The Economic Potential of Game Hunting on a Small Reserve

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Abstract

There is an increasing recognition that conservation projects need to provide tangible benefits to the communities involved in them. In Africa a common method of providing economic benefits to communities is to sell the right to hunt wildlife in conservation areas. The Makasa Nature Reserve is a joint project between a conservation body and a community. The reserve is a conservation project that aims to provide economic benefits to the community involved. There are a number of possible income generating strategies for the Makasa Nature Reserve. This study is an examination of the revenue that the reserve could generate from game hunting.

There are a number of wildlife species on the reserve that can be hunted but buffalo are the most attractive to hunters and the most lucrative for the reserve. In order to determine the number of buffalo that can be harvested a two-stage approach was used.

Firstly, a deterministic mathematical model of the buffalo population was developed in the study. This model was used to establish age structures of the buffalo population which will maximise a given objective function. An age structure that has a harvest level that will maximise the revenue of the reserve was selected as being the most appropriate for the buffalo population at Makasa.

In the second stage a stochastic model of the buffalo population was developed which incorporated environmental and demographic stochasticity. A management policy for the buffalo population, which was based on the age structure that maximises revenue, was developed. The stochastic model was used to aid the development of the management policy and to determine the average harvesting rate of buffalo from the Makasa reserve.

Using the information gathered on the harvesting rate of buffalo and combining it with the likely harvesting rate of other species from the reserve, it is possible to get a broad picture of the likely economic potential of game hunting on the Makasa Nature Reserve.

This approach of determining the offtake of the economically dominant species in the reserve and then combining this information with the likely offtake of other species in the reserve can be generalised and applied to similar reserves.

Preface

The work described in this thesis was conducted under the supervision of Prof JW Hearne of the Department of Mathematics and Applied Mathematics, University of Natal, Pietermaritzburg and Dr PS Goodman of the Natal Parks Board.

These studies present original work by the author and have not otherwise been submitted in any form to another University. Where use has been made of the work of others it is duly acknowledged in the text.

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Chapter 1: Introduction

This study was conducted in order to determine the economic potential of game hunting on the Makasa Nature Reserve. The Makasa Nature Reserve is a joint venture between the Natal Parks Board and the Makasa Community. The reserve is an example of the new type of conservation project that is emerging in Africa.

This chapter provides an introduction to conservation in Africa and the way in which it is changing. This is followed by a description of the Makasa Nature Reserve and a discussion on the possible income generating strategies for the reserve. Game hunting at the reserve is then discussed. The chapter is concluded with an introduction to mathematical modelling and outline of the rest of the study.

a) Conservation in Africa

In Africa conservation developed largely as a response to the declining populations of large mammals (Cumming, 1993). Game reserves, which are usually owned by the state, have been the traditional vehicle of conservation in Africa. The primary focus of these reserves was to protect the natural heritage of society. These reserves have played a very important role in preserving species and ecosystems, however, in recent years questions have been raised about the ability of these reserves to protect the environment in the long term.

A major problem associated with the establishment of parks was that communities were cut off from the resources located in these parks. Cumming (1993) points out that this loss of access to resources represents a social cost to communities which traditionally relied on the wildlife, the vegetation and the water in parks. Since the 1900s there has been a major increase in Africa's population resulting in more and more people relying on the same limited resources. This rise in population numbers, coupled with the loss of access to natural resources, is putting increasing pressure on the continent's parks.

Recently, there has been an increasing recognition that nature cannot be conserved at the expense of people. Conservationists are now beginning to see it as vitally important that local people receive tangible benefits from the conservation projects in their areas.

Furthermore, in the last decade there has been an increasing realization that in order for conservation to be successful it must preserve biodiversity and the biological processes in nature (Western and Wright, 1994). This means that conserving certain high profile species and scenic landscapes is not enough. Conservation must be extended to all forms of land use and should not only be practised in the limited areas that have been set aside for conservation.

This need to extend conservation practices to larger areas and to distribute the benefits of conservation to local communities has led to the development of new concepts like ecotourism and community-based conservation. Ecotourism is tourism that aims to protect natural resources and at the same time increase the benefits that local communities receive from tourism. Community-based conservation is an attempt to establish conservation projects within local communities that will provide tangible benefits to the communities involved.

Some examples of community-based conservation initiatives are the Richtersveld National Park in South Africa and Communal Area Management Programme for Indigenous Resources (Campfire) in Zimbabwe.

The Richtersveld National Park has resulted from co-operation between the local community that owns the land on which the park is located and the National Parks Board. The Richtersveld is a spectacular mountain desert on the banks of the Orange river in the Northern Cape. The park is awash with diverse plant life much of which is endemic to the area. The park is managed jointly by the Nama community, who own the park, and the National Parks Board, who pay the Nama people for access to the park. The Nama community continue to live on the land, use the resources of the park and graze their sheep and goats within its borders. (Financial Mail, 1994).

The Campfire initiative was established in order to allow local communities to manage the wildlife within their area and at the same time benefit from it. Under the Campfire system, local communities are granted the right to manage the wildlife in their area and to sell hunting concessions. (Maphosa, 1991). The proceeds of these concessions are then passed to the local communities, either by distributing cash to local households, or by ploughing the money into community development projects.

The Makasa Nature Reserve is a recently established community-based conservation project. The reserve is not generating any income and is currently reliant on funding. For this community-based project to be successful the reserve needs to generate sufficient income to pay for the running costs of the reserve and at the same time to provide economic benefits to the Makasa Community.

b) Makasa Nature Reserve

i) Introduction

The Makasa Nature Reserve is 1745 Ha in size and is managed jointly by the Makasa Tribal Authority and the Natal Parks Board. The reserve is an attempt to establish a conservation initiative that provides tangible benefits to the Makasa Tribe who were the original owners of the land (Goodman and Blok, 1996). The specific objectives of the reserve are to:

- ✖ restore and maintain indigenous plant and animal communities in the reserve
- ✖ promote the development of the local economy through sustained consumptive use of natural resources and ecotourism
- ✖ use the reserve to provide environmental education to the broader community and to demonstrate that the sustainable use of natural resources is a viable form of land use.

(Goodman and Blok, 1996).

ii) Background to the establishment of the reserve

Up until recently the land belonging to the Makasa Nature Reserve was owned by the South African government. On the southern border of the reserve is the communally owned land of the Makasa Tribe. In recent years the fence on this border had begun to disintegrate

(Cleminson, 1993) and the Makasa community began harvesting resources from the area and using the land for grazing their cattle. Nkosi Gumede, leader of the Makasa Tribe then made a request that control of the land be transferred to the Makasa Tribe in order to establish a Tribal Conservation area on the land (Goodman and Blok, 1996). However, control of the land was actually placed in the hands of the Natal Parks Board who were given the authority to establish a conservation area for the benefit of the Makasa Tribe. A management committee was established for the reserve with equal representation from the community and from the Natal Parks Board. Funding was obtained from the Green Trust to pay for the initial management costs of the reserve.

iii) Regional Context of the reserve

The Makasa Nature Reserve is located in Maputaland, which is the northernmost region of the province of KwaZulu-Natal. Maputaland is a large coastal plain which stretches from the Lebombo Mountains in the west to the Indian Ocean in the east. It is bounded in the south by St Lucia, the largest estuary in Africa, and in the north by the Mozambican border. Maputaland is an area of great biological diversity, it is the southern-most limit of a number of tropical species, and is a transition zone from a tropical climate to a sub-tropical climate.

Maputaland has six major ecological zones which run from north to south parallel to the coast. On the western boundary of Maputaland is the Lebombo zone which is made up of the Lebombo mountains. These mountains are the highest region of Maputaland and lie about 700 m above sea level (Mountain, 1990). The rest of Maputaland land is low-lying and has a maximum elevation of 150 m (Maud, 1980). At the foot of the Lebombo mountains, on the eastern side, lie the flood plains of the Pongola river which make up the Pongola zone. Adjacent to this zone is the Sand Forest Zone followed by the Mozi Swamp and Palm-belt Zone. The fifth zone is the Coastal Lake zone which includes the Kosi estuary, Lake Sibaya and Lake St Lucia. The final zone is called the Coastal zone and is made up of a narrow strip of land and sea on the ocean edge. It includes dune forests, the intertidal area and off-shore coral reefs. (Mountain, 1980).

Maputaland is a premier tourist destination in KwaZulu-Natal. It combines a wide variety of natural attractions which include a high diversity of wildlife and bird life, a coastal area with coral reefs and abundant marine life, inland lakes and estuaries, and diverse forms of vegetation including mangroves, dune forests and swamp forests. Maputaland is the home of many protected areas including the Mkuzi Game Reserve, the Greater St Lucia Wetland Park and the Tembe Elephant Park. A number of privately owned game reserves are located within the bounds of Maputaland, the most well known being the Phinda Resource Reserve.

Maputaland is located in the Ubombo and Ingwavuma districts of KwaZulu-Natal. These districts are inhabited by an overwhelmingly rural population. It is estimated that only 1,017 of the inhabitants of this area are urban dwellers out of a total population of 260,951 people (Central Statistical Services, 1994). The nearest major urban centres are Richard's Bay and Empangeni which are located south of Maputaland. According to official statistics only 12,4% of Maputaland's population are economically active (Central Statistical Services, 1994). As would be expected agriculture is by far the largest sector of the economy in this region (Data Research Africa, 1995).

iv) Description of the Reserve

Location

Makasa Nature Reserve lies north of False Bay Park (part of St Lucia) and south of the Mkuzi Game Reserve. It lies between 27° 45' S and 27° 47' 7'' S and 32° 22' E and 32° 27' 30'' E. The Phinda Resource Reserve borders the Makasa nature reserve on its western boundary and part of its northern boundary. Commercial agriculture including pineapple, game and cattle farming is practised on the eastern section of the northern boundary of the reserve (Goodman and Blok, 1996). To the east and south Makasa is bounded by communally-owned land on which subsistence agriculture is practised.

Topography

The Makasa Nature reserve and its surrounding areas are generally flat or gently undulating. The reserve is elevated at its eastern and western ends which are 53 m above sea level and 64 m above sea level respectively. The central area of the reserve is a low-lying vlei at 19 m above sea level. Both Tertiary and Quaternary marine sediments are found on the reserve. The elevated ground on the eastern and western boundaries is the remnants of a coastal dune system and the low-lying interdune area is an ancient delta that was once fed by the Mkuze river. (Goodman and Blok, 1996).

Climate

The climate in the region is sub-tropical, with hot and humid summers and warm dry winters (Goodman and Blok, 1996). The mean annual rainfall is in the region of 750 mm. However, rainfall in this region is erratic and the rainfall can vary immensely from year to year. Most of the rain occurs during the summer months. The mean annual temperature is between 22°C (Camp, 1995) and 23°C (Goodman and Blok, 1996). The area does not experience major extremes in temperature. The minimum temperature has been estimated to be 10.4°C and the maximum to be 30.7°C (Camp, 1995). Winds in the area are generally north-easterly or south-westerly and September-October is the windiest period (Goodman and Block, 1996).

Soils

Most of the soils in the Maputaland area are sandy and as a result are general very infertile (Maud, 1980). The soils in the west of Makasa comprise of deep well-drained grey-sands on the elevated areas and lower lying duplex sands which are not well-drained (Goodman and Blok, 1996). The central area is made up of poorly drained heavy clays and the eastern portion of the reserve is made up of a single dune of red sand (Goodman and Blok, 1996).

Vegetation

The reserve straddles two of the six major ecological zones in Maputaland area: the Sand Forest Zone and the Palm Forest Zone. As a result the vegetation in the area is diverse and is made up of patches of Sand Forest and interdune wetlands in the west, vlei grasslands and woodlands in the low lying central area, and Palm Veld Savannah in the east (Goodman and Blok, 1996). Some of the important species found in the sand forest patches at Makasa include: *Brachylaena discolor*, *Kraussia floribunda*, *Cussonia spp.*, *Dalbergia obovata*, *Tricalysia spp.*, *Ochna natalitia*, *Ziziphus mucronate*, *Sclerocarya caffra*, *Combretum molle*, *Trichilia emetica*, *Cordia caffra*, *Syzygium cordatum*, *Landolphia kirkii*, *Maytenus senegalensis*, *Spirostachys africana*, *Euclea natalensis* and *Albizia adianthifolia* (Cleminson, 1993). The more open areas are characterised by species such as *Acacia nilotica*, *Acacia gerardii*, *Acacia karoo*, *Maytenus heterophylla*, *Maytenus senegalensis*, *Euclea divinorum* and *Ziziphus mucronata* (Cleminson, 1993).

Vegetation that could be harvested from the reserve includes thatching grass, ilala palms to make palm wine, wood for fuel and fencing, and medicinal plants.

Bird Life

The diversity of bird life in the Maputaland area is far greater that any other part of South Africa (Cyrus, 1992). Maputaland has a total recorded bird list of 472 species, 384 of which have been sighted in Mkuzi Game reserve north of Makasa (Cyrus *et al*, 1980). The bird species of particular interest at Makasa occur in the forested areas and the wetlands (Goodman and Blok, 1996).

Game Species

A number of species have been introduced into the reserve, these include: white rhino, buffalo, waterbuck, zebra, nyala, impala, giraffe, warthog, reedbuck and blue wildebeest. It is believed that there are small populations of kudu, suni, red duiker and grey duiker present in the reserve.

Infrastructure

In the east of the reserve is a four bed guard camp with a solar powered bore hole. The bore hole caters for the needs of the reserve staff and will provide drinking water for animals during droughts. The capacity of the bore hole is not high and during dry periods the measured yield can be as low as 400 l per hour (Goodman and Blok, 1996). There seem to be no other possible sources of permanent water in the reserve.

The 21 km border of the reserve has an electric fence with two entrances on the southern border of the reserve. The fence meets the veterinary standards required for the presence of buffalo in the reserve (Goodman and Blok, 1996). There are currently a number of management tracks that run along the boundaries of the reserve and a track that provides access to the Guard Camp.

v) Agricultural Potential of the reserve

According to the classification system of the KwaZulu-Natal Department of Agriculture most of the Makasa reserve lies within bioresource group 23 (sandy bushveld) (Camp, 1995). This bioresource group is the equivalent to Acocks (1988) veld type 10 (lowveld) and Phillips (1973) bioclimatic unit 10 (subarid riverine and lowland mixed scrub and wooded savanna) (Camp, 1995).

Camp (1995) estimates that most of the land in the area of the reserve has a current carrying capacity of 6.2 Ha per animal unit and a potential carrying capacity of 3.4 animal units per Ha. Goodman (*pers. comm.*) has estimated a carrying capacity of 8 Ha per animal unit. Using these estimated carrying capacities and the Combud Enterprise Budgets for Beef farming in July 1995 (Department of Agriculture KwaZulu-Natal, 1995), the possible gross margins for cattle farming on Makasa could therefore be between R25 and R60 per Ha per year.

According to Camp (1995) only a limited number of crops can feasibly be grown commercially on this land. The majority of these crops can only be grown under irrigation because of the erratic nature of the rainfall in this area.

vi) Makasa Community

The Makasa community lives in the Makasa Tribal Authority Area which is south of the Makasa reserve. A survey was conducted in the area by A'Bear, Bainbridge and Montgomery (1996). The survey found that 7,302 people reside in the area that belongs to the Makasa Tribal Authority. Only 8% of the Makasa community described themselves as economically active in the survey and most economically active people had a high number of dependents.

The low number of economically active people is probably a result of the large percentage of the population under 18 years old (62%) and the lack of employment in the general area. From the survey it was estimated that the per capita income in the area is very low at R293 per year.

c) Income generating strategies

Currently the Makasa Reserve is not generating any income. A decision needs to be made on what combination of strategies will lead to the highest economic returns for the reserve. Decisions need to be made on the following issues:

- ✖ what land-use option will be used for the reserve?
- ✖ will rights of access to the reserve be leased to another party?
- ✖ will an accommodation facility be built on the reserve?

i) Land-use Options

There are two possible land use options on the Makasa Reserve:

- ✖ consumptive tourism in the form of game hunting
- ✖ non-consumptive nature tourism

Game Hunting

Game hunting is often used as a source of income for conservation projects and has been used in both Zimbabwe and Zambia to generate income for the benefit of local communities. Most of the game species at the Makasa reserve can be hunted. Furthermore, there are no predators on the reserve and the animals will need to be culled at some stage in order to prevent overpopulation and hence over-grazing from occurring.

Hunters will be attracted to the reserve because of the presence of buffalo and nyala. Buffalo are in demand since they are one of the 'Big Five' and they fetch a relatively high trophy price. Nyala is an antelope species that is typical of the Maputaland region, and the best specimens of Nyala are generally found there.

Nature Tourism

As a nature tourism destination, Makasa has a number of attractive features. These include, a range of game species, a number of bird species and an interesting range of vegetation. Buffalo are another major attraction for nature tourism as there are no other buffalo in the immediate area. Specialist ornithological and dendrological tours could be conducted on the reserve. One of the drawbacks of Nature Tourism at the reserve, is its small size. This means that only a small number of tourists can be present in the reserve at any one time. Furthermore, the length of time required to traverse the reserve is fairly short which could mean that most visits to the reserve will be brief. Another disadvantage from the point of view of nature tourism is the high number of other reserves in the area which offer similar experiences, but often on a larger scale. For example Mkuzi game reserve, just to the north, has almost all the same features as the Makasa reserve, but is over 20 times the size. On the other hand, the presence of many other tourist attractions helps to draw tourists to the general area and this could have a positive spin off for Makasa.

Combining Nature Tourism and Hunting

Nature Tourism and Hunting are not mutually exclusive. Hunting is generally not practised throughout the year and it should be possible to have part of the year set aside for hunting and the remainder used for nature tourism.

ii) Leasing rights to the Reserve

The rights to the reserve could be leased for all and part of the year. The rights that could be leased include the right to hunt a given quota of animals and the right of access to the reserve for general nature tourism. The Phinda Resource Reserve had already expressed an interest in leasing rights of access to the reserve. The main attraction of the reserve from Phinda's perspective is the presence of buffalo on the reserve. Currently Phinda has no buffalo of its own. Furthermore, access to the reserve represents an increase in the size of the land available to Phinda which as a result would then be able to accommodate more tourists.

iii) Building Accommodation on the Reserve

If accommodation was built on the reserve it could be used by nature tourists and/or by hunters. In general nature tourism makes a profit by providing accommodation to tourists, so some form of accommodation would be necessary if nature tours were to be run by the Makasa reserve. The income from hunting comes from the fees that the hunter pays per species and the fees paid for accommodation. For hunting to be profitable it is therefore not necessary to provide accommodation for the hunters on the reserve. They could be accommodated in one of the nearby resorts. If access rights to the reserve are leased to another party, accommodation would also not be necessary.

In favour of having accommodation on the reserve is the increased income generating opportunity. There are two factors against having accommodation on the reserve. Firstly, as the situation stands water would have to be trucked into the reserve to supply a tourist lodge. Secondly, the cost of building an accommodation facility is high and will require a substantial investment from the reserve.

d) Game Hunting

The aim of this project is to assess the income generating potential of game hunting on the Makasa Nature Reserve. Once the economic potential of game hunting on the reserve has been established this information will be discussed in the context of the different income generating strategies of the reserve.

Three types of hunting can take place on the reserve:

- ✖ Trophy Hunting: A trophy hunter aims to shoot an animal with the most impressive trophy. Usually, the hunter is looking for a male trophy as, on the whole, females are smaller than males. When a trophy hunter shoots an animal that has been sold to him/her, the reserve normally retains the meat of the animal. The skin and trophy of the animal belongs to the hunter. Trophy hunters are generally foreigners.
- ✖ Meat Hunting: Meat hunters are paying for the opportunity to experience a hunt and for the meat of the animal they shoot. Generally speaking meat

hunters shoot female animals. Most meat hunters are South African.

- ✖ Culling: Animals in the reserve can be culled for their meat, which is sold per kg. Culling would be conducted by reserve staff or individuals who are hired to cull the animals.

Table 1

This table shows the 1996 price range of species sold to trophy and meat hunters (Davies, *pers. comm.*) The current size of the populations of these species at Makasa are also shown in the table, along with the ideal size of the populations of these species (Goodman, *pers. comm.*)

Species	*Trophy Hunt Price Range*		*Meat Hunt Price Range*		*Current Population*	*Ideal Population*
	Min	*Max*	*Min*	*Max*		
White Rhino	75,000.00	90,000.00	0.00	0.00	2	7
Buffalo	20,000.00	23,000.00	6,000.00	8,000.00	32	80
Zebra	1,000.00	1,400.00	1,000.00	1,400.00	51	60
Waterbuck	3,000.00	4,500.00	0.00	0.00	3	20
Wildebeest	1,100.00	1,100.00	550.00	1,000.00	50	80
Reedbuck	600.00	600.00	0.00	0.00	21	10
Warthog	200.00	230.00	200.00	230.00	20	30
Nyala	2,500.00	3,000.00	400.00	400.00	95	100
Impala	300.00	320.00	100.00	230.00	120	100
Kudu	2,000.00	2,200.00	1,000.00	1,000.00	unknown	20
Suni	1,200.00	1,300.00	0.00	0.00	unknown	-
Red Duiker	1,200.00	1,300.00	0.00	0.00	unknown	-
Grey Duiker	150.00	180.00	0.00	0.00	unknown	-

Table 1 shows the list of species that could be available for hunting at Makasa along with the 1996 prices ranges for trophy and meat hunts. From the table it can be seen that white rhino are the most lucrative species to sell, however, with the low numbers of white rhino in the reserve, it is unlikely that rhino hunts could occur more than once every ten years. The next most lucrative species is the buffalo. It is not only lucrative to sell male trophy buffalo, but it is also lucrative to sell females for meat hunts. Since buffalo are also a species that will attract hunters to the reserve they will be the most important species in determining the profitability of the reserve. Since, buffalo are the most important species in determining the profitability of the reserve the majority of this project will be devoted to determining the likely offtake of buffalo from the reserve. In order to determine the likely offtake mathematical modelling was used.

e) Introduction to Mathematical Modelling

A model is an abstract description of a real-life situation. A mathematical model is a model that is created using mathematical tools. Models are implemented in order to solve problems. Models are generally a simplified representation of a complex system. Edwards and Hamson (1989) describe the process of creating a mathematical model as 'moving from the real world into the abstract world of mathematical concepts'. Once in the mathematical world the model is manipulated using mathematical techniques. The solution to the mathematical model is then translated back into the real world, so that it can be used to aid decision making.

Haefner (1996) maintains that there are three main uses for models:

- ✖ Aiding understanding of systems
- ✖ Predicting the future state of a system
- ✖ helping to control a system in order to provide a desired outcome.

Modelling is commonly used to study the population dynamics of animals. Examples in the literature are found in Fowler and Smith (1981), Norton (1994), Starfield and Bleloch (1986) and van Rooyen (1994).

f) Outline of Study

In order to determine the likely offtake of buffalo from the reserve a two-stage approach will be followed. The first stage will involve developing a deterministic model for buffalo in Chapter 2 and using this model to find age structures that will maximise given objective functions in Chapter 3. The second stage will involve the development of a stochastic model in Chapter 4. This model will include environmental and demographic stochasticity and will be used to develop a management policy based on the age structures determined in Chapter 3. In Chapter 5 the results of Chapter 4 will be used to get a general idea of the potential income of the reserve from hunting. The income will then be compared with the running costs of the reserve and the results discussed in the context of the decisions that need to be made about the income generating strategies of the reserve. A broad conclusion will be presented in Chapter 6.

Chapter 2: Single Species Model for Buffalo

In this chapter a general deterministic model for a single species will be developed. This model will be created by dividing the population of the species into distinct age and sex classes. Once the model has been developed it will be applied to buffalo. This is done by determining values for the parameters of the model that are specific to the buffalo population at the Makasa reserve.

a) Single Species Model

The model uses the fecundity and survival data recorded for specific age groups of the species concerned. Fecundity and survival data recorded for age groups of a species is referred to as life table data. In order to create a model using the life table data the population of the species is divided into discreet age classes, i, of the same length of time. For each age class i the age of animals in the class is greater than or equal to i and less than $i + 1$. These age classes can also be referred to as cohorts, which are defined by Caughley (1977) as 'a group of animals born simultaneously'. This type of modelling is often referred to as cohort modelling. Mathematical formulations of simple cohort models can be found in Caswell (1989) and Starfield and Bleloch (1986). Cohort Modelling is often used to model single species populations. Examples can be found in Fryxell *et al* (1988), Starfield and Bleloch (1986) and Sylven (1995).

The single species model is used to predict the structure of the animal population just after the end of the calving season.

i) Basic Model

Let $a_{i,t}$ denote the number of animals in age class i at time t. In order to determine the number of animals at time $t + 1$ in any age-class, except age class 0, the following equation is used:

$$a_{i+1,t+1} = p_i a_{i,t} \quad for\ i = 0,1,\ldots,n-1 \tag{1}$$

where p_i is the proportion of age class i that survives until after the next calving season and n is the last age class of the model.

In order to calculate the number of new-born calves in the year $t + 1$ the following equation is used:

$$a_{0,t+1} = \sum_{i=0}^{n-1} F_i a_{i,t} \tag{2}$$

where

$$F_i = p_i b_{i+1} \tag{3}$$

where b_i is the number of claves that will be born per animal in age class i.

Equations 1 and 2 can be combined and written in the matrix form:

$$\begin{bmatrix} a_{0,t+1} \\ a_{1,t+1} \\ a_{2,t+1} \\ \vdots \\ a_{n,t+1} \end{bmatrix} = \begin{bmatrix} F_0 & F_1 & F_2 & \dots & F_{n-1} & 0 \\ p_0 & 0 & 0 & \dots & 0 & 0 \\ 0 & p_1 & 0 & \dots & 0 & 0 \\ \vdots & & & & & \vdots \\ 0 & 0 & 0 & \dots & p_{n-1} & 0 \end{bmatrix} \begin{bmatrix} a_{0,t} \\ a_{1,t} \\ a_{2,t} \\ \vdots \\ a_{n,t} \end{bmatrix} \tag{4}$$

This type of matrix is commonly referred to as a Leslie matrix.

ii) Differentiating between the sexes

The formulation of the model as described above is too simple for the purposes of this study, since it is necessary to be able to differentiate between male and female animals. In order to do this equation 1 is rewritten as two new equations:

$$m_{i+1,t+1} = pm_i m_{i,t} \quad for\ i = 0,1,...,n-1 \tag{5}$$

where $m_{i,t}$ is the number of male animals in age class i at time t and pm_i is the proportion of male animals in age class i that survive to time $t + 1$.

$$f_{i+1,t+1} = pf_i f_{i,t} \quad for\ i = 0,1,...,n-1 \tag{6}$$

similarly, $f_{i,t}$ is the number of female animals in age class i at time t and pf_i is the proportion of female animals in age class i that survive to time $t + 1$.

Equation 2 is rewritten as three new equations:

$$a_{0,t+1} = \sum_{i=0}^{n-1} F_i f_{i,t} \tag{7}$$

where F_i is defined in equation 3 and b_i is now redefined as the number of animals born per female animal in age class i.

$$f_{0,t+1} = fbirths * a_{0,t+1} \tag{8}$$

where *fbirths* is the proportion of animals born that are female. Similarly for males

$$m_{0,t+1} = (1 - fbirths) * a_{0,t+1} \tag{9}$$

iii) Include hunting

In order to include hunting in the model, equations 5 and 6 must be modified as follows:

$$m_{i+1,t+1} = pm_i m_{i,t} - hm_{i,t} \quad for\ i = 0,1,...,n-1 \tag{10}$$

where $hm_{i,t}$ is the number of males in age class i that are hunted in time t.

$$f_{i+1,t+1} = pf_i f_{i,t} - hf_{i,t} \quad for\ i = 0,1,...,n-1 \tag{11}$$

where $hf_{i,t}$ is the number of females in age class i that are hunted in time t.

iv) Equilibrium Model

Equations 7, 8, 9, 10 and 11 can be used to predict the growth of the population from year to year. However, the aim of this project is to determine an optimal population structure that will maximise the returns of the population. Depending on the aims of the reserve there are a number of possible objective functions. Four different objective functions are described below, in order to differentiate between them they will be referred to as Models A to D.

Model A: Maximise Male Trophies

In order to maximise the number of male trophy (MT) animals that can be hunted in a given year, t, the objective function would be:

$$Maximise\ MT = \sum_{i=mta}^{n} hm_{i,t} \tag{12}$$

where mta is the youngest age at which a male can be considered to be a trophy.

Model B: Maximise Female Meat Trophies

In order to maximise the number of female meat trophies (FT) that can be hunted in a meat hunt in a given year, t, the objective function would be:

$$Maximise\ FT = \sum_{i=fta}^{n} hf_{i,t} \tag{13}$$

where *fta* is the youngest age at which a female is considered to be big enough for a meat hunt.

Model C: Maximise Meat Production

In order to maximise the kilograms of meat (M) culled in a given year, *t*, the objective function would be:

$$Maximise\ M = (\sum_{i=0}^{n} hm_{i,t} mm_i + \sum_{i=0}^{n} hf_{i,t} mf_i) * dp \tag{14}$$

where mm_i and mf_i are the average masses of male and female animals in age class i. *dp* is the dressing percentage, in other words the percentage of the carcass weight that is meat.

Model D: Maximise Revenue

In order to maximises the revenue (R) of the reserve in a given year, *t*, the objective function would be:

$$Max\ R = (\sum_{i=mta}^{n} hm_{i,t}) * mtp + (\sum_{i=fta}^{n} hf_{i,t}) * ftp + (\sum_{i=0}^{n} hm_{i,t} mm_i + \sum_{i=0}^{fta-1} hf_{i,t} mf_i) * dp * mp \tag{15}$$

where *mtp*, *ftp* and *mp* are the male trophy price, female meat hunt price and meat price per kg respectively. The meat from females hunted as trophies are not included in the total production of meat as hunters of female animals keep the meat.

Constraints

Once an objective function has been chosen it is necessary to set some constraints. Firstly, the reserve will have a limited food supply so it is necessary to place some sort of upper limit on the number of animals that can be allowed in the reserve. The upper limit in population numbers will be represented by the carrying capacity of the reserve available for the species concerned. The carrying capacity will be expressed in kgs of biomass of the species concerned and the following equation will be used to place a limit on the population:

$$\sum_{i=0}^{n} m_{i,t} mm_i + \sum_{i=0}^{n} f_{i,t} mf_i \leq CC \tag{16}$$

Secondly hunting must be non-negative:

$$\begin{aligned} hm_{i,t} &\geq 0 \quad for\ i = 0,\ldots,n \\ hf_{i,t} &\geq 0 \quad for\ i = 0,\ldots,n \end{aligned} \tag{17}$$

Thirdly, the proportion of sexually active males to sexually active females must always be higher than a given proportion s:

$$\sum_{i=am}^{n} m_{i,t} \geq \sum_{i=af}^{n} f_{i,t} * s \tag{18}$$

where am is the age at which a male first becomes sexually active and af is the age at which a female first becomes sexually active.

In order to find the equilibrium population structure the following constraint is required:

$$\begin{aligned} m_{i,t} &= m_{i,t+1} \quad for\ i = 0,\ldots,n \\ f_{i,t} &= f_{i,t+1} \quad for\ i = 0,\ldots,n \end{aligned} \tag{19}$$

b) Applying Single Species Model to Buffalo

In order to use the general single species model described above for buffalo, each of the parameters in the model must be set to a value appropriate for buffalo.

i) Introduction to buffalo

The African buffalo (*Syncerus caffer*) is a member of the Bovidae family and the tribe Bovini. Other members of the tribe include bison and oxen. Historically African buffalo were found in most parts of Africa south of the Sahara (Sinclair, 1977). In South Africa they occurred along the southern coast about as far west as Swellendam, but today they only occur in Mpumalanga south of Swaziland, in the Addo National Park in the Eastern Cape and in the Hluhluwe/Umfolozi Game Reserve in KwaZulu-Natal. (Skinner and Smithers, 1990).

African Buffalo are gregarious animals and are generally found in herds. Bachelor herds are sometimes formed away from the main herd and solitary bulls are often found. African Buffalo require a plentiful supply of grass, shade and water (Skinner and Smithers, 1990). They are bulk grazers, feeding mainly on medium to long grasses.

African Buffalo are large animals that stand about 1,4 metres at the shoulder. (Skinner and Smithers, 1990). They can weigh up to 800 kg (Skinner and Smithers, 1990), but the average weight of a buffalo is about 450 kg (Coe, Cumming and Phillipson, 1976). Buffalo cows are smaller than bulls and have smaller horns. The buffalo coat has short sparse hair and is between black and dark brown in colour.

ii) Cohort Information

On average the life expectancy of a buffalo varies between 15 and 20 years (Neethling, 1996). It is believed that a buffalo could potentially live to about 25 years of age, however in the wild a maximum age of 20 years is probably reasonable (Pienaar, 1969). For the purposes of this model the time step is taken to be one year and the buffalo population is divided into 20 age classes, ranging from age class 0 to age class 19. Parameter n is therefore set to 19.

Survival

Since the buffalo population at Makasa is not subject to any form of predation the survival rate of the buffalo is expected to be high. In fact, Prins (1996) calculated that 88.4% of buffalo mortality is as a results of predation. Since all mortality figures available on buffalo relate to populations under predation, these have not been used for this model. The standard mortality figures that have been used are shown in Table 2 on page 24. As can be seen from the table calves (age class 0) have the lowest survival rate. Sinclair(1977) calculated a survival rate of between 67% and 51,5% for calves. The 80% survival rate in the table is significantly higher, however, this seems justified because of the absence of predators. Furthermore, Pienaar (1969) found that the survival rate of calves in smaller and less nomadic herds is much higher than in larger herds. Since the Makasa herd is small and has a limited range a fairly high survival rate for calves can be expected.

Age Specific weights

The age specific weights used in the model are shown in Table 2 on page 24. These weights are based on Sinclair's (1977) data. Sinclair (1977) fitted a von Bertalanffy growth curve to his growth data for both male and female buffalo. However, he found that the weight of buffalo declines with old age in both sexes and therefore the curve was not appropriate for buffalo in age classes 11 and above. The weights of the buffalo for females from age class 0 to 10 and for males from age class 0 to 9 in the table are those calculated from Sinclair's growth curves. The remaining weights have been calculated by Goodman (*pers. comm.*) and are based on the actual weight data collected by Sinclair.

Fertility

Buffalo calves are born throughout the year, but the peak calving period occurs between February and May (Neethling, 1996). The average gestation period is about 340 days (Sinclair, 1977). Sinclair (1977) calculated the fecundity of female buffalo at different ages. These figures are used in the model and are shown in Table 2 on page 24. Significantly, Sinclair has found that female buffalo older than 10 years of age are still relatively fertile. Pienaar (1969) also found that older females are still fertile and this is further confirmed by

Carmichael *et al* (1977) who add the qualification that 'although even very old buffalo may be fertile, old age is accompanied by an increased calving interval and fewer offspring'. The calving interval of buffalo is believed to be dependent on the nutritional status of the herd (Neethling, 1996). A buffalo needs to attain a threshold in body-condition in order to conceive (Grimsdell, 1973). The fecundity data calculated by Sinclair (1977) follows the general pattern for ungulates that Caughley (1976) describes as follows: 'a steep rise over the first few years of life followed by a large plateau, often with a slight negative slope, that offers no hint of the sharp decrease of fecundity at old age that would signal menopause.'

Table 2

Survival, weight and fecundity data for the buffalo population at Makasa. The buffalo weights and fecundity are taken primarily from Sinclair (1977)

Age Class	*Survival Proportion*		*Buffalo weight*		*Calves per female*
	Males	*Females*	*Males*	*Females*	
0	0.80	0.80	152	161	0.00
1	0.90	0.90	243	252	0.00
2	0.99	0.99	330	331	0.00
3	0.99	0.99	406	396	0.12
4	0.99	0.99	469	446	0.28
5	0.99	0.99	520	483	0.82
6	0.99	0.99	560	510	0.82
7	0.99	0.99	591	529	0.82
8	0.99	0.99	615	543	0.82
9	0.99	0.99	633	553	0.82
10	0.99	0.99	690	560	0.82
11	0.99	0.99	690	530	0.66
12	0.98	0.98	673	500	0.66
13	0.98	0.98	656	472	0.66
14	0.98	0.98	639	460	0.66
15	0.97	0.97	622	448	0.66
16	0.97	0.97	605	436	0.66
17	0.96	0.96	600	423	0.66
18	0.95	0.95	600	423	0.66
19	0.00	0.00	600	423	0.66

iii) Other Parameters

Table 3

Buffalo values for the other parameters of the single species model

Name	*Description*	*Value*
mtp	Male Trophy Price	20000
ftp	Female Meat Hunt Price	6000
mp	Meat Price	5.5
mta	Minimum Age Male can be hunted as trophy	15
fta	Minimum Age Female can be hunted in meat hunt	8
am	Age males first become sexually active	8
af	Age females first become sexually active	3
fbirths	proportion of calves that are born female	0.5
s	minimum proportion of sexually active males to sexually active females	0.1
CC	maximum carrying capacity for buffalo in kg	3,600,000
n	last age class	19
dp	proportion of weight that is available as meat	0.505

Prices

The current price at which a game reserve can sell a male trophy buffalo for a hunt varies between R20,000 and R23,000 (Davies, *pers. comm.*). The price for which a female buffalo can be sold for a meat hunt is between R6,000 and R8,000 (Davies, *pers. comm.*). For this model the hunting prices have been set to the lower figure in both cases. The current price that game meat can be sold for in the Mkuzi area is in the region of R5,50 (Goodman, *pers. comm.*) and this is the figure that is used in the model.

Minimum Hunting Ages

To determine the minimum age at which a male buffalo reaches an acceptable trophy standard it is necessary to establish what is considered to be a trophy. There are two separate systems for rating a hunting trophy:

- ✖ the Roland Ward's record system
- ✖ the Safari Club International record system

For Roland Ward's several measurements of a buffalo trophy are taken, the most important of which is the x-y measurement which is used to rank the trophy (van Rooyen, 1989). The x-y measurement is the greatest outside width of the buffalo horns (see Figure 1). In order to gain entry to Roland Ward's record book the x-y measurement must be 45 inches (114.5 cm) or over. (Smith and Halse (eds), 1995).

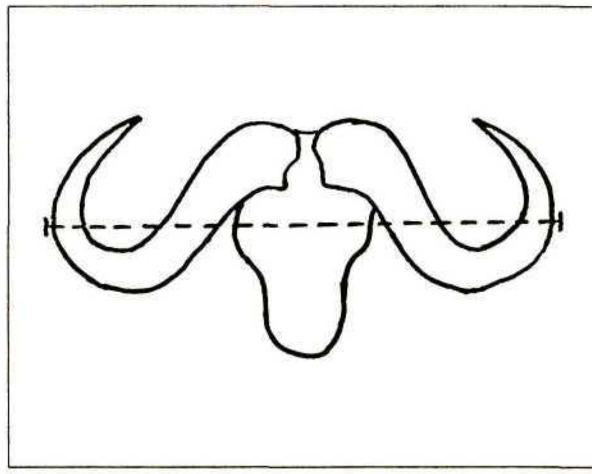

Figure 1: Rowland Ward's x-y measurement

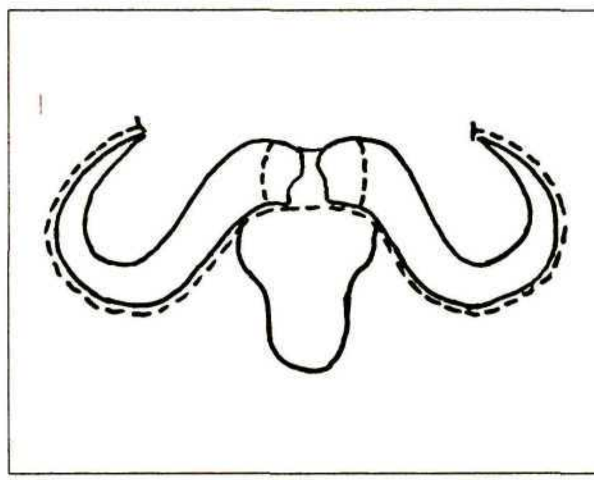

Figure 2: Safari Club International measurements

The Safari Club International system ranks trophies by the number of points scored. In order to rank a buffalo horn the following measurements are taken in inches (see Figure 2)

- ✖ the outside length of the horns across the forehead
- ✖ the size of both bosses (measure the widest part of the boss at a right angle to the long axis of each horn, beginning where the horn meets the skull at the front and ending where the horn meets the skull at the back)

(Safari Club International, 1987)

These three measurements are then totalled in order to establish the points ranking of the trophy. The minimum number of points required for entrance into the Safari Club International record book is 100 points (Safari Club International, 1987).

Since it is not easy to estimate how a trophy scores on the Safari club method without physically measuring the trophy, the Rowland Ward's x-y measurement is generally used when trying to determine the quality of a trophy.

Generally speaking most trophy hunters would like to bag a buffalo trophy with an x-y measurement of 40 inches (101.6 cm) (Paul, *pers. comm.* and Vaughan-Jones, *pers. comm.*). According to Paul (*pers. comm.*) a trophy hunter might be prepared to accept a trophy with an x-y measurement as low as 36 inches (91.4 cm). Vaughan-Jones (*pers. comm.*), however, maintains that a minimum acceptable x-y measurement is 38 inches (96.5 cm). 64 inches is the top x-y measurement of a buffalo trophy in Rowland Ward's 1995 edition. This trophy belonged to a female buffalo which was shot in 1946 at Lake Manyara in Tanzania (eds Smith and Halse, 1995). Generally speaking buffalo from East Africa have larger horns than their southern counter-parts (eds Smith and Halse, 1995).

The age at which a buffalo bull has a horn size of trophy quality is not clear. Du Toit and van Rooyen (1989) and Sinclair (1977) both suggest that the horn length reaches its maximum when a buffalo bull is 5 years old. Davies (*pers. comm.*) suggests that a buffalo is of trophy quality at age 6 or 7 and that a male buffalo can only be hunted once the boss of the horns have hardened. Hardening of the boss occurs when the bull is about 6 or 7 years of age (Pienaar, 1969). The only record of buffalo horn lengths that include data on the age of the buffalo was recorded by Pienaar (1969). The data collected by Pienaar is shown in the Table 4 on page 28.

From Pienaar's data it seems clear that the x-y length of the horn continues to increase as the animal gets older, and that a bull can only be classed as a trophy when it reaches the age of 15 or over. At 15 years and older the horns begin to wear away at the tips and although the horns have the longest x-y length, the length of the horn along the curvature is often less than in the younger age classes. (Pienaar, 1969). For the model a minimum age of 15 is assumed for a male trophy.

Since females are not hunted for their trophies, but rather for the experience of hunting a buffalo, it is not necessary to be concerned with the horn size of the female, it is only necessary for the buffalo to be fully grown. For this model the minimum age at which a female is large enough to be hunted in a meat hunt is set to age 8. This age was suggested by Goodman (*pers. comm.*).

Table 4

Buffalo x-y length data collected by Pienaar (1969)

Age Group	*x-y length of buffalo horns*												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*
0-1	24.1	21.6	34.3										
1-2	54.6												
2-3	64.8	54.6	68.6										
3-4	71.1	73.7	81.3	69.8	64.8								
4-5	78.7	82.5	83.8	95.2	81.3	71.7							
5-6	83.2	94.6	86.4	81.3									
6-8	96.5	94.0	71.1	87.0	94.6	90.2							
8-15	94.0	94.0	100.3	100.3	98.4	87.6	88.9	100.3	91.4	90.2	83.8	78.7	87.6
15>	102.9	100.3	101.6	101.0	94.0	104.1							

Age buffalo become sexually active

Female buffalo begin to mature sexually between 3 and 4 years old, and all females are sexually mature by the time they are 4½ years in age (Sinclair, 1977). At the age of 4½ years about half the buffalo bulls are sexually mature, and by the age of 6 all bulls are mature (Sinclair, 1977). However, Pienaar (1969) states that younger bulls are not allowed to participate in breeding activities by the older bulls until they are about 7-8 years in age. Grimsdell (1969) also found that until bulls reach the age of 8 they are prevented by the social structure of the herd from mating. For the model the age at which cows first become sexually active will be set to 3 and the age at which bulls first become sexually active will be set to 8. The minimum proportion of sexually active males to sexually active females is set to 0.1. This will ensure that there is at least one sexually active male to 10 sexually active females in the buffalo population.

Proportion of female births

The sex ratio of births in buffalo appears to be equal (Sinclair, 1977) so the proportion of calves born female will be set to 0.5.

Carcass Dressing Percentage

The carcass dressing percentage of buffalo is 50.5% (Ledger *et al*, 1967). The dressing proportion used for this model will be 0.505.

Carrying Capacity

The carrying capacity parameter is needed to place an upper limit on the size of the population. The value of the carrying capacity itself has no impact on the general results of the models. Once the offtake has been calculated for one carrying capacity, it can be calculated for any other carrying capacity by simply dividing the results by the original carrying capacity and multiplying by the new carrying capacity. The carrying capacity for this model was set to 3,600,000, which is 100 times the carrying capacity of the Makasa reserve. A large carrying capacity was chosen so that it was not necessary to deal in fractions of buffalo. For the stochastic model constructed in chapter 4 the correct carrying capacity of the reserve is used.

Further Constraints

A further constraint is added to the model which is specific to buffalo. For buffalo older than one year it is relatively easy to distinguish between male and female animals in the field. However, the sex of calves is more difficult to determine. When culling calves it will not be possible to be certain of the sex of the buffalo being culled. Since, it is vital to know the sex when culling in order for the model to predict the effects of the culling, it is prudent to add a constraint that prevents the culling of calves. In other words:

$$\begin{aligned} hm_{0,t} &= 0 \\ hf_{0,t} &= 0 \end{aligned} \qquad \textbf{(20)}$$

Chapter 3: Model Results

In Chapter 2 four models, A- D, were described. Each model had a different objective function. Using a spreadsheet programme with an optimizer the optimal equilibrium population for each model can be found by maximising the objective function of the model. The results of these models will be presented in this chapter.

Once the optimal population structures are found for the models, those models that are of most relevance to the Makasa Reserve will be selected. Sensitivity analysis will be conducted on the values of some of the parameters to see how the results of the selected models could change if the parameter values are incorrect.

a) Results

i) Model A: Maximise Male Trophies

The population structure that will maximise the number of male trophies that can be hunted is shown in Figure 3 on page 32. This population structure results in an offtake of 310 trophy males per year or just less than 4% of the total population. The total earnings of the model is R6,620,000. As can be seen in the graph the population structure is skewed towards males from age class 1 onwards, when the 293 female yearlings are culled (see Figure 4 on page 32). The females that are removed are not needed for reproduction. For every female member of the herd there are approximately 2.4 male members of the herd. A large number of the female buffalo in the herd are calves, and if calves are excluded from the calculation there are 2.8 males for every female in the herd. Bulls are considered to be of trophy quality if they are in age classes 15 to 19. However, for this model, hunting of bulls only occurs at age class 15, at which stage all members of the age class are hunted. None of the bulls are allowed to survive to an older age class, since in order to maximise offtake, the model advocates hunting bulls at the youngest age at which they are of trophy quality.

The age structure shown in Figure 3 on page 32 illustrates the trade-off that is occurring between the need for female buffalo to be present in the herd in order for male calves to be born and the need to minimize the number of female buffalo in the population so as much carrying capacity as possible is available for the male buffalo.

An interesting feature of the age structure of this model is that female buffalo are only culled when they are yearlings. Those female yearlings that survive the culling are allowed to live until they die of natural causes.

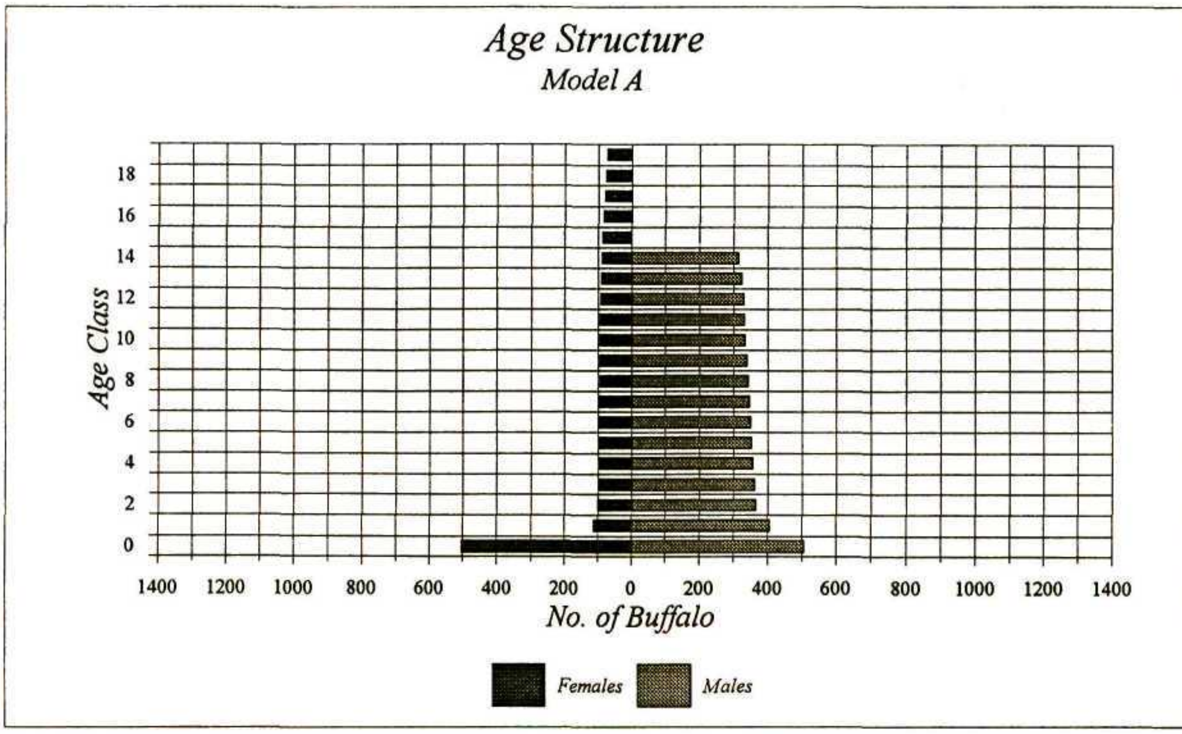

Figure 3: Graph showing the optimal age structure for maximising the offtake of male trophies

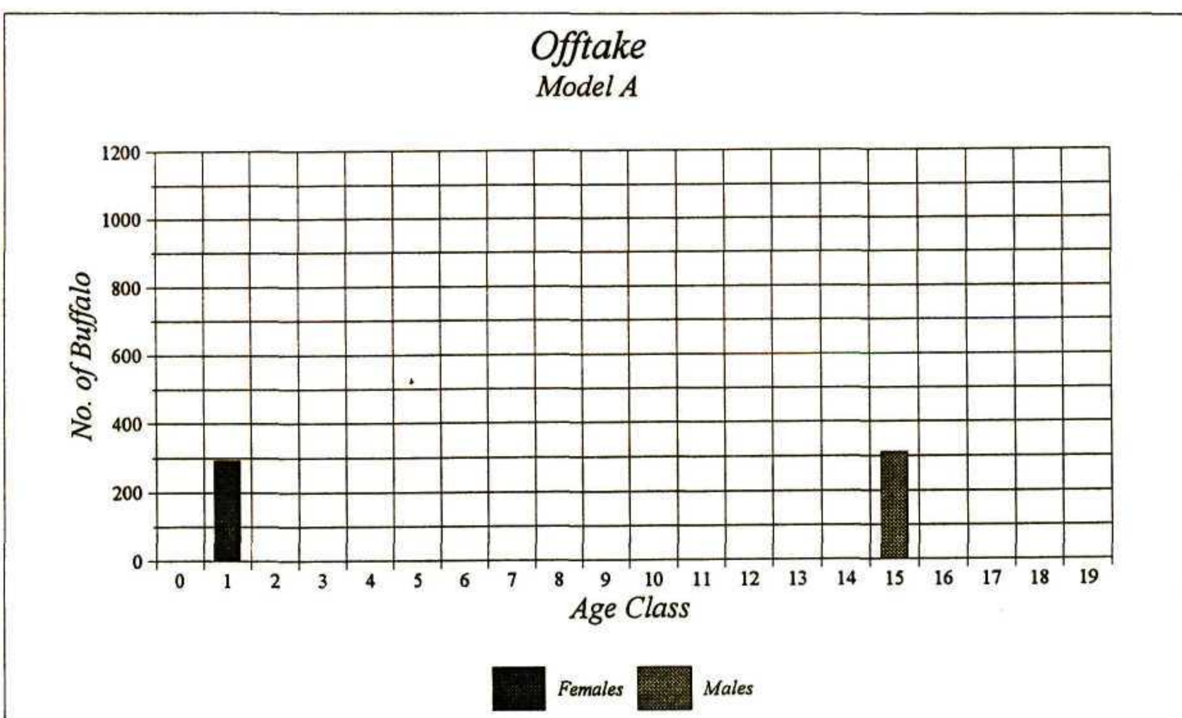

Figure 4: Graph showing the offtake of buffalo from an age structure that maximises the offtake of male trophies

ii) Model B: Maximise Female Meat Trophies

The population structure that maximises the number of female buffalo available for meat hunts is shown in Figure 5 on page 34. This population structure results in an offtake of 890 female buffalo who have reached the age of 8 or older. This is an offtake of just under 9% of the population. The total earnings per year of this age-structure would be R5,340,000. This model skews the buffalo population towards female buffalo, the sex ratio of the population is 1 male to 2.8 females. The majority of males in the herd are calves, and if calves are excluded the sex ratio of the population is one male to 8.6 females. The population is skewed in favour of females by culling 1001 male yearlings (see Figure 6 on page 34) reducing the number of male yearlings present in the population to 50. The remaining male buffalo are allowed to die of natural causes. The female buffalo are not subjected to any culling or hunting until they reach age 8, when they are of sufficient size to be included in meat hunts. In order to maximise the offtake of female trophies the vast majority of females in age class 8 are hunted, with only a few being allowed to survive until they reach age class 9, at which stage all the remaining cows are hunted.

The age structure shown in Figure 5 on page 34 illustrates the trade-off that is occurring between the need to have as many female buffalo as possible in order to maximise the number of female trophies and the need to have male buffalo present in the herd in order to fulfill the constraints of the model. The two constraints that require the presence of male buffalo in the herd are:

- ✖ The constraint that prevents the culling of calves, this means that male calves cannot be culled until they have become yearlings.
- ✖ The constraint that requires that for each sexually active female buffalo in the herd there is a minimum number of sexually active male buffalo in the herd.

If these two constraints where not present in the model, all male calves would be culled, leaving no male members of the herd and freeing up the carrying capacity that they use for more female buffalo. Obviously a buffalo population without bulls is not viable, and this illustrates the importance of the constraint that requires a minimum number of sexually active bulls.

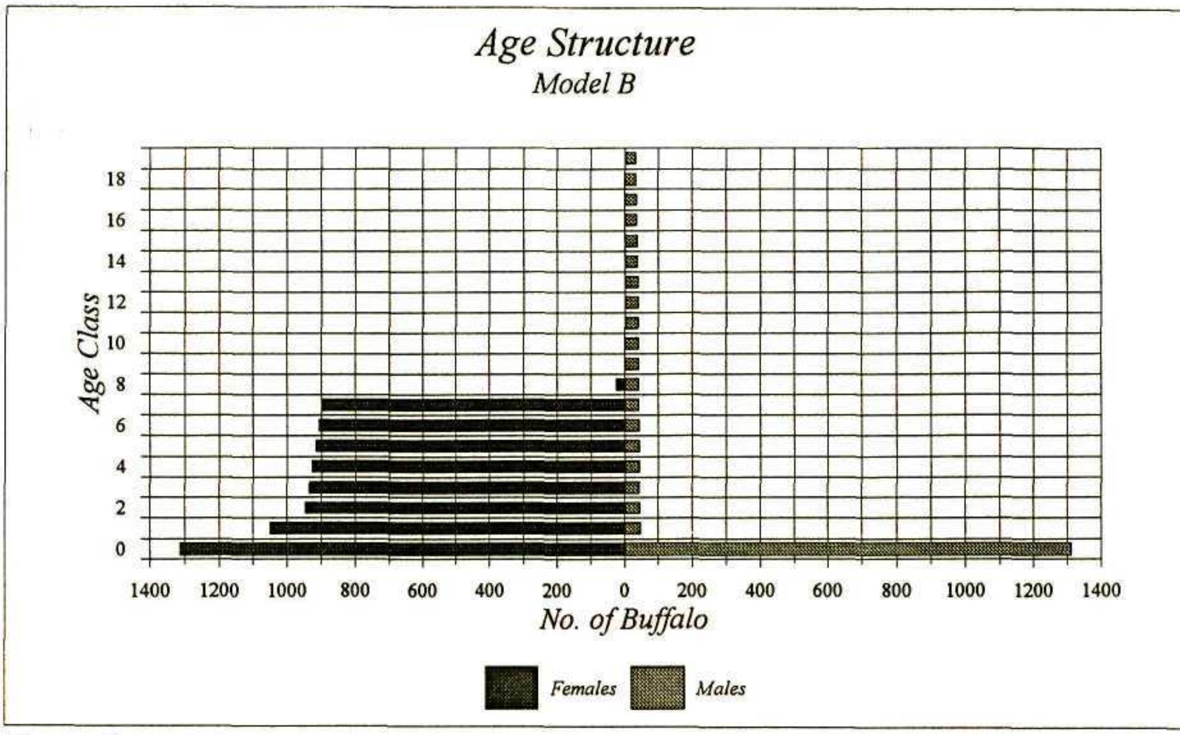

Figure 5: Graph showing the optimal age structure for maximising the offtake of female trophies

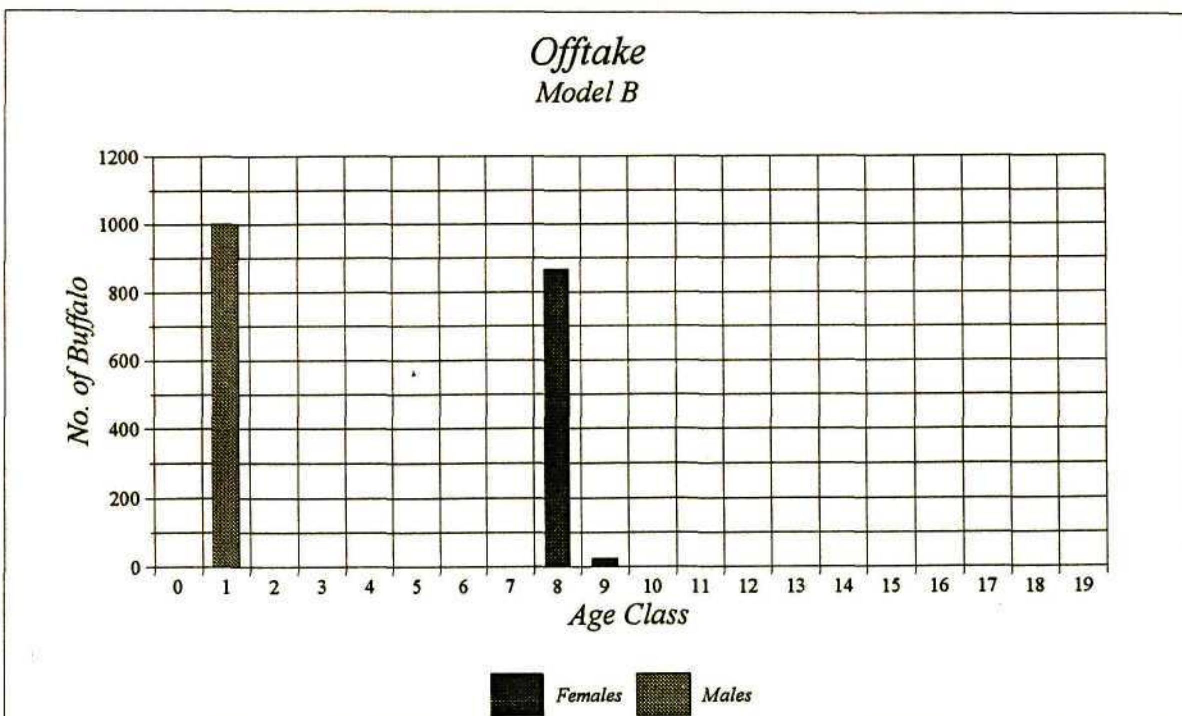

Figure 6: Graph showing the offtake of buffalo from an age structure that maximises the offtake of female trophies

iii) Model C: Maximise Meat Offtake

The structure of the buffalo herd that will maximise the amount of meat that can be hunted is shown in Figure 7 on page 36. In total this structure results in an offtake of 383,342 kg of meat which is worth R2,108,381. This structure is similar to the structure of a buffalo herd that maximises female meat hunts, in the sense that it is also skewed in favour of females. The population is skewed in favour of cows by culling 858 bulls in age class 3 (see Figure 8 on page 36), this is the majority of the bulls in the age class. The culling of the male buffalo is delayed to take advantage of the increased weight of three year old males which is double the weight of male yearlings. After age class 3 the weight of male buffalo still increases, but keeping these bulls in the herd for any longer would require more carrying capacity. To optimise the use of carrying capacity the bulls are culled a long time before they reach their peak weight. Since male buffalo are only culled when they reach age class 3 there are only 1.7 female buffalo present in the herd for every male buffalo. Female Buffalo in two age classes are culled, firstly 356 yearlings are culled and then 542 cows in age class 10 are culled. At age class 10, female buffalo have reached their peak weight and from age class 11 onwards the weight of a female buffalo begins to decline. Since female buffalo are needed in the herd for reproduction, the age at which they are culled can be delayed until they reach their peak weight.

Three year old males are not considered to be sexually active so it is still necessary to maintain a presence of males in the herd up until age 19. At age class 19 the males are culled in order to further increase the amount of meat that is produced per year.

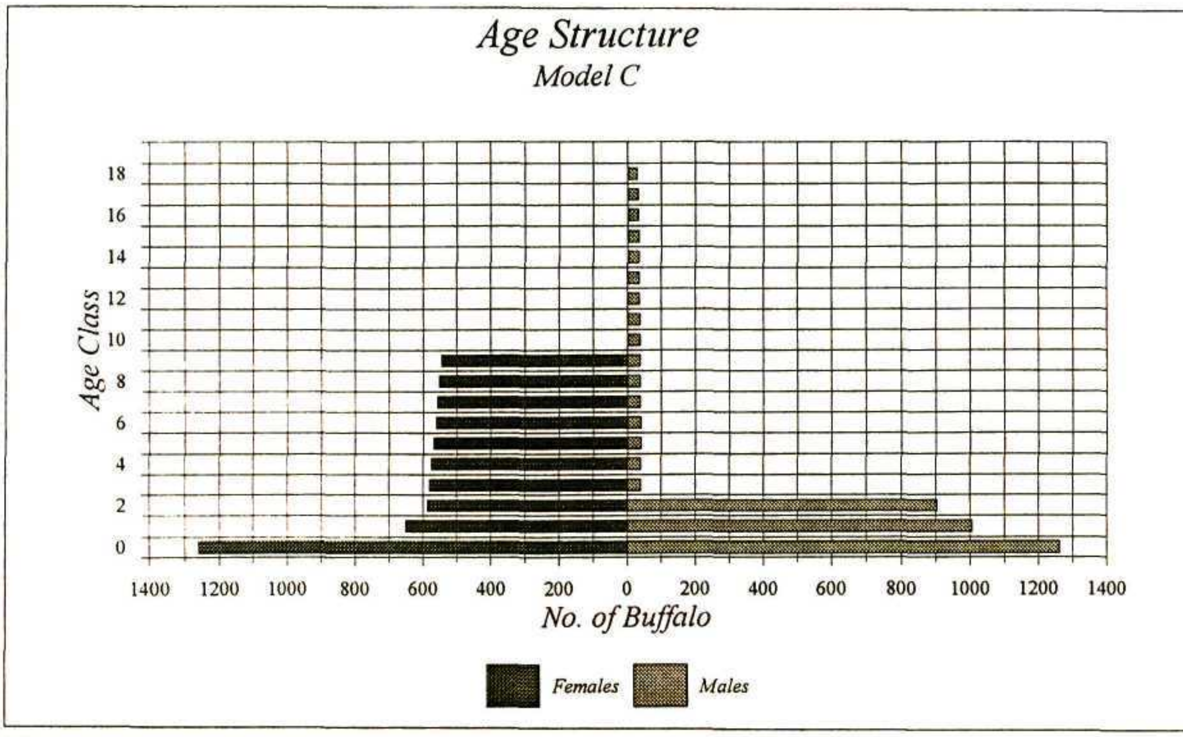

Figure 7: Graph showing the optimal age structure for maximising the offtake of meat

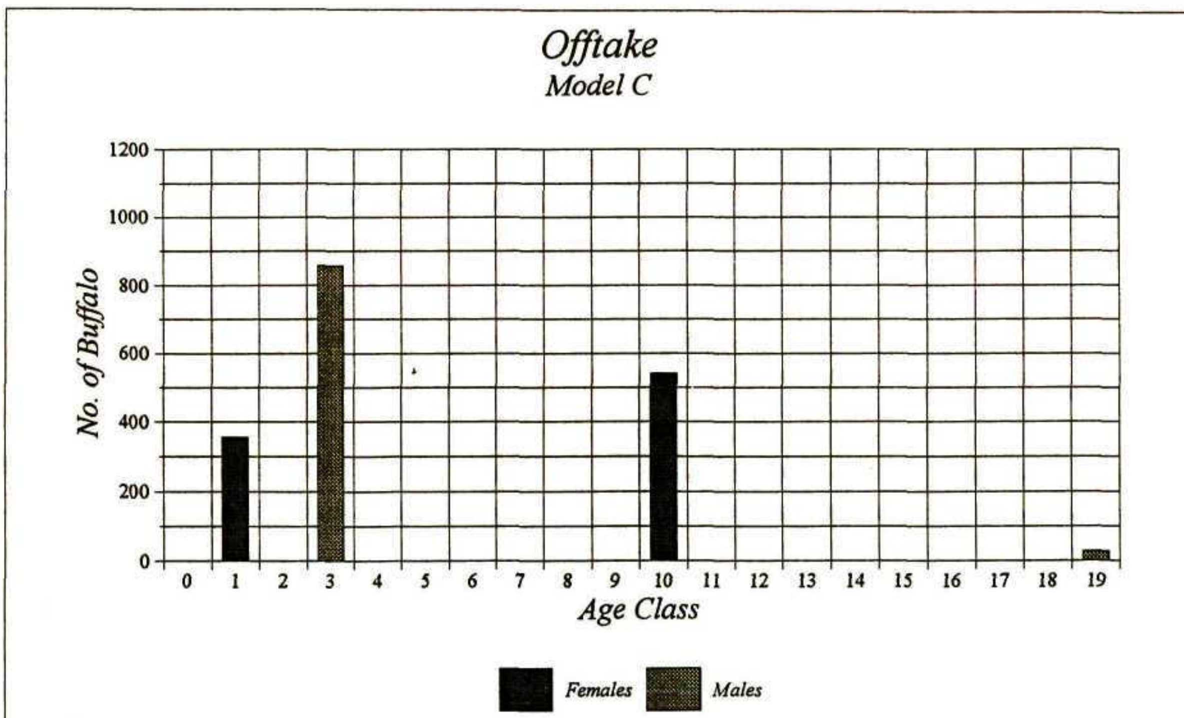

Figure 8: Graph showing the offtake of buffalo from an age structure that maximises the offtake of meat

iv) Model D: Maximising revenue

The population structure that will maximise the amount of money earned from hunting male trophies, female trophies and culling for meat is shown in Figure 9 on page 38. This structure results in an offtake of 289 male trophy buffalo (about 3.5% of the population), 320 female meat trophies (just under 4% of the population) and 90,810 kg of meat (this is the meat that the reserve gets from the male trophies that are hunted). For a graph of the offtake see Figure 10 on page 38. The total amount of money earned from these products is R8,199,543. This model skews the sex ratio of the herd towards males. For every female buffalo in the herd there are approximately 1.8 male buffalo.

An interesting feature of this population structure is the fact that until the 8th age class the ratio between male and female buffalo is even, and no offtake of either males or females occurs before this age class. Once the 8th age class is reached the females are large enough to be hunted and the majority of them are hunted at this stage, a very small minority are allowed to survive to the 9th age class, at which stage they are also hunted. The few females that are allowed to survive past age class 8 are obviously kept on in order to increase the number of calves that are born. All the male buffalo are hunted when they reach age class 15, which is the youngest age class whose members are of trophy quality.

Since this age structure is maximising revenue, it is in effect trying to meet multiple goals at the same time. The goal preference of the model is determined by the relative rand value of the different products. From Figure 10 on page 38 it can be seen that no culling takes place simply for the sake of producing meat, this means that the value of meat in relation to the value of male and female trophies is so low that it is not worth culling an animal for its meat. All the meat that is produced is the meat that the reserve keeps from the male trophies that are hunted (the meat of female trophies is kept by the hunter). Figure 11 on page 39 is a graph showing the contribution each of the three products (meat, male trophies, female trophies) makes to the total revenue. From this it can be seen that male trophies make the major contribution to revenue.

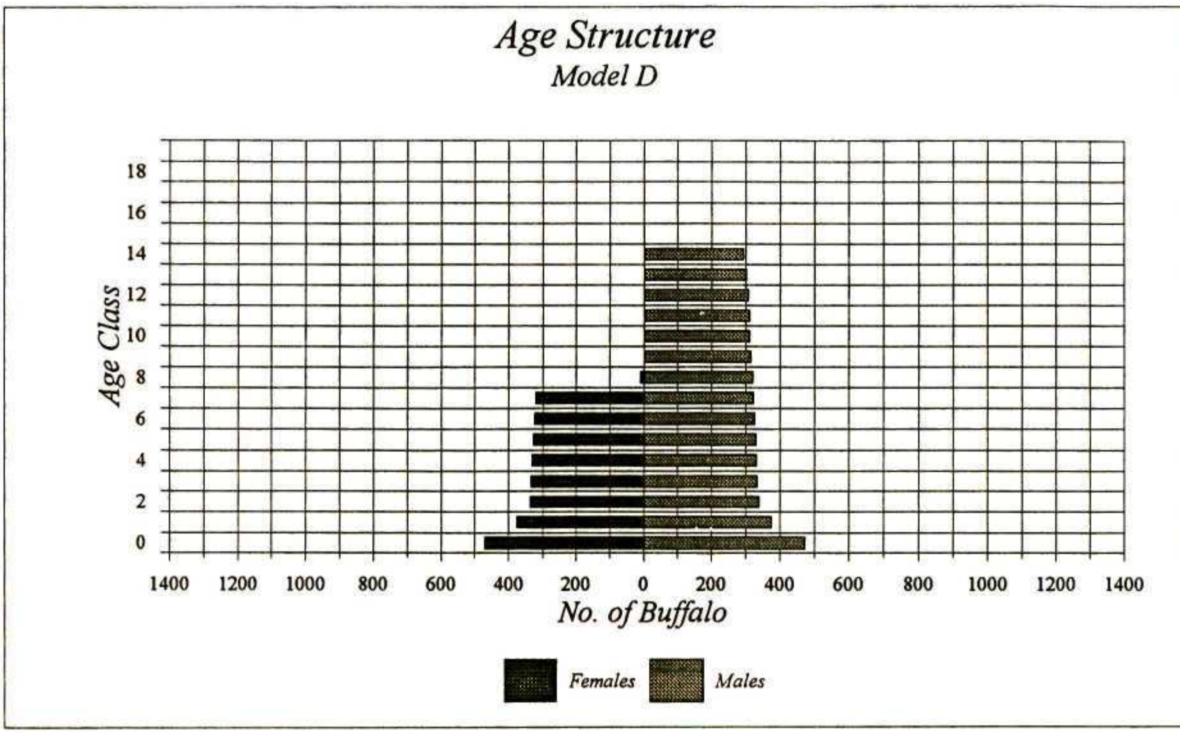

Figure 9: Graph showing the optimal age structure for maximising the revenue of the reserve

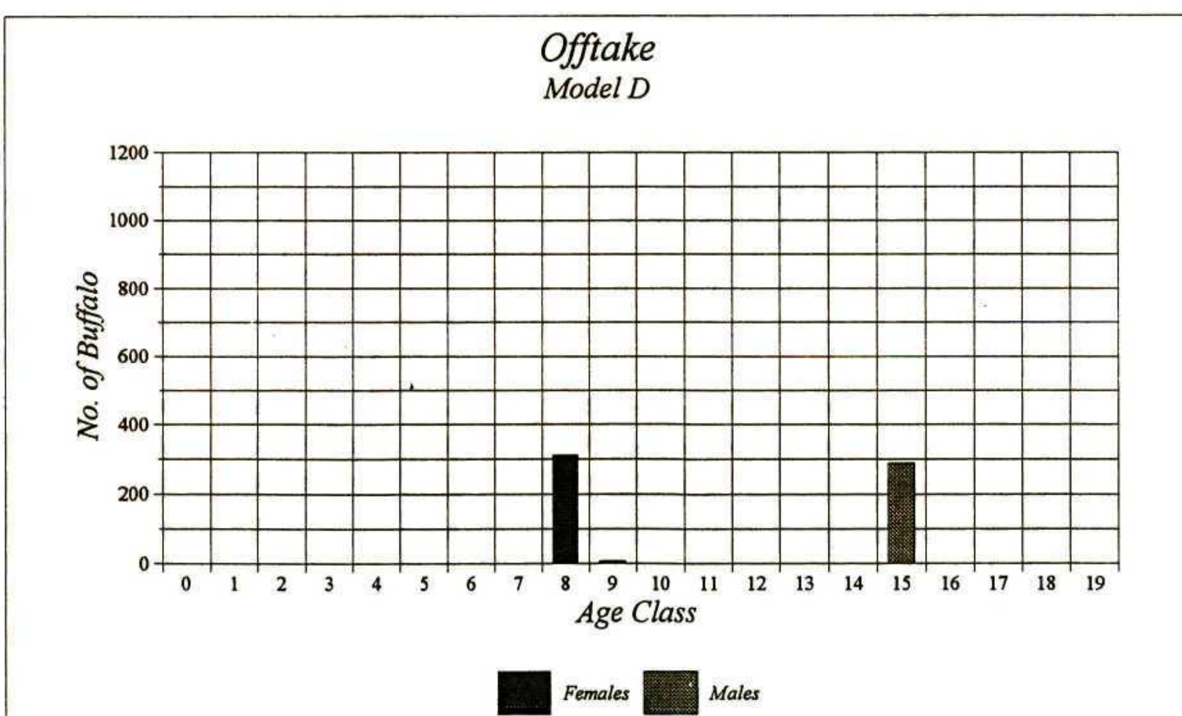

Figure 10: Graph showing the offtake of buffalo from an age structure that maximises the revenue of the reserve

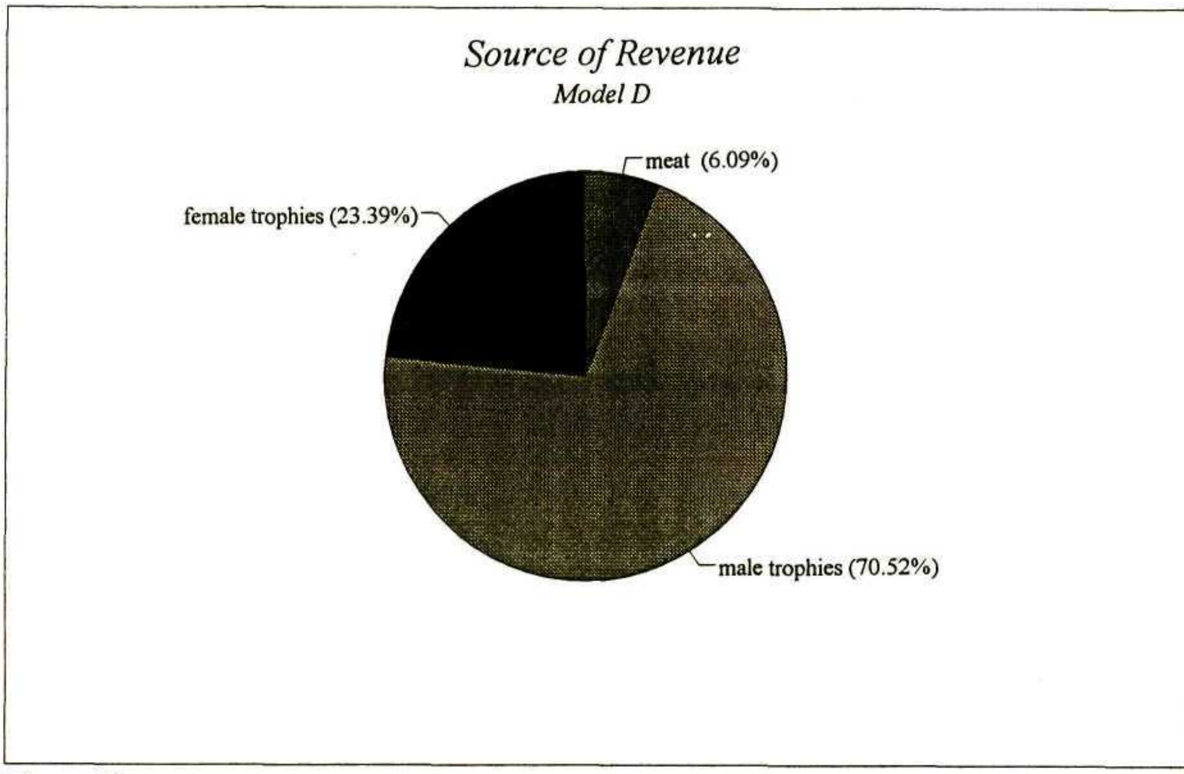

Figure 11: Graph showing the contribution of male trophies, female trophies and meat to the revenue of the reserve

v) Discussion of Results

From the results of Models A-D, it can be seen that there are two broad strategies that are followed when managing the age structure of an animal population. Firstly, the population can be skewed in favour of female animals, this strategy is illustrated in Model B which maximises the number of female trophies and Model C which maximises the amount of meat produced. Skewing an animal population in favour of females is expected to increase the production of meat and both Sylven (1994) and van Rooyen (1994) found this to be true for moose and impala populations respectively.

The second broad strategy skews the population towards male members of the herd, this strategy was used in Model A which maximises the number of male trophies and Model D which maximises the total revenue. Sylven (1994) also tested strategies to maximise the number of trophy moose that can be shot. Unfortunately she did not test the effect of a sex ratio of less than one female to one male, however, she did find that a moose population with an equal sex ratio would produce more trophy males than a moose population with a ratio of two females to one male. It should be noted that of all the models, D is the only one that could have used either strategy depending on the parameters used in the model. For example, if female trophies had a higher rand value than male trophies, Model D would rather use the strategy of biasing the population in favour of females.

Table 5

Table comparing the results of Models A, B, C and D

	Model A	*Model B*	*Model C*	*Model D*
Offtake of Male Trophies per 1,000kg of CC	0.0861	-	-	0.0803
Male Trophy offtake expressed as % of Model A Male Trophy offtake	100%	-	-	93%
Offtake of Female Trophies per 1,000kg of CC	-	0.2472	-	0.0889
Female Trophy offtake expressed as % of Model B Female Trophy offtake	-	100%	-	36%
Offtake of Meat per 1,000kg of CC	-	-	106.48kg	25.23kg
Meat offtake expressed as % of Model C Meat offtake	-	-	100%	24%
Revenue per 1,000 kg of CC	R1,838.89	R1,483.34	R585.66	R2,277.65
Revenue expressed as % of Model D Revenue	81%	65%	26%	100%
Ratio of Males to Females	2.4 : 1	1 : 3.8	1 : 1.7	1.8 : 1

While models B and C both have populations with a higher proportion of buffalo cows, the age-structures of the two model's are still fairly different. The age-structure of Model B, simply minimises the number of bulls in the herd, since the model is attempting to maximise female trophies and attaches no value to male buffalo. The age-structure of Model C, however is slightly more complex since it is maximising the amount of meat that can be produced by the herd. Since either males or females can be culled for meat, both sexes have a value in this model. However, female buffalo are more valuable, since the number of female buffalo will dictate the number of calves born and therefore the number of buffalo in the herd. As a result Model C is still biased towards female buffalo, however a much larger number of male buffalo are present in the herd than the herd of model B. This is illustrated by the ratio 1 male to 3.8 females in Model B as opposed to 1 male to 1.7 females in Model C (See Table 5 on page 40).

Similarly, Models A and D do not have the same age-structure even though they share the same broad strategy of biasing the population towards male buffalo. Model A is only maximising male trophies so it has no use for female buffalo. But, since, female buffalo need to be present for reproduction they need to be incorporated in the population structure. Model D, on the other hand, is maximising the revenue that can be generated from male trophy hunts, female trophy hunts and meat production. Since male trophies are the most lucrative, the model is essentially attempting to maximise male trophies. However, since females must be present in the herd it is also possible to produce a number of female trophies at the same time as producing male trophies. When comparing the results of Models A and D in Table 5 on page 40 it can be seen that Model D makes a very small sacrifice in the offtake of male trophies in order to have an offtake of 0.0889 female trophies per 1,000 kg of Carrying Capacity.

Comparing the offtake of male trophies for Model A and the offtake of female trophies for Model B in Table 5 on page 40 it is apparent that it is possible to take off a much larger number of female trophies than male trophies. This can be attributed to three factors:

- ✖ Firstly male trophies must have a minimum age of 15, while female trophies have a minimum age of 8. This means that for the population to produce the same offtake of male and female trophies, a much larger number of males are needed in the population than females.
- ✖ Secondly, on average male buffalo weigh more than female buffalo. This means that the average male buffalo eats more than a female buffalo. As a result the same carrying capacity can support fewer male buffalo than female buffalo.
- ✖ Thirdly, fewer males are needed for reproduction than females. This is reflected in the sex ratio of Models A and B. For Model A the ratio of males to females is 2.4 : 1, whereas for Model B it is 1 : 3.8.

The amount of money that is earned per 1,000kg of carrying capacity by the four models is shown in Table 5 on page 40. Obviously model D which maximises the amount of revenue will earn the most money. Model A, is the next highest earner of the 4 models, followed by Model B. Model C is the lowest earner by far of the 4 models.

b) Sensitivity Analysis

For the rest of this chapter some sensitivity analysis will be conducted on Models A and D. These two models are of the most interest since they result in the highest returns to the reserve. While the value of male and female trophies are likely to change with time, it should always be the case that male trophies are worth substantially more than female trophies. Furthermore, while there is a demand for female trophies in the long term the demand for male trophies is more secure.

Those parameters of Models A and D that are most likely to change or that could be incorrect are examined in depth in this section to see what effect these parameters might have on the two models (See Table 6 on page 42 for a list of these parameters).

Table 6

List of parameters that will be adjusted for the sensitivity analysis conducted on Models A and D

Name	*Description*	*Value*
mp	Meat Price	5.5
mtp	Male Trophy Price	20000
ftp	Female Meat Hunt Price	6000
mta	Minimum Age a Male can be hunted as trophy	15
f_i	The number of buffalo born per female buffalo in age class *i*	-
pm_i	Proportion of males of age class *i* that survive	-
pf_i	Proportion of females of age class *i* that survive	-

i) Meat Price (*mp*)

The price of Buffalo meat may increase slightly over time with inflation, however it is always likely to remain low in comparison to male and female trophy prices. The amount of money that can be made from one buffalo sold for meat varies between R422 for a calf to R1,916 for a male buffalo at peak weight. It is unlikely that the meat price will increase substantially in relation to the trophy prices. However, at Makasa a choice could be made to sell the buffalo meat to the Makasa community at a reduced price or to distribute the meat among the community for free.

The value of the parameter *mp* has no effect on Model A, as this model does not use this parameter. Model D, however, does use *mp* and could be effected by a change to the value of *mp*. In order to test the impact of a reduction of *mp* on model D, *mp* was set to zero. This resulted in no change to the age structure of the herd, or the offtake of buffalo. This implies that at its previous value of R5.50 *mp* was so low in comparison to the trophy prices of male and female buffalo it had no impact on the structure of the population. The reduction in *mp*, has one effect on Model D and that is to reduce the revenue that can be earned. However, the revenue earned from the sale of meat at R5.50 a kg only makes up a little over 6% of the total revenue earned (see Figure 11 on page 39). A reduction in *mp* will therefore not result in a major reduction to the revenue earned.

ii) Change in value of Male Trophy Price (*mtp*) in relation to Female Trophy Price (*ftp*)

In 1996 the price of male and female trophies was not fixed and a male trophy could be sold for between R20,000 and R23,000 and a female trophy could be sold for between R6,000 and R8,000 (Davies, 1996). The price of male trophies has changed a great deal over the past few years, for example in 1992 some male buffalo trophies were being sold for as little as R4,000 (Neethling, 1996). As a result of the fluid nature of buffalo trophy prices, it is useful to determine what impact the change in the value of *mtp/ftp* could have on the models. Since Model A does not use either *mtp* or *ftp* it is unaffected by any change to these values. Model D, however, does use both *mtp* and *ftp* and so a change in their values could effect Model D. In order to avoid confusion the value of *mp* is set to zero for this section. If *mp* is non-zero it adds an additional value to male trophies, since the meat of these trophies belongs to the reserve. It also places an economic value on any culling that takes place. A non-zero meat price could therefore cloud the effect that any changes to *mtp/ftp* have on Model D.

The effect of changing *mtp/ftp* to any value between 10 and 1 was tested on Model D. The range of 10 to 1 was chosen since from the current value of female and male trophies it seems unlikely that the value of male trophies will ever exceed the value of female trophies by more than 10 times. Furthermore, female trophies should always have a lower value than male trophies, so it is unnecessary to investigate a scenario where the value of a female trophy exceeds the value of a male trophy.

Changing *mtp/ftp* to any value between 10 and 2.39 had no impact on the age-structure of the population and the offtake of trophies for Model D. However, when the value of mtp/ftp fell below 2.39 a major change occurred in both the age structure of the population (see Figure 12 on page 45) and the offtake (see Figure 13 on page 45). Comparing the age structures shown in Figure 9 on page 38 and Figure 12 on page 45 it can be seen that Model D moves from having a sex ratio biased in favour of males when the value of *mtp/ftp* is greater than 2.39 to having a sex ratio biased in favour of females when the value of *mtp/ftp* falls below 2.39. It is obvious that when the price of a male trophy falls below 2.39 times the price of a female trophy, it is more profitable to maximise female trophies than male trophies.

The value of *mtp/ftp* is 3.33 when *mtp* and *ftp* are set to their original values of R20,000 and R6,000 respectively. If *mtp* was to remain static and *ftp* increased to above R8,368 the value of *mtp/ftp* would fall below 2.39 making is more profitable to maximise female trophies. The maximum price that a female buffalo could be sold for in 1996 was R8,000 (Davies, *pers. comm.*) which is not far from R8,368 and a small increase in the female trophy price coupled with a small decrease in the male trophy price could lead to a situation where maximising the number of female trophies is more profitable.

It is important to note at this point, that while maximising female trophies might theoretically be more profitable than maximising male trophies, in reality those female trophies will need to be sold and it is questionable whether there is the same level of demand for female trophies as male trophies.

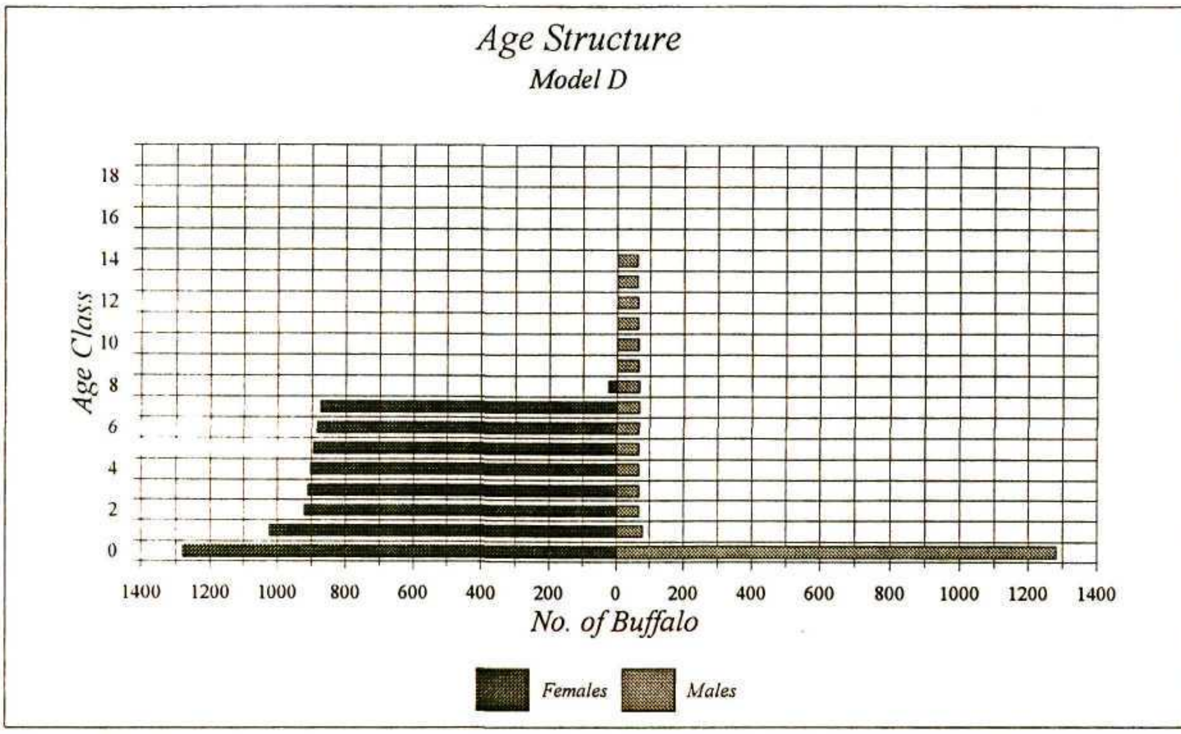

Figure 12: Graph showing the optimal age structure for maximising revenue when the value of *mtp/ftp* is between 2.39 and 1

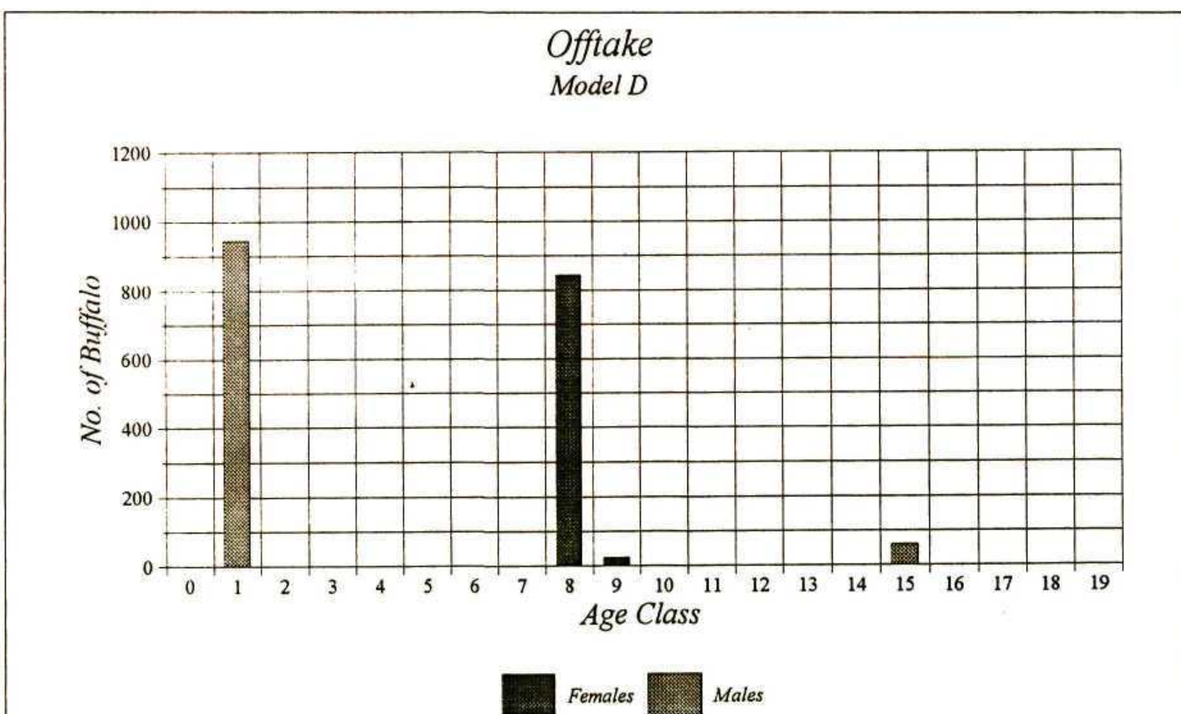

Figure 13: Graph showing the offtake of buffalo from an age strucuture that maximises revenue when the value of *mtp/ftp* is between 2.39 and 1

iii) Minimum Male Trophy Age (*mta*)

As has been discussed in Chapter 2, the minimum age at which a male buffalo can be considered to be a trophy buffalo is not very clear. The age 15 was selected in Chapter 2 as the minimum trophy age. However, there is very little scientific data to back up the selection of age 15 and conflicting information was received from various sources. It is important to get a picture of the type of impact a change in *mta* will have on Models A and D.

Model A

From Figure 14 on page 49 it can be seen that a change in *mta* has a major impact on the offtake of male trophies. When *mta* is set to 5 the offtake of male trophies is at its highest, which is 151% higher than the male trophy offtake when *mta* is 15. As the value of *mta* increases so the offtake of male trophies decreases. When *mta* is at the highest possible value of 19, the offtake of male trophies is the lowest, 28% lower than the male trophy offtake when *mta* is 15. If the value of *mta* changes from 15 to 14 the trophy offtake increases by 8%.

The reduction in offtake as the value of *mta* increases is a result of two factors:

- ✖ As the age of a buffalo increases, its chances of survival decrease. This is illustrated in Table 7 on page 48 which shows the value of l_i for each age class i. l_i is the proportion of buffalo born that will survive to age class i and is calculated by the equation:

$$l_i = \prod_{j=0}^{i-1} p_j \tag{21}$$

  For this model the value of l_i is the same for males and females since the survival values (p_i) for males and females are the same. As the age class increases so the proportion of buffalo that survive to that age class decreases. This means that the number of calves, c_i, that need to be born in order for 1 buffalo to survive to age class i increases as i increases. The value of c_i for each age class is shown in Table 7 on page 48. c_i is calculated using the following equation:

$$c_i = \frac{1}{l_i} \tag{22}$$

✖ In order for a buffalo to reach age class i, buffalo need to be present in the herd from age class 0 to i - 1. Thus, as the value of i increases so the number of buffalo that are present in the herd increases.

As a result of these two factors the carrying capacity cost of one trophy buffalo of age class i increases as i increases. The carrying capacity cost is different for males and females since they have different weights. The carrying capacity cost for males is referred to as $mcost_i$ and for females as $fcost_i$. The values of $mcost_i$ and $fcost_i$ are shown in Table 7 on page 48 and are calculated as follows:

$$\begin{aligned} mcost_i &= c_i * \sum_{j=0}^{i-1} (c_j * mm_j) \\ fcost_i &= c_i * \sum_{j=0}^{i-1} (c_j * mf_j) \end{aligned} \tag{23}$$

Since $cost_i$ for males and females increases as i increases, fewer trophies can be created with the same amount of carrying capacity. As a result, as *mta* increases the offtake of trophies decreases.

Table 7

Table showing the values of l_i, c_i, mm_i, mf_i, $mcost_i$ and $fcost_i$ for age classes 0 to 19

Age Class (i)	Proportion of buffalo that survive to age class i (l_i)	No. of Calves required for 1 buffalo to reach age class i (c_i)	Buffalo weight		Carrying Capacity investment required for 1 trophy in age class i	
			Males (mm_i)	Females (mf_i)	Males ($mcost_i$)	Females ($fcost_i$)
0	1	1	152	161	-	-
1	0.8	1.25	243	252	190	201
2	0.72	1.39	330	331	481	504
3	0.7128	1.4	406	396	819	843
4	0.7057	1.42	469	446	1238	1252
5	0.6986	1.43	520	483	1724	1715
6	0.6916	1.45	560	510	2267	2220
7	0.6847	1.46	591	529	2855	2758
8	0.6779	1.48	615	543	3481	3319
9	0.6711	1.49	633	553	4137	3902
10	0.6644	1.51	690	560	4818	4500
11	0.6577	1.52	690	530	5564	5111
12	0.6512	1.54	673	500	6317	5697
13	0.6381	1.57	656	472	7133	6325
14	0.6254	1.6	639	460	7948	6935
15	0.6129	1.63	622	448	8762	7545
16	0.5945	1.68	605	436	9674	8241
17	0.5766	1.73	600	423	10598	8946
18	0.5536	1.81	600	423	11663	9758
19	0.5259	1.9	600	423	12909	10718

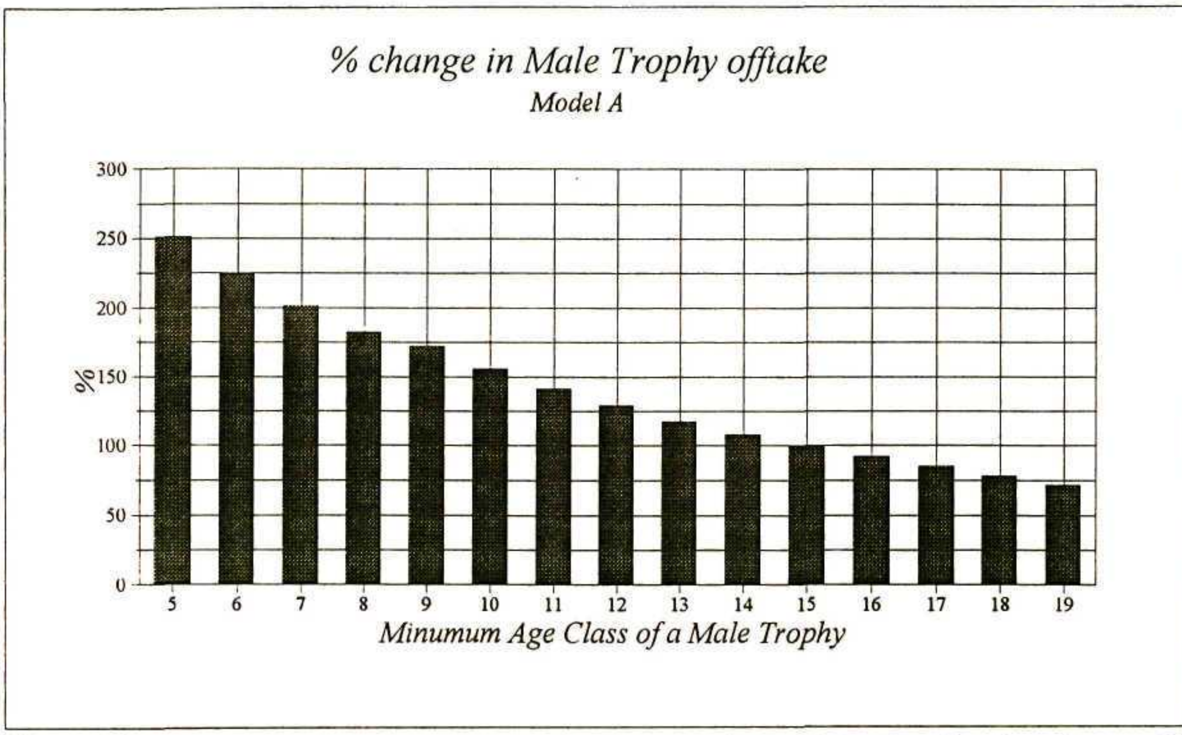

Figure 14: Graph showing the % change in offtake of male trophies for Model A as the value of *mta* changes. The offtake of male trophies is expressed as a % of the offtake of male trophies when *mta* is set to 15.

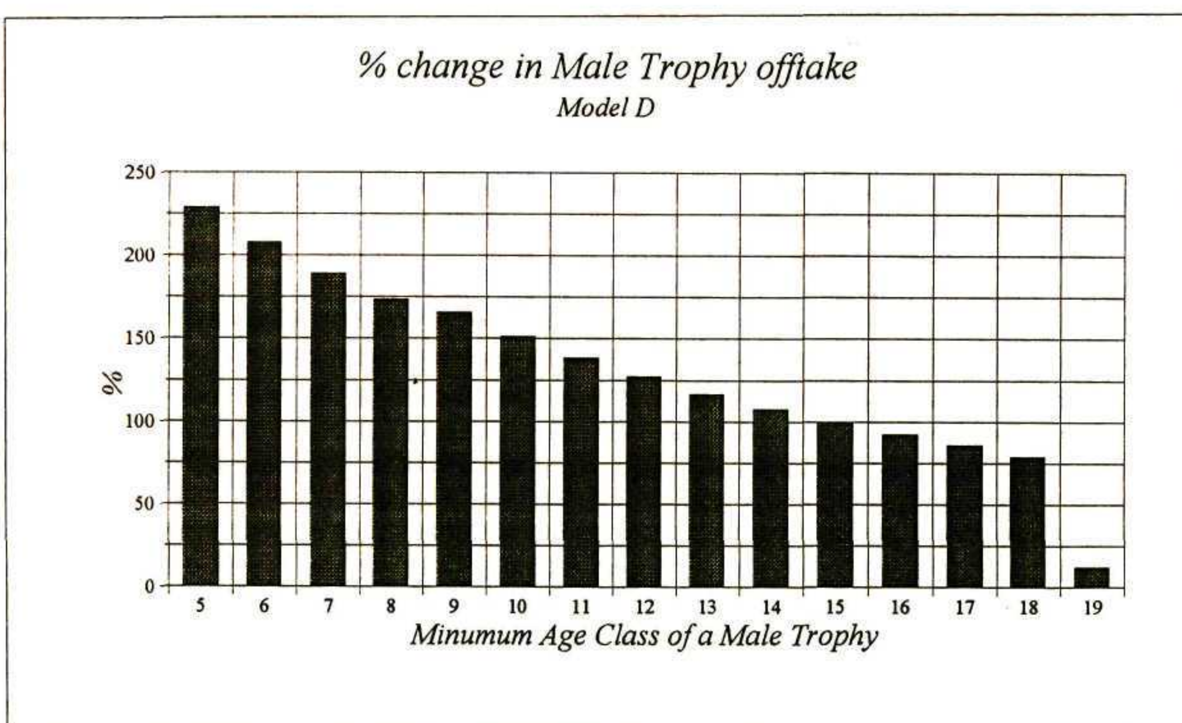

Figure 15: Graph showing the % change in offtake of male trophies for Model D as the value of *mta* changes. The offtake of male trophies is expressed as a % of the offtake of male trophies when the value of *mta* is 15.

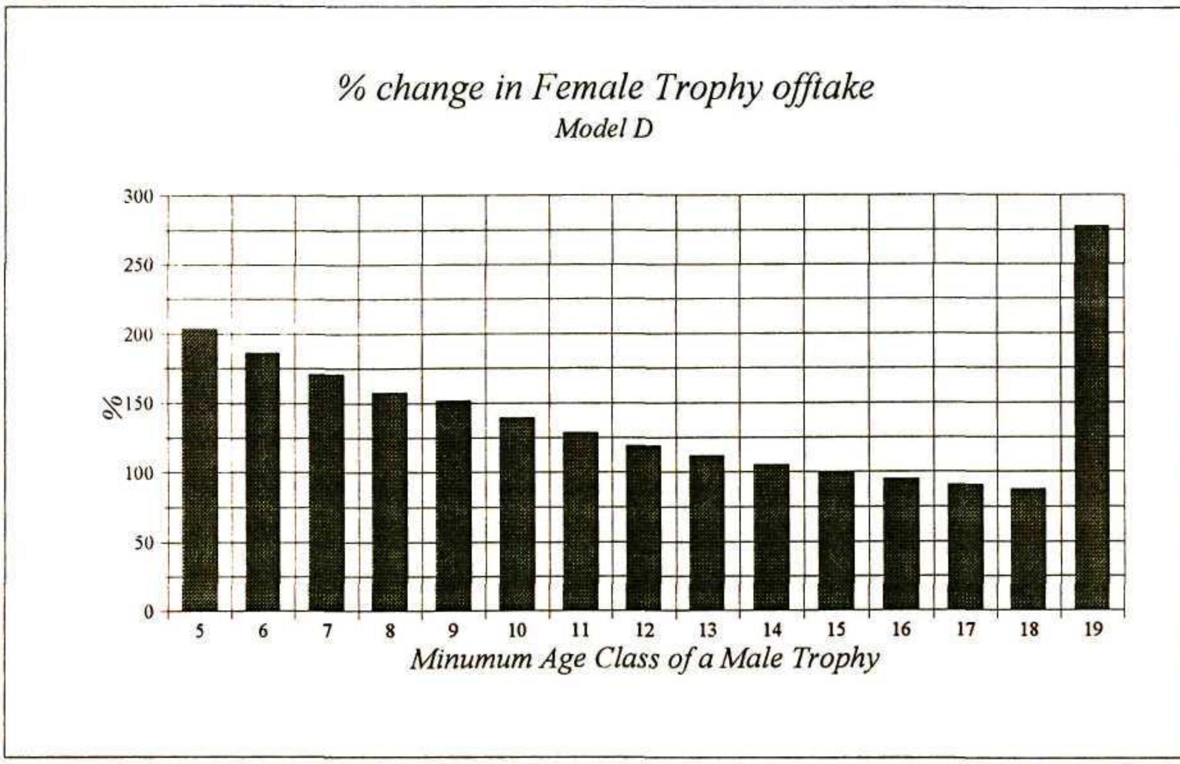

Figure 16: Graph showing the % change in offtake of female trophies for Model D as the value of *mta* changes. The offtake of female trophies is expressed as a % of the offtake of female trophies when *mta* is set to 15.

Model D

For this section the meat price (*mp*) was set to zero. This is to ensure that the results show the impact of a change in *mta* on Model D and are not clouded by the effect of a non-zero *mp*. A non-zero *mp* increases the value of male trophies and attaches a value to culled animals.

Figure 15 on page 49 and Figure 16 on page 50 show the effects that the change in *mta* has on the offtake of male and female trophies for Model D. A change in *mta* has a fairly significant impact on the offtake of male and female trophies. Similar to Model A, the number of male trophies decrease with an increase in the value of *mta*. The number of female trophies also decreases with an increase in the value of *mta*, until *mta* is set to 19. At *mta* equal to 19, the offtake of female trophies increases dramatically. This increase in female trophy offtake, occurs since Model D has moved to a strategy of maximising the offtake of female trophies, instead of maximising the offtake of male trophies. The value of one male trophy at R20,000 is approximately 3.33 times the value of one female trophy at R6,000. Since Model D is maximising female trophies when *mta* is set to 19, it implies that Model D can produce more than 3.33 female trophies for the same carrying capacity investment that is needed to produce one male trophy. This result is not surprising since while the value of *mta* is increasing the value of the minimum trophy age for a female (*fta*) is remaining static. This means that the carrying capacity investment required for one female trophy remains the same at 3,319, while that for one male trophy increases as *mta* increases (see Table 7 on page 48).

At this point it must be noted that the concept of carrying capacity investment discussed earlier is not sufficient to entirely explain the point at which Model D has swapped from a strategy of maximising male trophies to maximising female trophies. If we multiply 3,319 by 3.33, we find that the carrying capacity cost of 3.33 female trophies is 11,052. This is higher than the carrying capacity cost of one male trophy of age class 17 at 10,598, but lower than the carrying capacity cost of one male trophy of age 18 at 11633 (see Table 7 on page 48). If the concept of carrying capacity cost alone is used to try to understand the reason for changing from a strategy of maximising males to females, it would be expected that Model D would begin maximising females when *mta* is 18. This is not the case, so it is clear that some additional factors influence the change of strategy.

Examining the age structure for Model B which maximises female trophies (see Figure 5 on page 34), we see that a large number of male calves are present in the age structure, when these calves become yearlings the majority of them are culled in order to bias the sex ratio of the population to females. Those male calves present in the age structure, are essentially unwanted and take up additional carrying capacity. This means that an additional carrying capacity cost is attached to each fecund female in the age structure, since a fecund female automatically makes an equal contribution to the number of male and female calves in the population. This additional carrying capacity cost, means that the carrying capacity cost of one female trophy is in fact slightly higher that the cost outlined in Table 7 on page 48. This means that Model D changes strategies from maximising male trophy offtake to maximising female trophy offtake is when *mta* is 19 and not 18.

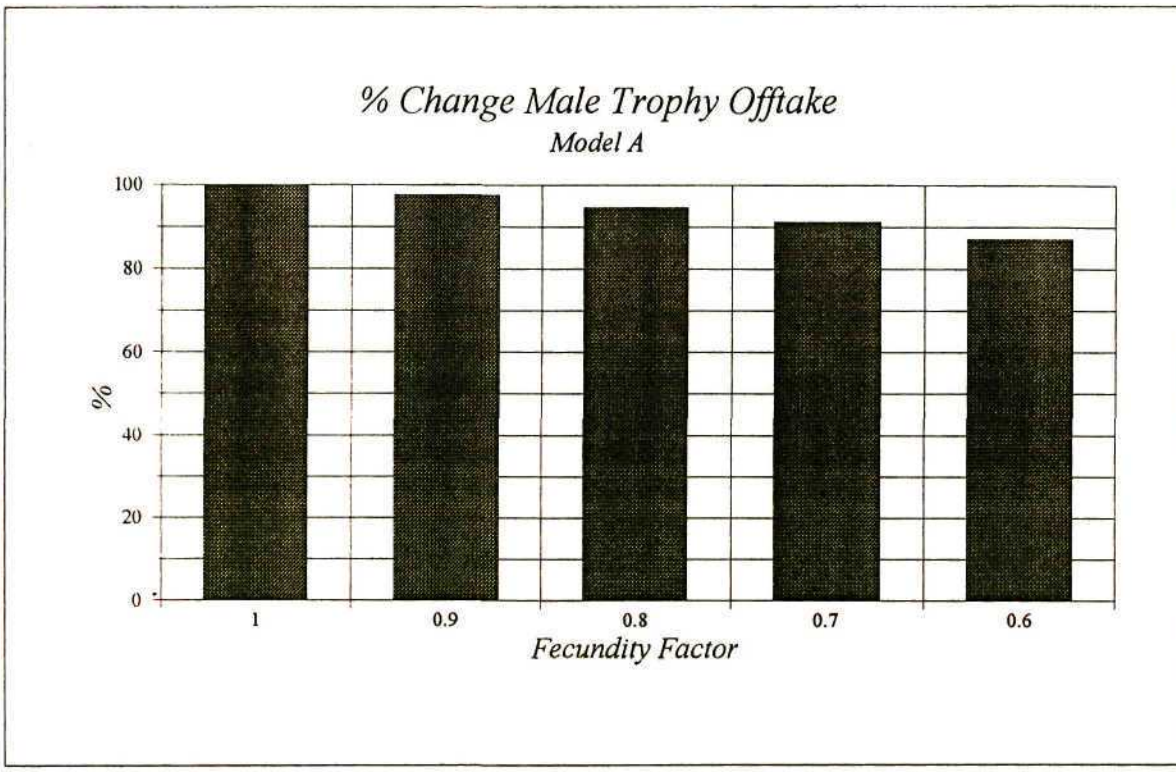

Figure 17: Graph showing the % change in male trophy offtake for Model A as the fecundity drops. A drop in fecundity is simulated by multiplying the fecundities of the buffalo by a fecundity factor. The offtake of male trophies is expressed as a % of the offtake of male trophies when the fecundity factor is 1.

iv) Fecundity (f_i)

The values used for f_i were taken from Sinclair (1977). There are other studies on buffalo fecundity (Carmichael *et al*, 1977 and Grimsdell, 1969) which indicate that values of f_i could be lower than those taken from Sinclair (1977). It seems possible that the values of f_i could decrease by as much as 40%. Therefore it is important to examine the effects that a change in fecundity could have on Models A and D.

Model A

A decrease in fecundity, means that a larger number of females need to be present in the herd in order for the same number of calves to be born. Similarly, an increase in fecundity means that fewer females need to be present for the same number of calves to be born. Figure 17 on page 52 shows the effect that a change in fecundity has on the male trophy offtake of Model A. The values for this graph were calculated by increasing or decreasing the original values of f_i by a fixed proportion. As would be expected, the graph shows that as the level of fecundity decreases, the male trophy offtake decreases. If the values of f_i are decreased by 40%, the offtake of male trophies will drop by 13%. When examining the structure of the buffalo population produced by Model A for various levels of fecundity, it was found that in general the age-structure remained the same as before. However, as the fecundity decreased the percentage of female buffalo in the herd increased.

It is also possible that there is not a uniform increase or decrease in fecundity. Model A was therefore run with two other changes in fecundity.

Firstly, Model A was run for the scenario where the age at which a buffalo first gives birth is delayed by one year. This was achieved by setting f_3 to zero and by setting f_4 to the original value of f_3, f_5 to the original value of f_4 and so on. This did not have a major impact on the model, the age structure remained the same and the male trophy offtake was reduced slightly.

Secondly, Model A was run with the original value of f_i for age classes 0 to 14, but f_i was reduced from its original value of 0.66 to 0.46 for age classes 15 to 19. This is to simulate a situation where there is a higher drop off in fecundity as the age of the buffalo increases. This change in the values of f_i had the effect of changing the age-structure of the buffalo population produced by Model A (see Figure 18 on page 54). The new age structure was achieved by culling fewer female yearlings and therefore allowing more females in age classes 2 to 14. At age class 15, all the female buffalo are culled. This new strategy has been followed by Model A since the fecundity of the older females is so low that it is no longer worthwhile to keep them in the herd. The number of male trophies that can be hunted in this scenario is only marginally lower than the male trophy offtake of the original scenario.

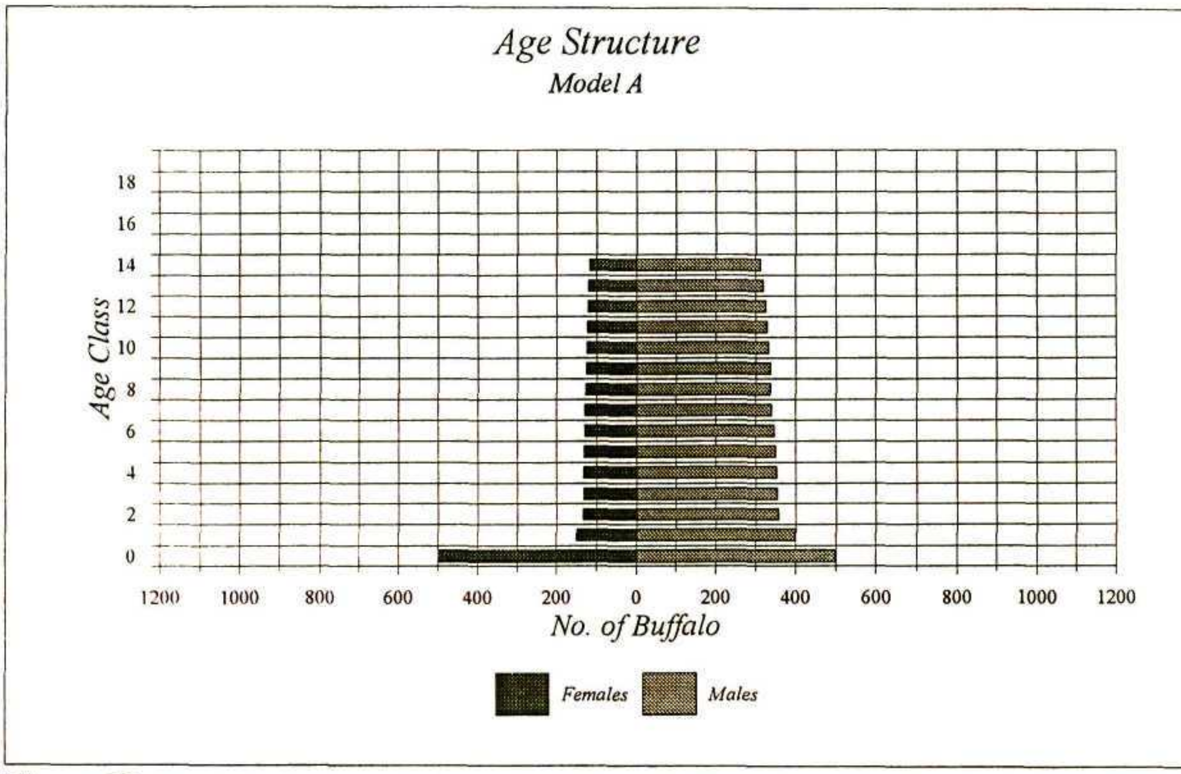

Figure 18: Graph showing the optimal age structure for maximising male trophies when the fecundity of female buffalo from age class 15 to 19 is reduced from 0.66 to 0.46.

Model D

The effect that increasing or decreasing the value of f_i has on the trophy offtake of Model D is shown in Figure 19 on page 55 and Figure 20 on page 56. The effect is very similar to the effect on Model A. As the fecundity drops, so the offtake of both male and female trophies drop. For a drop in the values of f_i by 40% male trophy offtake drops by 10% and female trophy offtake drops by 13%. Furthermore, the number of female buffalo in the herd increases as the fecundity levels drop. The age-structure of the herd remains more-or-less the same except the age at which females are hunted is delayed by one or two years, so that more females can be present in the herd.

Similarly to Model A, two further scenarios were run for Model D. Firstly, the scenario which emulates a one year delay in the age at which a buffalo first gives birth was run for Model D. This had much the same effect as the proportional drop in fecundity. The age-structure remains more-or-less the same, there is a slight decrease in the trophy offtake and the percentage of female buffalo in the population increases.

The second scenario which emulates a drop off in fecundity as the female buffalo reach age 15 had no effect on Model D. This is because there are no females older than age 9 present in the original model. This result is extremely interesting as it illustrates that inaccuracies in fecundity for the older age classes has no impact on Model D.

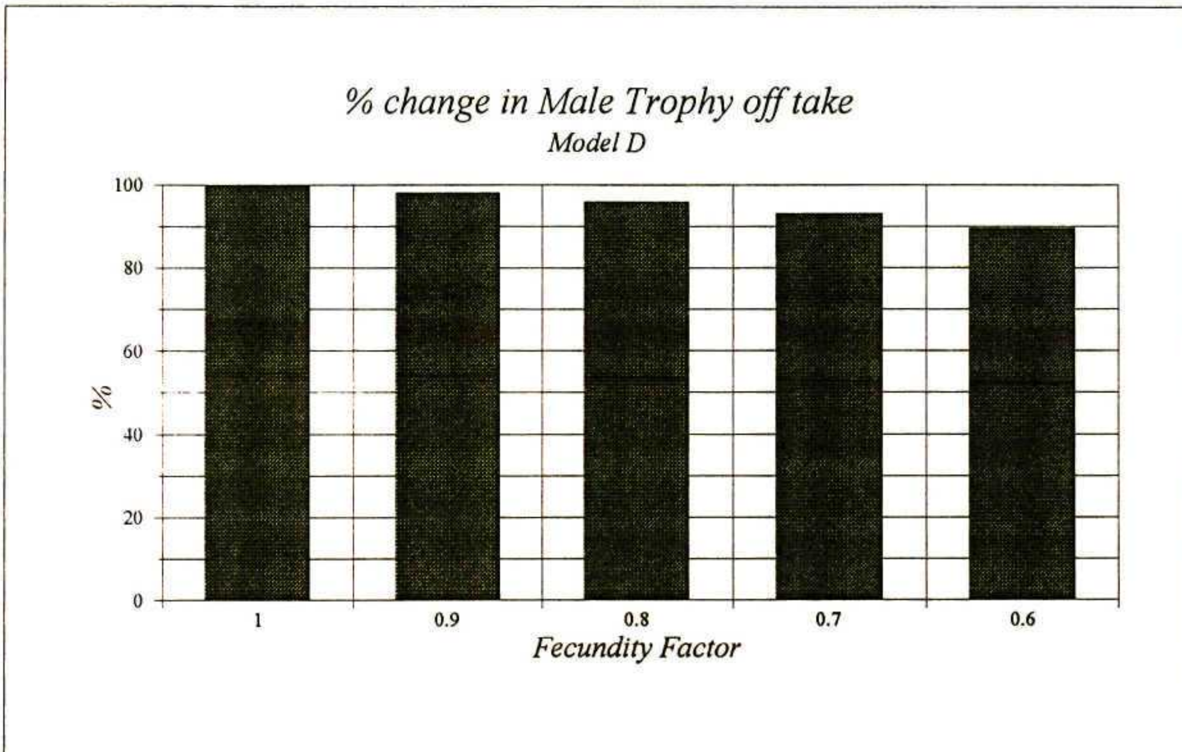

Figure 19: Graph showing the % change in male trophy offtake for Model D as the fecundity drops. A drop in fecundity is simulated by multiplying the fecundities of the buffalo by a fecundity factor. The offtake of male trophies is expressed as a % of the offtake of male trophies when the fecundity factor is 1.

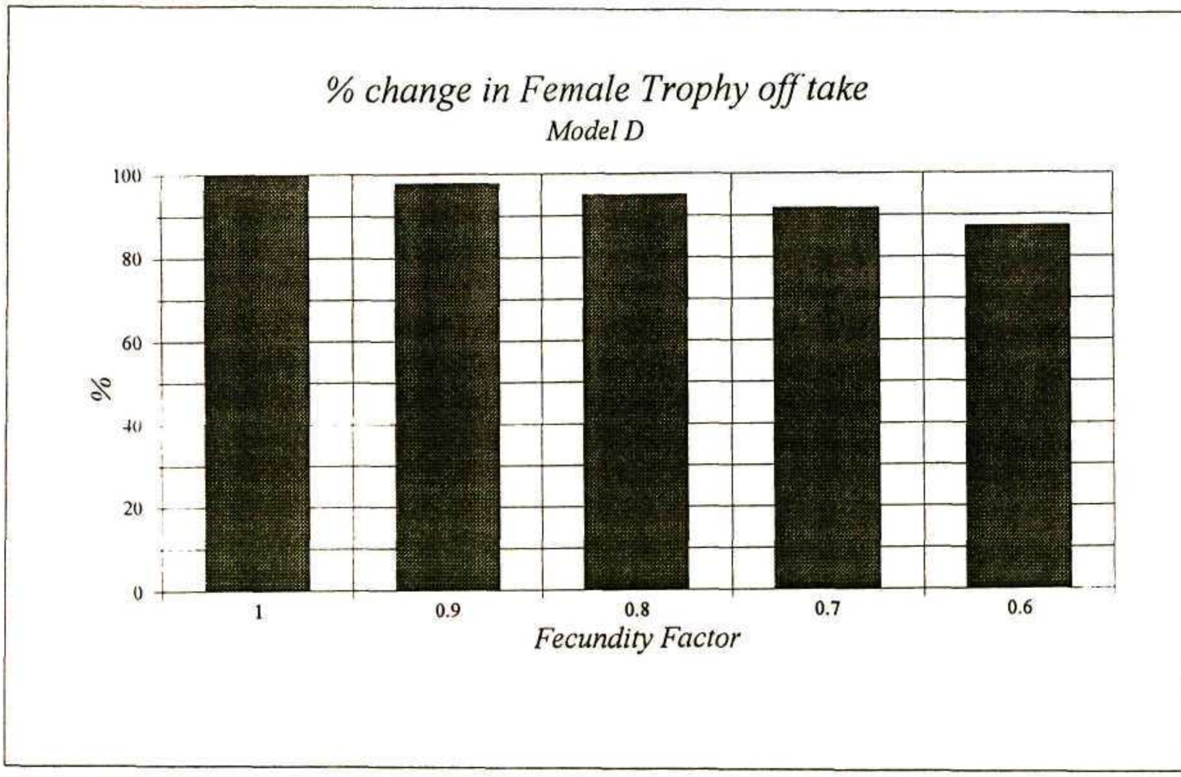

Figure 20: Graph showing the % change in female trophy offtake for Model D as the fecundity drops. A drop in fecundity is simulated by multiplying the fecundities of the buffalo by a fecundity factor. The offtake of female trophies is expressed as a % of the offtake of female trophies when the fecundity factor is 1.

v) Survival Rate (pm_i and pf_i)

As has already been discussed there are no survival statistics for a buffalo population that is not subject to predation. It is expected that the survival rates will be high and the values of pm_i and pf_i were chosen accordingly. It is possible that these values could be too high so it is useful to examine the effect that a decrease in survival rates could have on the results of Models A and D.

Model A

Figure 21 on page 58 shows the effect that a decrease in the rate of survival has on the trophy offtake of Model A. The rates of survival pm_i and pf_i are decreased by a fixed proportion which is shown on the x-axis of the graph. From this graph it can be seen that even a small drop in the survival rates has a dramatic effect on the offtake of male trophies which decreases dramatically. If the survival rates drop by 10%, there is a massive 68% drop in the offtake of male trophies. One of the reasons that this drop is so high is that male trophies can only be harvested at the relatively late age of 15. The drop in survival rate of age classes 0 to 14 all effect the number of buffalo that will survive to age class 15. At the same time as the trophy offtake drops, the percentage of female buffalo in the herd increases. The general age-structure that results for Model A is unchanged by the drop in survival rates.

Model D

Figure 22 on page 58 and Figure 23 on page 59 show the effect that a decrease in the rate of survival has on the trophy offtake of Model D. The rates of survival pm_i and pf_i are decreased by a fixed proportion which is shown on the x-axis of the graphs. From these graphs it can be seen that Model D responds to a drop in survival rates in a similar way to Model A. Even a small drop in the survival rates causes a dramatic drop in the offtake of both male and female trophies. If the survival rates drop by 10%, there is a 66% drop in the offtake of male trophies and a 61% drop in the offtake of female trophies. At the same time as the trophy offtake drops, the percentage of female buffalo in the herd increases. The general age-structure that results for Model D is unchanged by the drop in survival rates.

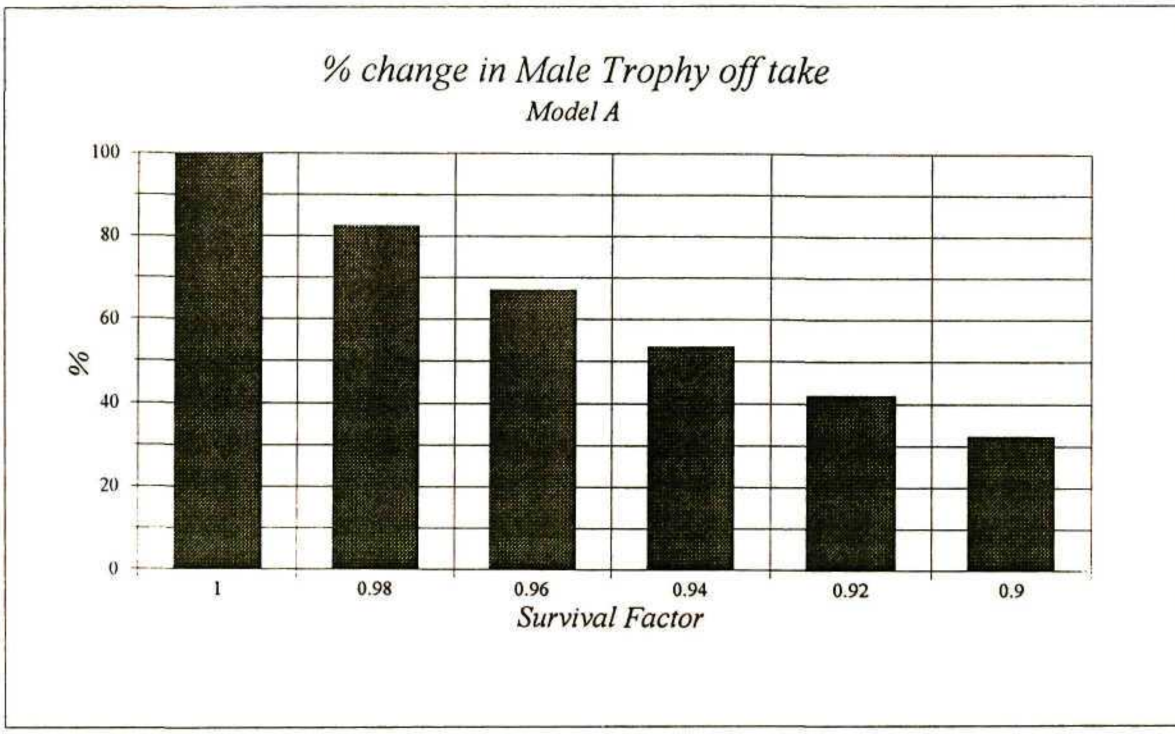

Figure 21: Graph showing the % change in male trophy offtake for Model A as survival drops. A drop in survival is simulated by multiplying the survivals of the buffalo by a survival factor. The offtake of male trophies is expressed as a % of the offtake of male trophies when the survival factor is 1.

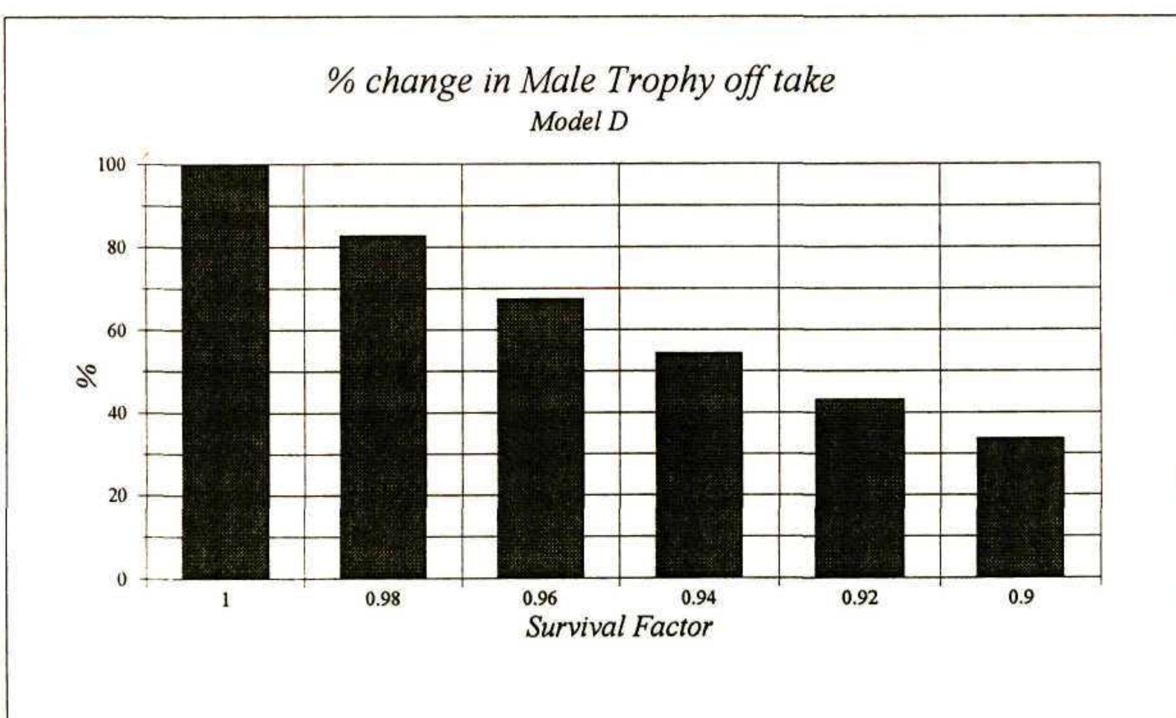

Figure 22: Graph showing the % change in male trophy offtake for Model D as survival drops. A drop in survival is simulated by multiplying the survivals of the buffalo by a survival factor. The offtake of male trophies is expressed as a % of the offtake of male trophies when the survival factor is 1.

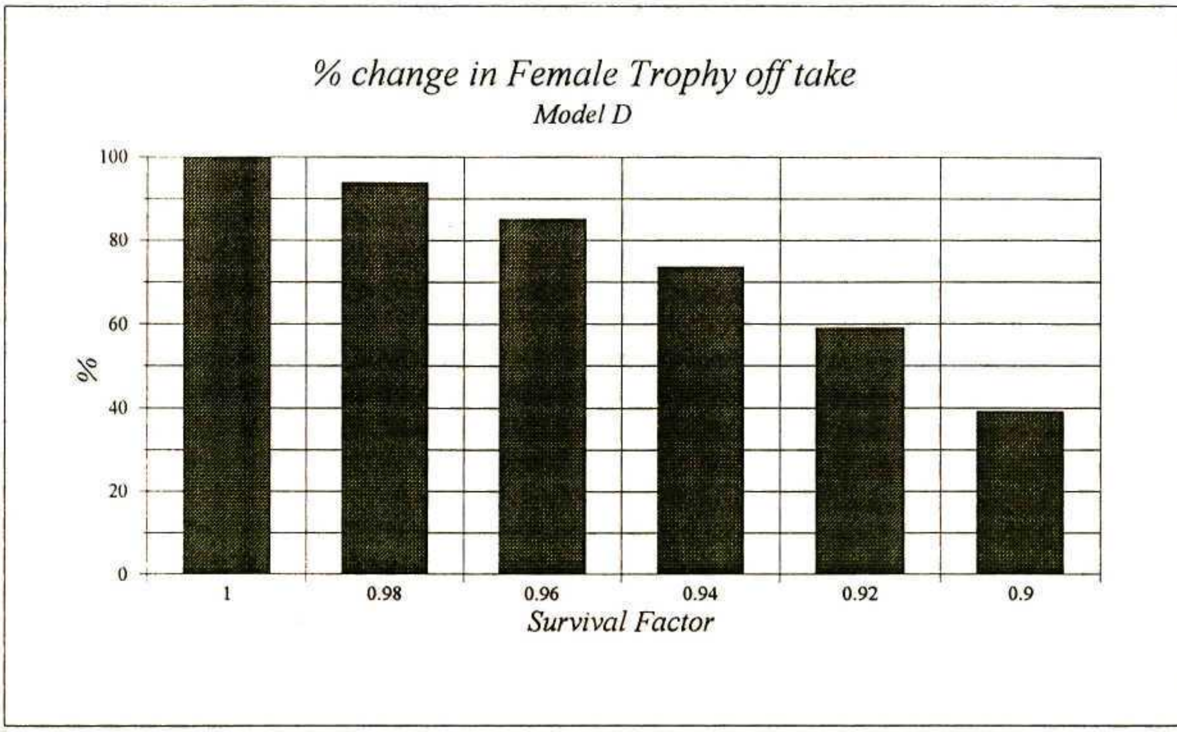

Figure 23: Graph showing the % change in female trophy offtake for Model D as survival drops. A drop in survival is simulated by multiplying the survivals of the buffalo by a survival factor. The offtake of female trophies is expressed as a % of the offtake of female trophies when the survival factor is 1.

vi) Discussion of Results

One of the major results of the sensitivity analysis is that, on the whole, the age structures of both Models A and D stay the same regardless of the parameter changes that take place. The exception for Model A, occurs when the fecundity of the older females drop to the point where it is no longer viable to keep them in the herd. For Model B, the exception occurs when the value of female trophies rise to such an extent in relation to male trophies that it becomes more economic to maximise female trophies. The fact that the population structure generally stays the same indicates that the results of Models A and D are fairly robust. It means that for most changes in the parameter values the same general age structure should be maintained. However, while the general age structure might remain the same for most parameter changes the ratio of male to female animals changes. This means that it is possible to easily choose the general age structure of the population, but small inaccuracies in the value of parameters will mean that the optimum ratio of males to females will probably not be selected. Fortunately, this is very easy to rectify, since by monitoring the population it should be easy to determine if there are too few or too many females in the population. If too few calves are being produced or more buffalo are dieing than expected, more female buffalo are needed in the population. On the other hand, if too many calves are being produced or the mortality rate is lower than expected, fewer females will be needed in the population.

Most changes in parameters values lead to changes in the trophy offtake of the models. Some changes do not have a very dramatic effect while others, like the change in survival rate, can have a profound effect on the trophy offtake.

c) Conclusions

For Makasa it appears that the optimum population structure would be that chosen by Model D (see Figure 9 on page 38). The population structure proposed by Model D is a convenient age structure for a number of reasons:

- ✖ It does not require the reserve to carry out any culling. All offtake is in the form of male and female trophies.
- ✖ Since no animals are culled before the age at which they first become sexually active, all of the buffalo should at some stage make a genetic contribution to the herd.
- ✖ Since all females are hunted before they reach age class 10, any inaccuracies in fecundity after age class 10 should have no effect on the returns of the buffalo population. This is also true of the survival rates for female buffalo in age class 10 and above.
- ✖ Since all males are hunted before they reach age class 16, any inaccuracies in survival rates from age class 16 onwards should have no effect on the returns of the buffalo population.

Furthermore, the returns of Model D compare favourably with the returns of Model A. Firstly, as has already been discussed the monetary returns will be higher than that of Model A. Secondly, the offtake of male trophies for Model D, is only 7% less than the offtake of male trophies for Model A. This means that even if it is not possible to sell the majority of female trophies, as long as some of the female trophies can be sold, it is still economically worthwhile to follow the strategy proposed by Model D.

Chapter 4: Stochastic Model

In Chapter 3 population structures that will maximise the results of a given objective function using equilibrium models were investigated. It was concluded that the model that maximises the total revenue of the reserve was of most interest to the Makasa Reserve. Now that a population structure which maximises the total revenue of the reserve has been established it is necessary to develop a management policy based on that structure. This policy should be easily applicable to the buffalo herd at Makasa.

In order to test how a buffalo population will respond to the management policy developed a stochastic model was created. This new model has two major aims:

- ✖ to determine if there is a likelihood of extinction under a given management policy.
- ✖ to estimate the average yearly offtake that will result from a given management policy.

a) Population Viability Analysis

In order to determine the likelihood of extinction of the buffalo population at Makasa population viability analysis (PVA) was employed. PVA is a process which is used to evaluate a specific population to determine what the likelihood is that the population will survive for a given length of time. PVA is commonly used to assess the level of extinction threat to a particular species (Mace and Lande, 1991) and to determine if a species that is re-introduced into the wild is likely to survive (May, 1991). PVA has been used to study a wide range of species (Lindenmayer *et al*, 1993). Examples of some of the species studied include the Sumatran rhino (Maguire *et al*, 1987), the Persian fallow deer (Saltz, 1996) and the northern spotted owl (Lande, 1988).

Shaffer (1981) points out that there are two broad categories of factors that lead to the extinction of populations:

- ✖ systematic pressures

- ✖ stochastic perturbations

Examples of systematic pressures are hunting pressure and erosion of habitat. These are outside pressures that are exerted on the species concerned and can normally be controlled through management. Some examples of stochastic perturbations are:

- ✖ Demographic stochasticity: the effect of random survival and reproduction in a population.
- ✖ Environmental stochasticity: this results from random changes to aspects of the environment of the population, such as food supply and the population of predators.
- ✖ Genetic stochasticity: this results from random changes in the genetic make-up of animal populations.

Demographic stochasticity can play an extremely important role in the extinction of small populations (Boyce, 1992). The smaller the population the higher its chances of becoming extinct as a result of random events. This can be illustrated by a simple example. Assume that a small population of two buffalo exists. There is a 10% chance that a buffalo will die in a given year. As a result, in one year there is a 1% chance that both buffalo will die and the population will become extinct. If a third buffalo is added to the population there will now be a 0.1% chance that the entire population will die off in one year.

b) Stochastic Model

The stochastic model used in this thesis incorporates both systematic pressures and stochastic perturbations. The systematic pressure comes in the form of a management policy that will be applied to the buffalo population. This policy will entail a high level of offtake from the buffalo on a yearly basis. The stochastic perturbations that are included in this model fall into the categories of demographic stochasticity and environmental stochasticity. Demographic stochasticity has been included because of the small size of the buffalo population at Makasa. Boyce (1992) contends that demographic stochasticity can be ignored for a population larger than about 30 animals. However, he adds a qualifier that this depends on the structure of the population. While the Makasa herd will be in the region of 80 animals, it will have a very uneven sex ratio which will be biased towards males. This is likely to make the herd even more susceptible to extinction, because of the low numbers of females in the herd. May (1991) contends that demographic stochasticity can be important for populations as large as a 100 animals.

The environmental stochasticity that is included in the model is in the form of a highly variant carrying capacity. These variations in carrying capacity will lead to changes in the fecundity and survival probabilities of the population.

i) Basic Model: Demographic Stochasticity

The model is used to project the growth of the buffalo population over a 100 year period. The size of the population is recalculated on a yearly basis by the model, which tracks each individual member of the buffalo population. In order to determine if a buffalo has survived from one year to the next and hence moved into the next age class a random number is generated which is greater than 0 and less than or equal to 1. If this number is less than or equal to the survival probability of buffalo in that age group the buffalo will survive and will be promoted to the next age group, otherwise the buffalo dies and is removed from the population. Once it has been determined which buffalo have survived the number of calves that are born can be calculated. This is done by generating a random number for each female buffalo that is capable of giving birth (ie all those females which are in age classes with a non-zero reproduction probability). If the number is less than or equal to the reproduction probability of the female buffalo, a calf will be born. In order to determine the sex of the calf another random number is generated. If the number is less than or equal to the probability of the calf being female, then the calf is born female otherwise it is born male. Once the sex of the calf has been determined it is added to the appropriate age group.

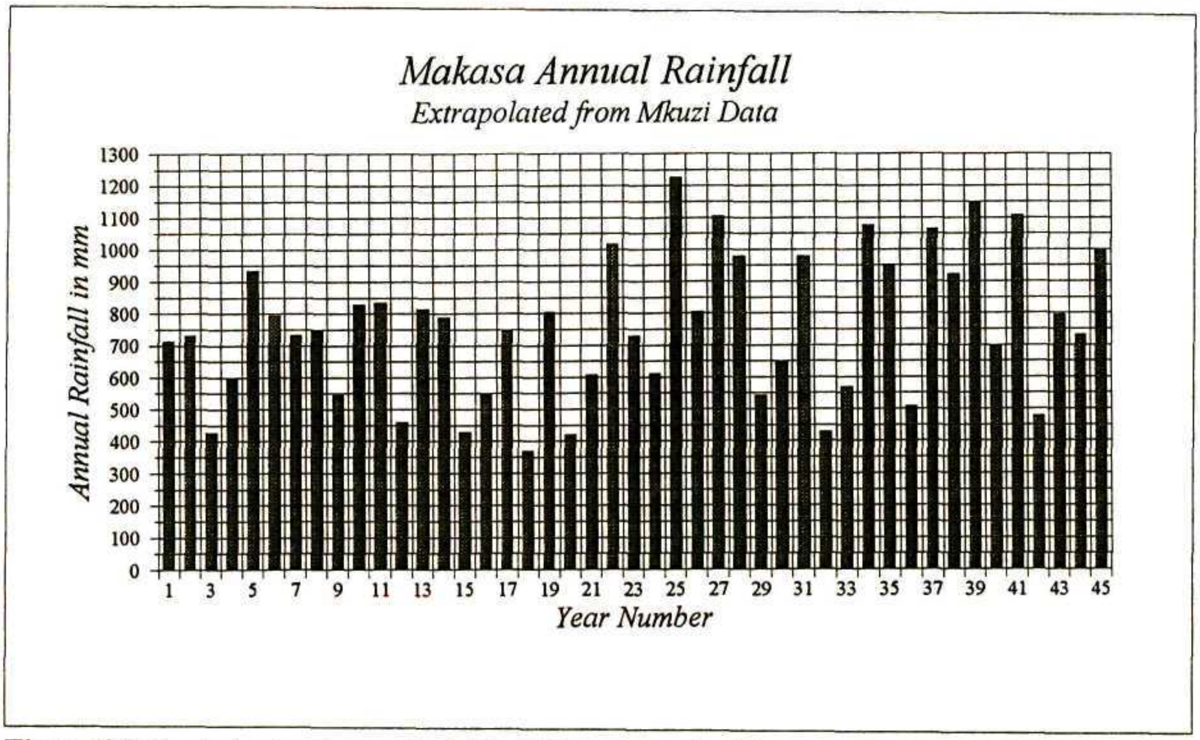

Figure 24: Graph showing the annual rainfall of Makasa extrapolated from a weather station at Mkuzi

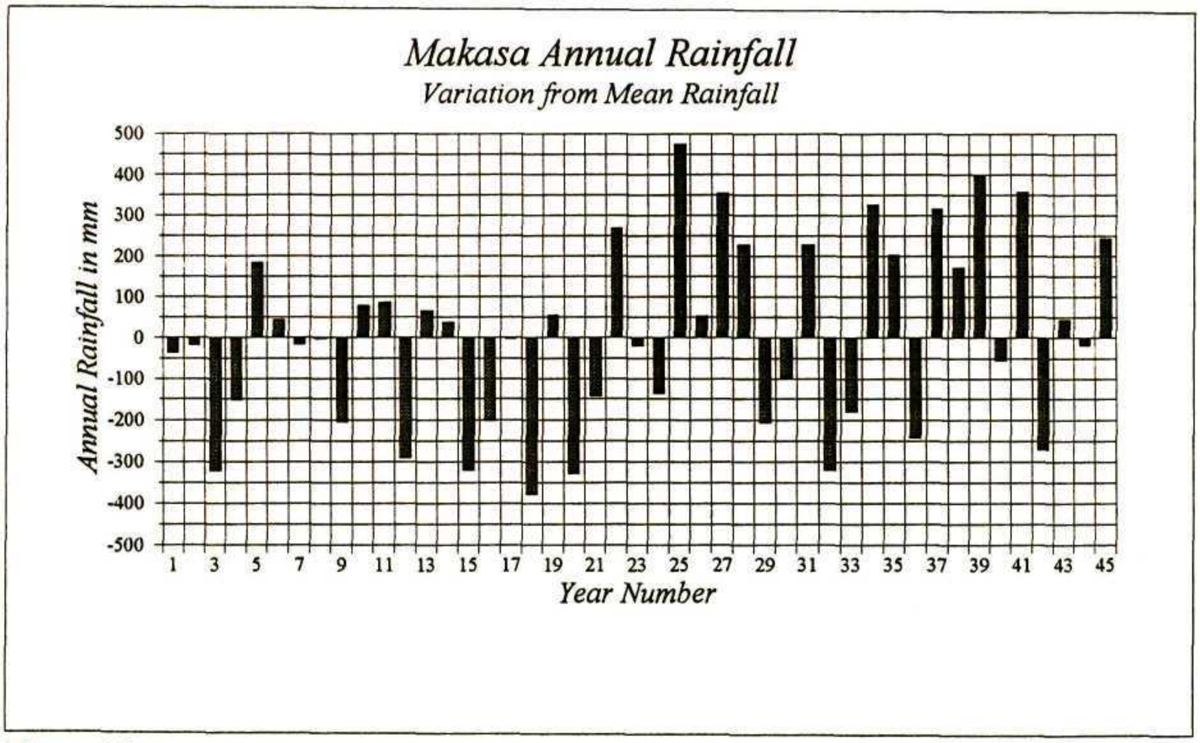

Figure 25: Graph showing the variation of Makasa annual rainfall from the mean rainfall

ii) Environmental Stochasticity

Now that the basic model has been established, it is necessary to incorporate environmental stochasticity. As has been discussed in Chapter 1, the annual rainfall at the Makasa reserve, varies greatly from year to year. Because of the high variation in rainfall, the food supply and hence the carrying capacity of the reserve will also vary greatly from year to year. This variation is included in our model by using annual rainfall data from the past 45 years from a weather station in the nearby Mkuzi Reserve. This area has an average annual rainfall that is 100 mm below that of Makasa (Goodman, *pers. comm.*). However, the variation recorded in this rainfall data is reflective of the type of variation found at Makasa (Goodman, *pers. comm.*). Since the annual rainfall at the Mkuzi weather station is on average 650 mm and that at Makasa is on average 750 mm a year, the rainfall values from the Mkuzi weather station were adjusted by increasing their values by 15%. This is to reflect the type of rainfall data expected for Makasa. This rainfall data is shown in Figure 24 on page 65. By subtracting the average annual rainfall at Makasa (750 mm) from the calculated rainfall Figure 25 on page 65 was constructed, this shows the variation from the mean of the rainfall data. From this graph it can be seen that the variation from the mean is very high.

From the rainfall data we would like to predict the carrying capacity of the reserve for buffalo. The carrying capacity is expressed in kilograms of biomass of buffalo that the food supply of the reserve can support. Based on advice from Goodman (*pers. comm.*), we know that the average rainfall of 750 mm is equivalent to 36,000 kg of carrying capacity for buffalo. Using this information a straightforward linear relationship to calculate the carrying capacity of year t from the rainfall of year t was derived:

$$CC_t = \frac{36000}{750} rainfall_t \tag{24}$$

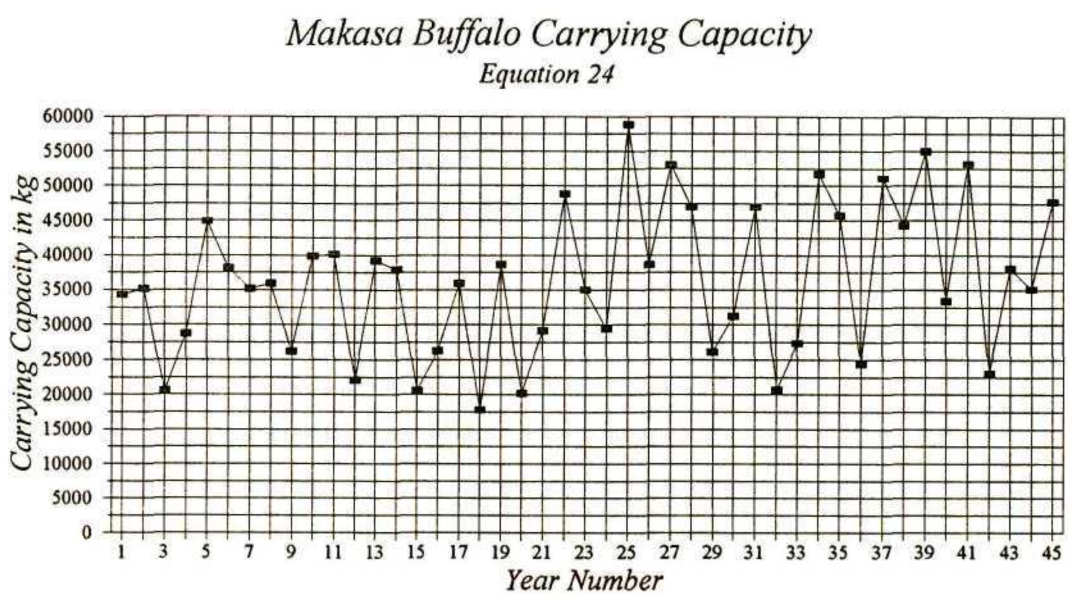

Figure 26: Graph showing the carrying capacity for buffalo at the Makasa reserve, derived from rainfall using equation 24

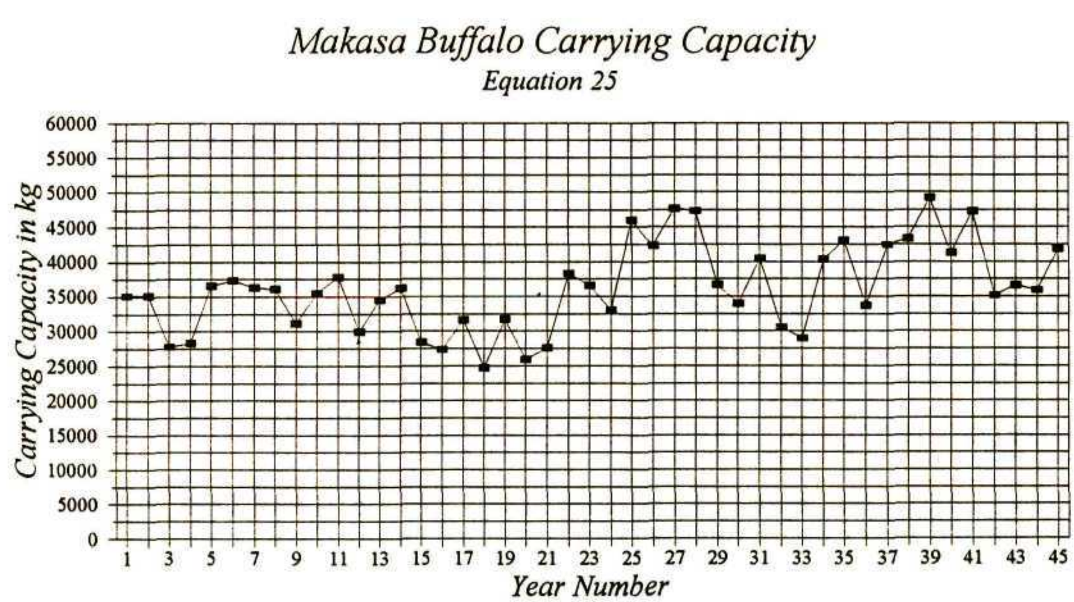

Figure 27: Graph showing the carrying capacity for buffalo at the Makasa reserve derived from rainfall using equation 25

A graph showing the yearly variation of carrying capacity based on this equation is shown in Figure 26 on page 67. The graph demonstrates the fairly abrupt changes that occur in carrying capacity from year to year. This is unrealistic as the state of the vegetation in the previous year will influence the state of the vegetation in the next year. The equation therefore needs to be adjusted, so that the carrying capacity that was calculated for previous years, effects the carrying capacity calculated for the current year. This was done using a moving average equation which has exponentially decreasing weights when moving backwards in time:

$$CC_t = CC_{t-1} + \frac{\frac{36000}{750} rainfall_t - CC_{t-1}}{2} \tag{25}$$

This means that the carrying capacity of previous years influence the carrying capacity of the current year, but the carrying capacity of the most recent years play a more important role than the carrying capacity for earlier years. This type of equation is also referred to as a first order information delay (Coyle, 1977). In order to calculate the carrying capacity for the first year, the value of CC_0 is set to the average carrying capacity which in this case is 36,000 kg. The new values for carrying capacity are shown in Figure 27 on page 67. This result is much smoother and does not exhibit the sort of abrupt changes in carrying capacity that the previous equation exhibits. Now, however, the carrying capacity fluctuation does not really reflect the actual carrying capacity fluctuation that can occur in the reserve. Goodman (*pers. comm.*) estimates that the carrying capacity of the reserve can vary from the average of 36,000 kg by over 50%. This means that the fluctuations in carrying capacity shown in Figure 27 on page 67 are not sufficient, since the variation from the average is under 33%.

A second attempt to emulate the carrying capacity fluctuations was made. In order to do this the carrying capacity value of an above average rainfall needs to be increased and the carrying capacity value of a below average rainfall needs to be decreased. The original equation 24 was changed to the following equation:

$$CC_t = (\frac{36000}{750} rainfall_t) * 2 - 36000 \tag{26}$$

Equation 25 was similarly adjusted:

$$CC_t = CC_{t-1} + \frac{(\frac{36000}{750} rainfall_t) * 2 - 36000 - CC_{t-1}}{2} \qquad \textbf{(27)}$$

The result of equation 27 is shown in Figure 28 on page 69. From Figure 28 it can be seen that the variation in carrying capacity is over 50% from the average.

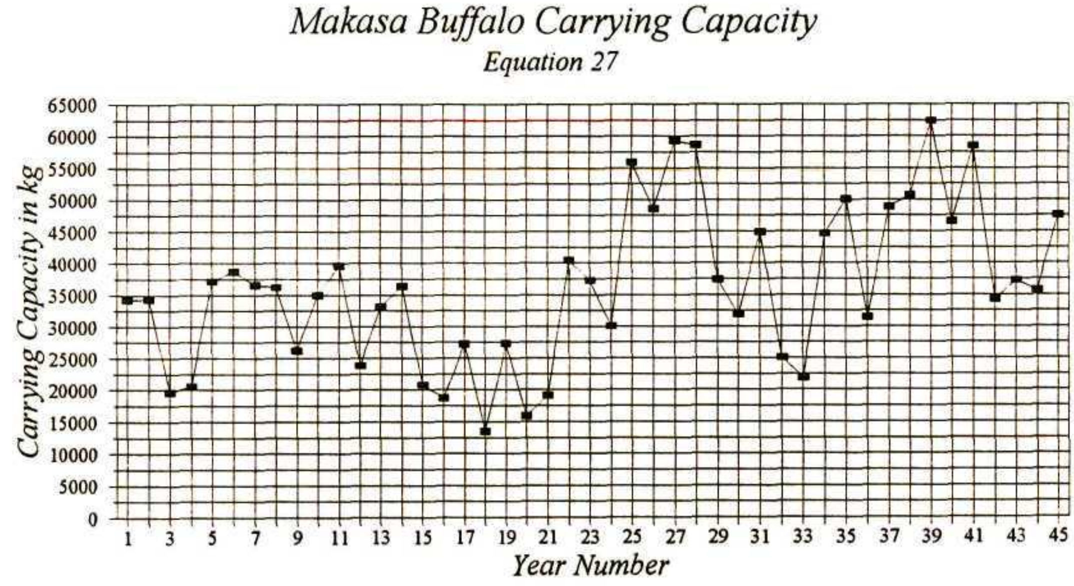

Figure 28: Graph showing the carrying capacity for buffalo at the Makasa reserve derived from rainfall using equation 27

The variation in rainfall was included in the model by randomly selecting one year out of the possible 45 years. The rainfall value from this year was then used to calculate the carrying capacity using equation 27. The next rainfall value in the sequence was then selected and the carrying capacity for that year was calculated. This process is repeated until the end of the sequence is reached at which point the first rainfall value in the sequence is selected, followed by the one after that are so on. As a result, the order of the rainfall values is not randomly selected, this is done in order to preserve the sequence of the rainfall fluctuations. If rainfall values are randomly selected, it could result in rainfall sequences that are not reflective of the likely sequences in the area. For instance, 20 years of above average rainfall could occur if the rainfall is randomly selected, this is clearly not the trend in rainfall in the area, so it is safer to use rainfall sequences that have already occurred.

Table 8

Maximum and Minimum Survival and Reproduction Rates

Age Class (i)	*Survival*		*Reproduction*	
	$maxp_i$	$minp_i$	$maxf_i$	$minf_i$
0	0.80	0.20	0.00	0.00
1	0.90	0.50	0.00	0.00
2	0.99	0.80	0.00	0.00
3	0.99	0.80	0.12	0.00
4	0.99	0.80	0.28	0.06
5	0.99	0.80	0.82	0.14
6	0.99	0.80	0.82	0.41
7	0.99	0.80	0.82	0.41
8	0.99	0.80	0.82	0.41
9	0.99	0.80	0.82	0.41
10	0.99	0.80	0.82	0.41
11	0.99	0.80	0.66	0.33
12	0.98	0.75	0.66	0.33
13	0.98	0.75	0.66	0.33
14	0.98	0.70	0.66	0.33
15	0.97	0.55	0.66	0.33
16	0.97	0.40	0.66	0.33
17	0.96	0.25	0.66	0.33
18	0.95	0.15	0.66	0.33
19	0.00	0.00	0.66	0.33

Now that the model is able to mimic carrying capacity fluctuations, it needs to change the value of mortality and reproduction probabilities in response to the changing carrying capacity of the system. In order to do this at the beginning of each year the model calculates the biomass of the buffalo population. This is done using the weights for each age class in Table 2 on page 24. Using the total biomass of the population and the actual carrying capacity of the reserve for that year the density index is calculated:

$$DI = \frac{Biomass}{CC} \tag{28}$$

The density index indicates the extent to which the population is over or under the carrying capacity of its environment.

Maximum and minimum survival and reproduction rates were determined for the model (see Table 8 on page 70). The maximum rates were taken from those used by the equilibrium model (see Table 2 on page 24). These maximum rates are used to determine survival and reproduction when the density index falls below 1. The minimum rates are used when the density index rises above 2. Overall the minimum survival rates lead to a population mortality about 30% higher than the maximum survival rates. This is the increase in mortality suggested by Goodman (*pers. comm.*). Furthermore, Goodman (*pers. comm.*) maintains that the youngest animals and the oldest animals will experience the highest stress from a decrease in food supply and therefore the highest mortality. For this reason the calf and yearling survival is set very low. For age groups 2 to 11 it is kept fairly high, until age group 12 is reached at which point the survival rates decrease with age.

For density index values between 1 and 2 the survival probabilities are calculated based on the maximum and minimum values. The calculation aims to mimic the effect that a shortage of food supply will have on the population. A small food shortage will initially have very little effect, but as the food shortage increases the effect becomes more and more dramatic. In order to mimic this situation, as the density index rises above 1 the survival probability will very gradually begin to decrease, then as the density index begins to approach 2 the survival probability will decrease more dramatically.

In order to create the effect described above the following equation is used to calculate the survival probability of age group *i* for density values between 1 and 0:

$$p_i = \frac{(1 - (DI - 1))(1 + a)}{(1 + a - (DI - 1))}(minp_i - maxp_i) + maxp_i \qquad \textbf{(29)}$$

a is a constant that controls the rate of decrease of the curve. For this model the value of a is set to 0.1, which results in the initial slow tapering of the curve and the final dramatic decrease. Figure 29 on page 72 shows the results of this equation for the survival probability of calves.

The reproduction probabilities are calculated in the same way as the survival probabilities. The maximum and minimum reproduction probabilities are shown in Table 8 on page 70. The

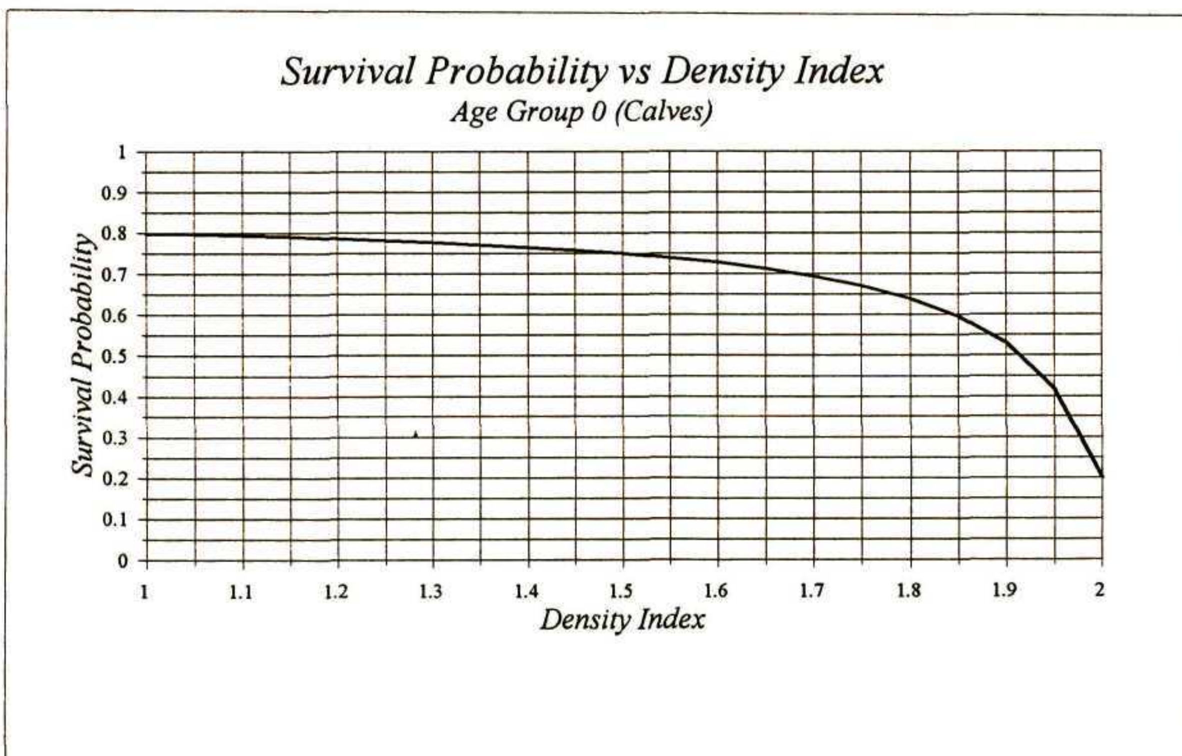

Figure 29: Graph showing the change in the survival probability of a calf as the density index increases

maximum probabilities are the same as the values used for the equilibrium model described in chapter 2. (See Table 2 on page 24). The maximum rates are used when the density index is less than 1 and the minimum probabilities are used for a density index of greater than 2.

The minimum fecundity probability for groups 3 to 6 were set to half of the maximum probability of age groups 2 to 5. This has the effect of mimicking a drop in the mean age of puberty. The remaining age groups had their fecundity probabilities set to half the maximum probability in order to lower the 'fecundity plateau'. These changes in fecundity follow the broad pattern of fecundity changes that occur in reaction to environmental changes that were described by Caugley (1976) for ungulate populations, where the female produces one offspring:

- ✖ a raising or lowering of the mean age at which puberty occurs
- ✖ a raising or lowering of the 'fecundity plateau' by a shift in reproduction rates

c) Developing a Management Policy

The optimum age and sex structure of the Equilibrium Model D for a carrying capacity of 3,600,000 is shown in Table 9 on page 74. The results of this model now need to be converted into a management policy that can be applied to the reserve. At Makasa the carrying capacity available for buffalo is 36,000 kg which works out to be 80 buffalo of an average weight of 450 kg. When the results of Model D are applied to such a small carrying capacity we tend to get fractions of buffalo. For instance the offtake of male buffalo for Model D at a carrying capacity of 36,000 kg is 2,89 buffalo. In order to get a general picture of the structure of the population for a carrying capacity of 36,000 kg some totals have been calculated in Table 10 on page 74. These totals have been calculated by rounding up any fraction of a buffalo to a whole buffalo. Using these totals and the age and sex structure of Model D a starting population was constructed for the stochastic model. The details of the starting population are shown in Table 9 on page 74.

Table 9

Population Structure of Equilibrium Model D with a maximum carrying capacity of 3,600,000kg and the Starting Population Structure of the Stochastic Model

Age Class	*Model D*		*Start Population*	
	Males	*Females*	*Males*	*Females*
0	472	472	5	5
1	377	377	4	4
2	340	340	4	4
3	336	336	4	4
4	333	333	4	3
5	330	330	3	3
6	326	326	3	3
7	323	323	3	3
8	320	9	3	0
9	317	0	3	0
10	313	0	3	0
11	310	0	3	0
12	307	0	3	0
13	301	0	3	0
14	295	0	3	0
15	0	0	0	0
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0

Table 10

Basic Population Structure of Model D for a Population with a carrying capacity of 36,000 kg

Model	*Total*	*Total*		*Total Without Calves*	
		Males	*Females*	*Males*	*Females*
D	79	50	29	46	24

i) Management Policy 1

In order to maintain the population structure of the equilibrium Model D, most females in age group 8 are hunted, a few are allowed to survive to age group 9 at which stage they are also hunted. All males in age group 15 are hunted. The first management policy developed is more or less a simple implementation of this. The management policy has two features:

- ✖ hunt all males in age group 15
- ✖ hunt all females in age group 8 (since only a tiny proportion of 1 female would be allowed to survive to age group 9 for the small population of the Makasa herd, it is not necessary to provide for this.)

The stochastic model was run 1000 times and each run was allowed to continue for a 100 year period. Looking at Table 11 on page 75 it is readily apparent that management policy 1 is a failure. In a period of 100 years, the extinction probability of this population is unacceptably high at 0.1. On closer examination of the results, it is found that the average size of the population at the end of the hundred year period is 27 buffalo. This indicates that if the model is run for a longer period of time, the population will definitely become extinct.

The reason for the failure of management policy 1, is that it implements a hunting policy that has no regard for the current state of the population. If, for instance, the number of females in the herd have dropped considerably because of a shortage of food supply, the management policy still advocates the hunting of any of these females that are in age group 8.

Table 11

Results of Stochastic Model for Different Management Policies

Management Policy	*Probability of Extinction*	*Off take per Year*	
		Males	*Females*
Policy 1	0.1	1.65	1.77
Policy 2	0	2.34	2.83
Policy 3	0	2.36	2.69

ii) Management Policy 2

Management policy 2 was developed in order to address the weakness of management policy 1. The two aspects of the new management policy are:

- ✖ hunt all males in age group 15.
- ✖ hunt all females in age group 8 and above, with the proviso that the number of females (excluding calves) must be kept at a minimum level of 24 buffalo.

From Table 11 on page 75 it can be seen that Management policy 2 is much more successful than management policy 1. There is no probability that the population will go extinct using this policy. This can be attributed to the high survival rates of buffalo when there is no shortage of food. The offtake of male and female buffalo per year is also much higher than that of management policy 1.

The average offtake of male buffalo per year for the stochastic model is 0.55 less than the offtake of male buffalo from equilibrium Model D, for female buffalo the offtake is 0.37 less. This is not surprising since the equilibrium model uses survival and fecundity proportions that are only applicable when there is no shortage in food supply. It is interesting to note that while both average offtakes are lower than that of the equilibrium model, the offtake of males is lower by a larger amount. This can be attributable to the fact that female buffalo only need to survive until they reach age group 8, whereas male buffalo need to survive until age group 15. Examining the minimum survival probabilities used by the model, it can be noted that at age group 12, the probabilities begin to decrease. Before age group 12 is reached, the survival probabilities have been kept at a steady rate.

In any one year the offtake of male trophies can range from 0 to as much as 10, the offtake of females can range from 0 to as much as 14. Obviously, the higher offtakes occur in exceptional circumstances and are a very rare occurrences. Figure 30 and Figure 31 on page 78 show the percentage chance of an offtake in a given year. For females, there is a fairly high chance of 15.75% that there will be no offtake. There are two circumstances under which no females will be hunted:

- ✖ no females survived to age group 8.

- ✖ the number of females (excluding calves) has fallen below the minimum level, so no hunting of females will take place.

For males, there is a 9.74% chance of no offtake. There is only one circumstance under which males are not hunted and that is if no males survived to age group 15.

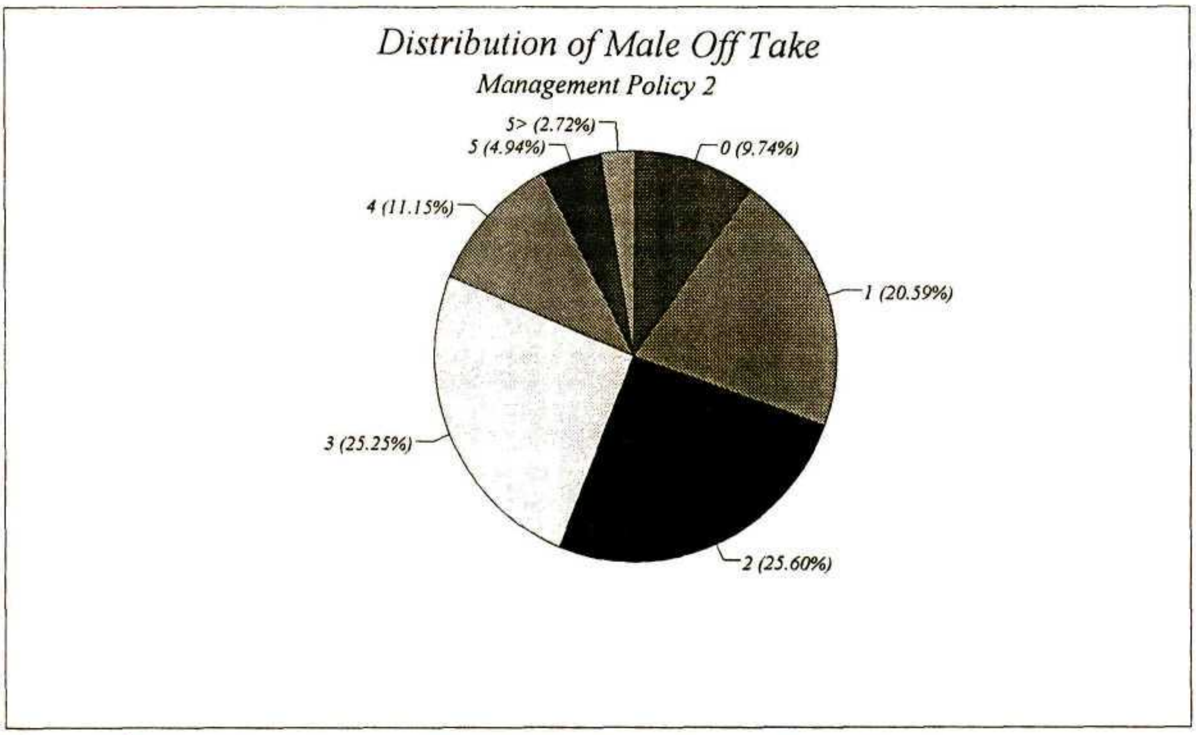

Figure 30: Distribution of the yearly offtake of male trophies under management policy 2

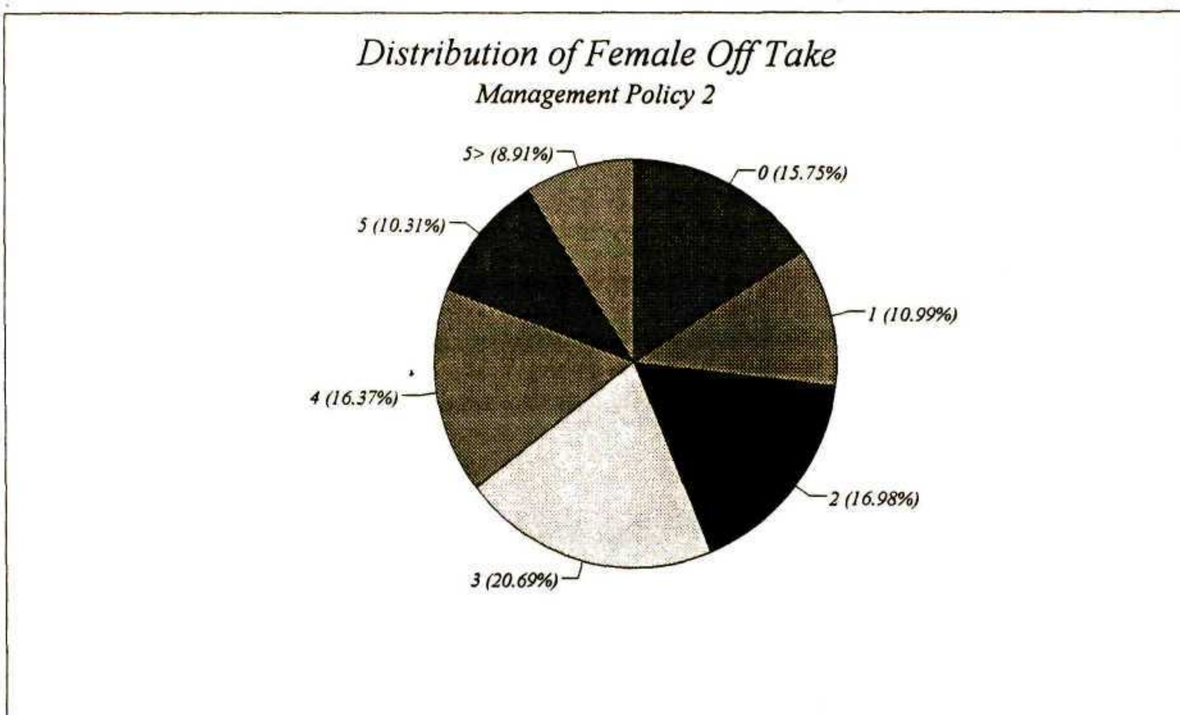

Figure 31: Distribution of yearly offtake of female trophies under management policy 2

iii) Management Policy 3

Management Policy 2 does not prevent the population of buffalo from rising above the maximum size set by Goodman (*pers. comm.*). The population can easily rise above this size if a few extra females are born, since they are only hunted when they reach age 8. This means that until these females reach the age of 8 there will be a higher number of females in the herd than advocated by the equilibrium model. When there are a higher number of females in the herd, a higher number of calves will be born, eventually further increasing the number of females in the herd. Because of the fluctuating food supply of the reserve, the buffalo population will ultimately experience a drop in number because of a shortage of food supply. If the population is allowed to rise above the maximum level set, it could experience a higher mortality than if it was prevented from rising above that level. This could occur since the drop in survival rates is linked to the extent to which the population exceeds the available food supply.

In order to deal with this concern management policy 3 was developed, which has the following aspects:

- ✖ hunt all males in age group 15.
- ✖ hunt all females in age group 8 and above, with the proviso that the number of females (excluding calves) must be kept at a minimum level of 24 buffalo.
- ✖ if the number of buffalo (excluding calves) exceeds 70, then cull as many female yearlings as necessary in order to reduce the population to 70, with the proviso that the number of females (excluding calves) must never fall below 24.

Examining Table 11 on page 75, it can be seen that the results of management policy 3 are very similar to management policy 2. There is no possibility of extinction under management policy 3. The offtake of males is marginally higher for management policy 3 than for management policy 2 and the offtake of females is slightly lower for management policy 3 than for management policy 2.

iv) Conclusion

Comparing the results of the three management policies, it seems that management policy 2 is the most appropriate. This policy does not endanger the buffalo population. The results of management policies 2 and 3 are almost identical and neither of the results is better than the other. Management policy 3 is however a more complex policy that requires some culling. It is unnecessary to implement this more complex policy since it has no real advantages for the reserve.

Chapter 5: Returns from Hunting

Chapters 2, 3 and 4 have been dedicated to determining the possible offtake of buffalo from the Makasa Reserve. Since buffalo is both the most lucrative species and the most attractive species to hunters on the reserve, other than rhino (which are not numerous enough to hunt on a regular basis), buffalo will play a key role in determining the economic returns from hunting on the reserve. In this chapter a broad picture will be drawn of the likely economic returns from hunting in the reserve. This will be compared to the running costs of the reserve to determine if hunting is able to meet those costs. The possibility of combining hunting with other tourism options will also be discussed.

a) Economic Returns from Hunting

i) Trophy and Meat Offtake

The likely offtake of buffalo has been calculated in the previous chapters. A "rule-of-thumb" method is now used to calculate the possible offtake of other species on the reserve that could be hunted. The possible offtake is shown in Table 12 on page 82. The total offtake for each species is set at half the growth in population from one year to the next. The total offtake is not set to the entire growth of the population, as not all the animals that are taken off will be of sufficient size to hunt. Generally speaking, the trophy offtake is set to 4% of the population, since normally 4% of a population will be of trophy quality. The one exception is zebra, since they are hunted for their skins, hunters are willing to hunt both male and female animals, for this reason the trophy offtake for zebra has been set to 8% of the population. The populations of suni, red duiker and grey duiker are difficult to properly monitor or control, so it will not be possible to determine the real offtake that is allowable from these populations. Goodman (*pers. comm.*) has determined that an offtake of 2 trophy quality animals a year should easily be possible.

The offtakes that have been calculated are obviously the sorts of offtake expected in a year where there is no major shortage of food supply. It is clear from the results of the buffalo population, that the offtake of species will vary immensely from year to year. The offtake should however fluctuate in a similar way to the buffalo population, since the fluctuations are caused by a shortage in food supply which will be experienced by all the animals on the reserve at the same time. The smaller species in the reserve will react in a slightly different way because they have a short life cycle and high reproduction rate so they will probably be more affected by a shortage of food supply than larger animals. On the other hand they should be able to recover from a drop in population numbers more quickly than larger animals.

Table 12

The growth rate of the different species at the reserve (Goodman, *pers. comm.*), the total number of trophy and meat animals that can be hunted from the target population in a year and the total number of animals in the target population which will be of trophy quality.

Species	*Target Population*	*Growth Rate*	*Total Offtake*	*Trophy Offtake*
White Rhino	7	1.08	0	0
Zebra	60	1.15	5	5
Waterbuck	20	1.15	1	1
Wildebeest	80	1.15	6	3
Reedbuck	10	1.3	2	0
Warthog	30	1.5	8	1
Nyala	100	1.3	15	4
Impala	100	1.25	13	4
Kudu	20	1.15	2	1
Suni	unknown	1.84	2	2
Red Duiker	unknown	1.58	2	2
Grey Duiker	unknown	1.54	2	2

ii) Packaging

Unfortunately it is not possible to simply sell every animal available for hunting on the reserve. Some species which are in demand from hunters can easily be sold. This is true for buffalo, which are one of the 'big-five' species and Nyala which is a species typical of the KwaZulu-Natal area. This means that while it is possible for a reserve to sell animals for hunting on an individual basis it will be more lucrative for the reserve to link the sale of the more attractive species to the less attractive species in the reserve. The linking of species is done by constructing hunting packages which are then sold to hunters. Table 13 on page 83 and Table 14 on page 85 show some possible packages that have been constructed based on the species offtake shown in Table 12 on page 82. The offtake of buffalo is assumed to be 3 male trophies and 3 females trophies. (This is a likely scenario in a year without a shortage of food supply.)

Table 13

Examples of possible Trophy Packages for the Makasa Reserve

Species	*Package 1*	*Package 2*	*Package 3*	*Package 4*
Buffalo	1	1	1	
Zebra	1	1	1	1
Waterbuck				1
Wildebeest	1	1	1	
Reedbuck				
Warthog				1
Nyala	1	1	1	1
Impala	1	1	1	1
Kudu				1
Suni	1			1
Red Duiker		1		1
Grey Duiker			1	1
Hunt Days	8	8	8	11
Minimum Value	26,100.00	26,100.00	25,050.00	11,550.00
Maximum Value	30,120.00	30,120.00	29,000.00	14,430.00
Min Value per Day	3,262.50	3,262.50	3,131.25	1,050.00
Max Value per Day	3,765.00	3,765.00	3,625.00	1,311.82

The number of days that are needed to hunt all the animals in the package are shown in both tables. The number of days is calculated by setting aside one day for each animal in the package plus two extra days (Davies, *pers. comm.*). This is the general rule for the number of days taken by a hunter but is not necessarily applicable on every occasion. The minimum value of the packages shown in the table is calculated by using the minimum value of the different species shown in Table 1 on page 12. Similarly, the maximum value is calculated using the maximum value of the species in the same table. The minimum and maximum value per day is calculated by dividing the minimum and maximum value of the package by the number of days needed for the package. At Makasa it is likely that the packages will be sold for an amount closer to the minimum value than the maximum value (Davies, *pers. comm.*). Davies bases this opinion of the fact that normally the extra amount paid for the species reflects the extra value the hunter places on hunting in a particular reserve. Since Makasa is not big and offers no facilities to hunters at this stage, it is not likely to be able to command high prices for its hunts.

Table 14
Examples of possible Meat Packages for the Makasa Reserve

Species	*Package 1*	*Package 2*	*Package 3*	*Package 4*	*Package 5*	*Package 6*
Buffalo	1	1	1			
Zebra						
Waterbuck						
Wildebeest	1	1	1			
Reedbuck						
Warthog	1	1	1	1	1	1
Nyala	1	1	1	2	2	2
Impala	1	1	1	2	2	2
Kudu						
Suni						
Red Duiker						
Grey Duiker						
Hunt Days	7	7	7	7	7	7
Minimum Value	7,250.00	7,250.00	7,250.00	1,200.00	1,200.00	1,200.00
Maximum Value	9,860.00	9,860.00	9,860.00	1,490.00	1,490.00	1,490.00
Min Value per Day	1,035.71	1,035.71	1,035.71	171.43	171.43	171.43
Max Value per Day	1,408.57	1,408.57	1,408.57	212.86	212.86	212.86

From the maximum and minimum value of the packages shown in the two tables it can be calculated that in a good year the value of trophy hunting will be between R88,800 and R103,670. The total number of days needed for these trophy hunts will be 35. The total value of meat hunting will be between R25,350 and R34,050 and the total number of days needed for the meat hunts is 42. The total value of the meat and trophy packages together will be between R114,150 and R137, 720.

In Chapter 4 it was calculated that an average of 2.34 male buffalo will be hunted a year which is 22% less than the 3 male buffaloes that have been used for the trophy packages. Similarly, in Chapter 4 is was calculated that an average of 2.83 female buffalo will be hunted a year which is 12% less than the 3 female buffalo used for the meat packages. This implies that on average the yearly income from the reserve from hunting will be in the region of 10% to 20% lower than the total value of the packages. It is important to note that the packages in Table 13 on page 83 and Table 14 on page 85 represent the type of offtake that can be expected in a fairly good year. In reality the returns will fluctuate immensely from year to year. In some years there could be no offtake of any species, if it is a particularly bad year, in other years there could be a large number of animals available for hunting.

b) Total Projected Expenditure of Makasa Reserve

The total expenditure projected for the Makasa Reserve by Keet (*pers. comm.*) is shown in Table 15 on page 86. The costs included by Keet (*pers. comm.*) in the projected expenditure of the reserve are:

- ✖ salaries
- ✖ transport and related costs
- ✖ maintenance costs
- ✖ management of the reserve
- ✖ administrative costs
- ✖ supplies and services
- ✖ capital costs

Table 15

Total Projected Expenditure of Makasa Reserve for next five years (Keet, *pers. comm.*)

	1997/1998	*1998/1999*	*1999/2000*	*2000/2001*	*2001/2002*
Total Projected Expenditure	290,628.00	314,224.85	337,217.75	361,003.10	388,919.49

Comparing the projected expenditure of the reserve with the possible income from hunting in a reasonable year which is between R114,150 and R137,720 it is clear that hunting is not sufficient to meet the running costs of the reserve.

c) Income generating Strategies

In chapter 1 three issues were highlighted on which a decision has to be made:

- ✖ what land-use option will be used for the reserve?
- ✖ will rights of access to the reserve be leased to another party?
- ✖ will an accommodation facility be built on the reserve?

These questions will be discussed with reference to the results on safari hunting

i) Land-use options

It is clear from the projected expenditure of the reserve that hunting will not be able to meet the cost of running the reserve. Therefore the option of only practising hunting on the reserve is economically unfeasible. This leaves two remaining options:

- ✖ to use the reserve exclusively for nature tourism
- ✖ to use the reserve for a combination of nature tourism and game hunting

In order for a combination of nature tourism and hunting to be feasible, the hunting that takes places must be for a small enough portion of the year to allow for other activities. The meat and trophy packages that have been constructed in the previous section are projected to require 77 hunting days. Obviously the amount of hunting that takes place will fluctuate with the availability of animals to hunt, and the number of hunting days required could increase or decrease from year to year. However, even if the number of hunting days required were to double, more that half the year would still be free for other activities.

ii) Leasing rights to the Reserve

The rights to the reserve could be leased for all or part of the year. The rights that could be leased are the right to hunt in the reserve and the right of access to the reserve. Leasing the right to hunt in the reserve will no doubt have a similar value to the reserve organising the hunting itself, so this option will not be dealt with. Leasing rights of access to the reserve is an attractive concept because it would lead to a predictable income from year to year, something not provided by hunting. The two options that need to be considered in the case of leasing land rights are:

- ✖ leasing of access rights for all of the year

- ✖ leasing of access rights for part of the year

Examining the results of the projected packages that were drawn up in a previous section, it is clear that some of the hunting packages are very lucrative and other not lucrative at all. Figure 32 on page 89 shows the minimum daily income for the 77 hunting days. From this graph it can clearly be seen that the first 24 hunting days are very lucrative, and are valued at over R3,000, the next 32 days are not nearly as valuable, but are still valued at over a R1,000. The last 21 days are much less valuable at under R200. Any offer to lease access rights for the reserve can easily be compared to the graph by converting it into the income per day from the leasing of access rights. If the income per days excceds the value of the most lucrative days the option of leasing access rights for the entire year should be taken. It is more likely, however, that the daily rate that the reserve can charge for access will be below R3,000. The actual value of the offer will determine how many days should be set aside for hunting. For instance, if the income per day from the access rights is greater than R200 but less than R1,000 the last 21 days of hunting should be abandoned in favour of leasing the access rights of those days.

iii) Building Accommodation on the Reserve

Building accommodation of the reserve presents no conflict with allowing hunting on the reserve. In fact hunting will enhance the profitability of any accommodation that is built on the reserve, since the hunters could be required to hire the accommodation on the reserve in order to have the right to hunt on the reserve. In the case where accomodation has been built the longer the hunts last, the longer the period of guaranteed occupancy for the reserve.

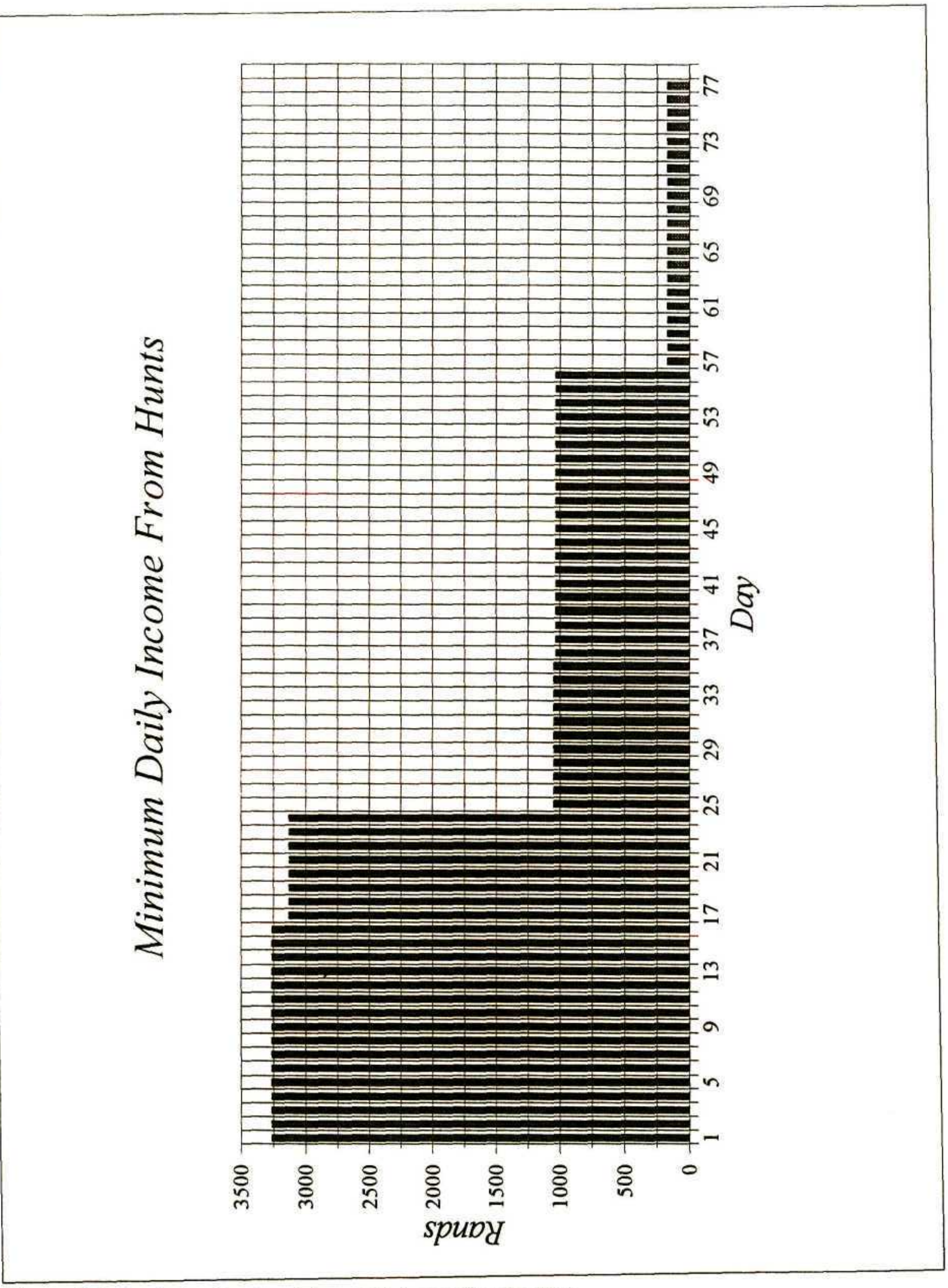

Figure 32: Graph showing the minimum daily income from hunting

Chapter 6: Conclusion

The aim of this study was to investigate the economic potential of a small game reserve. The approach used to investigate the economic potential of a reserve was to identify a species in the reserve that will play a major role in determining the profitability of hunting. In the case of Makasa, buffalo were identified as a key species because buffalo are attractive to hunters and can be sold at a much higher rate than other species. Once buffalo were identified as a key species a two-stage approach was developed to determine the profitability of buffalo.

The first stage involved creating a deterministic model of the buffalo population. This model was used to establish an age structure for the buffalo population that will maximise the revenue resulting from the harvesting of buffalo. The second stage involved developing a management policy based on the age structure that was established using the deterministic model. Since the buffalo population at the reserve is small and the food supply of the reserve is subject to fluctuations a stochastic model was required to help develop the management policy by testing the effectiveness of the policy. The stochastic model incorporated both environmental and demographic stochasticity. Once the management policy has been selected, the stochastic model can be used to establish the average yearly harvest of buffalo from the reserve.

This two stage approach which is used to determine the harvest level of buffalo can be applied to any species by changing the parameter values of the models.

The results of the stochastic model on the yearly harvest of the reserve can be combined with the likely harvest rates of other species in the reserve in order to get a broad idea of the possible economic potential of hunting on the reserve.

This approach used for the Makasa Nature reserve can be generalised and used for another reserve which has a species that dominates the likely returns of the reserve from hunting. The four general steps of this approach are:

- ✖ identify the dominant species in the reserve

- ✖ construct a deterministic model for that species and establish an optimal age structure for the species
- ✖ construct a stochastic model to develop a management policy based on the age structure of the species
- ✖ combine the results of the stochastic model with the likely offtake of other species in the reserve to get a picture of the magnitude of the returns from hunting

While this general approach can be used for other reserves it is important to bear in mind that this approach is limited because it does not consider the impact of competition between species. Competition could lead to a depressed level of off take for some species.

References

A'Bear, DR, Bainbridge, WR and Montgomery, AD (1996). *Progress Report No 1: Development of an Integrated development plan for the Southern Maputaland Biosphere reserve*. Unpublished Report.

Acocks, JPH (1988). *Veld types of South Africa* 3rd edition. Leistner, OA and Momberg, BA (eds). Botanical research Institute, Pretoria.

Boyce, MS (1992). Population Viability Analysis. *Annual Review of Ecology and Systematics*, **23**, 481 - 506.

Bruton, MN and Cooper, KH eds (1980). *Studies on the ecology of Maputaland.* Rhodes University, Grahamstown and the Natal Branch of the Wildlife Society, Durban.

Camp, KGT (1995). *The Bioresource Units of KwaZulu-Natal.* Cedera Report No N/A/95/32 and associated memoirs. KwaZulu-Natal Department of Agriculture, Cedera.

Carmichael, IH, Patterson, L, Drager, N and Breton, DA (1977). Studies on Reproduction in the African Buffalo (Syncerus Caffer) in Botswana. *South African Journal of Wildlife Research*, **7(2)**, 45-52.

Caswell, H (1989). *Matrix Population Models: Construction, Analysis and Interpretation.* Sinauer Associates Inc Publishers, Sunderland.

Caughley, G (1976). Wildlife Management and the Dynamics of Ungulate Populations. In: *Applied Biology, Volume I.* Coaker, TH (ed). Academic Press, London. 183-246.

Caughley, G (1977). *Analysis of Vertebrate Populations.* John Wiley & Sons, Chichester.

Central Statistical Services (1994). *Provincial Statistics 1994 Part 5: KwaZulu/Natal, CSS Report No 00-90-05*. Central Statistical Services, Pretoria.

Cleminson, T (1993). *Quantification of the resource base of and harvest impact on coastal hardwood species by a rural community*. Unpublished Report.

Coe, MJ, Cumming, DH and Phillipson, J (1976). Biomass and Production of Large African Herbivores in Relation to Rainfall and Primary Production. *Oecologia* **22**, 341-354.

Colye, RG (1977). *Management System Dynamics*. John Wiley & Sons, London.

Cumming, DHM (1993). Conservation Issues and Problems in Africa. In: *Voices from Africa: Local Perspectives on Conservation*. Lewis, D and Carter, N (eds). World Wildlife Fund, Washington. 23 - 47.

Cyrus, DP (1992). Ornithology. In: *Environmental Impact Assessment: Eastern Shores of Lake St Lucia Kingsa/Tojan lease Area: Specialist Reports, Volume 1, Part 1*. CSIR Environmental Services. CSIR Environmental Services, Pretoria. 347-373.

Cyrus, DP, Robso, NF, Cooper, KH, Bruton, MN and Bennett, G (1980). The Birds of Maputaland*: A checklist and general comments*. In: *Studies on the ecology of Maputaland*. Bruton, MN and Cooper, KH (eds). Rhodes University, Grahamstown and the Natal Branch of the Wildlife Society, Durban. 307 - 321.

Department of Agriculture KwaZulu-Natal, Division of Agricultural Economics (1995). *Combud Enterprise Budgets KwaZulu-Natal July 1995*. Department of Agriculture, Pretoria.

Data Research Africa (1995). *The structure and growth of the regional economy of KwaZulu/Natal: A Quantitative forecast and a Qualitative Assessment*. Data

Research Africa, Durban.

Du Toit, JG and van Rooyen, J (1989). Trophy Hunting. In: *Game Ranch Management.* Bothma, J du P (ed). JL van Schaik, Pretoria. 319-328.

Edwards, D and Hamson, M (1989). *Guide to Mathematical Modelling.* Macmillian, London.

Financial Mail (1994). Negotiating a Barren Beauty. National Parks Board: A survey. *Supplement to the Financial Mail,* **134(8)**, 13.

Fowler, CW and Smith, TD (eds) (1981). *Dynamics of Large Mammal Populations.* John Wiley & Sons, New York.

Fryxell, JM, Mercer, WE and Gellately, RB (1988). Population Dynamics of New Foundland Moose using cohort analysis. *Journal of Wildlife Management,* **52(1)**, 14-21.

Goodman, PS and Blok, R (1996). *Makasa Nature Reserve Concept Plan: Draft.* Unpublished Report

Grimsdell, JJR (1973). The Reproduction in the African Buffalo, Syncerus Caffer, in Western Uganda. *Journal of Reproduction and Fertility,* Supplement **19**, 301-316. As cited by Carmichael, IH, Patterson, L, Drager, N amd Breton, DA (1977) Studies on Reproduction in the African Buffalo (Syncerus Caffer) in Botswana. *South African Journal of Wildlife Research,* **7(2)**, 45-52.

Grimsdell, JJR (1969). *Ecology of buffalo, Syncerus caffer, in Western Uganda.* PhD Thesis, Cambridge.

Haefner, JW (1996). *Modelling Biological Systems: Principles and Applications.* Chapman and Hall, New York.

Lande, R (1988). Demographic models of the northern spotted owl (*Strix ocidentlalis caurina*) *Oecologia* **75**, 601 - 607.

Ledger, HP, Sacks, R and Smith, NS (1967). Wildlife and food production. *World Reveiw of Animal Production*, **3(11)**, 13-37. As cited by Williamson, G and Payne, WJA (eds) (1978) An introduction to Animal Husbandry in the Tropics (3rd Edition). Longman, London.

Lindenmayer, DB, Clark, TW, Lacy, RC and Thomas, VC (1993). Population Viability Analysis as a Tool in Wildlife Conservation Policy: With Reference to Australia. *Environmental Management*, **17(6)**, 745-758.

Mace, GM and Lande, R (1991). Assessing Extinction Threats: Toward a Reevaluation of IUCN Threatened Species Categories. *Conservation Biology*, **5(2)**, 148 - 157.

Maguire, LA, Seal, US and Brussard, PF (1987). Managing critically endangered species: the Sumatran rhino as a case study. In: *Viable populations for conservation*. Soule, ME (ed). Cambridge University Press, Cambridge. 141 - 158.

Manson, AD, Camp, KGT and Smith JMB (1995). *Soil Potential and Land Capability Course Notes*. Cedera Report No N/A/95/46. KwaZulu-Natal Department of Agriculture, Cedera.

Maphosa, G (1991). Campfire and Rural Development in Bulilimanangwe - Zimbabwe. *Environmental Education Bulletin* **5**, 26-30.

Maud, RR (1980). The Climate and Geology of Maputaland. In: *Studies on the ecology of Maputaland*. Bruton, MN and Cooper, KH (eds). Rhodes University, Grahamstown and the Natal Branch of the Wildlife Society, Durban. 1-7.

May, RM (1991). The role of ecological theory in planning re-introduction of endangered species. In: *Beyond Captive Breeding: Re-introducing Endangered Mammals to the Wild.* Gipps, JHW (ed). Clarendon Press, Oxford. 145-163.

Mountain, A (1990). *Paradise under Pressure: St Lucia, Kosi Bay, Sodwana, Lake Sibaya, Maputaland.* Southern Book Publishers, Johannesburg.

Neethling, D (1996). One of the best of the Big 5. Farmer's Weekly. **October 18**. 15-17.

Norton, PM (1994). Simple spreadsheet models to study population dynamics, as illustrated by a mountain reedbuck model. *South African Journal of Wildlife Research*, **24(4)**, 73-81.

Phillips, J (1973). *The agriculture and related development of the Tugela basin and its influent surrounds.* Town and Regional Planning Report, Vol 19. Natal Town and Regional Planning Commission, Pietermaritzburg.

Pienar, U de V (1969). Observations on the developmental biology, growth and some aspects of the population ecology of African buffalo in the Kruger National Park. *Koedoe,* **12**, 29-52

Prins, HT (1996). *Ecology and Behaviour of the African Buffalo.* Chapman and Hall, London.

Safari Club International (1987). *SCI Record Book of Trophy Animals: Africa Field Edition. Edition VI, Volume I.* Safari Club International, Tucson.

Saltz, D (1996). Minimizing Extinction Probability due to Demographic Stochasticity in a

Reintroduced herd of Persian Fallow Deer *Dama dama mesopotamica*. *Biological Conservation*, 75, 27 - 33.

Shaffer, ML (1981) Minimum Population Sizes for Species Conservation. *BioScience*, **3(2)**, 131-134.

Sinclair, ARE (1977). *The African Buffalo: A study of Resource Limitation of Populations*. The University of Chicago Press, Chicago.

Skinner, JD and Smithers, RHN (1990). *The mammals of the Southern African Subregion*. University of Pretoria, Pretoria.

Smith, SJ and Halse, ARD (eds) (1995). *Rowland Ward's Records of Big Game XXIV Edition*. Rowland Ward Publications, Houghton.

Starfield, AM and Bleloch, AL (1986). *Building Models for Conservation and Wildlife Management*. Macmillian Publishing Company, New York.

Sylven, S (1995). Moose Harvest Strategy to Maximise Yield Value for Multiple Goal Management - A Simulation Study. *Agricultural Systems* **49**, 277-298.

van Rooyen, AF (1994). Harvesting Strategies for impala using computer simulation. *South African Journal of Wildlife Research*, **24(4)**, 82-88.

van Rooyen, N (1989). Handling of Trophies. In: *Game Ranch Management*. Bothma, J du P (ed). JL van Schaik, Pretoria. 337-374.

Western, D and Wright, RM (1994). The Background to Community-based Conservation. In: *Natural Connections: Perspectives in Community-based Conservation*. Western, D, Wright, RM and Strum, SC (eds). Island Press, Washington. 1-13

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