Helicopters were used for the game census and also when required for other activities on the reserve and it was important to maximize this opportunity by recording and photographing all opportunistic sightings of black rhinoceroses. In addition, an arrangement with local wildlife veterinarians has resulted in further opportunities to carry out ear-notching operations, with the secondary benefit of acquiring positive observations of black rhinoceroses. The veterinarians use the opportunity to expose veterinary students from throughout the world to some aspects of wildlife veterinary practice, and they then cover the helicopter flying costs and provide their services free of charge.

Although the camera traps were used in small numbers and for a short period of time, the success rate suggests that they could be used in a more structured application of the method. An additional benefit of the camera deployments is where multiple photographs are taken of the same animal over consecutive months and years, analyses of growth rate (Goddard 1967), horn development and configuration, and changes in body condition are possible. The proportion of photographs that were identifiable was quite low (50%) but the cost per identifiable sighting was the lowest of all methods. The principle drawback of camera traps was their coverage. To cover 150 fixed sites throughout the reserve would require 50 cameras. Each camera would be left at a site for one month and each site would be monitored once every three months. This would cost R160000 for the cameras and about R50000 per year for the batteries. Additional costs would be for the salary of the person required to monitor the cameras and the vehicle. While camera traps will remain an efficient way of monitoring in the more remote areas of the GFRR where their placement along well used trails and near waterholes could result in the regular detection of rarely seen animals it is unlikely that the returns from additional cameras will justify the costs. This is particularly so since the current monitoring programme resulted in 92% of all known animals being recorded at least once in 2008, and 97% in 2007 (Figure 3.4). Thus a compromise should be that sufficient cameras are obtained to allow the remote areas to be adequately monitored.

Radio telemetry has been considered as a possible method for monitoring the black rhinoceroses and with the broken terrain of the GFRR, the microlight would be an excellent platform for locating transmitter equipped animals. However, the number of animals that could be equipped would be limited by cost, and the battery-life of transmitters would require regular immobilisation events. Mature cows customarily accompanied by calves at foot would largely be excluded from the programme.

In conclusion, the present monitoring programme has resulted in more than 80% of all known animals being located at least once each year between 2002 and 2008, an average number of sightings per year of 11.5 per known animal, and the population having the status of being "completely known" (Brooks 1998). This has provided a very robust data set that is used in the next chapter to describe the demography of the population. Perhaps the most effective and economical way to improve the monitoring programme would be to use the mircolight to search for animals that had not been observed in the previous three months. This would build on the already very successful programme and should result in a greater proportion of known animals being seen at least once per year.

CHAPTER 4

POPULATION STRUCTURE AND DYNAMICS

INTRODUCTION

Black rhinoceroses have been re-introduced to a number of fenced conservation areas in Southern Africa as part of the SADC RMG plan for the conservation of the species (Brooks & Adcock 1997; Emslie 2006). Of primary concern to managers of these populations is the maintenance of high productivity so that the populations become sources from which other populations may be started (Goodman 2001; Emslie 2006). The maintenance of high productivity requires a detailed understanding of the population biology, demography, and responses to population manipulations (Hrabar & du Toit 2005; Patton *et al.* 2008; Linklater & Hutcheson 2010).

The productivity of a population of ungulates is reflected in a number of parameters including age at sexual maturity (ASM), gestation length, intercalf interval (ICI), the proportion of adult females giving birth in any one year, reproductive lifespan and mortality rates (Knight 2001; Conway *et al.* 2002) and as these factors vary, so will population dynamics. Population growth rates are also influenced by a range of interacting biotic and abiotic factors including predation, climatic variability, disease and density (Clutton-Brock *et al.* 1997; Hrabar & du Toit 2005). While predation may play an important top down role in the population dynamics of smaller ungulates (Smuts 1978) it is less likely to be important in the megaherbivores such as the black rhinoceros (Schenkel & Schenkel-Hulliger 1969; Estes 1991; Berger 1995). Predation by large carnivores (lions, spotted hyaenas and leopards) on black rhinoceroses is rare and mostly on young animals (Berger 1994;

1995). In the absence of human interference and predation, stochastic events and food quality and quantity most often limit population growth rate (Goddard 1970; Woolley 2010). Both climatic variability and density function by reducing resource quality and quantity which in turn slows down the rate of reproduction by increasing the ASM, increasing the ICI, increasing mortality and decreasing the calving rate (Clutton-Brock *et al.* 1991, 1997; Owen-Smith 1990, 2001). It is also likely that intraspecific aggression will increase at high densities (Adcock *et al.* 1998) and this will result in increased mortality of both adults and juveniles (Hrabar & du Toit 2005). This may be particularly apparent in polygynous species where males defend both territories and breeding rights. The black rhinoceros is polygynous (Garnier *et al.* 2001) and males compete for mating opportunities (Berger 1994). Fighting establishes a male dominance hierarchy which may be associated with the location of used space in prime areas (near to water; Skinner & Chimimba 2005). Less dominant adult and subadult males may be injured or killed in these fights (Hitchens 1968; Hitchens & Anderson 1983).

Small populations may experience an Allee effect with low levels of reproductive performance, such as in obligate co-operators and obligate co-operative breeders such as the African wild dog (Courchamp *et al.* 2000). In addition small populations are less resilient to stochastic events than are larger populations. Thus there is a need to maintain a population that is large enough to be immune to the effects of stochastic events and the Allee effect. Since increasing density can affect population growth rate as discussed above, there is a need to find a balance between maintaining maximum population growth rate and avoiding density dependent effects on reproduction. According to Hrabar & du Toit (2005), the major challenge for managers of black rhinoceros populations is finding this balance.

The first signs of density dependence may be seen at a population density of about half of the ecological carrying capacity (*K*/2; Caughley 1977) and the RMG recommends that populations be held at about 75% of *K* (Brooks & Adcock 1997). The use of carrying capacity as the basis for management decisions such as when to start removing excess animals assumes that *K* can be accurately estimated. Although carrying capacity has been used as a management tool for many years (McLeod 1997), its applicability has been the subject of considerable debate. While it may be applied in stable environments, it is not applicable in environments characterized by stochastic, unpredictable change (McLeod 1997) and Owen-Smith (2002) describes it as a vague and misleading concept. Carrying capacity *K* is neither easily calculated nor fixed in time (Owen-Smith 1990). Nevertheless, *K* does provide a starting point, and the RMG has estimated carrying capacities for a number of reserves using a comparative approach and has recommended that *K* on the GFRR is 0.6 rhinoceroses /km^2 (Adcock 2006). An alternative approach is to use adaptive management. Adaptive management is not a new concept (Holling 1978) and it combines the use of ecological theory, observation and comparisons across multiple sites to inform management decisions and to predict the outcome of those actions (Walters 1997). Comparisons across multiple sites are problematic as there are few long term studies of the demography of black rhinoceroses and consequently, management decisions may not be supported by the necessary knowledge (Linklater 2003). Hrabar & du Toit (2005) suggest that re-introduced populations of the black rhinoceros provide unique opportunities to study the growth response of expanding populations and thus provide some of the required information to support adaptive management. Adaptive management requires careful monitoring of the population looking particularly for signs of density dependent effects on key reproductive parameters including ASM, ICI, mortality and calving rate. Once these are detected, the population is managed by removing surplus animals (Brett 2001; Goodman 2001). By contrast, management decisions based on a proportion of *K* requires only an annual census. Clearly the two approaches are not mutually exclusive and the present study, where a value for *K* has been proposed and where the population has been carefully monitored lends itself to the use of both methods and the proposed population density of 75%*K* can be adjusted based on the observations.

In view of the requirement to manage the population of the black rhinoceros on the GFRR at its most productive level, the major aim of the research was to monitor the performance of the population and to establish values for all the important reproductive and population parameters. A further aim was to establish if density dependent or other factors were having a negative influence on reproductive performance.

The reproductive biology of the black rhinoceros has been studied in captive and free ranging animals (Bertschinger 1994; Fouraker & Wagener 1996). As with all very large mammal species, reproduction is slow. The gestation is long (15 months; Hitchins & Anderson 1983; Skinner & Chimimba 2005), calves suckle for between 12 to 19 months (Goddard 1967; Schenkel & Schenkel-Hulliger 1969; Hitchins & Anderson 1983; du Toit 1994) and the ASM is six to eight years (du Toit 1994). As a result of the long gestation and the long period of lactation, the ICI is also long and the percentage of adult females giving birth in any one year is low (16-45%; Goddard 1967; Hrabar & du Toit 2005). The lifetime productivity (calves per lifetime) is low (about 14; Owen-Smith 1988) and is balanced by low natural rates of mortality (Conway *et al.* 2002; Adcock 2009). Although the reproductive biology of the black rhinoceros is reasonably well known, a secondary aim of this chapter is to make a contribution to our understanding of the reproduction of this species.

METHODS

Data collection has been described fully in Chapter 3. Where data describe an aspect of the population for a particular year, the data either represent the sum of occurrences (births, deaths) in that year, or the state of the population (size, sex ratio) at the end of the year.

Confidence Levels (CL)

The level of precision around the recording of dates for key life history events such as age at first birth, or date of birth varied and all records were allocated a confidence level (CL) that denoted the accuracy with which the event was recorded. The confidence levels used were those adopted by the SADC RMG:

? = no idea; 0 = Likely to be out by more than 1 year; 1 = correct to within 1 year; 2 = correct to within 6 months; 3 = correct to within 3 months; 4 = correct to within 1 month; 5 = correct to within 1 week.

Age Categories

The age categories used were those prescribed by the SADC RMG (Emslie *et al.* 1993; Adcock & Emslie 2000):

A class: birth to 3 months of age; B class: 4 months to 1 year of age; C class: 1 year to 2 years of age; D class: 2 years to 3.5 years; E class: 3.5 years to 7 years of age; F class: > 7 years of age.

Due to the A class being limited to the first three months of a neonates' life, only calves born between September and December of a particular year were reflected in class A for that year. In some analyses, the age classes have been simplified by grouping A, B & C as juveniles, D & E as subadults and F as adults.

Rainfall

In this chapter, mean monthly rainfall were for 1983-2008 from three weather stations on the GFRR. (Kamadolo, Retreat and Botha's Post; see Chapter 2). In the analysis of the effect of rainfall on reproductive seasonality, births per months were compared with rainfall in that month, in the preceding month (= rain-1) and in the month before that (= rain-2).

Gestation Length

In this study a gestation length of 15 months has been used (Hitchins and Anderson 1983; Bertschinger 1994; Skinner & Chimimba 2005; Berkeley & Linklater 2010).

Population Size

The population size used was based on the number of known animals on the GFRR at the end of each year. In the early years of the study this number was affected by re-introductions and in 2006, by a removal of five animals.

Density of Black Rhinoceroses

Density was presented as animals/km^2 and was calculated as the estimated annual population size divided by 440km^2 which is the total area, and equates to the area that will be available to black rhinoceroses in 2010 when new areas are included.

Population Growth Rate

Population growth rates were calculated using the population size corrected for the removal of animals in 2006 by adding five to the population size for the final three years of the study.

The introductions were accommodated by calculating population growth rates for the periods during which no re-introductions occurred. Population growth rate was calculated using the slope of the regression line through a plot of LogN population size against years (= observed rate of increase; Caughely 1977) and annual growth rate was calculated as:

$$r = (Nt_x - Nt_{x-1}) / Nt_{x-1}$$

where Nt_x is the population size in year x

Nt_{x-1} is the population size in the preceding year.

Selection of Data for Analysis

Where a particular analysis required precision around a length of time, or age, a subset of data was selected with high confidence levels (4&5) and this is reported in the text.

While some analyses used the entire data set from 1986 to 2008, in some cases such as sex ratios and calving rates, the values fluctuated widely in the early years of the study and a subset was selected to represent the period once these fluctuations had settled down. In most cases the subset was for the period after the final re-introduction (2000) and thus the data were less likely to have been influenced by the repeated introductions. The subsets used are described in the text.

Statistical Analyses

The statistical analyses used have been mentioned at relevant places in the results. Where percentages have been used in the analyses, it was after arcsine transformation. All tests were done using Statistica (version 9; StatSoft inc. Tulsa, OK, USA).

RESULTS

Population trend

The population of black rhinoceroses on the GFRR grew through natural recruitment and re-introductions from an initial four animals in 1986, to an estimated 144 at the end of 2008 (Table 4.1; Figure 4.1). Re-introductions occurred between 1986 and 2000 (Table 4.2) and in 2006, five animals were removed from the GFRR. The re-introduction in 2000 was effectively of 19 animals as one female died shortly after release. Population growth rates are described later in the results.

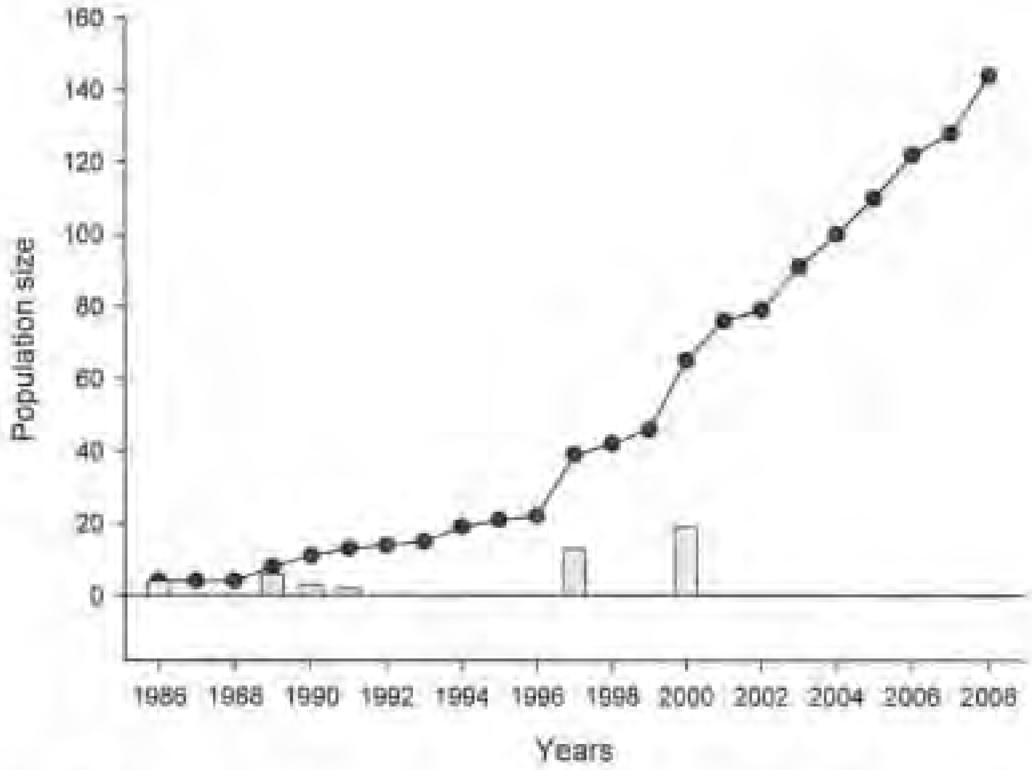


Figure 4.1: Annual changes in estimated population size with re-introductions shown as grey bars.

Table 4.1: Summary of re-introductions, births and deaths of black rhinoceroses. Estimated annual population is at the end of December each year. One of the 20 animals released in 2000 died shortly after release.

Year	Re-introductions	Births	Deaths	Estimated annual population
1986	4			4
1987				4
1988		1	1	4
1989	6		2	8
1990	3	1	1	11
1991	2	3	3	13
1992		2	1	14
1993		1		15
1994		4		19
1995		2		21
1996		1		22
1997	13	4		39
1998		4	1	42
1999		4		46
2000	20 (19)	1	2	65
2001		12	1	76
2002		3		79
2003		15	3	91
2004		11	2	100
2005		12	2	110
2006		18	1	122
2007		10	4	128
2008		18	2	144
Totals	48	127	26	/

Table 4.2: Sex ratios and age classes of founder black rhinoceroses and their survival to adulthood. D, E & F are age classes.

	Number of re-introduced rhino to the GFRR		Total survivors to adulthood or potential breeding status	
Year	Males	Females	Males	Females
1986	2 (2F)	2 (E,F)	1	2
1989	3 (D,2E)	3(3E)	1	1
1990	1 (E)	2 (2F)	1	1
1991	1(F)	1 (D)	1	1
1997	6 (5D,F)	7(5D,2E)	6	6
2000	10 (D,E,8F)	10 (3D,5E,2F)	10	9
Totals	23	25	20	20

Population Age Structure

The numbers and proportions of animals in each of the age classes has changed as the population increased (Tables 4.3; Figures 4.2 & 4.3). The re-introductions of animals in age classes D, E, & F resulted in substantial increases in the relative size of the adult and sub-adult age classes which were particularly apparent when the total population was small (Figures 4.2 & 4.3). The translocation out of the population in 2006 (classes D & E), had little impact on the sub-adult age class due to the increased size of the population.

Juveniles (classes A, B & C) made up a variable proportion of the total population from a maximum of 32% in 1994 when the population was 19, to a minimum of 8% in 2000 when the population was 65 (Figure 4.3A). Between 2004 and 2008 juveniles comprised 22.8 ±2.2% of the population. The patterns for males and females were similar and between 2004 and 2008, juvenile females comprised 21.3±3.6% of all females and juvenile males comprised 24.6±4.5% of all males (Tables 4.4 & 4.5). The proportion of sub-adults (classes D & E) varied, and after an initial peak of 50% in 1989, the proportion declined and then increased to a second peak of 59% in 1997. The proportion then declined to a low of 21% in 2004 after which there was a steady increase (Figures 4.3B & 4.4B). The proportion of adults (class F) was initially high as a result of the re-introduction of adult animals. This proportion declined to 1989 and thereafter oscillated through three cycles, reaching peaks in 1992, 1996 and 2002 (Figures 4.3C & 4.4C). From 2003 to 2008, the proportion of adults in the population declined from 54% to 44%. The trend for adult males and females was slightly different, and adult males reached a peak in 2002 and thereafter declined (61% - 43%). The proportion of adult females peaked more recently (2004; Figure 4.4C) and has declined since then (53%-44%).

There was no significant effect of density on the proportion of animals in the three age classes between 2001 and 2008 (adults, $r^2 = 0.34$, $F_{1,6} = 3.14$, $P>0.05$; sub-adults, $r^2 = 0.034$, $F_{1,6} = 0.2$, $P>0.05$; juveniles $r^2 = 0.27$, $F_{1,6} = 2.25$, $P>0.05$).

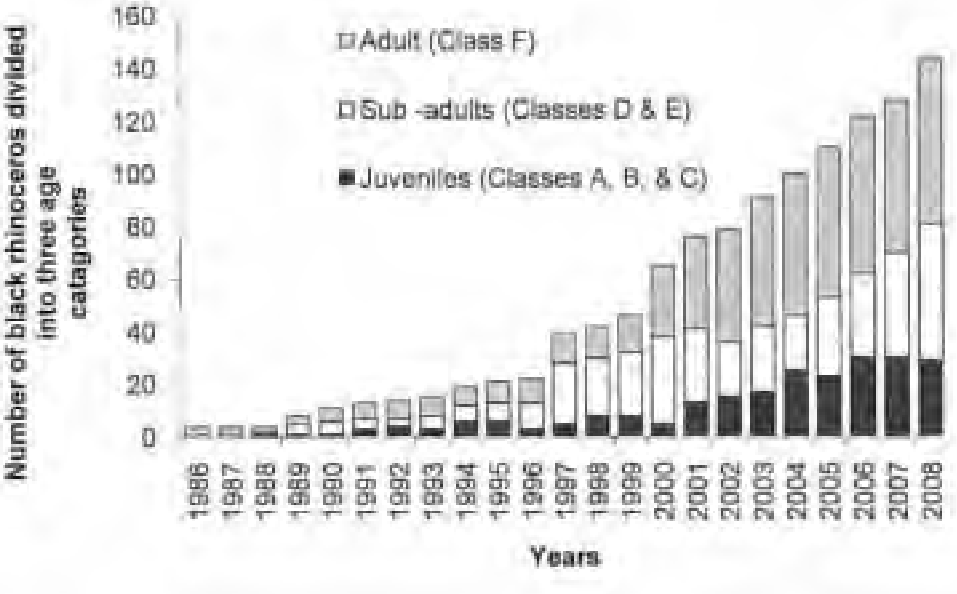


Figure 4.2: Annual changes in the number of black rhinoceroses in each of three age classes (juvenile, sub-adult and adult). The two major re-introductions in 1997 (13 animals), and 2000 (19 animals) can be seen in the increased column heights for these two years.

Table 4.3: Age structure of the black rhinoceros population on the GFRR on 31st December each year. Data are numbers of animals in each age class. The percentage of adult (F class) animals is given.

	Age	Years 1986 – 2008																						
Class	category	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
F	>7 yrs	3	3	2	3	5	6	7	7	7	8	9	11	12	14	27	35	43	49	54	57	60	58	63
E	3.5-7 yrs		1	1	2	4	2	1	3	5	5	6	8	18	20	27	22	20	14	11	14	14	25	30
D	2- 3.5 yrs	1			2	1	2	2	2	1	2	4	15	4	4	6	6	1	11	10	16	18	15	22
C	1 - 2 yrs				1		1	2	1	2	4	2	1	4	4	4	1	12	3	14	11	10	18	11
B	4mnth-1yr			1		1	2	1	2	3	1	1	4	1	4	1	9	3	9	8	7	16	8	13
A	<3mnths							1		1	1			3			3		5	3	5	4	4	5
Total population		4	4	4	8	11	13	14	15	19	21	22	39	42	46	65	76	79	91	100	110	122	128	144
% F class per year		75	75	50	38	45	46	50	47	37	38	41	28	29	30	42	46	54	54	54	52	49	45	44

Table 4.4: Age structure of the male black rhinoceroses on the GFRR on 31st December each year. Data are numbers of animals in each age class. The percentage of adult (F class) animals is given.

	Age	Years 1986 – 2008																						
Class	category	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
F	> 7yrs.	2	2	1	1	1	2	3	3	3	3	3	4	5	6	14	18	22	23	23	26	26	23	26
E	3.5 - 7 yrs.				1	2	2			1	2	2	3	7	9	10	8	6	4	5	5	5	11	12
D	2- 3.5 yrs.				1				1	1		1	7	3		4	2		7	4	4	8	7	11
C	1 - 2 yrs.							1	1		1	2	1		3			8		4	5	5	9	6
B	4 mnth.- 1 yr.						1	1		1	1	1		1			6		2	4	3	7	5	4
A	< 3 mnths.										1			2			2		2	1	4	4	2	1
Total males		2	2	1	3	3	5	5	5	6	8	9	15	18	18	28	36	36	38	41	47	55	57	60
% F class per year		100	100	100	33	33	40	60	60	50	38	33	27	28	33	50	50	61	61	56	55	47	40	43

Table 4.5: Age structure of the female black rhinoceroses on the GFRR on 31st December each year. Data are numbers of animals in each age class. The percentage of adult (F class) animals is given.

	Age	Years 1986 – 2008																						
Class	category	86	87	88	89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08
F	> 7yrs.	1	1	1	2	4	4	4	4	4	5	6	7	7	8	13	17	21	26	31	31	34	35	37
E	3.5 - 7 yrs.		1	1	1	2		1	3	4	3	4	5	11	11	17	14	14	10	6	9	9	14	18
D	2- 3.5 yrs.	1			1	1	2	2	1		2	3	8	1	4	2	4	1	4	6	12	10	8	11
C	1 - 2 yrs.				1		1	1		2	3			4	1	4	1	4	3	10	6	5	9	5
B	4 mnth.- 1 yr.			1		1	1		2	2			4		4	1	3	3	7	4	4	9	3	9
A	< 3 mnths.							1		1				1			1		3	2	1		2	4
Total females		2	2	3	5	8	8	9	10	13	13	13	24	24	28	37	40	43	53	59	63	67	71	84
% F class per year		50	50	33	40	50	50	44	40	31	38	46	29	29	29	35	43	49	49	53	49	51	49	44

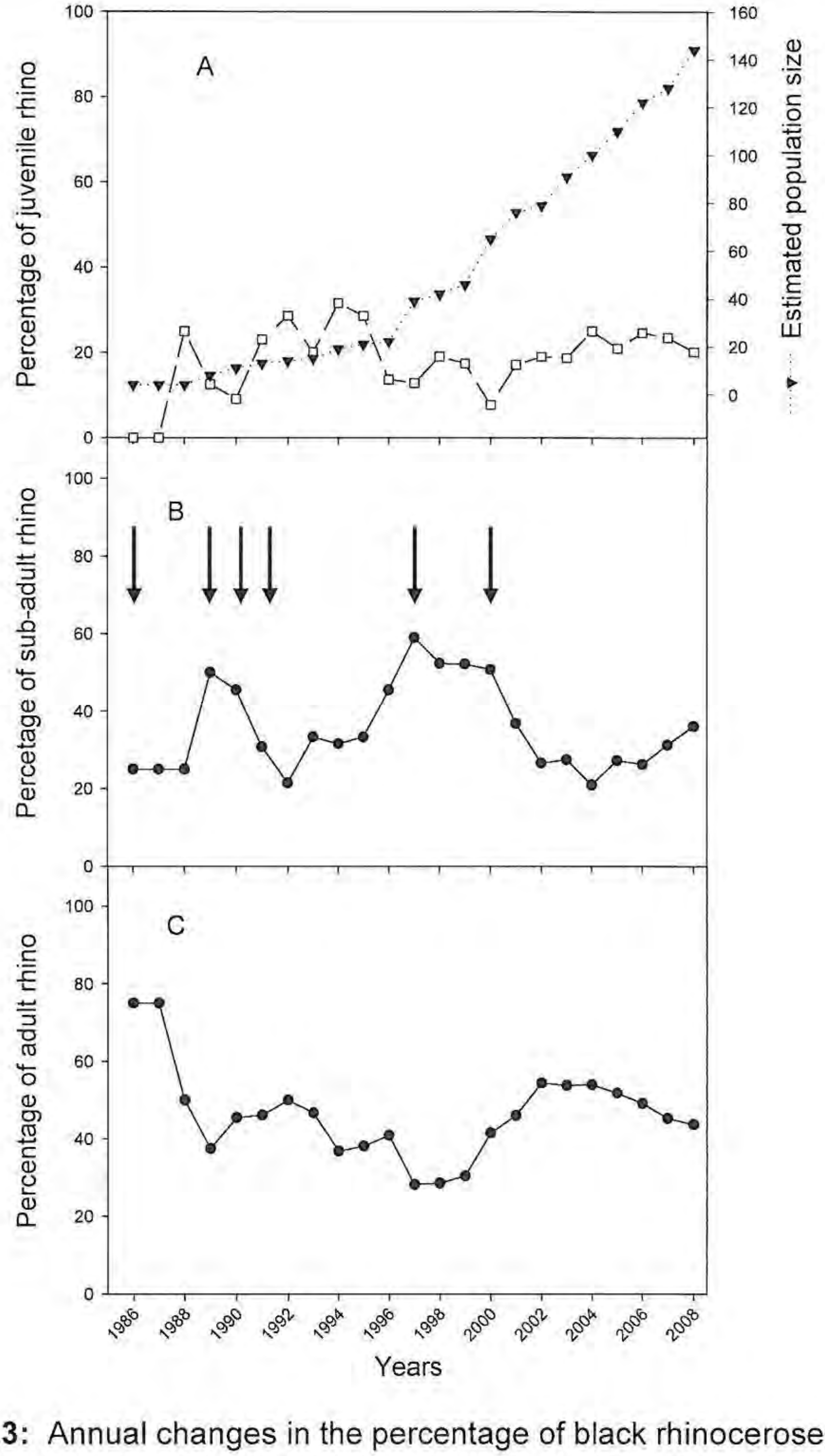


Figure 4.3: Annual changes in the percentage of black rhinoceroses in three age classes. A, juvenile, B, sub-adult and C, adult. Annual changes in estimated population size are shown in A. Re-introductions are indicated in B by vertical arrows.

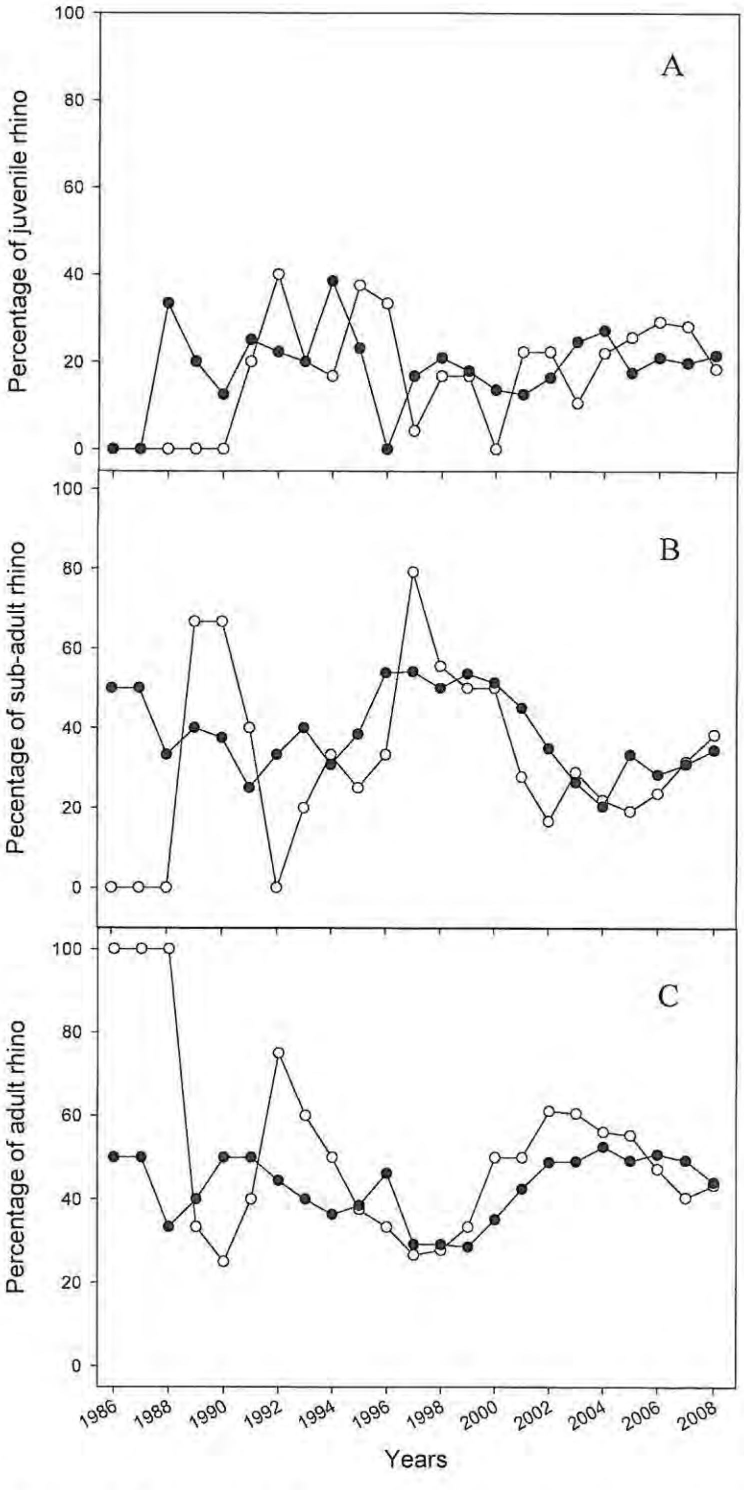


Figure 4.4: Annual changes in the percentage of all female (solid symbols) and all male (open symbols) black rhinoceroses in three age classes. A, juvenile, B, sub-adult and C, adult.

Sex Ratio

The sex ratio of the re-introduced black rhinoceroses was close to parity and survivors of equal proportion reached maturity (Table 4.2). Births, deaths and a single translocation out of the reserve have combined to influence the sex ratio at the end of each year (Table 4.6; Figure 4.5). Since the year 2001 (after the final re-introduction) the sex ratio of sexually mature rhinoceroses (classes E & F) (1.3:1) and of all animals has had a slight female bias (1.3:1) Table 4.6). However, the observed proportions of males and females were not significantly different from expected assuming equal likelihood of producing male and female calves ($\chi^2 = 16.8$; df = 17; P>0.05)

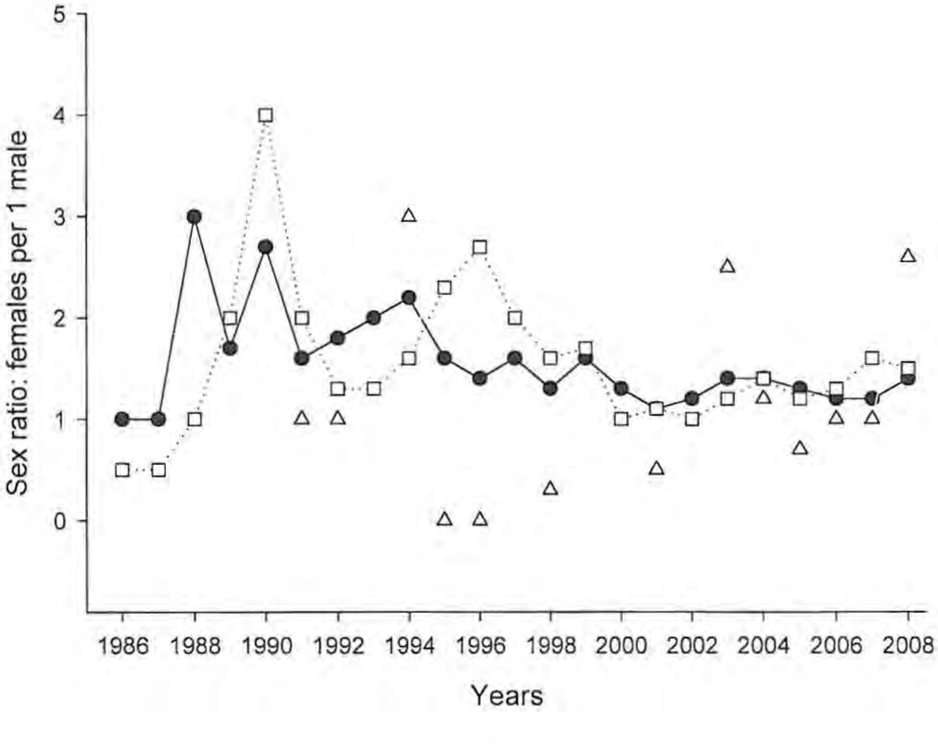


Figure 4.5: Annual changes in the sex ratio of all rhinoceroses on the GFRR (solid circles), those in age classes E & F (open squares and dotted line), and of young born in the year (open triangles).

Table 4.6: Sex ratio of all black rhinoceroses and of age classes E & F on the GFRR at the end of each year. Sex ratio is females per male.

Year	males	females	unknown	Sex ratio F:M	Sex ratio F:M (E & F)
1986	2	2	0	1.0	0.5
1987	2	2	0	1.0	0.5
1988	1	3	0	3.0	1.0
1989	3	5	0	1.7	2.0
1990	3	8	0	2.7	4.0
1991	5	8	0	1.6	2.0
1992	5	9	0	1.8	1.3
1993	5	10	0	2.0	1.3
1994	6	13	0	2.2	1.6
1995	8	13	0	1.6	2.3
1996	9	13	0	1.4	2.7
1997	15	24	0	1.6	2.0
1998	18	24	0	1.3	1.6
1999	18	28	0	1.6	1.7
2000	28	37	0	1.3	1.0
2001	36	40	0	1.1	1.1
2002	36	43	0	1.2	1.0
2003	38	53	0	1.4	1.2
2004	41	59	0	1.4	1.4
2005	47	63	0	1.3	1.2
2006	55	67	0	1.2	1.3
2007	57	71	0	1.2	1.6
2008	60	84	0	1.4	1.5

One hundred and twenty seven births were recorded between 1988, when the first birth was recorded, and the end of 2008 (Table 4.7). Of these, 73 were female, 52 male and two died, one each in 1991 and 2003, before they were sexed. The annual sex ratio of new born animals varied and there has been an overall female bias (1.4 females per male; Table 4.7). In five years, more males were born than females and in 11 years the reverse was the case

(Table 4.7). In addition, the mortality rate of males was greater than that for females (reported later) and this has contributed to the bias in the population.

Table 4.7: Sex ratio (females per male) of calves born during each year. One calf in each of 1991 and 2003 died before sex was established.

Year	Calves				
	Total	M	F	%F	Sex ratio F:M
1986	0	0	0	/	/
1987	0	0	0	/	/
1988	1	0	1	100	/
1989	0	0	0	/	/
1990	1	0	1	100	/
1991	3	1	1	33	1.0
1992	2	1	1	50	1.0
1993	1	0	1	100	/
1994	4	1	3	75	3.0
1995	2	2	0	0	0.0
1996	1	1	0	0	0.0
1997	4	0	4	100	/
1998	4	3	1	25	0.3
1999	4	0	4	100	/
2000	1	0	1	100	/
2001	12	8	4	34	0.5
2002	3	0	3	100	/
2003	15	4	10	66	2.5
2004	11	5	6	55	1.2
2005	12	7	5	42	0.7
2006	18	9	9	50	1.0
2007	10	5	5	50	1.0
2008	18	5	13	72	2.6
Totals	127	52	73	58	1.4

Fourteen females each produced four or more calves and there was substantial variation between these animals in the sex of their calves. Eight females produced more female calves than males, four produced more males and two produced equal numbers of male and female calves. Three females produced calves of one sex only (Table 4.8).

Table 4.8: Sex of the calves of 14 individual female rhinoceroses that each had four or more calves. For female 3, one calf died soon after birth and sex was unknown.

Female	Total calves	Female	Male
1	9	6	3
2	8	6	2
3	4	3	0
4	4	0	4
5	4	2	2
6	4	2	2
7	4	1	3
8	7	5	2
9	5	1	4
10	6	4	2
11	4	1	3
12	5	3	2
13	4	4	0
14	5	3	2

Age at Sexual Maturity

Females: Age at first calving

In this analysis, a subset of females with a confidence level of between 2 and 5 for their own birth dates and the birth dates of their first neonates (*n*=16), and a second subset with a confidence level of 4 or 5 for their own birth dates and the birth dates of their first neonates (*n*=8) were used. For the subset of

16, the mean age at first calving of females born on the GFRR, was 80.2 ± 14.7 months (~ 6 years, 8 months; Table 4.9). For the second subset, with greater precision around the dates and length of time, the mean age at first calving was 80.3 ± 13.9 months (~ 6 years, 8 months). Since there was no significant difference between the two means (Student's t test; t = 0.009; df = 22; P>0.05) the full data set has been used. Of the 16 females, 12.5% calved before the age of five, 25% before six, 62.5% before seven, 81.3% before 8, and 100% by 9.3 years. The range in age at first parturition was from 58 months (4 years, 10 months) to 111 months (9 years, 3 months). Six of the 13 births occurred while the adult was six years old.

Assuming a gestation of 15 months the mean age for mating and first conception would be 65.2 ± 14.7 months (~ 5 years, 5 months). The earliest recorded mating was at 43 months (3 years, 7 months) and the latest 96 months (8 years). The oldest females that had not given birth were a founder female of an estimated 15 years of age and a first generation female of 9.7 years.

Table 4.9: Age at first parturition. Sub-set of sixteen females with confidence levels of between 2 and 5. Animals that comprised the subset of eight are indicated with an asterisk.

	Rhino female							
Reproductive data	Alpha	Celiwe*	Basari*	Fungile*	Gina	Ivy	Kim*	Julia*
Birth date of breeding female	Aug. 1988	18 Feb. 1991	Feb. 1990	23 Dec. 1992	20 Jan. 1993	2 Jun. 1994	1 Dec. 1994	1 July. 1994
Conf. level of birth date	2	4	4	4	5	5	4	4
First parturition								
Neonates' birth date (first calf)	*2 June. 1994*	*2 Dec. 1995*	*23 Apr. 1996*	*2 Oct. 1998*	*Apr. 1999*	*30 May. 2000*	*19 Jan. 2001*	*1 July. 2002*
Conf. Level of first birth date	*5*	*4*	*4*	*5*	*2*	*3*	*5*	*4*
Age at first parturition in months	70 mnths.	58 mnths.	74 mnths.	70 mnths.	75 mnths	72 mnths.	73 mnths.	96 mnths.
Age at first parturition in years	5y 10m	4y 10m	6y 2m	5y 10m.	6y 3m	6y	6y 1m	8y

	Rhino female							
	Qiqa	Rita*	Priscilla*	Andazi	Wendy	Odette	Una*	Zena
Birth date of breeding female	25 Feb. 1997	Mar. 1997	20 Feb. 1997	May. 2000	Feb. 1999	Feb. 1997	Sept. 1998	May. 1999
Conf. level of birth date	3	4	4	3	4	3	4	2
First parturition								
Neonates' birth date (first calf)	*22 Apr. 2003*	*Jan. 2004*	*Mar. 2005*	*Apr. 2005*	*Mar. 2006*	*May. 2006*	*May. 2006*	*Apr. 2007*
Conf. Level of first birth date	*5*	*5*	*4*	*5*	*4*	*5*	*4*	*4*
Age at first parturition in months	74 mnths.	82 mnths.	97 mnths.	59 mnths.	85 mnths.	111 mnths.	92 mnths.	95 mnths.
Age of first parturition in years	6y 2m	6y 10m	8y 1m	4y 11m	7y 1m	9y 3m	7y 8m	7y 11m

Intercalf Interval, Births per year and Births per Lifetime

The intercalf interval (ICI) has been calculated using three different data sets. Firstly, the full data set for 33 black rhinoceroses that each had more than one calf. Secondly, a subset of these for which the confidence levels (CL) for the birth of a calf and the following calf were 3 or greater and finally a further subset for which the CL for both births were 4 or 5. In the full data set, there were 88 intervals, of which one was very long (54 months) and was omitted. The mean ICI was 28.7±4.8 months (2 years, 4 months) and there was no significant difference in the mean ICI of the females (one-way ANOVA; $F_{31,44}$ = 1.45; P>0.05). The modal ICI was 24 months, the shortest ICI was 22 months (1year, 10 months; CL 5) and the longest were 42 and 44 months (Figure 4.6). For the first subset (CLs 3-5), there were 57 ICIs from 26 animals and the mean ICI was 28.2±4.9 months. For the final subset (CLs 4-5) there were 27 ICIs from 14 animals and the mean ICI was 26.7±3.9 months. There was no significant difference between the mean ICIs from the three data sets (one-way ANOVA; $F_{2,155}$ = 1.10; P>0.05).

Using the three ICIs reported above (values rounded to 29, 28 and 27 months), births per year per breeding female were 0.41 to 0.44 and years per birth between two years, five months and two years three months. Assuming a birth rate of one calf per two and-a-half years, adult females could be expected to produce four calves every 10 years. Twelve females each had four or more calves (4-9 calves). For each female, the length of time from birth of first calf to birth of last calf was divided by the number of births minus one to give another value for ICI that should incorporate any event such as natural abortion or failed mating that would slow down the reproductive process. For these females, mean ICI was 28.5± 2.9 months with a maximum of 33 months for three calves. Assuming that the likelihood of failed reproduction would have increased with the number of calves produced, the 12 females were divided into two groups, one that each had six or more calves (*n*=5) and the remainder with five or less. There was no significant effect of number of calves on mean ICI (6 or more calves; 28.9±1.7 months; 5 or fewer calves; 28.3±3.8 months; $F_{1,10} = 0.14$; $P>0.05$).

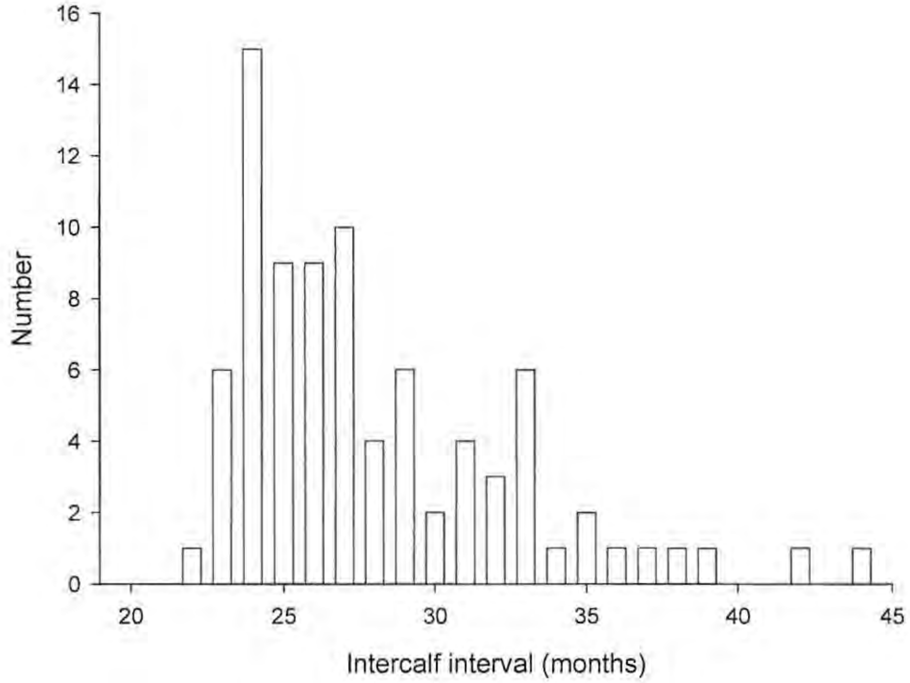


Figure 4.6: Histogram showing the distribution of intercalf intervals.

Births per lifetime

Data on age of reproductive senescence were not available from the GFRR but two females had young at 22 and 24 years of age. Mean age at first parturition was 6 years and 8 months and if we assume conservatively that females ceased reproductive activity at 24 years of age, then the reproductive life was about 18 years. Given the data on ICI, a female black rhinoceros may be expected to have about seven calves. This is a conservative calculation and the two oldest breeding females on the GFRR have both had nine calves.

Calving Rate

This analysis includes females of age classes E and F since results from the present study have shown that females may begin breeding while in the E age class. The numbers of females in the two age classes and the percentage of those calving each year changed through the study (Table 4.10; Figure 4.7). Initially, when the population size was low, the percentage of females calving varied widely but as the population grew, so the number of females calving stabilized (Figure 4.7). This was clearest for the F class and combined E and F class females where the population was larger. Between 2003 and 2008, the percentage of E class females calving was low (0 to 17%; mean = 8.5±5.7%; Figure 4.7A) while that of F class females calving oscillated between 54 and 32% (mean = 41±11.7%; Figure 4.7B). For E and F class females combined, the percentage of females calving per year has oscillated between 42% and 20% (mean = 32.8±8.4%; Figure 4.7C). There was no relationship between calving rates of F class females and either year (linear regression; $r^2 = 0.001$; $F_{1,21} = 0.027$; $P>0.05$) or density ($r^2 = 0.0005$; $F_{1,21} = 0.011$; $P>0.05$).

Two females (a founder and a female born on the reserve in 1999) were in the age class F but did not breed.

Table 4.10: Calving rate of age class E and F females. Data are numbers in each age class, the numbers calving and that number as a percentage.

	Age class E			Age class F			E&F	
Year	#	calving	%	#	calving	%	calving	%
1986	0	0	/	1	0	0	0	0
1987	1	0	0	1	0	0	0	0
1988	1	0	0	1	1	100	1	50
1989	1	0	0	2	0	0	0	0
1990	2	0	0	4	1	25	1	17
1991	0	0	/	4	3	75	3	75
1992	1	0	0	4	2	50	2	40
1993	3	0	0	4	1	25	1	14
1994	4	1	25	4	3	75	4	50
1995	3	1	33	5	1	20	2	25
1996	4	1	25	6	0	0	1	10
1997	5	1	20	7	3	43	4	33
1998	11	1	9	7	3	43	4	22
1999	11	1	9	8	3	38	4	21
2000	11	1	9	13	0	0	1	4
2001	7	3	43	17	9	53	12	50
2002	14	0	0	21	3	14	3	9
2003	10	1	10	26	14	54	15	42
2004	6	1	17	31	10	32	11	30
2005	9	1	11	31	11	35	12	30
2006	9	0	0	34	18	53	18	42
2007	14	1	7	35	9	26	10	20
2008	18	1	6	37	17	46	18	33

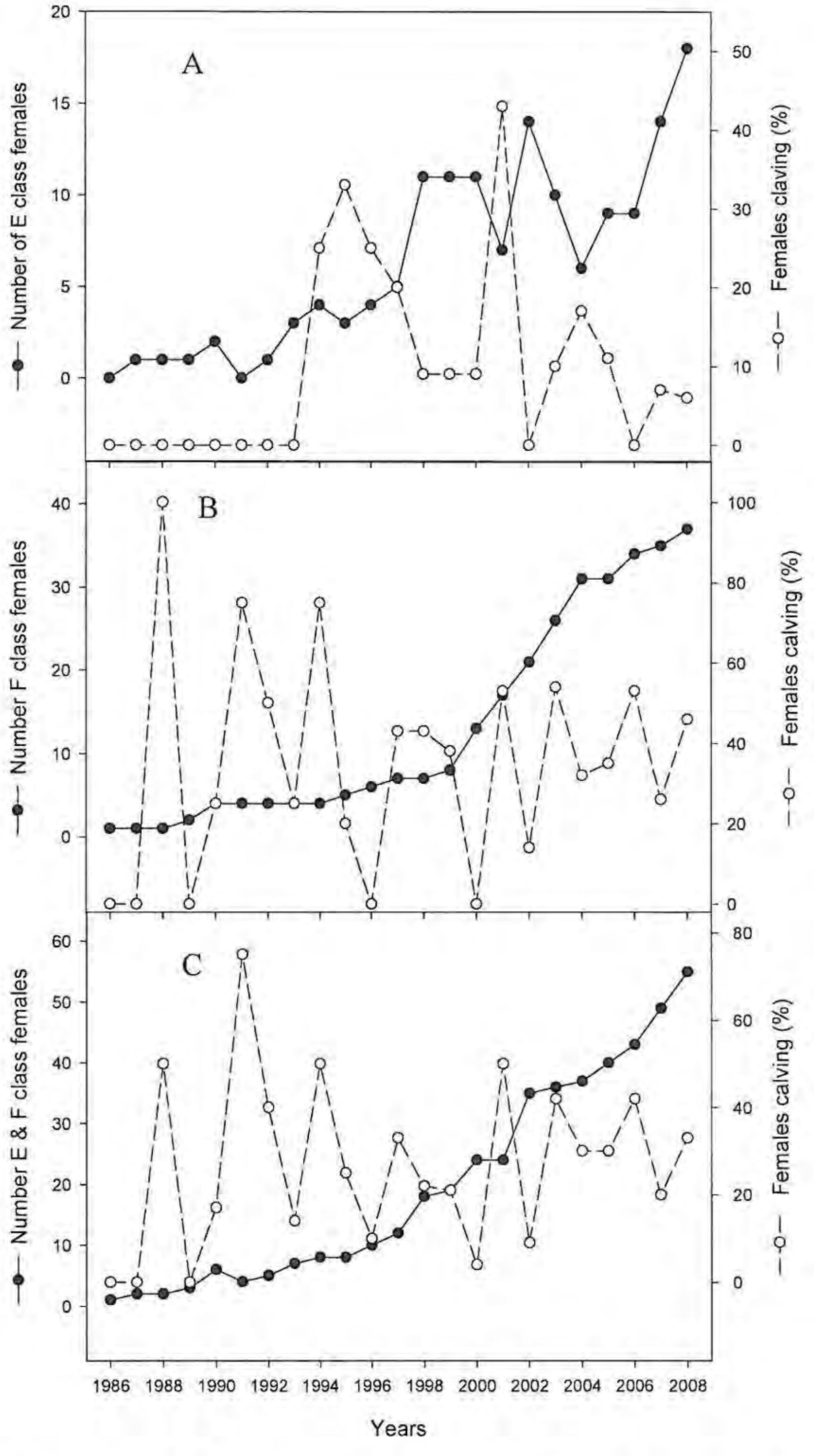


Figure 4.7: Changes in the number of age class E (A), F (B) and classes E & F combined (C) females and the percentage of those that calved, through the study.

Reproductive Seasonality

A subset of births (*n*=63) with CL 4 or 5 was selected to test if any seasonality of births occurred (Table 4.11).

Table 4.11: The observed occurrence of births (CL 4 or 5) per year.

Years	Months												Annual
	Jan	Feb	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	totals
1988													0
1989													0
1990		1											1
1991		1	1										2
1992		1										1	2
1993	1												1
1994		1				1	1					1	4
1995	1											1	2
1996				1									1
1997		1	1										2
1998					1				1	1	1		4
1999		1											1
2000													0
2001	1						1		1				3
2002							1						1
2003				1			1						2
2004	2				1				1		1		5
2005			1	2			1		1				5
2006	1		3	1	2		2			1		2	12
2007			1	3					2		1		7
2008	1	1		1			3			1		1	8
Totals	7	7	7	9	4	1	10	0	6	3	3	6	63

There was no significant difference in the mean number of births recorded per month (ANOVA; $F_{11,\ 240}$ =1.49; P>0.05). However, there was a pattern in the occurrence of births, with a tightly synchronized peak of births in mid winter (July) and a less synchronized period of births in summer (Figure 4.8). The summer births coincided with increased monthly rainfall during summer and the reduction in births in winter, with the exception of the peak in July, coincided with the drier winter (Figure 4.8).

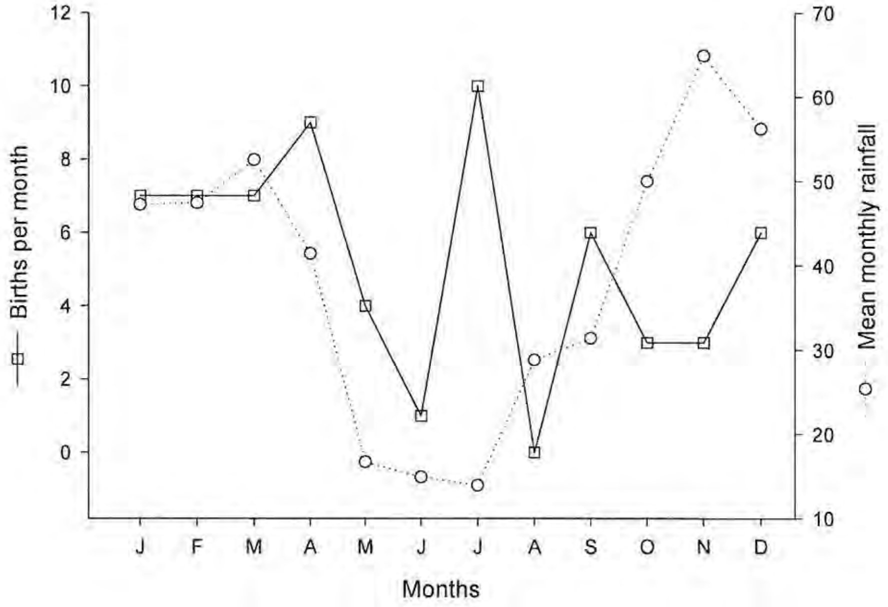


Figure 4.8: The relationship between mean monthly rainfall (rain -1) and the number of births in that month.

Using all data for births, there was no relationship between births per month and monthly rainfall (Linear regression; $r^2 = 0.04$; $F_{1,10} = 0.05$; $P>0.05$). However, if the peak of births in July was excluded from the analysis, there was a weak relationship between births and rainfall in the preceding month (month -1; $r^2 = 0.56$; $F_{1,9} = 11.6$; $P<0.05$) but not rainfall two months earlier ($r^2 = 0.3$; $F_{1,9} = 3.9$; $P>0.05$) or rain in the month of birth ($r^2 = 0.15$; $F_{1,9} = 1.65$; $P>0.05$).

Eight females gave birth at least once in July with one female having three calves in July. Of these 10 July births, six were preceded by a birth with a CL of 4 or 5. Two of the preceding births were in May (intercalf interval of 26 months), two were in September (inter-birth interval of 22 months), one was in February (intercalf interval of 29 months) and one was in July (intercalf interval of 24 months). The female that gave birth three times in July had consecutive births in July 2002, September 2004, July 2006 and July 2008. This is discussed further below.

While examining the data for intercalf interval, it became apparent that there could be a relationship between the month in which a female was born and the month in which her first calf was born. To analyse this, a subset of 16 nulliparous females (CL 2-5) for their own birth dates and the birth dates of their first neonates was selected from the full set of 63 births and this was further refined to a sub-set of 8 females (CL 4-5) for birth dates of both the dams and their first neonates (Table 4.9). All births occurred no more than four months either side of the birth of the mother and for the subset of eight births, seven occurred within five months of the month in which the mother was born (Figure 4.9). However, for neither data set was the frequency of births significantly different from random (χ^2 =16.2; df=11; P>0.05; χ^2= 15.5; df= 11; P>0.05). A similar pattern was apparent when the month of birth of an offspring was compared with that of the next offspring (CL 4 or 5, *n* = 26; Figure 4.10). In this case, 22 of 26 births (84.6%) occurred three months either side of the month in which the previous calf had been born and the distribution of births was significantly different from random (χ^2= 30.4; df=11; P<0.05).

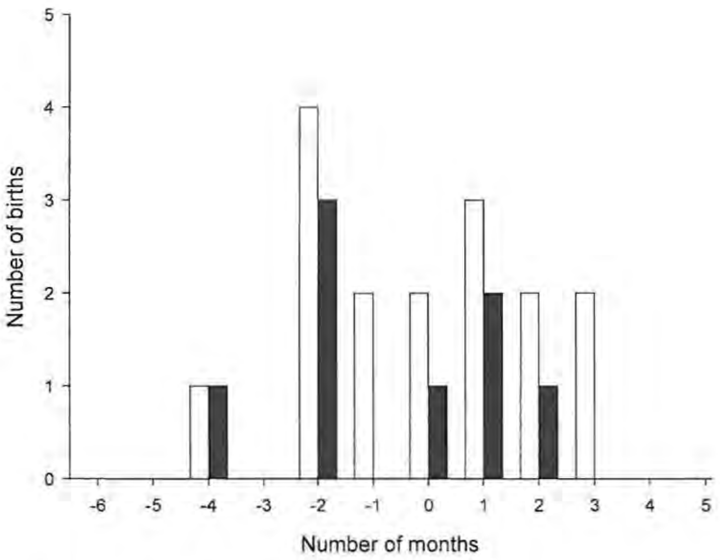


Figure 4.9: The relationship between the month in which the mother was born and month of birth of her first young. Zero on the x axis is birth in the same month as that of the mother. Solid bars are for the subset of 8 births; open bars for the group of 16 births.

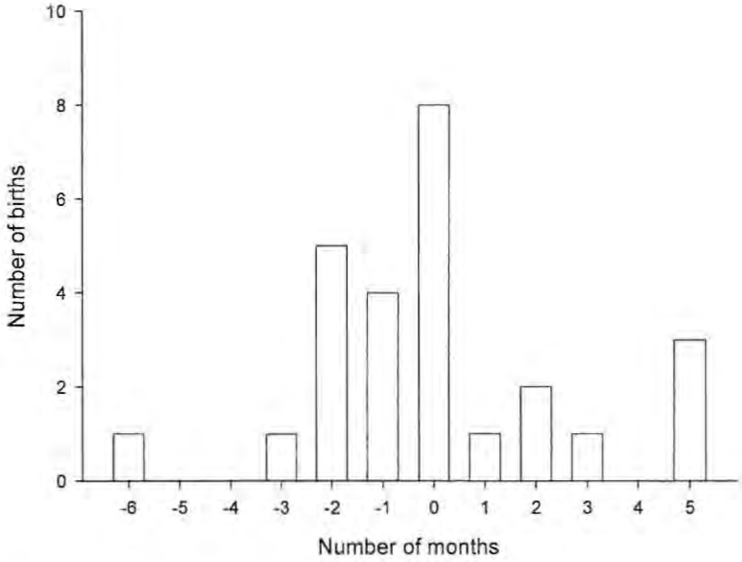


Figure 4.10: The relationship between month of birth of a calf, and the month in which the next calf was born.

Mortality

Of the 48 founders, four died in their first year. These deaths were assumed to have been associated with the introduction and have not been included in further analyses of mortality. A further eight founders died before reaching age class F. Twenty six deaths were recorded, of which 14 were males and 10 females, three were of juveniles (sex unknown for two of these), 12 sub-adults and 11 adults (Table 4.12).

Table 4.12: Summary of all recorded deaths on the GFRR. Numbers in parentheses are the number of deaths as a percentage of animals in that age class. ? = sex unknown for two juveniles.

	Female			Male			Total
	J	SA	A	J	SA	A	
1988						1(50)	1
1989		1(50)			1(50)		2
1990					1(50)		1
1991	?	1(50)	1(25)	?			3
1992						1(33)	1
1993							0
1994							0
1995							0
1996							0
1997							0
1998			1(14)				1
1999							0
2000		2(11)					2
2001		1(6)					1
2002							0
2003	?			?	1(9)	1(4)	3
2004					1(11)	1(4)	2
2005			1(3)		1(11)		2
2006		1(5)					1
2007		1(5)				3(13)	4
2008				1(9)		1(4)	2

In the early years of the study, deaths represented a high percentage of all animals in that age class (Table 4.12). However, as the population grew, so this percentage dropped and from 2004, the percentage mortality in all age classes was less than 13% (Table 4.12; Figure 4.11). Although there has been a trend of increasing numbers of deaths per year, between 1998 and 2008, the deaths per year as a percentage of the estimated population size stabilized at 1.7± 1.2 %. (Linear regression of deaths (%) against years for 1998-2008; $r^2 = 0.09$; $F_{1,9} = 0.08$; $P>0.05$).

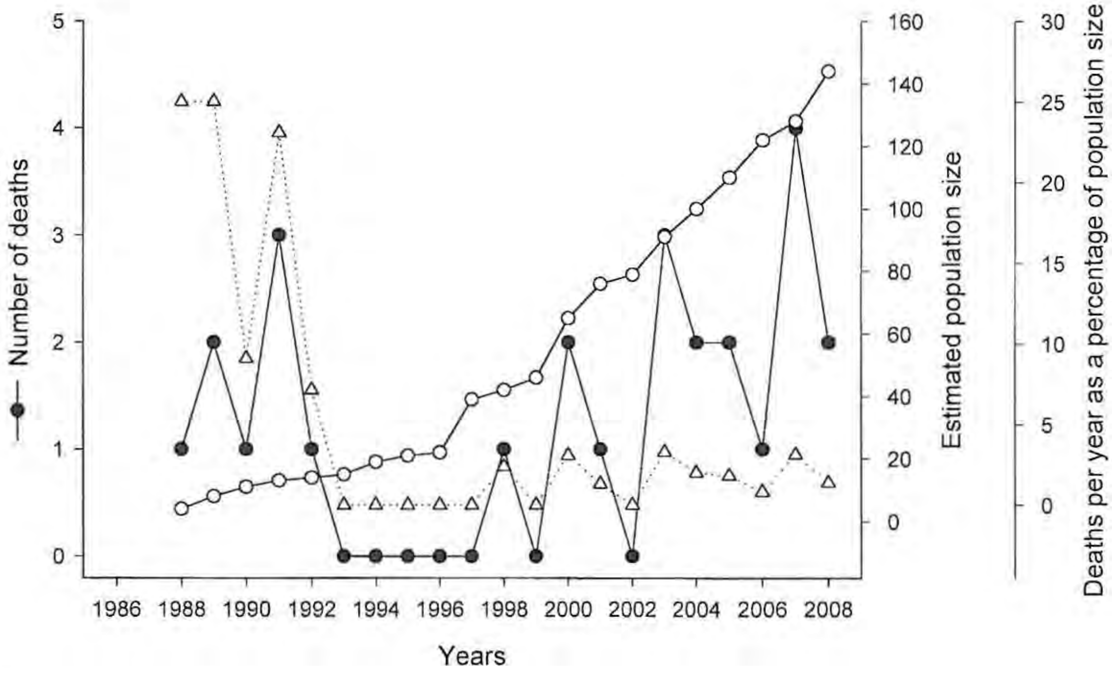


Figure 4.11: Deaths of black rhinoceroses per year (absolute numbers, solid circles; as a percentage of populations size, open triangles) and estimated population size (open circles).

Since 2001, 14 deaths have been recorded of which 10 were of males and of these six were of adult males (Table 4.12; Figure 4.12). Although there was no significant effect of sex (two-way ANOVA; $F_{1,42} = 1.7$; $P>0.05$) or age class ($F_{2,42} = 0.7$; $P>0.05$), or a significant interaction between the two factors

($F_{2,42}$ = 1.1; P>0.05) on the occurrence of deaths, the trend was for more males to die than females and this was most apparent in the adult class (Figure 4.12; Table 4.13).

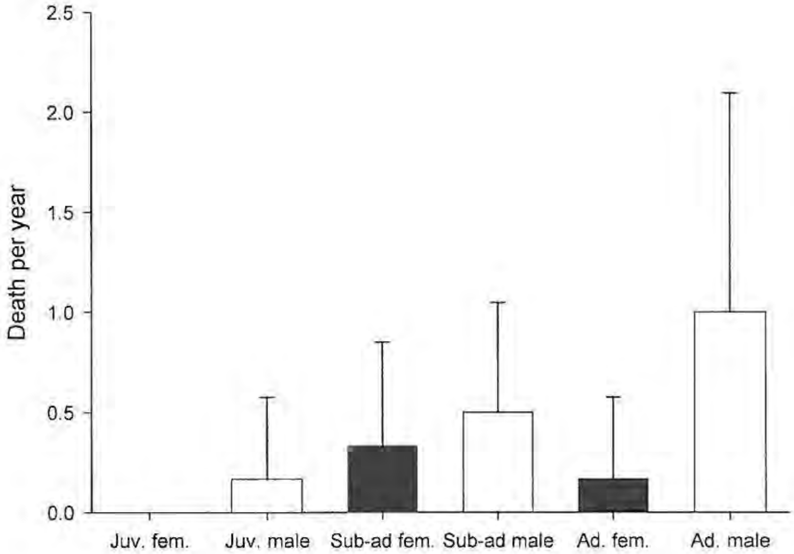


Figure 4.12: Summary of deaths by age class and sex from 2001 to 2008. Data are means + 1sd.

Table 4.13: Summary of mortality from 2001 to 2008. Data are numbers of deaths, mean number of deaths/year, and that number as a percentage of all members of the sex and age class.

	Female			male		
	number	X±1sd	%	number	X±1sd	%
Juvenile	0	/	/	1	0.13± 0.35	1.1±3.2
Sub-adult	3	0.37±0.52	2.0±2.8	3	0.37± 0.52	3.9±5.4
Adult	1	0.13±0.35	0.4±3.2	6	0.75±1.03	3.2±4.5

Factors Affecting Reproductive Parameters

Age at first parturition.

Using the two sets of data in Table 4.9, there was a significant relationship between the density of black rhinoceroses on the GFRR and age at first birth. As density increased, so did the age at first birth (Figure 4.13. Linear regression, full data set $r^2 = 0.40$; $F_{1,14} = 9.26$; $P<0.05$; subset of 8 births, $r^2 = 0.71$; $F_{1,6} = 14.7$; $P<0.05$).

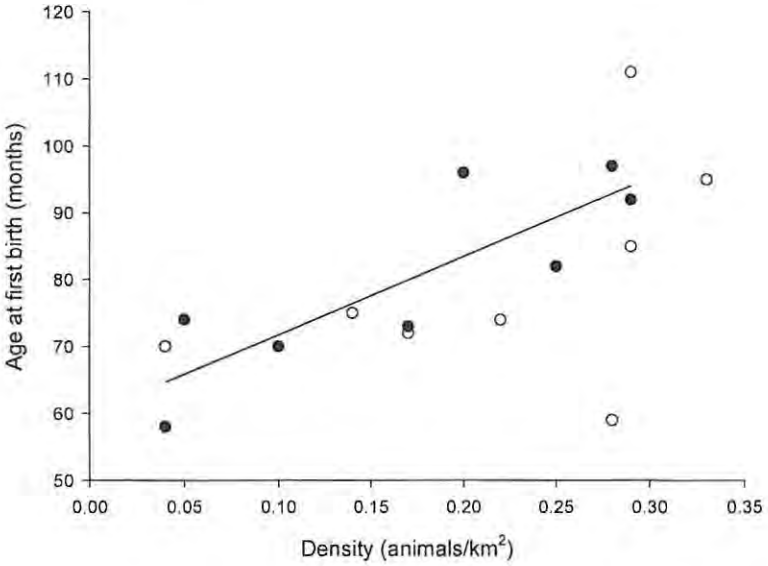


Figure 4.13: Effects of density on age of first parturition. Open symbols are for full data set and closed symbols for the subset of data.

Intercalf interval (subset of 32 females and 74 births; CL 3-5)

There was no relationship between intercalf interval and population size, rainfall in the year of birth of the second calf, age of the mother, sex of the calf or sex of the preceding calf (Table 4.14).

Table 4.14: Summary of the statistical results of the analysis of the effect of various factors on intercalf interval. Linear regression analyses for all except sex of calf and preceding calf which were analysed by one-way ANOVA.

Factor	r^2	df	F	P
Year	0.0014	1,72	0.10	>0.05
Rainfall	0.0005	1,72	0.04	>0.05
Age of mother	0.000001	1,72	0.0008	>0.05
Sex of calf	/	1,72	0.08	>0.05
Sex of preceding calf	/	1,33	3.07	>0.05
Pop size	0.002	1,72	0.14	>0.05

Sex ratio of calves

In years with above average rainfall, more females were conceived than males and in three of four years, the sex ratio had a female bias. In years with average rainfall, more males were conceived and in three of four years, the sex ratio had a male bias. However, there were only two years with below average rainfall and in one the sex ratio was equal and the other had a female bias. In an ANOVA with arcsine transformed percentage of female calves against rainfall (above, below of average), there was no significant effect of rainfall in the year of birth, the previous year (= year of conception) or two years previous (year, $F_{2,16} = 0.62$; $P>0.05$; year -1, $F_{2,15} = 1.9$; $P>0.05$; year-2, $F_{2,14} = 0.49$; $P>0.05$).

There was no significant effect of density on the percentage of female calves born each year through the study (Linear regression; $r^2 = 0.2$; $F_{1,21} = 0.61$; $P>0.05$). For the period after the final re-introduction (2001 to 2008) there was also no significant effect of density on percentage of females ($r^2 = 0.06$; $F_{1,6} = 0.40$; $P>0.05$).

Calving rate (percentage of females of E and F class giving birth).

Through the study, there was no significant relationship between density and calving rate for age category E (Linear regression; $r^2 = 0.01$; $F_{1,21} = 0.22$; $P>0.05$), age category F ($r^2 = 0.005$; $F_{1,21} = 0.12$; $P>0.05$) and age categories E and F combined ($r^2 = 0.02$; $F_{1,21} = 0.42$; $P>0.05$). From 2001 to 2008, when calving rates appeared to have stabilized (see Figure 4.7), there was no significant relationship between density and calving rate for age category E (Linear regression; $r^2 = 0.24$; $F_{1,6} = 1.88$; $P>0.05$), age category F ($r^2 = 0.008$; $F_{1,6} = 0.0505$; $P>0.05$) and E and F categories combined ($r^2 = 0.02$; $F_{1,6} = 0.03$; $P>0.05$).

Mortality rates

There was no significant effect of density on mortality rates (Linear regression; $r^2 = 0.27$; $F_{1,21} = 7.7$; $P>0.05$), nor was there an effect of density of adult males on overall mortality ($r^2 = 0.15$; $F_{1,18} = 3.2$; $P>0.05$). However, there was a significant but very weak relationship between the density of adult males and male mortality ($r^2 = 0.21$; $F_{1,18} = 4.7$; $P<0.05$) and male mortality increased with increasing density of adult males.

Population Growth Rate

The repeated re-introductions of animals in the early years of the study made analysing growth rate problematic. The removal of five animals in 2006 was incorporated by adding five to the estimated population sizes for 2006, 2007 and 2008. In the first three years the population did not grow at all and it was only after the re-introductions that occurred between 1989 and 1991 that population growth began. From 1992 to 2008, the growth rate was 15% (slope of plot of LogN population size against year; Figure 4.14). There were no re-introductions in the years 1992-1996 and during this time growth rate was 12.4%. After the final reintroduction in 2000, growth rate was 10% (Figure 4.14).

Population growth rate, calculated as $(Nt_x - Nt_{x-1})/ Nt_{x-1}$ varied through the study from 0 to a maximum of 0,27 between 1993 and 1994 when the population size increased from 15 to 19 (Figure 4.15). Note that in this analysis, years in which animals were re-introduced have been omitted as the re-introduction resulted in a meaningless increase in growth rate. After the final re-introduction in 2000, the rate of increase peaked at 0.16 in 2001, and between 2001 and 2008, the mean rate of increase was relatively steady (Figure 4.14; mean rate of increase 2001-2008 = 0.11±0.048). For all data there was no significant relationship between population growth rate and either year (Figure 4.15; Linear regression; $r^2 = 0.10$; $F_{1,15} = 1.7$; $P>0.05$) or density (Figure 4.16; $r^2 = 0.057$; $F_{1,15} = 0.91$; $P>0.05$). In the period after the final re-introduction (2001-2008), there was no evidence of declining population growth rate with increasing density (Linear regression; $r^2 = 0.007$; $F_{1,6} = 0.05$; $P>0.05$).

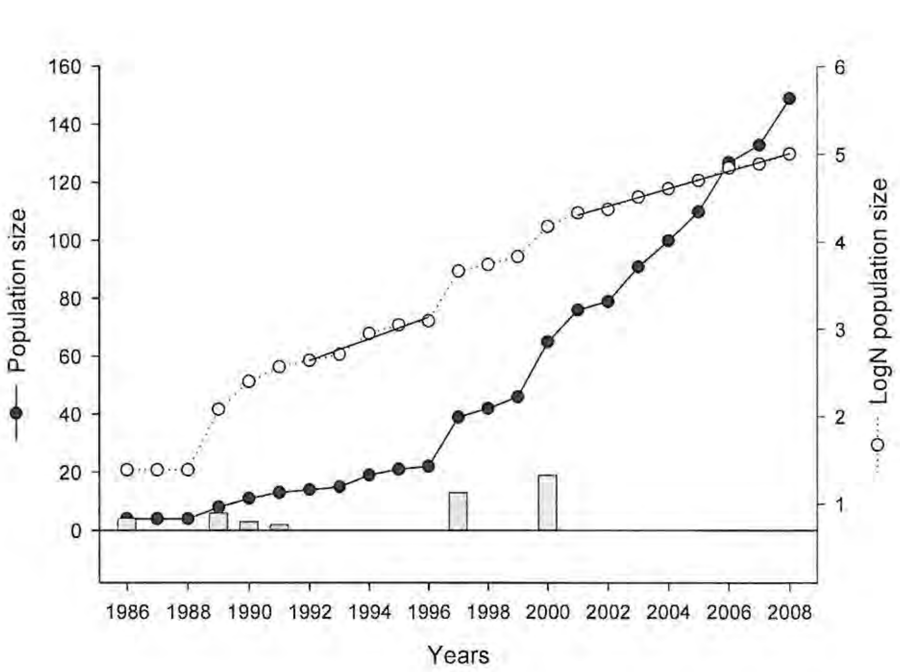


Figure 4.14: Annual changes in the population size of black rhinoceroses on the GFRR (closed circles and solid line). LogN transformation of the population size (open circles) is shown with re-introductions shown as grey bars. The slope between 1992 and 1996 was (0.124) and between 2001 and 2008 (0.100)

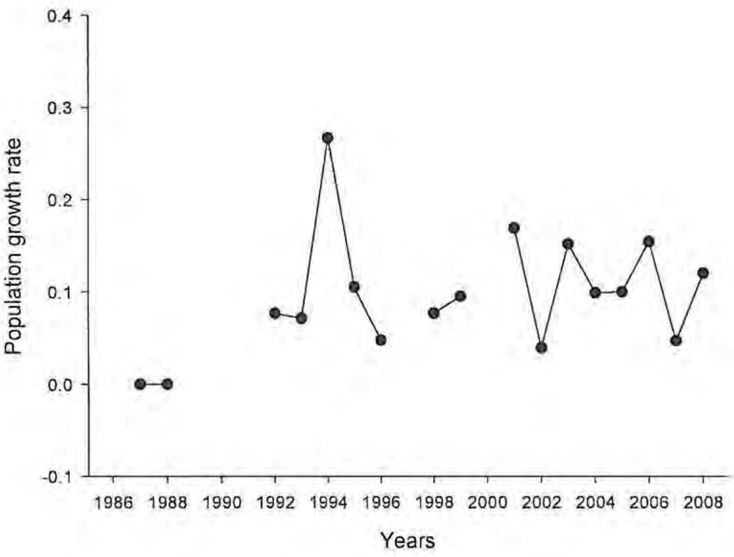


Figure 4.15: Annual changes in population growth rate. Note that data for the years in which re-introductions occurred have been omitted.

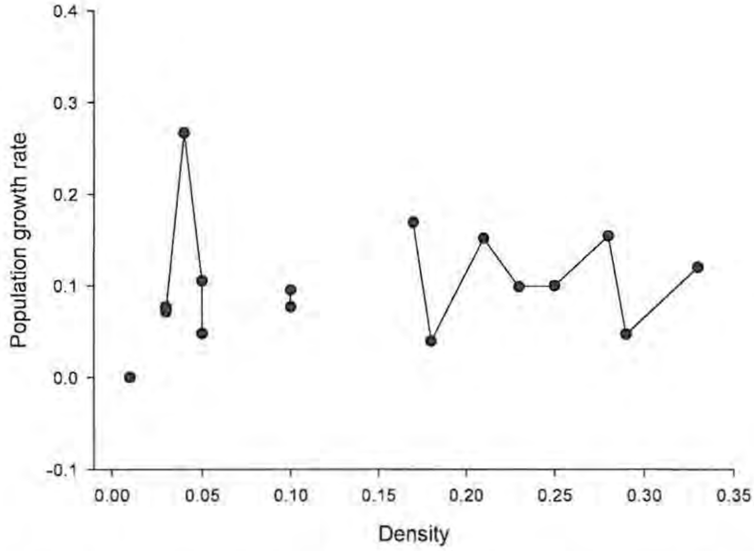


Figure 4.16: Plot of population growth rate against density of black rhinoceroses. Note that data for the years in which re-introductions occurred have been omitted. Density is rhino / km^2.

Summary of Key Reproductive Parameters

The key reproductive parameters of the black rhinoceros population in the GFRR are summarised in Table 4.15.

Table 4.15: Summary of the key lifehistory and reproductive parameters of the black rhinoceros population in the GFRR.

Age structure (2008; Figure 4.3)		
Juveniles	20%	
Sub-adults	36%	
adults	44%	
Sex ratio (females: 1 male; 2001-2008)		
Population	1.3	
Births	1.3	
Age at Sexual Maturity (months)	80.2±14.7	
Gestation length (months)	15	
Intercalf interval (months)	28.7±4.8 months	
% F class females calving/ year	41.0±11.7	
Births/year	0.41 – 0.44	
Years/birth	2ys, 3 months – 2 ys, 5 months	
Reproductive lifespan (years)	18 (29; see discussion)	
Births/lifetime	7 (11-12; see discussion)	
Mortality (Table 4.13)	Female	Male
Juvenile	No deaths	1.1±3.2%
Sub-adult	2.0±2.8%	3.9±5.4%
Adult	0.4±3.2%	3.1±4.5%

DISCUSSION

The estimated upper carrying capacity for the black rhinoceros on the GFRR is just under 0.6/km^2 (Adcock 2006) and if density dependence starts to appear at K/2 (Caughley 1977) then the population on the GFRR is just beyond the point at which the first signs of density dependence should appear. In this discussion emphasis is placed on comparing the results from the GFRR with those from other populations of the black rhinoceros and highlighting areas in which the population may be responding to increasing density.

Population Age Structure

Population age structure is never constant in ungulates (Clutton-Brock & Coulson 2003). Different age classes are affected differently by density, climate and predation and as a result mortality rates differ in the different age classes (Clutton-Brock & Coulson 2003). Typically, populations that are increasing in number are characterised by a high proportion of young animals and a relatively low mean age for the population (Coulson *et al.* 2004). As a population approaches carrying capacity so the tendency is for infant survival and fecundity to decline and the population to become older with a higher proportion of adult animals (Coulson *et al.* 2004). Owen-Smith & Mason (2005) report a ratio of juveniles relative to adult females of between 0.2 and 0.5 for stabilizing populations of zebra, wildebeest, impala and giraffe in the Kruger National Park. In the GFRR, the mean number of juveniles per adult female over the final three years of the study fell within this range at 0.33 juveniles per adult female. A rapidly declining population of Thomson's gazelle in the Serengeti comprised 12% juveniles and 70% adults (Borner *et al.* 1987). Since the black rhinoceros population on the GFRR was growing rapidly, just approaching K/2 and may have been just starting to show density dependent effects (see later discussion), the population structure should have been characterised by a high proportion of young animals rather than older animals. Since the final re-introduction in 2001, the black rhinoceros population on the GFRR was characterised by a stable proportion of juveniles (20% in 2008), a steadily increasing proportion of sub-adults (36% in 2008) and a steadily decreasing proportion of adults (44% in 2008). The declining proportion of adult black rhinoceroses reflects the earlier decline in the proportion of sub-adults and since the proportion of sub-adults was increasing in the final years of the study, it can be expected that this will be reflected in an increase in the proportion of adults in future years.

The age structure of the black rhinoceros population on the GFRR was similar to that reported for other re-introduced populations of the species. The proportion of juveniles was exactly the same in Ndumu Game Reserve in KwaZulu-Natal (density 0.38/km^2 and 24 years after 1st re-introduction; Conway & Goodman 1989) and in the Pilanesberg National Park (PNP) the population was about 52% adult, 28% subadult and 20% juvenile (density 0.1/km^2 and 20 years after 1st re-introduction; data estimated from Hrabar & du Toit 2005, Figure 1). In East Africa, healthy black rhinoceros populations comprise about 60% adult animals (Owen-Smith 1988), in comparison with a declining population in the Hluhluwe Game Reserve (KwaZulu-Natal, South Africa) where the percentage of adults was 82% (Owen-Smith 1988).

Although the population structure on the GFRR was not stable and there were cycles of change in the proportions of sub-adult and adult animals, there was no significant effect of density on the proportion of juveniles or adults and thus no evidence that density was influencing the population structure.

Sex Ratio

The overall sex ratio of a population will be affected by differential mortality of the sexes and by any bias in the production of male and female young. The Trivers-Willard hypothesis (TWH) proposes that females in a polygynous system (as is the case for the black rhinoceros; Garnier *et al* 2001), in good condition will produce more sons than daughters and that the opposite will hold for females in poor condition (Cameron 2004). It is argued that male young in polygynous systems will eventually produce more young than females who are severely limited by the reproductive rate of the species (which is very low in very large species; Owen-Smith 1988). However, for a male to compete with other males for the right to mate, he must be large and strong and thus produced by a female in good condition. Females in poor condition will not produce large strong male young and it is unlikely that they will win the right to mate and therefore the mother produces female calves (Owen-Smith 1988; Cameron 2004). It is therefore likely that the sex ratio amongst the calves will be affected by rainfall and the condition of the vegetation which together influence female condition. It is also possible that as the population reaches carrying capacity, so the condition of the vegetation will decline and this too will influence female condition (Owen-Smith 1988; 2001).

On the GFRR, the sex ratio of re-introduced animals was balanced and thus the female bias that was present throughout most of the study was due to natural processes. The sex ratio in the population as a whole and for calves was about 1.3 females per male. In the last eight years of the study, the mortality rate of males was greater than of females and this was, to a certain extent, balanced by the removal of four females and one male from the reserve in 2006. While the majority of females produced more female calves than male calves, four of 14 produced more male calves. Elsewhere, the sex ratio of black rhinoceros populations varies from having a male bias (Lake Nakuru N.P., Okita-Ouma *et al.* 2009; Hluhluwe-Imfolozi Park, Hitchins & Anderson 1983), through being balanced (various reserves in East Africa, Kiwia 1989; Schenkel & Schenkel-Hulliger 1969) to having a female bias (adult and sub-adults at PNP; Hrabar & du Toit 2005).

On the GFRR, the sex ratio was just outside the range proposed in the management plan of between 1.5 and 4 females per male (Peinke and Fike 2010) but greater than the minimum of 1.25 females per male proposed for populations of more than 100 animals (Adcock 2009).

In the PNP, the sex ratio of calves is affected by rainfall in the year of conception with more males being conceived in years of above average rainfall (Hrabar & du Toit 2005; Berkeley & Linklater 2010). Rainfall is taken as a surrogate for female body condition and these results support the TWH. In the GFRR, the trend was the opposite and while the data indicated that rainfall (maternal condition) may have affected sex of the calf, the pattern was that for females in better condition to have conceived female calves. The effect of rainfall was not consistent across all breeding females on the GFRR since three of fourteen animals that had each produced four or more calves, produced calves of a single sex suggesting that they were in some way resistant to the effects of rainfall. The same phenomenon has been reported on the PNP where one of 13 females produced calves of a single sex (Hrabar & du Toit 2005).

Age at Sexual Maturity

Age at sexual maturity (ASM) varies both between and within species. At the species level it is set by factors including body size and longevity (Bronson 1989) while within a species, it may vary in time and space depending on factors including density, climate and body condition (Bronson 1989; Rachlow & Berger 1998). Fertility is linked to body weight and condition, and in *K*-selected species such as rhinoceros, females tend to reach sexual maturity at 80% of adult weight in their sixth year (Adcock 2009). ASM may be assessed in a number of ways including studies of the histology of reproductive organs, changes in blood hormone levels, and observations of the onset of oestrous behaviour, the occurrence of mating and the age at first birth. These approaches are applicable under certain conditions and the most appropriate for free ranging, cryptic species in dense vegetation is observation of the occurrence of the first birth. Estimating the ASM in this way relies on precision around the date of birth of the mother and of her first calf. While high levels of precision are possible under captive conditions, it is well known that captivity affects reproductive events such as ASM and intercalf interval (Smith & Read 1992; Hermes *et al.* 2004). Under free ranging conditions, it is much more difficult to observe both the birth of the mother and the birth of her first calf and thus the values for ASM are likely to include an error, the size of which is hard to define. On the GFRR, age at first birth was recorded and age at first conception was estimated by subtracting 15 months (gestation length) from the age at first birth. Although some variation in the gestation length has been reported for the black rhinoceros, 15 months is the norm (Hitchins and Anderson 1983; Bertschinger 1994; Skinner & Chimimba 2005; Berkeley & Linklater 2010).

On the GFRR, the mean age at first birth was 80.3 months (six years, eight months) while the earliest was 58 months (four years ten months). The average age at first conception was estimated to be 65 months (five years, five months) and the earliest, 43 months (three years, seven months). On the PNP, the average age of females at birth of their first calf is seven years and three months with a range from six to nearly 10 years (Hrabar & du Toit 2005). In the PNP 33% of females calve before the age of seven while in the present study 63% calved by the same age suggesting that in the GFRR, ASM is earlier than in the PNP. A range of other studies have produced similar values for ASM (East Africa, about six years, Owen-Smith 1988; Ngorongoro Crater population, six to seven years, Mills *et al.* 2006; HIP, six years, six months to 12 years, Hitchins & Anderson 1983; Addo Elephant National Park, six years and three months, Hall Martin 1986). In captivity, the ASM can be high at eight to nine years (Smith & Read 1992), but in some instances can equate with what is expected in a wild population (6 yrs female, 7 years male: Fouraker & Wagener 1996).

For all these studies, the age at first conception may be estimated by subtracting 15 months, giving a value of between three and-a-half and five and-a-half years. This matches with recorded observations of females showing mating behaviour at ages of between three and-a-half and four years (Schenkel and Schenkel-Hulliger 1969). There are two likely causes of the variation in ASM (birth of fist calf) reported above. Firstly, some of the variation will result from different levels of error around the recording of the timing of birth of the mother and the first calf. Secondly, there is evidence that ASM is affected by density and rainfall. In the PNP, there is a trend (not statistically significant) for ASM to increase as density increases (Hrabar & du

Toit 2005). Hrabar & du Toit (2005) note that high rainfall in the high density years may have masked the effect of density on ASM. On the HIP ASM was lower (6.5 years) at low density (0.1/km^2) than at high density (ASM 12 years; density 0.7/km^2; Hitchins & Anderson 1983). In the present study there was a significant inverse relationship between density and ASM suggesting the first signs of a density dependent response and this will be discussed further later.

In the present study no data on the ASM of male black rhinoceroses were collected. Males first show spermatogenic activity at eight years and do not hold a territory until nine years of age (Hitchins & Anderson 1983). Thus ASM for males should be taken as nine years.

Intercalf Interval

As density increases, a point is reached where birth rates decline and mortality rates increase (Owen-Smith 2001). Intercalf interval (ICI), which is one measure of birth rate, is one of the indicators that defines a healthy population and increase in ICI and delay in the ASM are demographic responses to adverse climate such as drought, and population over-crowding (Owen-Smith 2001; Hitchins & Anderson 1983).

Like ASM, precise measurement of the ICI requires precise dates for the birth of one calf and the following calf. In the present study, the ICI was estimated using all data, with a range of confidence limits. Thus, while ICI could not have been underestimated, some of the values would have included an error of as much as six months. The mean ICI was 28.7 months (2 years, 4 months) while the modal ICI was 24 months. The significance of the mode being 24 months will be mentioned in the discussion of reproductive seasonality later. The shortest ICI was 22 months and the longest were 42 and 44 months. Data from field observations are not surprisingly variable, with minimum ICI ranging from 19 months (PNP, Hrabar & du Toit 2005), 20 months (Bertschinger 1994), 26 months (Hitchins & Anderson 1983), 27 months (Ngorongoro, Goddard 1967; Hall-Martin 1986), about 3 years (Ngorongoro, Mills *et al.* 2006) and maximum ranging from 48 months (Hitchins & Anderson 1983), 62 months (Hrabar & du Toit 2005) and 89 months (Bertschinger 1994). While some values for ICI will be inflated as a result of inaccuracy around the recording of the date of the first or second birth, other apparently long ICIs will result from natural breaks in the reproductive process. Thus, the minimum value will allow calculation of the maximum possible number of young born per year or reproductive lifetime, but the mean value has real biological meaning.

ICI is affected by density and rainfall in various ways. In PNP, as density increased from 0.04 to 0.1/km^2, the ICI declined. This is contrary to most published data which indicate that as density increases, ICI increases (Owen-Smith 1988, Rachlow & Berger 1998, for white rhinoceros; Owen-Smith 2001). It is possible that at the very low densities, the population was too small to allow normal interactions between males and females as the females came into oestrus (a form of Allee effect; Stephens, Sutherland & Freckleton 1999) and that as density increased so this problem was reduced and the ICI decreased (Hrabar & du Toit 2005). However, even at the highest density in the PNP (0.1/km^2 which was the original estimate for the carrying capacity), there was no density dependent effect on ICI. In the present study there was no evidence of a density or rainfall effect on ICI.

Births per year and Lifetime Productivity

The estimation of births per year (or years per birth) and births per lifetime uses mean ICI and requires knowledge of the reproductive lifetime for the species. Again, while it is possible to accurately estimate the reproductive lifetime of captive animals, captivity is known not to reflect the situation in the wild (Smith & Read 1992; Hermes *et al.* 2004). If the typical ICI is taken as between two and-a-half and three years (see examples above), then the mean number of births per year will range from 0.4 to 0.33. The reproductive lifetime is about 25 years in captivity (Smith & Read 1992) but is thought to be longer in the wild (Owen-Smith 1988). Schenkel & Schenkel-Hulliger (1969) estimate that female black rhinoceroses continue breeding until 30-35 years of age while Owen-Smith (1988) suggests that breeding ceases at 40 years. If 35 years is taken as a conservative estimate of the age of reproductive senescence, then the reproductive lifespan is 29 years (six to 35). The number of calves produced by a typical female will then range from 11–12. This is less than estimated by Owen-Smith (1988) who used a reproductive lifespan of 34 years (6-40) and suggested that a typical female will have as many as 14 calves.

Calving Rate

The proportion of adult females giving birth in any one year will be affected by gestation length and by ICI. Since ICI may be affected by density dependant and independent factors, the same factors will affect calving rate. At high density, it is expected that ICI will increase and the calving rate will decline. Under ideal conditions of low density (excluding any Allee effect) and above average rainfall, the ICI should be at its minimum and calving rate will be at its greatest.

In the present study, 41% of all F class females and 33% of E and F class females (age greater than 3.5 years) gave birth each year. With a mean ICI of 2.3 years and all adult females breeding, the maximum possible calving rate with females breeding asynchronously would be 43.5%. The fact that the recorded calving rate is slightly lower is probably because a small number of females were breeding more slowly and two animals at an age of nine or more years had not bred. The calving rate is higher than in other studies (PNP, 16 to 45% of all adult females breed each year; Hrabar & du Toit 2005; 25%, East Africa, Goddard 1967), and greater than the minimum (33%) proposed by the RMG (Adcock 2009). Calving rates have been calculated differently in different studies and comparisons should be made with care. At low densities in the PNP, the proportion of adult females breeding increased with increasing density. However, at high densities, increased juvenile deaths resulted in a decline in maternal success. In the present study, there was no significant effect of density (0.2– 0.35/km^2) on the proportion of females calving each year.

Reproductive Seasonality

In large, long lived species, mating will be cued by some predictable environmental cue such as photoperiod, to ensure that birth occurs at an appropriate time (Bronson 1989). Unlike small, short lived mammals which may respond to unpredictable periods of rainfall or plant secondary compounds, large species tend to show far less reproductive flexibility (Bronson 1989). Hrabar and du Toit (2005) report that conceptions in black rhinoceroses in the PNP are related to rainfall and that the number of conceptions per month increased with an increase in monthly rainfall. While this is the case, for the reasons given above, it is unlikely that rainfall is the environmental cue that stimulates mating in the black rhinoceros (Hitchins & Anderson 1983).

The bimodal pattern of births, and by inference conceptions, reported for the GFRR (present study) has been reported in some previous studies (Hitchins & Anderson 1983; Bertschinger 1994; Hrabar & du Toit 2005). By contrast, in the Addo Elephant National Park, a single period of conceptions (spring to mid-summer) occurs (Hall-Martin 1986). The bimodal pattern is interesting because while there is a peak of births during the wet summer months, there is a second peak of births in the middle of the dry winter. The timing of births to occur in summer is easily understood in relation to the energetic requirements of the lactating cow, but the births in mid winter are less easily explained. The very large body size of the black rhinoceros will enable females to store fat which may provide a buffer against periods of reduced food quality and or quantity and may support births in mid-winter (Bronson 1989). While this fat store may allow successful rearing of calves born in the middle of winter, it does not explain the tightly synchronised peak of births in the middle of winter.

On the GFRR, the timing of a birth was correlated with both the month in which the female was born and the month of the preceding birth. If the month of birth of the mother is to be the same as the month in which she gives birth for the first time then the sum of the age at first conception and the gestation length (15 months) must be a multiple of 12. On the GFRR this was not quite the case and mean age at first conception was five years, five months which combines with a 15 month gestation to give six years, eight months. Clearly, for the animals in which the month of birth of the mother was the same as the month of birth of her first young, the age at first conception would have to have been five years and nine months.

The relationship between the month in which one young was born and the month in which the next young was born is to be expected since the modal ICI was 24 months. A similar phenomenon has been reported in Antarctic fur seals where dates of parturition are consistent within individuals but vary in the population (Boyd 1996). With a modal ICI of 24 months, and a 15 month gestation it is likely that there was a nine month period of lactation anoestrus that followed parturition. This would probably have been terminated as suckling intensity declined and a new oestrous cycle triggered.

Mortality

Mortality will be affected by a range of factors including density and climate (Adcock *et al* 1998; Jolles 2007; Okita-Ouma *et al.* 2009). Management plans for re-introduced populations of black rhinoceros have suggested a range of mortality rates from a maximum of 3% for adult animals (Knight 2001); less than 4% for adults, less than 5% for sub-adults and less than 10% for calves (Ezemvelo KZN strategy for biological management of black rhinoceros; Conway *et al.* 2002); and less than 4% across all ages (RMG; Adcock 2009). Annual mortality rates, between January 2005 and December 2006, averaged 1.3% in Namibia and 2.3% for South African populations (Adcock 2009). On the GFRR, following the final re-introductions, annual mortality rates of females were low for juveniles (no deaths recorded) and adults (0.4%), and higher for sub-adults (2.0%), while annual mortality rates of sub-adult and adult males were higher and were highest for the sub-adults (3.9%). There was a significant but weak relationship between density and male mortality, a possible early indicator of a density dependent effect. Adult males compete for mating opportunities and it is to be expected that as the density of adult males increases, so will mortalities. On the PNP, between 1985 and 2001 22 deaths were recorded with 13 adult mortalities no sub-adult mortalities and 9 juvenile deaths and there was no effect of rainfall or density on mortality (Hrabar & du Toit 2005). However, on the PNP there was some evidence of increasing juvenile mortality with increasing density. Known causes of mortality on the GFRR and PNP were old age, aggression and fighting (Present study; Hrabar & du Toit 2005). The very low levels of mortality amongst juvenile black rhinoceroses may be due to an absence of predators. A number of studies have reported that predation by spotted hyaenas and lions is an important cause of juvenile mortality (Hitchins & Anderson 1983; Berger 1994 for review; Plotz & Linklater 2009) and these predators are not present on the GFRR.

Population Growth Rate

Population growth rate will be affected by a number of interacting factors including the age structure, sex ratio, access to water and quality of food, and density. Okita-Ouma *et al.* (2009) suggest a maximum intrinsic growth rate for black rhinoceros populations of 9% while young populations or populations under ideal conditions, have the potential to grow faster (Owen-Smith 1988). Furthermore, a female bias to the population will result in increased growth rates (Owen-Smith 1988; Okita-Ouma *et al.* 2009). In fact, the effect of sex ratio is not clear cut and in three parks in Kenya one park with a strong female bias had a low intrinsic growth rate while one with a male bias had a high growth rate (Okita-Ouma *et al.* 2009). Population growth rates vary in time and space. In East Africa, a small population of black rhinoceroses in the Masai Mara displayed a partial recovery to 35 individuals at a growth rate of 9.8% per annum (Walpole *et al.* 2001). In the Ngorongoro crater, Tanzania, a birth rate of 13.6% was recorded between December 1980 and September 1982, but was countered by a mortality rate of 8%, reducing real growth to

5.6%, at a density of 0.08/km^2 (Kiwia 1989). Between 1993 and 2003, the Ngorongoro crater population exhibited a growth rate of 8.0%, excluding human induced mortalities (Mills *et al.* 2006). In the Addo Elephant National Park the black rhinoceros population grew at 9% (Hall-Martin 1986). In the southern African sub-region the SADC RMG set a target for all populations at a minimum of 5% per annum increase (Emslie 2006).

Population growth rates in the present study were above the 9% suggested by Owen-Smith (1988) and this was probably a result of the relatively low density, female bias and low mortality. There was no effect of density on population growth rate.

In summary, 22 years after the initial release of black rhinoceroses to the GFRR, the population possessed many characteristics of a growing population that was not yet being affected by density. Annual population growth rate was 10% per annum, the sex ratio had a slight female bias and the population comprised approximately 20% juveniles, 36% sub-adults and 44% adults. The ASM and ICI were both relatively low for black rhinoceroses while the calving rate was relatively high. Mortality of juveniles was low while that of sub-adults and adults, and particularly of males was elevated. However, there was a significant positive relationship between density and ASM and a trend of higher levels of mortality in adult and sub-adult males than females. Together these may represent the first signs that the population is responding to density dependent effects and this is discussed further in the final chapter.

CHAPTER 5

FINAL CONCLUSIONS AND MANAGEMENT IMPLICATIONS

Anecdotal historical records report observations of the black rhinoceros in the thicket vegetation of the river valleys of the Eastern Cape Province (Paterson 1790; Skead 2007). However, the extirpation of this species from the Cape Province more than a century ago has meant that there is no information on whether or not thicket vegetation provided a suitable habitat. The reintroduction of black rhinoceroses to reserves in the Eastern Cape Province created an opportunity to assess the suitability of thicket vegetation and the possibility of the Eastern Cape Province contributing to the conservation of the species. In particular, the reintroduction of black rhinoceroses to the GFRR created the opportunity to conduct the present study. Balancing the competing demands of maintaining a large population of black rhinoceroses at maximum reproductive rates (Adcock 2000), while avoiding density dependent effects that slow reproduction (Caughley 1977), required an intensive monitoring programme that provided the data for this thesis.

The combination of observation methods used on the GFRR resulted in the population being reported to the RMG in the completely known format (Brooks 1998) with 80% of known animals sighted at least once each year and an average of 11.5 sightings per year per known animal. This mix of observation methods and the overall monitoring effort provided sufficient data to allow the analysis of demography and the effects of density reported in Chapter 4. While the demography of the population from first introduction to 2008 is well understood, it is very important that monitoring continues and indeed is intensified and this will be justified later. In Chapter 3 it was recommended that the most effective and economical way to improve the monitoring programme would be to use the mircolight to search for animals that had not been observed in the previous three months. In addition, the remote camera programme could be structured to give better coverage of areas that were less frequently visited by Field Rangers. The threat to both the black and white rhinoceros from poaching continues to increase (> 300 rhino killed in S.A. in 2010: Pienaar, J. Department of Economic Development & Environmental Affairs, Bisho. pers. comm.) and in the Eastern Cape Province, there have been a number of incidences (8 between 2008 and 2010: Pienaar, J. Department of Economic Development & Environmental Affairs, Bisho. pers. comm.). In view of this there is a need to strengthen the Field Ranger team and develop a security and monitoring unit. This will result in more rangers in the field who will not only provide security for the black rhinoceroses but also observational records. On the GFRR the rangers provided more than half of all the sightings, although the cost per sighting was the highest (Chapter 3) and any increase in the number of rangers should result in improved monitoring. The goals of the monitoring programme should remain that all animals born on the GFRR are individually identifiable via ear notches, that the population retains the completely known status and that the current rate of sighting is maintained or improved.

As reported in Chapter 4, the growth rate of the population of black rhinoceroses on the GRRR has oscillated around 10% since 2000 and there was no significant effect of density on population growth rate. However, there were the first signs of density dependent effects on reproduction, with a significant inverse effect of density on age at first parturition and on mortality of sub-adult and adult males. The predicted ecological carrying capacity of the GFRR for black rhinoceroses is 0.6/km^2 (= 264 animals/ 440km^2) (Adcock 2006) and it is suggested that populations be held at *K*/2 to avoid density dependence (Caughley 1977 = 132 animals) or 75%*K* (Adcock 2006 = 198 animals). In 2008, at the end of the study, there were 144 black rhinoceroses on the GFRR and since the first signs of density dependence were detected, a programme of removals must be initiated. To illustrate this point, it is possible to model the population growth rate using a simple spreadsheet model. If the population continues to grow at 10% per annum from the 144 in 2008, then by 2012, the population will be 210 (Figure 5.1) and the density 0.47/km^2 which is just over 75% of the carrying capacity of Adcock (2006).

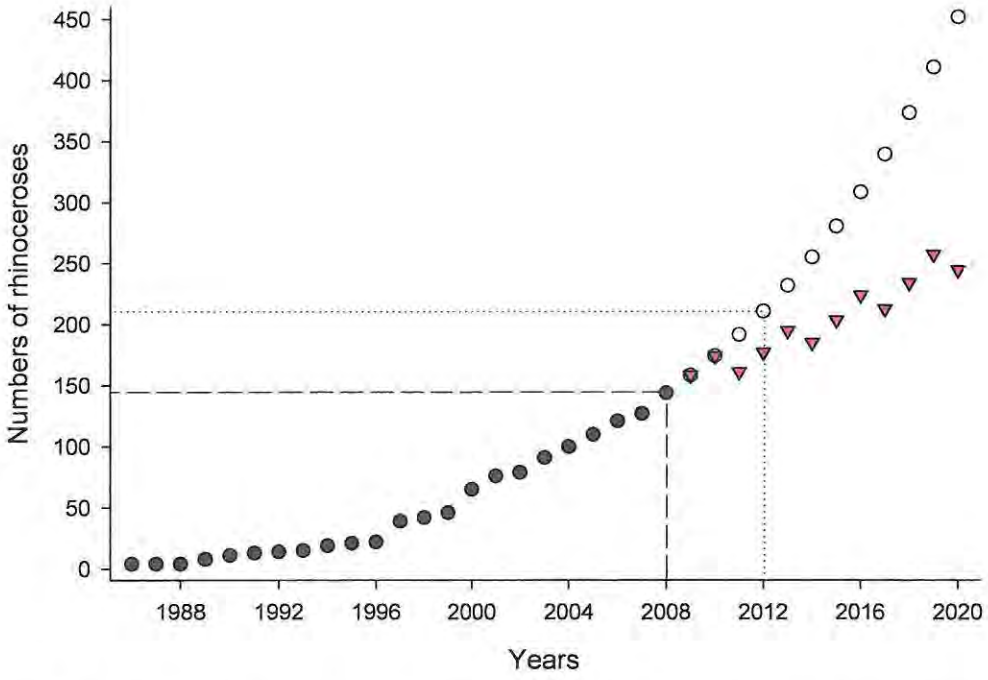


Figure 5.1: Growth rate of the black rhinoceros population on the GFRR. Data from 1986 – 2008 are real (closed black circles). Data from 2009 – 2020 are modelled assuming a 10% growth rate (open circles). Red triangles indicate the population growth rate with 15% of the population removed every three years.

In fact, a removal programme has been proposed where 15 – 16% of the population is removed every three years (Emslie 2006; Peinke & Fike 2010), a rate of removal that is similar to that proposed in other management plans (Conway & Goodman 2005). Harvesting should ideally mirror the sex ratio and age structure of the population, with the understanding that capture and translocation of juveniles may be problematic (Conway *et al.* 2002). If it is assumed that these removals will not affect the population growth rate of 10% then this can be modeled simply and the results suggest that the population will continue to grow and in 2012 will be 177 and in 2019 will be greater than 250 (Figure 5.1). Since the sex ratio is female biased (Chapter 4) and the species is polygynous, the sex ratio and age of the animals selected for removal will have a substantial effect on the population growth rate. The data produced in Chapter 4 must now be used as the basis for a more complex model to examine the likely effects of removals of different numbers of animals and results from this must inform the management decisions. While it is possible to model how the population will respond, it is essential that monitoring continues and that an adaptive management approach, where decisions are modified based on the observed outcome of interventions, is adopted.

An additional factor that must be considered when planning management interventions for the black rhinoceros population is that the strategic management plan for the GFRR allows for the reintroduction of the larger carnivores such as lion, as well as elephants (Jackelman *et al.* 2007). The reason for doing this is to create a more natural ecosystem and it is the case that both lions and elephants occurred in the area historically (Skead 2007). However, it is possible that both lions and elephants will interact negatively with the black rhinoceroses. As reported in Chapter 4, lions are known to kill young black rhinoceroses and it is reasonable to expect that this will occur on the GFRR. Secondly, as megaherbivores, the black rhinoceros and elephant share the ability to bring about a change in the vegetation, and in thicket vegetation, it is very likely that elephants will browse more than graze. In some habitats minimal competition for food resources between elephant and black rhinoceros is evident (Emslie & Adcock 1994), but this trend is reversed when densities of both species are high (Okita-Ouma *et al.* 2008). In addition, interspecific aggression between elephants and rhinoceroses may occur (Berger & Cunningham 1998). Thus, the re-introduction of lions and elephants is likely to affect the reproductive rate of the black rhinoceros. In view of the endangered status of the species, the escalating poaching experienced in 2009 and 2010 in South Africa, and the Key 1 status of the GFRR population (Emslie & Brooks 1999), it would be prudent to place re-introductions of carnivores and elephants on hold. Finally, two species that may compete for resources with black rhinoceros are eland (Emslie & Adcock 1994), and kudu, the latter with the highest species biomass on the GFRR (Peinke & Peinke 2009). Densities of these two browsing species will need continuous monitoring and may need to be managed.

Although not part of this thesis, material for genetic analysis was collected and will be analysed and reported elsewhere. The GFRR founder population came from KwaZulu-Natal where the black rhinoceroses were descendants of about 110 animals that survived in South Africa in 1933 (Emslie & Brooks 1999; Skinner & Chimimba 2005; Enright 2008). Maternity of neonates on the GFRR was well documented but paternity was not and the contribution that dominant bulls have made to the population is unknown. Once the results of the genetic analyses are known, management interventions may be required to increase the genetic diversity. The most likely source would be animals from the Kruger National Park which has the largest population of *D.b. minor* which are descendants of founders from Zimbabwe and KwaZulu-Natal (Hall-Martin & Knight 1994).

In conclusion, the reintroduction of black rhinoceroses to the GFRR has been successful and the population now represents a valuable resource for the conservation of the species. The key challenges now are to protect the animals from poaching, to manage the population size, age and sex structure, and to manage the genetic diversity.

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APPENDIX 2A

Total annual rainfall (mm) from sites on the GFRR and "Bucklands" based on records covering the period 1967 to 2008.

YEAR	Kamadolo	Retreat	B.Post	Bucklands	Galaza	Grasslands
1967				455.1		
1968				222.7		
1969				348.1		
1970				592.6		
1971				588.4		
1972				410.0		
1973				461.7		
1974				745.1		910.5
1975				431.5		
1976				779.7		629.6
1977				613.4		
1978				515.1		484.9
1979				604.1		643.1
1980				352.8		404.1
1981				573.5		497.5
1982				403.8		252.0
1983	301.2			342.3		
1984	205.3			299.4		
1985	732.8	706.0		770.9		802.0
1986	334.4	378.5		373.7		376.4
1987	326.8			330.7		
1988	452.2			595.1		558.7
1989	469.1		590.6	697.4		570.6
1990	250.4	307.2	389.3	278.1		263.4
1991	356.1	477.3	468.7	454.6		
1992	179.0	251.0	308.8	209.8		
1993	428.1	609.1	591.5	531.1		
1994	439.4	478.3	487.0	465.3		
1995	422.9	541.7	609.2	494.9		
1996	436.8	521.3	584.2	485.2		
1997	402.6	468.0	473.0	408.7		
1998	429.2	565.7	473.5	524.3		
1999	355.4	447.5	387.5	410.7		
2000	443.7	563.0	594.5	532.5		
2001	458.8	553.9	550.5	520.3		
2002	533.9	617.4	549.5	592.7		
2003	285.8	327.0		317.2		
2004	396.0	443.1		431.0	703.0	
2005	432.6	491.4		497.6	690.0	
2006	540.2	545.4	632.6	623.9	863.5	
2007	446.8	426.4	436.7	424.2	535.5	
2008	452.2	427.6		430.2	427.9	
Mean Annual precipitation	404.29	483.18	507.94	479.50	643.98	532.73

APPENDIX 2B

Monthly rainfall for the "Kamadolo" weather station for the period 1983 to 2008.

YEAR	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1983	0.0	4.0	6.5	13.0	3.0	12.5	95.5	0.0	40.6	68.7	29.6	27.8
1984	6.0	6.2	13.0	31.2	4.4	53.0	9.3	0.0	14.9	31.6	23.1	12.6
1985	40.8	136.2	46.3	37.0	16.5	7.7	2.6	0.0	3.2	138.2	169.9	134.4
1986	28.0	19.2	22.0	10.9	0.0	15.2	2.7	36.8	37.8	69.4	89.6	2.8
1987	7.4	48.4	22.2	16.2	38.4	13.5	9.0	15.6	105.2	19.4	17.9	13.6
1988	20.2	114.9	37.9	43.5	12.4	10.0	4.0	7.0	56.2	23.2	23.6	99.3
1989	15.5	39.4	25.7	98.6	7.6	0.0	7.0	0.0	11.0	88.7	162.6	13.0
1990	36.5	32.5	38.2	24.5	18.1	4.1	0.0	7.2	26.1	25.0	9.4	28.8
1991	24.2	44.4	26.6	3.0	3.1	10.0	0.0	25.6	18.8	134.1	37.2	29.1
1992	3.5	32.4	21.0	9.6	8.2	11.2	2.0	21.4	4.0	36.2	26.0	3.5
1993	43.5	45.0	3.5	28.0	7.5	15.0	4.5	5.2	77.5	35.6	43.1	119.7
1994	46.6	60.8	87.5	3.0	16.3	13.5	10.9	35.2	3.7	39.3	0.0	122.6
1995	62.7	18.7	77.7	20.7	16.8	2.5	8.7	0.0	36.0	34.7	57.2	87.2
1996	16.5	60.7	47.5	10.6	10.9	1.7	2.2	17.6	7.1	9.8	195.3	56.9
1997	11.4	9.0	24.5	74.3	22.3	59.2	16.1	17.1	10.0	84.2	66.1	8.4
1998	23.1	46.7	74.5	36.0	11.6	0.0	6.0	16.4	25.3	40.5	59.3	89.8
1999	64.1	10.8	64.4	32.1	10.5	2.6	58.3	2.8	17.2	44.8	14.3	33.5
2000	65.1	7.5	123.2	53.1	21.5	3.9	0.0	2.4	49.9	35.4	79.2	2.5
2001	36.8	10.2	44.2	94.5	5.6	11.2	11.7	31.8	55.2	42.4	67.0	48.2
2002	59.4	4.7	17.6	26.3	15.3	21.0	49.6	171.1	84.5	6.0	14.2	64.2
2003	13.4	46.8	48.0	21.0	37.8	3.0	2.0	22.3	5.1	36.7	23.1	26.6
2004	43.0	86.1	12.0	52.7	4.0	12.0	9.3	17.3	82.2	14.3	26.2	36.9
2005	50.3	54.1	27.8	86.2	27.0	6.3	3.0	14.5	19.9	25.9	114.1	3.5
2006	55.6	51.2	7.3	30.8	61.6	9.9	8.2	123.7	30.4	77.6	29.9	54.0
2007	38.0	31.6	109.9	20.2	11.8	20.3	5.9	24.2	4.4	27.1	57.0	96.4
2008	87.3	78.7	53.3	25.2	21.7	21.0	2.0	25.0	16.7	14.2	73.5	33.6
Averages:	34.57	42.32	41.63	34.70	15.92	13.09	12.71	24.62	32.42	46.27	58.02	48.03

All measurements in millimetres

APPENDIX 2C

Monthly rainfall for the "Retreat" weather station for the period 1985 to 2008.

YEAR	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1983												
1984												
1985	46.5	107.0	37.0	38.0	5.5	6.5	2.5	0.0	0.0	130.0	234.0	99.0
1986	41.0	23.5	17.5	23.0	1.0	22.0	5.0	39.5	41.0	75.0	82.0	8.0
1987												
1988												
1989												
1990	28.5	56.5	55.5	37.5	9.5	6.0	1.5	19.4	19.0	38.4	8.2	27.2
1991	21.9	60.3	32.3	3.5	4.0	12.5	1.8	38.2	27.4	165.0	57.4	53.0
1992	18.0	25.5	49.0	22.5	7.0	16.0	2.0	40.5	12.0	26.5	30.0	2.0
1993	54.5	48.5	9.2	51.4	18.5	29.5	7.0	9.5	69.5	34.0	61.3	216.2
1994	56.7	76.3	55.4	14.0	13.0	7.3	23.0	41.1	5.0	46.1	1.0	139.4
1995	86.1	23.9	108.9	40.5	14.8	11.2	8.7	2.6	31.2	50.5	51.2	112.1
1996	30.0	71.4	77.3	15.5	10.1	3.5	4.5	12.3	12.6	25.7	189.4	69.0
1997	32.4	40.9	36.0	78.4	36.6	81.7	16.7	16.0	13.1	68.0	40.1	8.1
1998	31.8	93.0	63.7	58.5	15.0	0.0	9.0	31.6	23.4	47.1	113.4	79.2
1999	77.9	18.9	61.0	44.0	16.0	6.0	59.0	5.9	14.0	37.7	33.1	74.0
2000	84.5	10.0	153.2	44.2	9.0	6.0	0.0	3.0	58.1	45.0	131.0	19.0
2001	43.0	12.0	61.0	95.8	10.0	11.6	17.8	35.0	70.5	17.6	119.0	60.6
2002	82.0	6.8	54.2	26.3	13.9	21.0	59.5	173.0	78.8	5.0	30.0	66.9
2003	18.0	36.1	61.9	30.0	56.8	0.0	3.0	20.9	5.0	46.5	28.8	20.0
2004	47.9	45.1	19.2	55.0	8.0	15.0	12.0	14.0	114.9	13.0	9.0	90.0
2005	52.8	93.0	36.2	77.4	26.0	2.0	2.0	22.0	16.0	24.0	140.0	0.0
2006	34.0	46.3	8.5	56.0	59.8	22.0	0.0	116.8	31.0	99.0	19.0	53.0
2007	40.0	37.0	103.3	14.0	16.0	28.0	4.0	7.8	2.0	50.0	36.0	88.3
2008	84.9	68.2	39.9	31.0	12.0	22.7	2.0	33.4	11.0	17.0	71.5	34.0
Averages:	48.21	47.63	54.30	40.79	17.26	15.74	11.48	32.50	31.21	50.53	70.73	62.81

APPENDIX 2D

Monthly rainfall for the "Botha's Post" weather station for the period 1989 to 2008

YEAR	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
1989	28.8	33.8	83.0	146.5	7.5	6.5	9.0	0.0	4.0	132.0	103.5	36.0
1990	60.5	68.0	74.1	33.5	14.5	10.5	2.0	9.8	29.0	36.9	15.5	35.0
1991	50.5	36.0	48.7	5.5	10.0	17.5	0.0	24.0	21.7	153.0	67.3	34.5
1992	19.0	26.2	52.0	22.5	7.0	26.0	3.5	46.5	6.8	45.3	46.0	8.0
1993	73.0	65.5	16.5	54.0	18.5	25.0	5.0	11.5	56.5	34.0	71.0	161.0
1994	67.5	76.0	41.0	9.0	19.0	10.0	34.0	28.5	6.0	68.0	1.5	126.5
1995	132.5	81.0	45.1	29.6	20.0	13.0	3.5	1.5	15.1	40.5	109.0	118.4
1996	52.2	120.0	85.5	14.5	12.5	5.5	4.5	12.5	16.0	36.5	198.5	26.0
1997	63.5	17.0	36.0	137.5	34.5	58.0	13.0	3.0	6.0	63.0	40.5	1.0
1998	27.0	77.0	39.0	25.0	12.5	0.0	9.0	26.5	38.0	42.0	96.0	81.5
1999	40.0	13.5	90.0	40.0	18.0	8.0	36.0	0.0	14.0	41.0	25.5	61.5
2000	106.5	26.0	138.5	63.0	6.0	12.0	0.0	0.0	83.0	41.0	116.5	2.0
2001	63.5	15.0	94.0	90.0	6.0	3.0	58.0	8.0	73.0	11.0	100.0	29.0
2002	52.0	13.0	26.0	26.0	6.0	20.0	75.0	159.0	94.0	9.0	27.0	42.5
2003												
2004												
2005												
2006	54.4	103.7	8.3	66.0	65.0	8.1	8.0	129.5	20.6	72.1	14.9	82.0
2007	49.5	63.8	108.5	14.5	15.0	31.0	19.0	6.0	4.5	24.2	20.4	80.3
2008												
Averages:	58.78	52.22	61.64	48.57	17.00	15.88	17.47	29.14	30.51	53.09	65.82	57.83

APPENDIX 2E

List of all indigenous mammalian species known to occur on the GFRR.

Numbering as per "The Mammals of the Southern African Subregion" – Skinner & Chimimba (2005)

Order Afrosoricida

No.16	*Amblysomus hottentotus*	Hottentot golden mole

Order Macroscelidea

No. 20	*Macroscelides proboscideus*	Round-eared elephant-shrew
No. 23	*Elephantulus rupestris*	Western rock elephant-shrew

Order Tubulidentata

No. 27	*Orycteropus afer*	Aardvark

Order Hyracoidea

No. 28	*Procavia capensis*	Rock hyrax

Order Proboscidea

No. 31	*Loxodonta Africana* (*n* = 2)	African savanna elephant

Order Lagomorpha

No. 34	*Lepus saxatilis*	Scrub Hare
No. 35	*Pronolagus rupestris*	Smith's red rock rabbit

Order Rodentia

No. 42	*Cryptomys hottentotus*	African mole-rat
No. 45	*Georychus capensis*	Cape mole-rat
No. 46	*Hystrix africaeaustralis*	Cape porcupine
No. 47	*Thryonomys swinderianus*	Greater canerat
No. 50	*Pedetes capensis*	Springhare
No. 59	*Graphiurus murinus*	Woodland dormouse
No. 65	*Rhabdomys pumilio*	Four-striped grass mouse
No. 73	*Grammomys dolichurus*	Woodland thicket rat
No. 79	*Mus minutoides*	Pygmy mouse
No. 83	*Mastomys coucha*	South'n multimammate mouse
No. 91	*Micaelamys namaquensis*	Namaqua rock mouse
No. 98	*Otomys irroratus*	Vlei rat
No.100	*Otomys unisulcatus*	Bush vlei rat
No.101	*Desmodillus auricularis*	Cape short-tailed gerbil
No.112	*Saccostomus campestris*	Pouched mouse
No.115	*Dendromus melanotis*	Grey climbing mouse

Order Primates

No.128	*Papio hamadryas*	Chacma baboon
No.129	*Cercopithecus pygerythrus*	Vervet monkey

APPENDIX 2E (continued)

Order Eulipotyphla

No. 134	*Myosorex varius*	Forest shrew
No. 137	*Suncus infinitesimus*	Least dwarf shrew
No. 141	*Crocidura cyanea*	Reddish-grey musk shrew
No. 143	*Crocidura flavescens*	Greater red musk shrew
No. 148	*Atelerix frontalis*	South African hedgehog

Order Chiroptera

No. 173	*Tadarida aegyptiaca*	Egyptian free-tailed bat
No. 176	*Miniopterus schreibersii*	Schreibers' long-fingered bat
No. 189	*Myotis tricolor*	Temminck's hairy bat
No. 210	*Nycteris thebaica*	Egyptian slit-faced bat
No. 214	*Rhinolophus clivosus*	Geoffroy's horseshoe bat
No. 218	*Rhinolophus capensis*	Cape horseshoe bat

Order Carnivora

No. 227	*Proteles cristatus*	Aardwolf
No. 228	*Parahyaena brunnea*	Brown hyaena
No. 231	*Panthera pardus*	Leopard
No. 233	*Caracal caracal*	Caracal
No. 234	*Felis silvestris*	African wild cat
No. 238	*Genetta genetta*	Small-spotted genet
No. 239	*Genetta tigrina*	Large-spotted genet
No. 243	*Suricata suricatta*	Suricate
No. 246	*Cynictis penicillata*	Yellow mongoose
No. 250	*Galerella pulverulenta*	Cape grey mongoose
No. 253	*Atilax paludinosus*	Marsh mongoose
No. 256	*Otocyon megalotis*	Bat-eared fox
No. 258	*Vulpes chama*	Cape fox
No. 260	*Canis mesomelas*	Black-backed jackal
No. 261	*Aonyx capensis*	African clawless otter
No. 263	*Mellivora capensis*	Honey badger
No. 264	*Poecilogale albinucha*	African striped weasel
No. 265	*Ictonyx striatus*	Striped polecat

Order Perissodactyla

No. 274	*Diceros bicornis*	Black rhinoceros

Order Suiformes

No. 277	*Potamochoerus larvatus*	Bushpig
No. 278	*Phacochoerus africanus*	Common warthog

Order Whippomorpha

No. 279	*Hippopotamus amphibius*	Hippopotomus

Order Ruminantia

No. 322	*Syncerus caffer*	African buffalo
No. 323	*Tragelaphus strepsiceros*	Greater kudu
No. 325	*Tragelaphus scriptus*	Bushbuck
No. 327	*Tragelaphus oryx*	Eland
No. 331	*Alcelaphus buselaphus*	Red hartebeest
No. 339	*Sylvicapra grimmia*	Common duiker
No. 349	*Raphicerus campestris*	Steenbok
No. 350	*Raphicerus melanotis*	Cape Grysbok

APPENDIX 3A: Monitoring results from some rhino populations elsewhere in the SADC RMG sub-region: Jan. 2005 to Dec. 2006 (from Adcock 2009).

Country	Area	2006 pop.	Sub Species	Methods	Results
Namibia	Kunene West	152	*D.b.bicornis*	Special monitoring team, conservancy staff,	61 to 69% of population identifiable
Namibia	Waterberg Plateau	41	*D.b.bicornis*	Foot & horse patrols, aeria surveillance, notching ops.	Highest priority, but lack of staff led to decline in 05/06.
Namibia	Etosha	763-865	*D.b.bicornis*	166 blocks of 4km. X 4km. flown in grid pattern by aircraft (05), and helicopter (06)	High degree of accuracy and precision considering huge area
RSA	Addo E.N.P.	46	*D.b.bicornis*	Helicopter, exteran researchers, camera traps.	Dense vegetation and topography in Nyati area
RSA	Mountain zebra N.P.	4	*D.b.bicornis*	Aerial survey, external researchers, telemetry	Small population. All rhino monitored each month.
RSA	Mokala N.P	7	*D.b.bicornis*	External researchers, staff telemetry.	Introduced in 2006. New population.
RSA	Tswalu (Pvt.)	26	*D.b.bicornis*	Field Rangers, researcher	Rhino located once a month.
RSA	Eastern shores	21	*D.b.minor*	Field Rangers, WWF rhino monitoring, photgraphy	Field ranger shortage, not all areas adequately covered.
RSA	HIP	246	*D.b.minor*	Stastistical programme, capture field rangers, notching, census,	96% of population known.
RSA	Ithala G.R.	37	*D.b.minor*	Field rangers, roads, photographic database	High proportion of rhino (D - F classes) known.
RSA	Mkhuze G.R.	60	*D.b.minor*	Field rangers, statistical analysis	Varied intensity of coverage
RSA	Weenen N.R.	11	*D.b.minor*	Intensive monitoring effort over 2 days each month, notching.	Small population. All rhino known.
RSA	Western shores	7	*D.b.minor*	Incidental sightings.	Sighting frequency is low.
RSA	Madikwe G.R.	47	*D.b.minor*	Field rangers, aerial census, notching ops.	Intensive notching programme in 2006.
RSA	Pilanesberg	59	*D.b.minor*	Annual census, annual notching, Field rangers.	Monitoring data from 2001 revised & updated
RSA	Kruger N.P.	429	*D.b.minor*	Stratified block census in south & central areas. 136 blocks (3km. x 3km.) flown out of a total of 673.	Trail run of this method. Results extrapolated and. promising.
RSA	Marakele N.P.	27	*D.b.minor*	Aerial surveys, field rangers, telemetry, notching.	Evidently all known.
RSA	Kwandwe (Pvt.)	11	*D.b.minor*	Game drive vehicles, Checked by Field rangers on a monthly basis.	All known.
Zimbabwe	L-B2 (Custodian)	73	*D.b.minor*	Dedicated rhino monitoring patrols. Air/telemetry opserations. GPS plotting records, digital photography.	Aim to have two positive obs. per animal per year. Rhino with telemetry located every 6 weeks from air.
Zimbabwe	L-C1 (Custodian)	20 - 25	*D.b.minor*	Limited by land invasion	Information on pop. minimal.