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THE EFFECTS OF ARTIFICIAL CONTROL ON THE FERAL CAT FELIS CATUS LINNAEUS POPULATION ON MARION ISLAND

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The effects of artificial control on the feral cat *Felis catus* Linnaeus population on Marion Island

by

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ABSTRACT

Hunting was used as one method in a long-term campaign to eradicate feral cats on sub-Antarctic Marion Island. A total of 872 cats were shot during 14 725 man-hours over four years. Accurate estimation of cat numbers was not possible, but cats sighted per hour of night hunting was a reliable index of density. Hunting resulted in a marked decrease in density, but became ineffective at low densities and gin trapping was incorporated into the programme. Eighty cats were trapped. Fecundity decreased with the decrease in cat density. Birds decreased significantly in the diet of cats, ascribed to decreased availability as a result of cat predation. Chicks formed a substantial proportion of birds taken. Breeding success of two burrowing petrel species increased with the decrease in cat numbers. Hunting successfully removed large numbers of cats and recovery of bird populations appears likely. The prospects of eradicating the cats are good.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

Sub-Antarctic islands are biologically unique owing to their volcanic origin and extreme isolation. The result of their isolation is poor species diversity and an impoverished fauna and flora. These island species have evolved in the absence of grazing or predation and they are thus highly vulnerable to disruption by aggressive alien species (Walton 1986).

The indigenous fauna of sub-Antarctic islands uniquely lacks mammalian herbivores and carnivores, and consequently these islands have been occupied by vast populations of burrowing or ground-nesting seabirds. In the past their isolation has been their protection, but having evolved in the absence of terrestrial predators these birds possess few or no defence mechanisms against predation, and their nesting habits also offer little protection.

Populations of feral domestic cats *Felis catus* have become established on many islands, six of which are classified as sub-Antarctic (Holdgate 1966; Clark & Dingwall 1985; Leader-Williams 1985)(Figure 1). The introduction and spread of cats on sub-Antarctic islands has been ecologically disastrous, and ground-nesting seabird populations have declined dramatically or become extinct on all these (Holdgate 1966; Jones 1977; Taylor 1979; Pascal 1980; Van Aarde 1980; Brothers 1984; Van Rensburg 1985; Veitch 1985; Schramm 1986; Fugler, Hunter, Newton & Steele 1987; Imber 1987; Weimerskirch, Zotier & Jouventin 1988).

Five domestic cats were introduced to Marion Island as pets in 1949 and by 1975 an estimated 2139 ($\pm$ 290 S.E.) feral cats were killing approximately 450 000 burrowing petrels per year (Van Aarde 1978; 1980). The population was estimated at 3405 cats in 1977 (Van Aarde 1978). The local extinction by 1965 of the common diving petrel *Pelecanoides urinatrix* was ascribed to cat predation (Williams 1984), while the

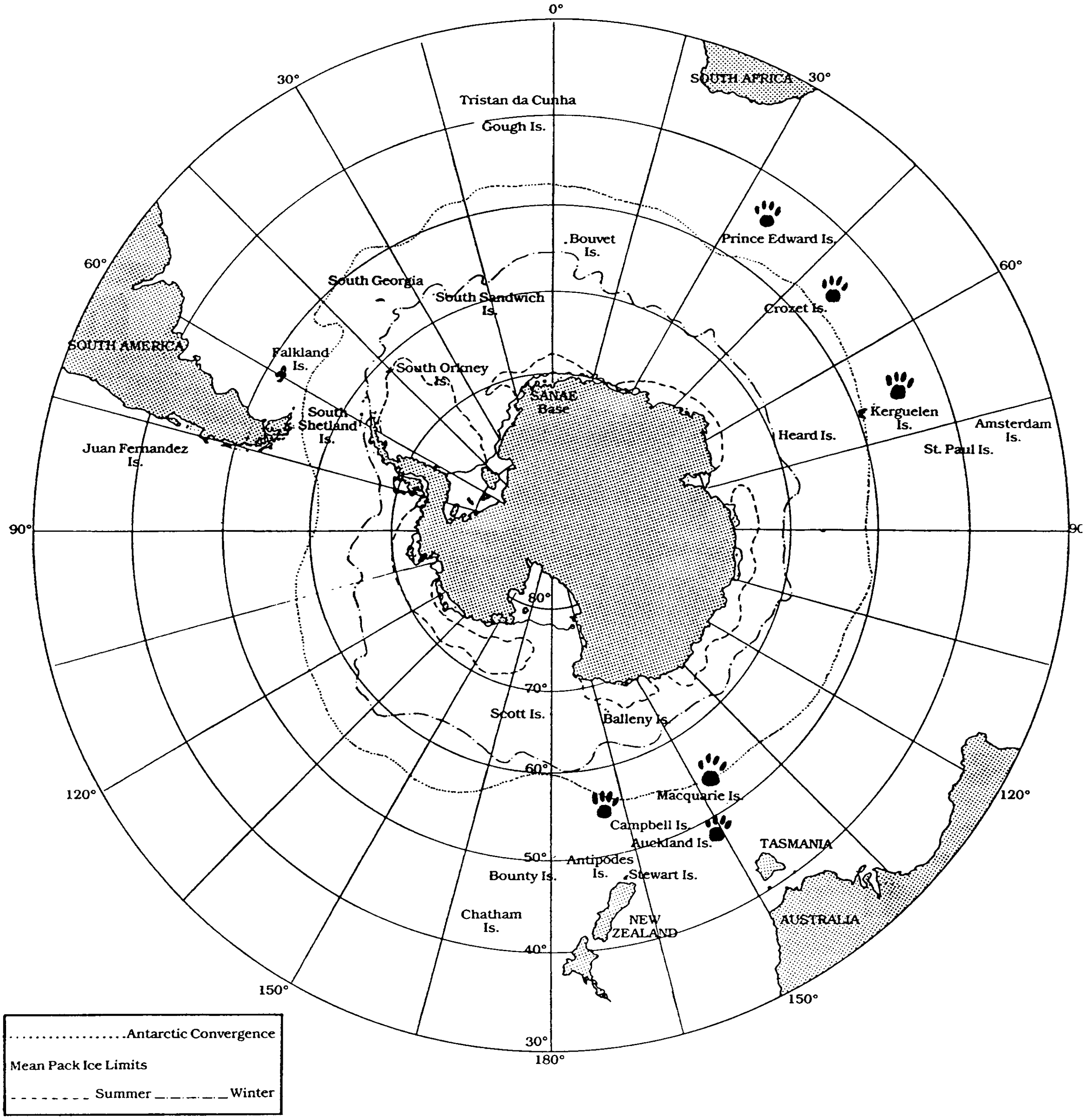

Figure 1: The southern islands, showing Marion Island (Prince Edward group) and other sub-Antarctic islands where cats have been introduced (paw print indicates the presence of cats).

numbers and breeding success of several other species had declined sharply, particuarly winter-breeding great-winged petrels *Pterodroma macroptera* and grey petrels *Procellaria cinerea* (Schramm 1986; Van Rensburg & Bester 1988*a*; Newton & Fugler 1989), which are classified as vulnerable in the South African Red Data Book - Birds (Brooke 1984).

The house mouse *Mus musculus* is the only other alien mammal found on Marion Island. Mice have been present since before 1818, probably introduced by early sealers (Watkins & Cooper 1986). Mice do not directly affect birds, but apparently have a significant effect on vegetation through seed gathering and predation. They also have a significant influence on invertebrates by predation and consequently on the decomposer subsystem of the island ecosystem (Rowe-Rowe, Green & Crafford 1989; Crafford 1990). Presently there are no plans to attempt controlling the mice.

The southern oceanic islands are of great scientific interest because of their biological uniqueness and as such merit deliberate conservation directed towards preventing the establishment of feral populations and the control or elimination of established populations (Walton 1986). However, the aims of restoration of disturbed islands need to be carefully and sensibly defined (Simberloff 1990). Complete restoration of Marion Island to its former state, before the introduction of alien plants and animals, is impossible. The decline of bird populations on Marion Island was deemed sufficient reason for implementing a programme to eradicate the cat population to allow, as far as possible, the recovery of affected bird populations or the successful immigration of new populations.

When a population has reached pest proportions, four possible management options can be taken. These are no action, occasional control in perpetuity, regular control in perpetuity or eradication (Parkes 1990). Attempts to eradicate cats on islands have met with varied success. Cats have been eradicated from New Zealand islands ranging in size from 28 ha Herekopare Island with 33 cats removed in one month to 2817 ha Little Barrier Island with 151 cats having been killed over four years (Fitzgerald & Veitch 1985; Veitch 1985). Cats were thought to have been completely removed from 400 ha Jarvis Island (central Pacific Ocean) where 120 cats were killed in six weeks (Rauzon 1985), but a programme on sub-Antarctic Macquarie Island (12 000 ha) where 522 cats were removed over ten years (Brothers & Copson 1988) failed to eradicate the cats.

The very large area over which cats occur (19 000 ha), the rugged terrain which is difficult to traverse, combined with long distances and adverse weather, and the substantial logistic support required, militated against eradication as a viable option on Marion Island. However, detailed ecological knowledge (Van Aarde 1978, 1979, 1980, 1983), the success of biological control in initially reducing the population (Van Rensburg 1986; Van Rensburg, Skinner & Van Aarde 1987), the feasibility of hunting as a secondary control measure (Van Rensburg & Bester 1988*b*) and knowledge of other methods (e.g. Veitch 1980, 1985; Bell 1989), most of which had previously been tested on the island (Erasmus 1979), suggested that eradication was possible on Marion Island.

Measures to control the cat population were initiated in 1977. At the high densities present on Marion Island at that time (Van Aarde 1979), biological control with the viral disease feline panleucopaenia was the most efficient and cost effective method (Erasmus 1979). The disease resulted in a decrease from an estimated 3405 cats in 1977 to 615 (± 107 S.E.) in 1982 (Van Rensburg *et al.* 1987). However, evidence suggested that biological control was becoming ineffective and that the rate of decline appeared to be slowing and the population stabilising (Van Rensburg *et al.* 1987). With the population reduced to approximately 600 cats mechanical control by means of hunting became feasible, and after a trial hunting experiment (Van Rensburg & Bester 1988*b*) a full scale hunting effort was initiated in the austral spring of 1986. Gin-trapping was incorporated into the programme during the winter of 1989.

The Marion Island cat programme comprised a number of distinct phases, of which the present is the latest. The objective of the present phase was to attempt to finally eradicate the cat population by mechanical means. In order to assess the effectiveness of the eradication effort the following questions were posed:

1) how was the effectiveness of mechanical control influenced by changes in population size?

2) what were the effects of feline panleucopaenia and mechanical control (intensive hunting) on the density, distribution, age structure and sex ratio of the population?

3) did the diet of cats change with changes in population size?

4) how did predation by the present cat population affect the survival of the chicks and fledgelings of burrowing petrel species?

It must be appreciated that this work was carried out within the constraints of a management operation, with the consequent lack of rigorous experimental procedures. In addition, much of the data collection and analysis were carried out in such a way as to make the results comparable with previous work on this cat population.

This thesis reports on the eradication programme conducted from the beginning of the first hunting season in 1986 to the end of the 1989-90 season. However, for completeness, the detailed history of the programme presented in Chapter 2 covers the period from 1962, when international concern was first voiced about the effects of man and introduced species on sub-Antarctic islands, up to the incorporation of poisoning into the eradication programme in 1991.

CHAPTER 2: HISTORY OF THE CAT ERADICATION PROGRAMME ON MARION ISLAND

This chapter reviews all information on the history of the cat programme on Marion Island to provide the scientific basis for the present report on the eradication campaign. Much of this information is derived from unpublished minutes of meetings, reports, letters and theses.

In June 1962, at the 13th Conference of the International Council for Bird Preservation, concern was voiced about the effects of man and domestic animals on the avifauna of sub-Antarctic islands, and an appeal was made to governments to recommend measures to protect and conserve sub-Antarctic fauna and flora. As a result of this appeal Dr E.M. Van Zinderen Bakker was asked at the first meeting of the South African Scientific Committee on Antarctic Research (SASCAR) to establish the effects of domestic cats, which had been introduced to Marion Island in 1949, on the bird populations of the island (Unpublished SASCAR minutes, June 1963). In October 1965 he reported that the feral cat population was not large enough to be threatening bird populations, and that they were actually contributing to the control of mice in the base station (Unpublished SASCAR minutes, October 1965). However, ten years later the cats were considered to be having a detrimental effect on bird populations, and an investigation of the cats was recommended (Condy 1974). With proposals of Anderson & Condy (1974) as guidelines SASCAR approved a project on the cats, stressing that the primary aim of the programme was to eradicate the population.

Since the programme required knowledge of the ecology of the population, a detailed study of feeding, habitat selection and reproduction in the cat population was carried out from December 1974 to April 1976 (Van Aarde 1977, 1978, 1979, 1980, 1983, 1984).

While this investigation of the ecology of the population was in progress plans were already being made for the first step towards eradicating the cats. At an *ad hoc* discussion in June 1975 it was agreed that a multi-faceted effort would be necessary to eradicate the cats from Marion Island. Two methods were considered most likely to be successful, namely biological control with cat influenza, and poisoning. The Department of Infectious Diseases in the Faculty of Veterinary Science, University of Pretoria, was asked to prepare a report as to what a cat 'flu programme would entail. At the 2nd *ad hoc* meeting in July 1975 a sub-committee of SASCAR was appointed to advise on biological control of the cat population with the viral disease feline panleucopaenia (FPL). Meanwhile, at the 4th meeting of the Work Group for the Monitoring of Sea Pollution in July 1975 it had been strongly recommended that Marion Island not be disturbed in any way, so as to provide a reference point for monitoring pollution. Suitable control measures had to be found with this recommendation in mind.

By March 1976 research on the feasibility of FPL as a biological control agent was well under way and a proposal for a biological control programme using FPL was presented (Howell 1976). FPL was deemed the most appropriate technique at the high cat densities present at that time, and it was decided that the proposed programme should be implemented. Since July 1975 all trapped cats were held alive in cages on the island for use as carriers for the release of FPL, and by March 1976 more than 20 cats were being held in captivity. It was recommended that a detailed motivation for a biological control programme using FPL be prepared for SASCAR to consider, and in July 1976 the final decision was taken to release FPL. However, even before the disease was introduced it had been recognised that FPL would not remove all of the cats and that an integrated control programme incorporating various methods would be necessary. The *ad hoc* Task Group on the Use of Poisons and Other Methods for the Control of Cats and Mice on Marion Island considered a number of methods, some of which were to be tested for feasibility for use on the island, while others were rejected as unsuitable.

With cats being caught and held in captivity during the winter of 1976 (Bester 1976), the catching and live trapping of cats was continued in earnest in November 1976. In March 1977, 96 cats held in captivity were innoculated with the FPL virus and over a period of three days released at 93 locations around the island using dedicated helicopter support (Erasmus 1979). From November 1976 to May 1978 research was undertaken to establish the effect of the release of the disease on the cat population. The efficacy of several other control methods was tested at the same time.

Cage traps had been used previously on the island (Van Aarde 1975*a,b*, 1976; Bester 1976; Keith 1978; Scholtz 1978) and were again tested by Erasmus (1979). The poor efficiency of these traps was clear. Live trapping gave a low success rate of 702.4 hours per cat and it was concluded that trapping had little value as an eradication method. The main reason suggested for the low trapping success was that, the cats being predators and not scavengers, no successful attractant bait could be found (Erasmus 1979). Twenty different attractant baits were tested on the island, including baits used for caracal *Felis caracal* in South Africa (Van Aarde 1975*b*), and others that had been specially formulated (Van Aarde 1975*b*; Bester 1976; Keith 1978; Scholtz 1978). Limited success was obtained with natural prey of cats and raw liver.

Sodium monofluoroacetate (10-80) was selected as a possible poison as it posed little threat of pollution and according to the literature birds have higher tolerances than mammals. Toxicity trials were carried out on the island on likely non-target birds, but it was found that these all had similar lethal doses to cats, and it was recommended that experiments with 10-80 be abandoned (Erasmus 1979). The massive campaign that would be necessary to lay poison baits, and the lack of suitable bait, also made poisoning impractical. It was however acknowledged that poisoning could perhaps be used under very specific circumstances (Keith 1978; Scholtz 1978; Erasmus 1979).

Cadmium and lithium in bait were considered as sterilising agents, but following the recommendation that the island be kept free of pollution this method was rejected. The lack of suitable bait would also make this method impractical (Unpublished SASCAR minutes, March 1976).

During three separate hunting periods (Van Aarde 1977; Keith 1978; Erasmus 1979), day hunting had removed 190 cats at 2.64 hours per cat (Erasmus 1979). Keith (1978), who had used a .22 calibre rifle, concluded that day hunting was unsuccessful and too time consuming, and that hunting at night was dangerous. Van Aarde (1977) had used a .410-gauge shotgun and this was considered to be a more effective weapon than a .22 rifle. There was also doubt as to whether better results would be obtained by hunting at night (Keith 1978).

The use of dogs as cat predators was at first thought to be inappropriate because of the terrain and the possible impact of the dogs on birds. However, it was subsequently decided to test the efficacy of three Jack Russel terriers on the island. This resulted in three cats being killed at a rate of 6.67 hours per cat and the method was dismissed. However, the dogs used had been trained in the hunting of rock hyrax, not cats, and were used on only six days for a total of 20 hours of hunting (Linger 1978). Dogs were again tested on the island in August 1989. One German shepherd and one Labrador were used for three days of hunting, and although unsuccessful it was concluded that dogs would be a useful method for use in conjunction with any other methods (Bekker 1989). He stressed however that dogs would need to be specifically trained to hunt cats and that considerable technical support for the dogs was essential.

Poison gas was unsuitable, due to the honeycomb nature of the terrain with innumerable crevices and burrows, and due to the danger to burrowing birds.

A sticky substance containing poison, applied to burrow entrances and ingested by cats while grooming, was considered too time consuming, costly and impractical due to the number of burrows that would need to be treated. The possibility of poison leaching into the environment, with unknown consequences, was also considered unacceptable.

Catnip oil and jackrabbit distress calls were unsuccessful as attractants (Erasmus 1979).

Coyote-getters were unsuccessful due to lack of suitable attractant bait (Keith 1978; Scholtz 1978).

It is important to note that much of the abovementioned testing was carried out during only seven days on the island in October-November 1978 due to the interruption resulting from an emergency voyage of the relief vessel back to Cape Town. Testing was therefore inadequate and the results not entirely unequivocal.

In February 1978 the opinion had been expressed that the cats could never be eradicated, but that they could be further controlled by a combination of mechanical methods. In August 1978 hunting was proposed as the method of choice, preferably to be implemented as soon as possible. A large hunting team, working for long periods, applying a great deal of effort, would be required to remove as many animals as quickly as possible. Shotguns were the most effective weapons and hunting teams should use these. Hunting at night was attempted, but was unsuccessful because the headlamps did not "hold" cats (i.e. spotlights were not used) and was considered to be too dangerous. It was also recognised before the programme began that hunting, like the disease, would only be partially effective, after which it would be necessary to incorporate other methods.

In the 18 months after FPL was released it was estimated that the cat population had decreased by 53.6%, but despite this decrease bird populations were still being adversely affected (Schramm 1983; Van Rensburg 1986). In 1980, three years after the release of FPL, the Specialist Evaluation Group on Marion Island Cats was formed by SASCAR's Biological Sciences Subcommittee to evaluate the cat situation. The group subsequently recommended that further control, monitoring and applied research were essential, and that an official conservation policy for the Prince Edward Islands be formulated (Unpublished SASCAR minutes, 1980). As a result, a third full scale study was undertaken between April 1981 and May 1983 to determine the then current effect of FPL on the cat population, social structure of and space use by cats, the effect of the remaining cats on bird populations and the cost effectiveness of hunting as a secondary control measure (Van Rensburg 1985, 1986; Van Rensburg *et al.* 1987; Van Rensburg & Bester 1988*a*,*b*). Hunting at night using 12-guage shotguns proved feasible and an intensive hunting programme began in the austral summer of 1986, scheduled to last for three extended summer seasons between August 1986 and May 1989. The delay of three years between the decision that hunting was feasible and the start of the hunting programme was due to the time taken for final reports to be processed and evaluated, proposals to be made and funding to be obtained.

Hunting proved extremely effective but it was soon apparent that the aim of eliminating all the cats by the end of the three year programme would not be realised (Bloomer & Bester in press). An extension to the programme was requested, with a view to also using methods that had been unsuccessful, inappropriate or impractical when the population was large, and to have hunting teams remain on the island during the winter of 1989 (Bester 1988). In 1988 the Department of Environment Affairs solicited an independent evaluation of the eradication programme by the South African National Parks Board. During a short visit to the island in August-September 1988 and based largely on interviews with past and present team members, scrutiny of reports and papers and a necessarily brief period in the field the evaluation team reported the following: that there was a need to eliminate the cats, that the chances of eradication were good, that continued sporadic control would be an unsatisfactory substitute for total elimination, that hunting was dangerous and that the programme did also have some negative environmental impact (Randall & De Vos 1989). They also thought that the cats would not be eradicated by the scheduled end of the programme and recommended that the programme be continued. They supported hunting during winter, that dogs and baits again be tested and that controlled gin trapping and poisoning be used. These methods had previously been inadequately tested when cat densities were high and would possibly prove more appropriate at the low cat density resulting from the intensive hunting campaign.

Towards the end of the third season, with hunting becoming ineffective, other methods had to be applied in conjunction with, and to eventually replace, hunting (Bloomer & Bester in press). Gin trapping was successfully tested in the winter of 1989 and greatly intensified the following year (Bloomer & Bester in press). The use of biological lures imported from the U.S.A. showed that at least some work well at attracting cats (MRI unpublished results). A large scale poisoning campaign, using 10-80 injected into the carcasses of day-old chickens, was initiated in May 1991. The exercise is governed by a very strict and detailed protocol for the use of the poison (Bester & Naude 1991) to minimise the detrimental effects on the biota and the environment, and to safeguard personnel.

CHAPTER 3: CONTROL OF THE CAT POPULATION

INTRODUCTION

According to Veitch (1985), eradication of cats can only be achieved by the combined and persistent use of several methods. To make the operation as economical as possible a quick initial reduction is required, followed by a large and persistent effort, using a combination of methods, to remove the remaining animals.

Very little effort has been expended on the control of cats on sub-Antarctic islands, and attempts to eradicate cats from other islands have met with varied success. Successful cases have been on small continental islands with small cat populations and more hospitable conditions, for example Herekopare Island (28 ha, 33 cats; Fitzgerald & Veitch 1985; Veitch 1985), Little Barrier Island (2817 ha, 151 cats; Fitzgerald & Veitch 1985; Veitch 1985) and Jarvis Island (400 ha, 120 cats; Rauzon 1985). On sub-Antarctic Macquarie Island (12 000 ha) cats were not eradicated after ten years of intermittent control (Brothers & Copson 1988).

While hunting was ineffective as a control measure on Marion Island at the high population density and growth rate prior to biological control with feline panleucopaenia, hunting was considered feasible at the low density and zero growth rate resulting from the disease (Van Rensburg & Bester 1988*b*).

AIMS

The ultimate goal of the control programme on Marion Island was the eradication of the cat population. This chapter describes hunting methods, and determines the effectiveness of the hunting programme and how this was influenced by changes in population size by using various measures of hunting effort and hunting returns. The programme was closely monitored to enable control techniques to be adapted so as to maintain maximum effectiveness. Comparisons were made between hunting seasons and with previous hunting attempts.

STUDY AREA

Marion Island (46°54'S, 37°45'E) is one of the two islands in the Prince Edward group in the southern Indian Ocean (Figure 1). The island has an area of 29 000 ha and comprises three principal regions, namely coastal (0-100 m asl), interior (100-500 m asl) and central montane (500-1230 m asl) regions (Figure 2). The central mountains are covered by snow and ice fields, particularly in winter. Most cats are found in the coastal and interior regions, an area of approximately 19 000 ha.

Marion Island lies in the sub-Antarctic and is continuously subject to low temperatures with little seasonal variation (annual mean 5 °C), strong westerly winds and high humidity. Mean annual precipitation (in the form of rain, sleet and snow) is 2576 mm and is evenly distributed throughout the year. Winter is characterised by more frequent, stronger storms than in summer and a higher occurrence of snow (Schulze 1971).

The island has a tundra biota. Based on physiognomic and topographic characteristics the coastal and interior regions can be divided into six and five habitat types respectively (Van Aarde 1977). Detailed descriptions are given by Van Aarde (1977) and Smith (1987), but features of relevance to the present study can be summarised as follows:

Vegetated black lavas: the well-drained lavas are broken and rugged and dominated by the low-growing fern *Blechnum penna-marina*, while the poorly-drained lavas are marshy, dominated by short grasses and mosses. The vegetated lavas are relatively easily traversed while it is difficult

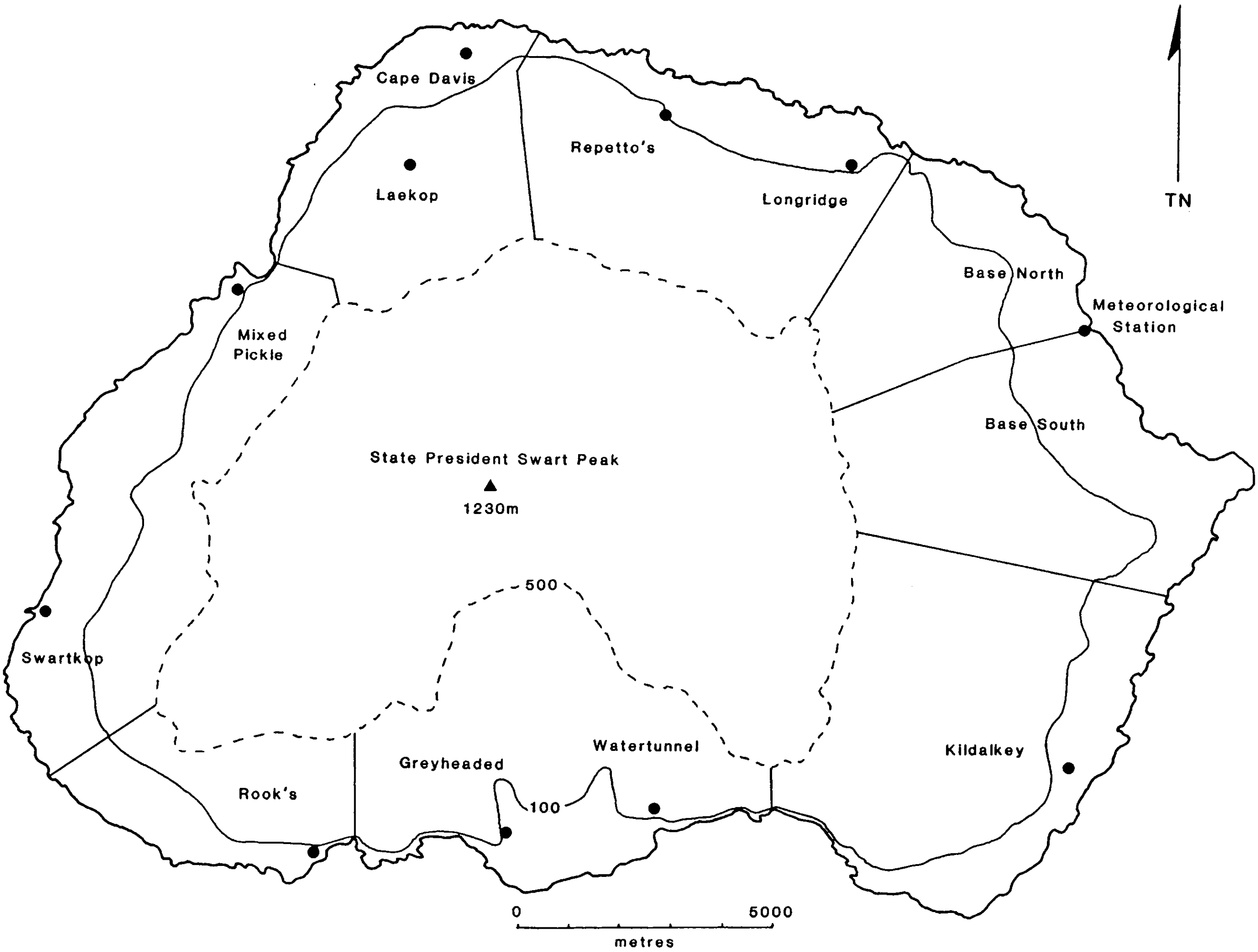

Figure 2: Marion Island, showing hunting areas, field huts (•) and 100 m and 500 m contours.

to cross the marshes.

Bare black lavas: These are extremely broken, rugged and unvegetated. Due to the very loose and brittle nature of the lava they are difficult and hazardous to negotiate.

Grey lavas: the coastal grey lava slopes have deep soils and are dominated by grasses; some are marshy. The inland grey lava highlands are desolate and windswept and the *fjaeldmark* vegetation is dominated by *Azorella selago*. The better-drained grey lavas are generally easily negotiated.

Volcanic cones: their bases are covered by *B. penna-marina* while the upper slopes consist of bare scoria. Although they are steep, the vegetated slopes are fairly easily negotiated but the upper slopes are loose and difficult to walk across.

Cotula hummocks: this coastal community is dominated by *Cotula plumosa*. The terrain is generally flat and easily negotiable.

The absence of high or dense vegetation has facilitated hunting, despite the volcanic nature of the terrain with innumerable holes and crevices in which cats can seek refuge.

MATERIALS AND METHODS

Hunting

Hunting took place on Marion Island during four eight-month summer seasons (1986-87, 1987-88, 1988-89, 1989-90), and one four-month winter season (1989). The terms winter and summer refer to the months between the two annual relief voyages to the island, the first in April (autumn) and the second in August (spring). The use of these terms is retained for simplicity, summer referring to the eight months between August and April and winter to the remaining four months.

Hunting was carried out by teams of two hunters, by eight teams in each of the first three summers, by four teams in the winter and by five teams in the fourth summer. Each team was equipped with a four-shot semi-automatic 12-gauge shotgun (using AAA and SSG shot) and a handheld 100 000 - 200 000 candlepower spotlight operating from a 12V motorcycle battery. Teams hunted from the base station and ten field huts around the island, with one or two huts serving a specific hunting area. The island was divided into eight hunting areas, ranging in size from 1400 ha to 4100 ha, the demarcation of which was based on ease of access, negotiability and natural boundaries (Figure 2). Huts were resupplied by helicopter during relief voyages with food, gas for heating and cooking, and fuel for the portable generators used to charge the batteries.

A grid based on 30 second intervals of latitude and longitude was superimposed on a topographical map of the island and used to determine position (Van Aarde 1979). Each grid square covered an area of 67 ha.

Hunters worked mainly at night, on foot, in reasonably good weather (no mist or heavy rain) and in all but the strongest wind. Hunters did not follow fixed routes, but did attempt to traverse all grid blocks in a hunting area at least once every session in order to cover the island as fully as possible. Day hunting was carried out unsystematically or in search of known cats.

During the first two summers hunting sessions were of 10 days duration followed by four-day rest periods at the base station. During the third summer sessions were about 20 days long with five days off, during the winter 15 days with five days off, and in the fourth summer sessions were 25 days with five days back at base. Hunters were initially rotated after each session with one hunter remaining in an area and the second moving to another area so that one hunter was familiar with the situation from the previous session. Once cat numbers had decreased to levels where few cats were being seen hunters concentrated on areas of the most sightings, but regularly hunted in all other areas. Areas were occasionally left unhunted for up to a month to allow cats to recolonise. With fewer teams present during the winter of 1989 and following summer, each team hunted in more than one area per session, using a combination of hunting and trapping.

Before leaving for Marion Island most hunters were trained in the use of shotguns, and undertook skeet shooting to practise firing at moving targets. Approximately half of each new hunting team took part in a training course on Dassen Island, approximately 50 km north of Cape Town, South Africa. Dassen Island has an area of 222 ha and a population of feral cats. During four days on the island hunters were trained in hunting technique and instructed in safety precautions, recording of data and sample collection. This course, together with a regularly updated field manual (Bester & Van Rensburg 1986) detailing all procedures, prepared teams for the season on Marion Island and contributed to compatibility between data sets from the different seasons.

<u>Trapping</u>

Five walk-in cage traps (Condy, Anderson, Heijnen & Smit 1975), baited with fresh meat or fish and checked daily, were used during the third summer from September 1988 to February 1989. Gin traps (Lane "Ace" rabbit traps - Lane Hardware Pty Ltd, Gladesville, NSW, Australia) were tested during the winter season (n = 48) and trapping was intensified (96 additional traps) during the summer of 1989-90. Traps were set for individual cats and baited with lures (Rocky Mountain Wildlife Products, LaPorte, Colorado, USA) or a variety of tinned fish (with tins punctured to release the scent but prevent mice *Mus musculus* from removing the bait). Traps were set at entrances to refuges and lairs, near sites of activity, in crevices, passages between rocks or vegetation forming natural walkways, and riverbeds. Traps were also set in the entrances of "igloos" constructed from rocks and vegetation, with the bait or lure placed inside the chamber. The methods were similar to those of Veitch (1985), who provides a detailed discussion of trapping cats. Traps were serviced as often as possible but too infrequently to record meaningful trapping times. Time taken to service traps was not included in hunting times and trapped cats were recorded separately from shot cats.

Recording of data

For every hunt the following data were recorded: date, time at start and end, duration, grids traversed, number of cats seen, shot at, hit, wounded and killed, time, location and habitat type of all sightings, and where possible age classes and coat colour patterns. Ages were recorded as juvenile, subadult or adult based on body size (Van Aarde 1977). Coat colour pattern was recorded as black, or striped or blotched tabby, and whether piebald spotting was present (Van Aarde & Robinson 1980). It was arbitrarily assumed that 50% of wounded cats would also die. Sightings thought to be of the same individuals were back-referenced to previous sightings, to avoid including cats in population estimates more than once.

Killed cats were weighed, classified according to age and colour as described above, and sexed. Blood and samples of spleen, liver, small intestine and lymph gland were collected for epidemiological studies. Ten millilitres of blood were drawn (from the heart if possible) and allowed to clot. The serum was transferred to glass tubes and stored in a cool place prior to centrifugation at the base station. The serum was frozen. Skulls were collected for accurate age determination (see Chapter 4) and stomachs for diet analysis (see Chapter 5). All samples were frozen at the base station until analysis. Serum and tissue samples were returned to South Africa and await analysis by the Department of Infectious Diseases, Faculty of Veterinary Science, University of Pretoria. Pregnancy in adult females was noted and the number and sexes of foetuses recorded.

At the end of each hunting session all data were immediately processed to monitor coverage of grid blocks, compile hunting statistics for briefing hunters before the commencement of each session and for later evaluation of the programme.

"Huntability" was defined as the percentage of cats sighted that were shot at, "hunting efficiency" as the percentage of cats shot at that were hit, "killing efficiency" as the percentage of those hit that were killed and "hunting success" as the percentage of those seen that were killed (Van Rensburg & Bester 1988*b*). Sighting rates per session are given as a mean for the number of areas hunted during each session. Statistical analyses were by chi-square and student's *t*-tests (Zar 1984). All chi-square tests were carried out on original observations, although results are presented as percentages.

RESULTS

Details of hunting effort and returns for night hunting and day hunting are given in Table 1. A total of 14 725 man-hours were hunted during 4 486 hunting trips over the five seasons. Eight hundred and seventy two cats were shot dead and in the last three seasons an additional 80 were trapped. By assuming that 50% of wounded cats would die it is estimated that an additional 172 were killed.

Night hunting

Changes between seasons

Between the first and fourth summers cats sighted per hour hunted decreased from 0.50 to 0.099 and kills per hour decreased from 0.14 to 0.016. Sighting rates and kill rates during winter were the same as for the previous summer. Huntability and hunting success decreased

Table 1: Hunting effort and hunting returns for night hunting and day hunting on Marion Island from 1986 to 1990 (N = night, D = day).

	86-87		87-88		88-89		WINTER		89-90		TOTAL	
	N	D	N	D	N	D	N	D	N	D	N	D
Hunting trips	897	430	859	176	932	206	186	9	501	290	3375	1111
Hours hunted	2768	1051	2999	493	3437	481	708	19	1933	836	11845	2880
Cats seen*	1395	135 (35)	786	42 (12)	603	16 (9)	119	0	191	6	3094	245
Cats shot*	393	50 (15)	174	22 (10)	124	12 (5)	35	0	31	1	757	115
Cats trapped	-		-		2		15		63		80	
TOTAL KILLED	458		206		143		50		95		952	

* Figures in parentheses are numbers seen and shot outside timed day hunting trips

significantly over the four summers (χ^2_3 = 58.23; $p < 0.001$ and χ^2_3 = 21.40; $p < 0.001$ respectively) while hunting efficiency and killing efficiency did not change (Table 2). Huntability and hunting success during winter were higher than for any summer except the first (Table 3).

There was no significant difference in sighting rate between the end of the first season and the start of the second (t_{16} = 0.645; $p >$ 0.05), nor between the end of the second season and the start of the third (t_{20} = 2.026; $p > 0.05$).

Changes within seasons

Figure 3 presents sighting rates for each season. Sightings per hour decreased during each summer and increased in winter (least-squares line of best fit; R^2 = 0.586, 0.337, 0.213 and 0.260 for each summer, 0.309 for winter). The decrease in sighting rate in the first summer was highly significant (p = 0.0003). During the second and third summers the decreases were not significant (p = 0.015 and p = 0.179 respectively). It is clear that the slopes of the lines become less steep each summer.

Within summers no consistent patterns in changes in huntability, killing efficiency, hunting efficiency and hunting success were evident. Hunting success and efficiency increased in all four summers. Huntability decreased in the first, second and fourth seasons but increased in the third, while killing efficiency increased in the first and third seasons but decreased in the second and fourth.

Day hunting

There were marked differences between night hunting and day hunting (Table 3). Sighting rates were from three to 14 times higher at night than during the day. In the first and fourth summers kill rates were three and 16 times higher at night than during the day, while day and night were similar in the second and third summers. Hunting success was

Table 2: Hunting details for night hunting on Marion Island from 1986 to 1989.

	86-87	87-88	88-89	WINTER	89-90
Huntability % (shot at/sighted)	44	32	30	37	25
Hunting efficiency % (hit/shot at)	79	80	79	81	85
Killing efficiency % (killed/hit)	80	85	86	92	76
Hunting success % (killed/sighted)	28	22	21	29	16

much higher for day hunting in the first three summers and similar to night hunting in the fourth summer.

Trapping

Two cats were caught in cage traps at 1 473 trap-hours per cat. Fifteen cats were caught in gin traps during three months of winter trapping, representing 30% of the 50 cats killed during winter. In the fourth summer, 66% (63 of 95) were trapped. All non-target species caught in gin traps from May 1989 to May 1990 are listed in Table 4.

DISCUSSION

The absence of reliable population estimates before and during the present hunting campaign (see Chapter 4) precludes direct assessment of the effects of hunting. However, since cats sighted per hour hunted at night is considered to be the most reliable index of density, the decrease in sightings per hour (despite increases in hunting effort) is a measure of the population decline due to hunting. From extensive experience it is believed that increased wariness and learned avoidance

Table 3: Sightings per hour, kills per hour and hunting success for night hunting and day hunting on Marion Island from 1986 to 1990 (N = night, D = day).

	86-87		87-88		88-89		WINTER	89-90	
	N	D	N	D	N	D	N	N	D
Sightings per hour	0.50	0.13	0.26	0.09	0.18	0.03	0.17	0.099	0.007
Kills per hour	0.14	0.05	0.06	0.05	0.04	0.03	0.05	0.016	0.001
Hunting success %	28	57	22	72	21	68	29	16	17

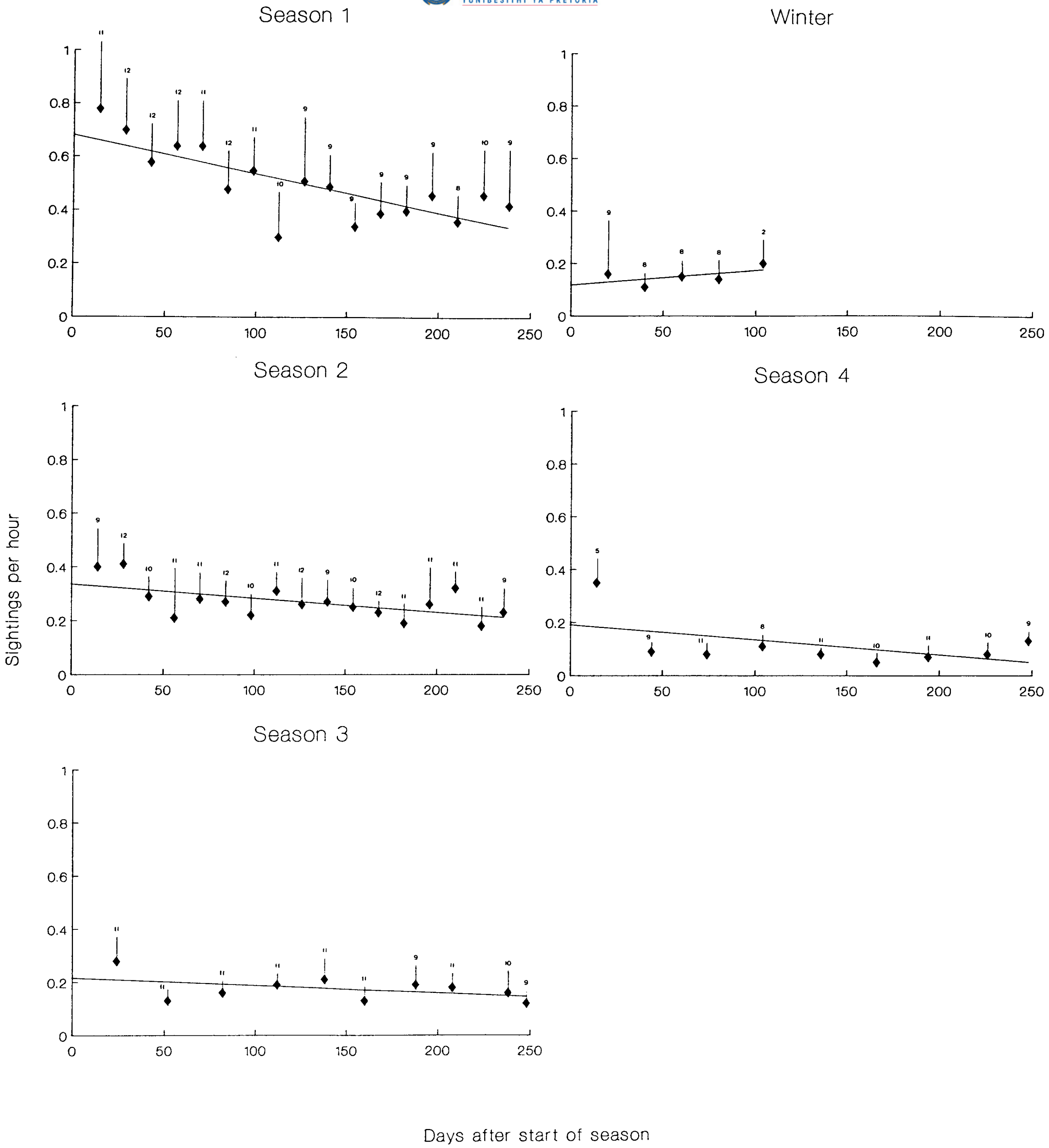

Figure 3: Number of cats sighted per hour of night hunting per session during each of five hunting seasons on Marion Island. (Vertical bars = plus one standard deviation, numbers above bars = number of areas hunted per session).

Table 4: Non-target species caught in gin traps on Marion Island from May 1989 to May 1990.

Species	Number
Subantarctic skua *Catharacta antarctica*	22
Salvin's prion *Pachyptila salvini*	9
Blue petrel *Halobaena caerulea*	3
Lesser sheathbill *Chionis minor*	3
White-chinned petrel *Procellaria aequinoctialis*	2
Rockhopper penguin *Eudyptes chrysocome*	1
House mouse *Mus musculus*	23

of hunters by cats will not affect the number of sightings, but will increase the approach distance and therefore decrease the rate of killing cats. The significant decrease in huntability as well as the disparity between the decreases in sighting rates and kill rates support this.

The increase in sightings per hour over winter is ascribed partly to the increased occurrence of snow, allowing tracks to be followed until a cat was sighted, and to hunters concentrating on areas where most cats were seen. The presence of snow also increased huntability and hunting success by allowing persistent tracking and a greater chance of relocating and killing cats. It is thought that the redeployment of six experienced hunters from the previous summer also led to greater hunting success due to their intimate knowledge of the island and of cat habits.

Hunting efficiency and killing efficiency are reflections of the skill of the hunters, and these remaining constant over the five seasons is ascribed to similar levels of skill of the different teams. However, during the course of a season, experience of hunting and tracking, and knowledge of cat behaviour, all combine to increase the skill and therefore success of the hunters. Marksmanship also improves with practise. This is reflected in the increases in hunting efficiency in each summer and killing efficiency in the first and third summers.

The marked differences between night hunting and day hunting are the result of the cats being largely nocturnal (Van Rensburg 1986) and easier to spot at night. Hunting success is however much higher by day because there is no spotlight to advertise the hunter's presence and hunting takes place under conditions favouring stealthy approach. However, since seeing cats at night improves the chances of killing cats when the area is revisited during the day, the similar kill rates recorded for day hunting and night hunting after the first season do not imply that day hunting is as efficient as night hunting.

Since areas that were apparently cleared of most cats were recolonised after leaving the area unhunted, it appears that cats in marginal habitat (high altitude and less suitable terrain) colonise favourable areas on finding them less densely populated. This tended to concentrate cats in a smaller area. In winter cats move down to lower elevations which also concentrates them, another point in favour of also hunting during winter. Only 12 cats were killed above 500 m; Van Aarde (1979) found most cats below 450 m due to lack of prey and relatively inhospitable conditions at higher altitudes. Initially most hunting took place below about 500 m, but hunters were obliged to hunt higher than this as cats became scarcer at lower elevations.

To eradicate a pest the rate of removal must be higher than the population's rate of increase (Van Rensburg *et al.* 1987; Parkes 1990). It had been recognised from the outset that the effectiveness of biological and mechanical control would be density dependent. Feline panleucopaenia would only be partially effective, after which it would no longer maintain the population decline. This would also be the case with hunting. The progressive reduction in the rates of decline in sighting rates each summer indicated that hunting alone was not removing sufficient cats to continue significantly reducing their numbers, and the number of hours hunted for each cat killed was making hunting ineffective. Financial and logistic constraints precluded increasing hunting effort by employing more hunters. This had been anticipated, and trapping was incorporated into the programme. Mass trapping had proved successful elsewhere (Rauzon 1985, Veitch 1985), and the combination of hunting and trapping was expected to bring the population down to a lower level than hunting alone.

The use of cage traps was impractical as a control measure (Erasmus 1979; this study), but experimentation with gin trapping showed that as the population decreased and more traps were deployed, trapping became a more effective technique than hunting alone, with the percentage of cats trapped increasing from 30% to 60%. An important factor has been the reduced size of the population, allowing individual cats (from night sightings) to be targeted and therefore a great deal of effort to be directed at specific cats. Traps are more effective because they remain set for long periods and are therefore effectively in operation for much longer. This is one of the reasons why trapping has been successful despite being dismissed as a useful control technique during an earlier stage of the cat programme (see Chapter 2).

Inevitably, non-target species will also be trapped, although care in setting traps can reduce these to a minimum. Of the birds present on the island, sub-Antarctic skuas *Catharacta antarctica* and lesser sheathbills *Chionis minor* were the two most likely to be vulnerable to trapping since they are predators/scavengers, very curious and present on the island in small numbers. Those caught during the trapping period represented only 1.25% and 0.15% respectively of their breeding populations on Marion Island (Hunter 1990; Heymann, Erasmus, Huntley, Liebenberg, Retief, Condy & Van der Westhuizen 1987). The death of non-target birds in traps has been accepted because of the long-term benefits of the trapping programme to the avifauna of the island.

CHAPTER 4: EFFECTS OF CONTROL ON THE CHARACTERISTICS OF THE CAT POPULATION

INTRODUCTION

In 1975 the cat population on Marion Island was estimated to consist of approximately 2100 cats (Van Aarde 1983). The age structure of the cat population represented that of an increasing population, with 71% of all cats being younger than three years of age, with a rate of increase of 23% per year (Van Aarde 1983). In 1977 the population was estimated at about 3400 cats (Van Aarde 1983). By 1982, after the introduction of biological control with feline panleucopaenia, the population had decreased by 29% per year to approximately 600 cats (Van Rensburg *et al.* 1987). During 1982 the rate of decrease slowed to 8% per year, indicating the stabilisation of the negative population growth rate (Van Rensburg *et al.* 1987). Feline panleucopaenia had significantly decreased litter sizes and the age structure of the population showed a decrease in subadult numbers.

Once a population has been reduced to very low numbers and is under constant pressure, social structures and breeding are often disrupted (Gosling & Baker 1987; Bell 1989). It had been hoped that, in addition to reducing the number of cats, the hunting programme would have this added effect on the population, making it more vulnerable to eradication.

AIMS

This chapter aims to determine the effects of intensive hunting on the characteristics of the cat population, including size, distribution, age structure and sex ratio.

MATERIALS AND METHODS

Characteristics of the cat population were derived from 857 cats killed during the first three summers (1986-87) of the hunting programme. Characteristics of the 1982 population (Van Rensburg *et al.* 1987) were used as a control against which the effects of hunting were evaluated. Some data from Van Rensburg *et al.* (1987) were not directly comparable with the present data due to differences in interpretation and the original data were therefore re-examined. Results from the three seasons were also compared with one another.

Cat distribution and habitat preference were determined by mapping where cats were killed rather than from where they were seen, to eliminate biases resulting from resightings of individuals. All cats killed during the three seasons were combined for this purpose. Habitat types were plotted on the 1:50 000 geological map of the island (Verwoerd 1971) and their areas calculated using the "Multarea" programme (H.M. Dott, Mammal Research Institute) on a Quantimet 520 image analyser (Cambridge Instruments Ltd, Cambridge, United Kingdom). The number of cats killed in each habitat type was used to calculate the number of kills per hectare.

The skulls collected from 804 killed cats were grouped into age classes on the basis of dentition. Adult cats (>9 months of age) had permanent dentition, subadults (3-9 months) were undergoing tooth replacement and juveniles (<3 months) had deciduous dentition (Van Aarde 1983; Van Rensburg *et al.* 1987). Age determination of adult cats was based on counts of cementum lines in teeth (Van Aarde 1983).

Adult females were examined for signs of lactation and pregnancy and the number and sexes of foetuses noted. To determine mating dates and hence seasonality of breeding, the last possible date of mating for each lactating female was estimated by assuming that cats were collected on the first day of lactation and subtracting a 65-day gestation period (Scott & Lloyd-Jacob 1955) from the dates of their collection. Estimates of the mean number of litters per year were based on the mean prevalence of pregnancy and the duration of visible pregnancy (Caughley 1977). Prevalence of pregnancy, the proportion of adult females pregnant at a particular time, was measured during each month in which pregnancies were found. These were averaged to give the mean prevalence P. The incidence of pregnancy, I, the average number of times a female became pregnant during the year, was found by dividing the mean prevalence of pregnancy by the duration of visible pregnancy. Duration of visible pregnancy was expressed as a fraction of the length of the season in which pregnancies were found; in the cat pregnancy is visible for two months. The Leslie fecundity estimation was used where $F_x = m_x . l_l$, with F_x being the number of female offspring that will survive to enter the first reproductive age class produced per female in each age class, m_x the age specific fecundity and l_l the probability that a newborn will survive to enter the first reproductive age class (Michod & Anderson 1980). Assuming that litter size at birth is equal to observed prenatal litter size, l_l was estimated as *litter size at weaning / prenatal litter size*. Litter size at weaning was determined from kittens found together in the open.

The following methods were used to estimate the size of the cat population at the start of the eradication programme.

Stratified sampling. (a) A population estimate was extrapolated from data collected in a representative, unhunted study area of 3280 ha stratified into coastal (0-100 m asl) and interior (100-450 m asl) zones and divided into 49 equal sized (67 ha) grid blocks (after Van Rensburg *et al.* 1987). The area was traversed during the day along a single route in September 1986 whenever weather permitted (n = 9 days). All cats seen were recorded. Population size was estimated from $\hat{Y} = \sum N_i \bar{y}_i$, where N_i = total number of grid blocks in the ith zone, $\bar{y}_i$ = mean number of cats per grid block in the *i*th zone and $\hat{Y}$ = population estimate (Jolly 1969). Based on coat colour pattern and body size, resightings of individuals were excluded as far as possible. (b) This method was also used with all cats seen during the day in the first season in one hunted area and (c) with all cats seen during the day in the first season over the whole island.

Retrospective estimate. The ages of all cats killed were extrapolated back in time to determine the number present at the start of the hunting programme. Added to this were the number estimated to have died from natural causes (using the Van Rensburg *et al.* (1987) estimates of age-specific natural mortality) and the estimated number of survivors at the end of the third season. The number of survivors was taken to be all sightings in the last month of the third season, during which 11 hunting teams attempted to comprehensively hunt over the whole island.

Manipulation of a density index. Population size was calculated from an index of density (number of cats seen per hour of night hunting for consecutive 10-day periods in the first season) measured before and after the removal of a known number of cats from the population, using $N_1 = I_1C / I_2 - I_1$ where I_1 = index before removal, I_2 = index after removal, C = number removed (removals being negative) and N_1 = population size before removal (Riney 1957).

Comparative statistical analyses were by chi-square, one-way analysis of variance (ANOVA) and Student's *t*-tests (Zar 1984). All chi-square tests were carried out on original observations, although results are presented as percentages.

RESULTS

The localities where all cats were killed (n = 857) during the period under review are shown in Figure 4. Sixty-six percent were found in the coastal region below 100 m, while 99% were found below 500 m.

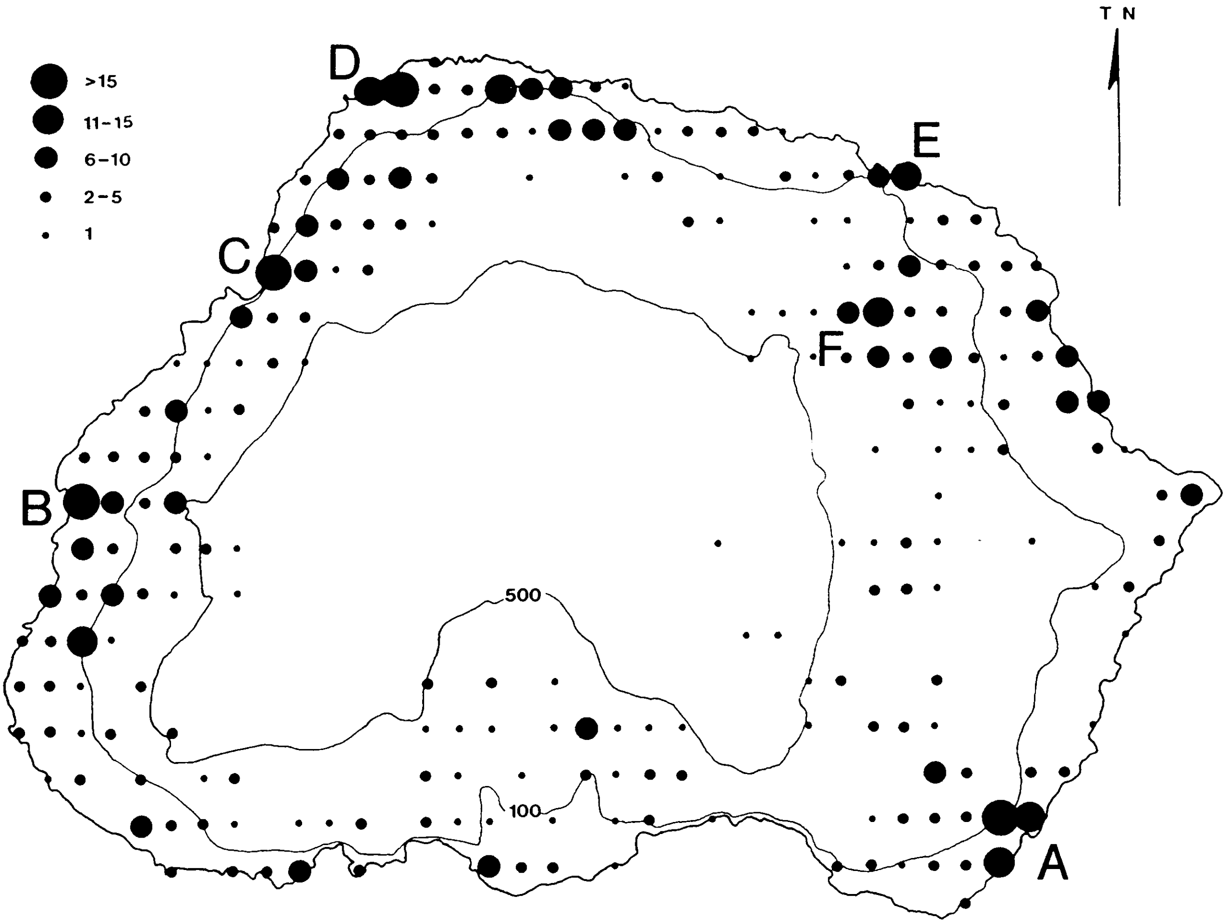

Figure 4: Localities of 857 cats killed on Marion Island from 1986 to 1989. Circles indicate number of cats killed per 67 ha grid block. 100 m and 500 m contours are shown. (See p. 42 for explanation of marked areas).

Number of kills per hectare, being an index of cat density, in each habitat type is shown in Figure 5. The highest density of kills was on coastal volcanic cones, while the remaining coastal habitat types had similar densities of kills, and these were all higher than the densities in corresponding habitat types in the interior region. In the interior areas the highest density was also found on volcanic cones.

The age ratio of the population (adults : immatures) did not differ significantly between 1982 and season one ($\chi^2_1 = 3.51$; $p > 0.05$)(Figure 6). However, within the immature class the proportions of juveniles increased and subadults decreased significantly ($\chi^2_1 = 26.14$; $p < 0.001$). There was a significant change in the age structure of the population over the three seasons ($\chi^2_4 = 31.00$; $p < 0.001$), with the proportions of juveniles and subadults increasing and adults decreasing.

The adult year-class age distribution did not change significantly between seasons ($\chi^2_{14} = 18.33$; $p > 0.1$) but did differ significantly between 1982 and the three seasons combined ($\chi^2_8 = 54.97$; $p < 0.001$)(Figure 7). In contrast to 1982, no age class IX animals were collected in any of the three seasons of hunting, nor were any age class VIII animals collected in the third season.

Overall adult, subadult, juvenile and prenatal sex ratios did not differ significantly from parity. There were no changes in sex ratios as hunting progressed.

Reproductive data for 1982 and the three hunting seasons are presented in Table 5. Mean prenatal litter sizes did not change between seasons (One-way ANOVA; $F_{2;13} = 1.53$; $p > 0.05$). Mean prenatal litter size for the three seasons combined was 4.63 (S.D. = 1.40; $n = 117$; range 1-9), which was not different from the 1982 data (Student's t-test; $t_{121} = 0.22$; $p > 0.05$). Mean prenatal litter sizes did not differ between 1975 and 1982 (Van Rensburg *et al.* 1987).

Mean litter size at weaning did not change between seasons ($F_{2;36}$ =

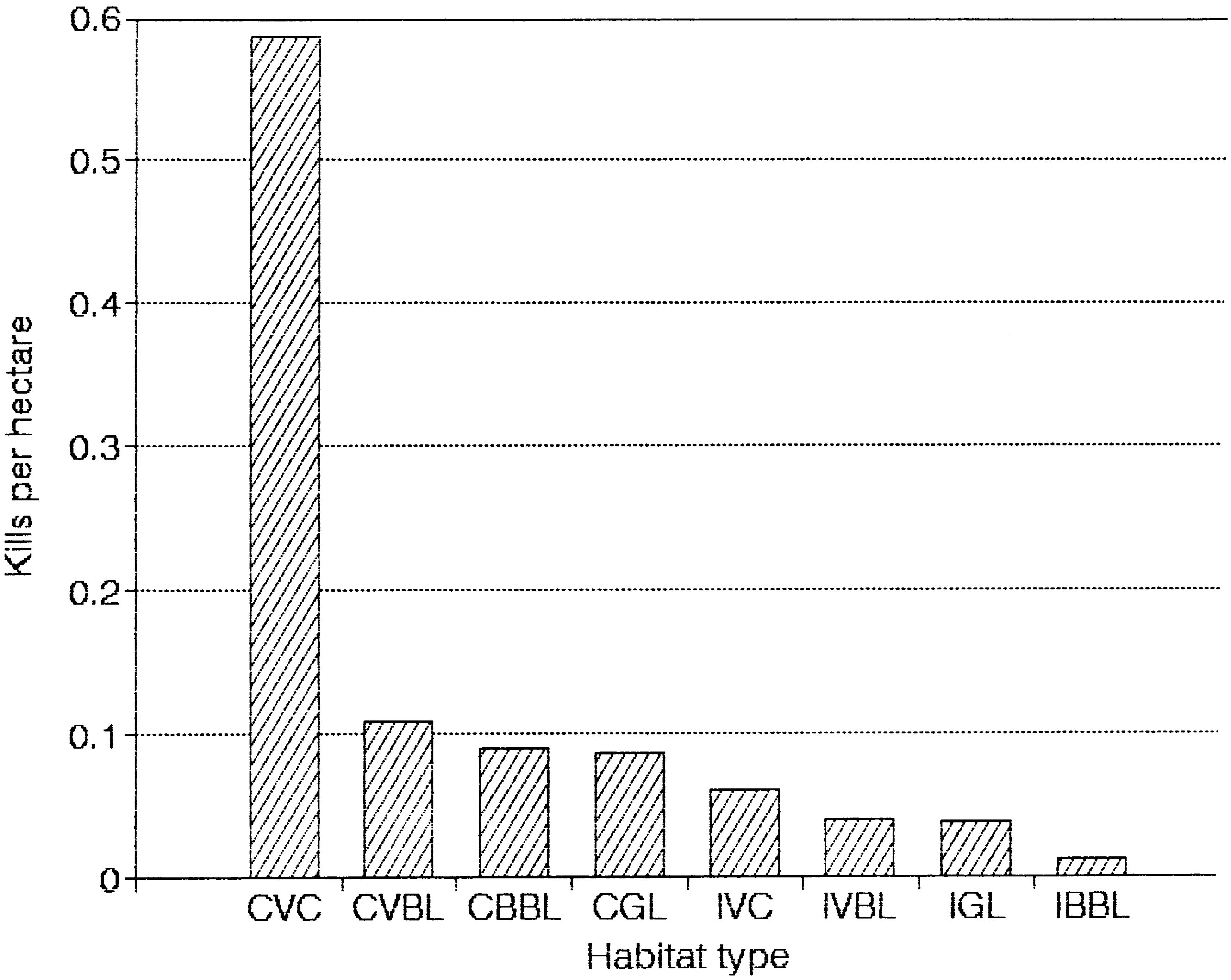

Figure 5: Number of cats killed per hectare in different habitat types on Marion Island from 1986 to 1989. (C = coastal, I = inland, VC = volcanic cones, VBL = vegetated black lava, BBL = bare black lava, GL = grey lava).

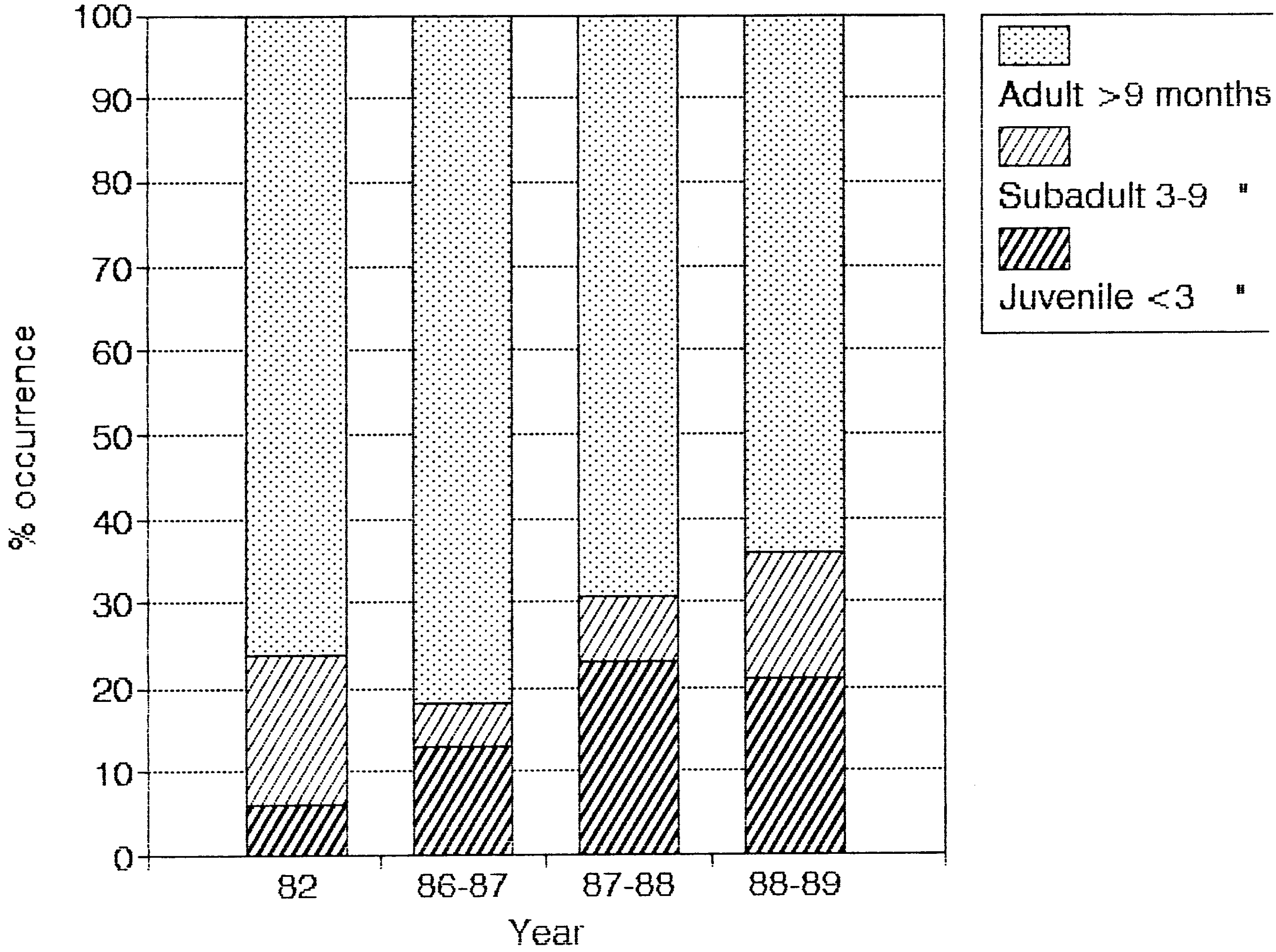

Figure 6: Age structure of the cat population on Marion Island in 1982 and from 1986 to 1989, based on killed cats.

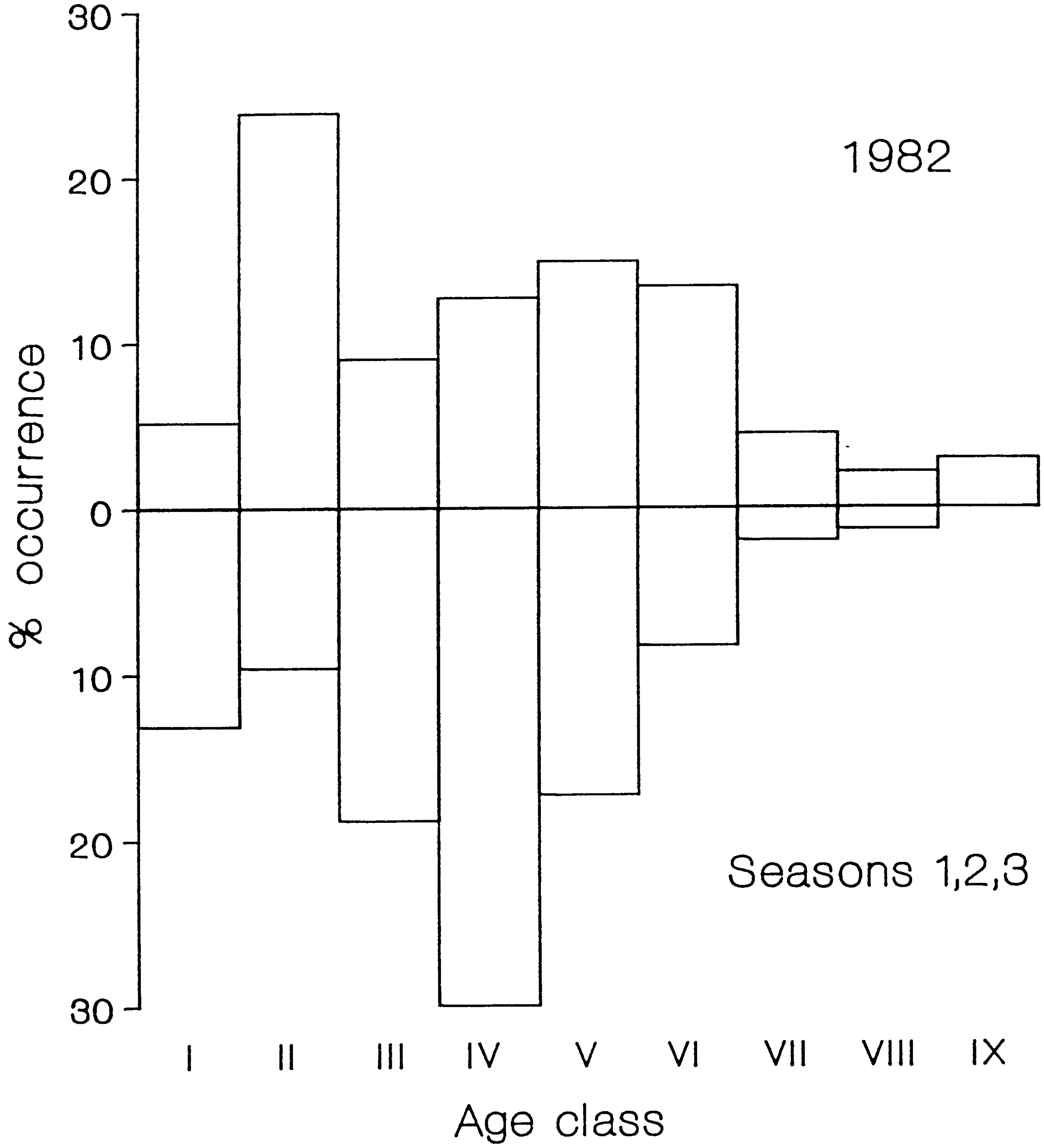

Figure 7: Adult year-class age distribution of the cat population on Marion Island in 1982 and for the combined populations from 1986 to 1989, based on killed cats.

Table 5. Reproductive data for the cat population on Marion Island in 1982 and from 1986 to 1989 (figures are given ± one S.D.)

	1982*	1986-87	1987-88	1988-89
Prenatal litter size	4.50 ± 1.70 *n* = 8	4.57 ± 1.39 *n* = 75	5.00 ± 1.35 *n* = 27	4.27 ± 1.86 *n* = 15
Litter size at weaning	1.65 ± 0.71 *n* = 31	2.60 ± 1.12 *n* = 15	2.43 ± 1.01 *n* = 14	2.60 ± 1.58 *n* = 10
Reproductively active females	93.6%	72.8%	64.0%	66.7%
Litters per year	2**	1.7	1.4	1.3
Mean fecundity (surviving female young per female)	1.54	1.49	1.19	0.98

* Van Rensburg *et al.* (1987)
** No precision given

8.89×10^{-2}; $p > 0.05$). Mean litter size at weaning was 2.54 (S.D. = 1,19; $n = 39$; range 1-6) which was similar to the 2.66 recorded in 1975 (Van Aarde 1983). Litter size at weaning decreased significantly between 1975 and 1982 (Van Rensburg *et al.* 1987).

The proportion of reproductively active females was significantly lower in season one than in 1982 (72.8% as opposed to 93.6%; $\chi^2_1 = 5.35$; $p < 0.025$). The proportion of reproductively active females declined over the three seasons, from 72.8% to 66.7% ($\chi^2_2 = 2.12$; $p > 0.1$).

Mean number of litters per female per year decreased from 1.7 to 1.3 over the three seasons, compared to two (*sic*) litters per year in 1982 (Van Rensburg *et al.* 1987). Between 1982 and the first season mean fecundity decreased from 1.54 to 1.49 surviving female young per female per year. During the course of the hunting programme mean fecundity decreased from 1.49 to 0.98 (Figure 8). There was no evident decline in reproductive output with increasing age.

Dates of mating back-calculated for lactating females indicated

Figure 8: Age-specific fecundities (F_x; surviving female young per female) of adult females collected during each of the three hunting seasons on Marion Island (● = no females collected).

that mating occurred in every month of the year except June, with peaks in September and January.

Estimates of the size of the population at the start of the first season varied between 46 and 851, with a mean of 663 for the two methods other than stratified sampling (Table 6).

DISCUSSION

Due to the shift in emphasis from hunting to trapping after the third summer, only hunting data from the first three hunting seasons are considered to be comparable. Therefore only these are discussed.

Hunting effort above and below the 100 m contour were not substantially different, and it is thought that the differences seen in the distribution of kills are not entirely due to possible differences in hunting effort. The distribution of cats showed the same clumped pattern as in the past, which largely corresponds to the distribution of burrowing petrels (Van Aarde 1979). Petrels form a major component of the diet of cats (Van Aarde 1980; Chapter 6) and consequently highest densities of cats are found in areas of suitable habitat for petrels. Lack of prey and relatively inhospitable conditions account for very few cats being found above 500 m (Van Aarde 1979).

The method of determining habitat preference used here gives a misleading impression of the actual densities of cats in different areas. As immigrant and newborn cats replaced those removed, the apparent density of cats increased with time. Preference for high density areas is unquestionable, but it is difficult to distinguish between areas in which cats are resident and areas which cats visit frequently to hunt. On coastal volcanic cones, which are too small to support many cats, given their home ranges (Van Rensburg 1986), high densities of burrowing petrels possibly attract cats from surrounding areas.

TABLE 6. Estimates of the number of cats present on Marion Island at the start of the first hunting season using different methods.

Method	Estimate for island
Stratified sampling:	
a) defined study area	46
b) one hunting area	267
c) whole island	144
Retrospective census	476
Manipulation of density index	851

Since Van Aarde (1979) found coastal grey lava slopes to have the highest density of cats, owing to these slopes being a preferred bird habitat, this explains the preference of coastal areas to interior regions. In this study however no distinction was made between grey lava slopes and ridges, owing to problems of interpretation caused by so many hunters collecting data. Here coastal grey lava includes both Van Aarde's (1979) slopes and ridges, and contains large areas of mire and rocky terrain which are not suitable for birds. Because grey lava slopes are preferred bird habitat (Van Aarde 1979), these slopes would certainly have yielded higher densities of cats in this study. Bare black lava is over-represented, also due to differences in interpretation by the hunters. In a number of instances cats were found on the very edges of bare black lava, which are vegetated, or in vegetated valleys within bare black lava.

The areas of high density in Figure 4 correspond largely to areas favoured by birds. For example area A is a coastal volcanic cone with large numbers of blue petrels *Halobaena caerulea*. Areas B, C and D are also in the vicinity of large blue petrel colonies, while area E is on Van Aarde's (1979) grey lava slopes, also home to blue petrels (Fugler *et al.* 1987). Large numbers of Salvin's prions *Pachyptila salvini* are found in area F (pers. obs.).

There was a significant difference between the age structures of the 1975 (pre-FPL) and the 1982 (post-FPL) populations, with fewer cats less than one year old, which are particularly susceptible to feline panleucopaenia (Reif 1976), being found in 1982 (Van Rensburg *et al.* 1987). Since there was no difference in the ratio of adults to immatures in the population between 1982 and the first season, this suggests that the disease may still be prevalent. However, the return of litter size at weaning to pre-disease levels suggests that the disease is no longer killing very young animals. The question of the prevalence of the disease in the population is being addressed in a separate study.

Because hunting pressure has fallen mainly on adults (by virtue of greater numbers), the population became progressively younger over the three seasons, with a shift towards juveniles and subadults in the population. Furthermore, the lowered maximum age of animals shot indicates a decreased likelihood of older animals surviving.

The changes in adult year-class age distribution between 1982 and the first season of the hunting programme were not due to the present hunting effort, but are ascribed partly to the effects of limited experimental hunting in 1982 (Van Rensburg *et al.* 1987). Hunting took place over two periods, from January to May 1982 and from October 1982 to May 1983. One hundred and fifty cats (25% of the estimated population in 1982) were removed. Kittens born before the first hunting period could shot during both periods, but many kittens born subsequently would have survived the second hunting period, some not yet having emerged from their dens by the end of hunting and others because there was less time to be encountered by hunters. The surviving kittens formed a large cohort in age class IV in 1986-87. In addition, adults were being removed continuously, which had two effects: age classes V to VIII were reduced due to continuous losses and age class III and younger would also be reduced due to fewer kittens being produced after hunting, as there were fewer adults left to produce them.

The constant 1:1 sex ratio, together with the absence of any changes in the adult age distribution over the three seasons, suggest that no adult group was particularly vulnerable to hunting. Van Aarde (1977) found the adult sex ratio to favour males in all months except April and May. His cats were collected by day hunting, and the preponderance of males may have been due to their being more mobile and therefore more susceptible to hunting (Van Rensburg & Bester 1988*b*). The increase in the number of females shot during April and May may have been due to the fact that females were suckling young at that time and were possibly more susceptible to hunting because they remained in the vicinity of the lair. In the present case, because hunting was very intensive and hunters covered the entire study area, differences in behaviour were possibly nullified and the 1:1 sex ratio is perhaps a true reflection of the population sex ratio.

The difference in fecundity between 1982 and the first hunting season was largely due to decreases in the proportion of females breeding and the number of litters produced per year. This decrease in fecundity occurred despite an increase in litter size at weaning between 1982 and season one. The absence of sampling during the winter and spring of 1982 (June-September), and therefore the possible exclusion of non-breeding females, could in part explain the very high proportion of breeding females found in 1982. However, decreases in the proportion of females breeding and in the number of litters per year also resulted in a decrease in fecundity over the three hunting seasons. This is considered to be a direct result of the hunting campaign.

Although it is generally accepted that the availability of males does not limit population fecundity, reduced density may result in reduced mating success (Elseth & Baumgardner 1981); at very low densities encounters between males and females may be so rare that many females do not find mates, with a consequent decrease in the proportion successfully breeding. Although it was found in urban fox *Vulpes vulpes* populations that productivity in controlled populations increased (Harris & Smith 1987), the density of cats on Marion Island may have become so low that the converse has occurred. Males may no longer readily find females, which also results in females breeding fewer times per year. The 1975 population was large enough for all females to find mates and breed twice a year (Van Aarde 1978) and in 1982 ninety-three percent of adult females bred, and each also produced two litters per year. Similar density-dependent decreases in fecundity were found in cat control programmes in New Zealand (Bell 1989) and in coypu *Myocastor coypus* in Britain when numbers declined to very low levels after an intensive trapping programme (Gosling & Baker 1987). This density-dependent decrease in fecundity has enhanced the chances of success of the programme because fecundity can be expected to decrease even further as the cat population is reduced.

In the present study it was assumed that lactating cats were collected on the first day of lactation, from which the gestation period was subtracted to give an estimate of the latest possible date of mating. However, since lactation in the cat in 60 days (Robinson 1977), this estimate can be inaccurate by up to two months. Despite this limitation, however, the method does give an indication of the spread of mating dates. Mating was found to take place throughout the year, with the exception of June. Cats could however have been collected at any time during the 60-day lactation period and it is therefore possible that mating also took place during June. Van Aarde (1978) found that mating was strictly seasonal, with the season lasting from August to January. He however did not collect females in two months of winter, and this, together with the small sample size of 17 pregnant females used to back-calculate the mating season (using foetal growth and age), perhaps resulted in an incomplete representation of the mating season. Furthermore, as in the present study, breeding cats were also collected during winter on Macquarie Island (Jones 1977; Brothers, Skira & Copson 1985). It appears therefore that breeding on Marion Island is aseasonal, with peaks during the more favourable summer months. However, since female cats are polyoestrus and can undergo subsequent oestrus cycles if they do not mate (Liberg 1983), hunting has possibly also influenced the breeding season through disturbance and by reducing the density of males. Females may cycle several times before being mated, which would lengthen the breeding season.

The wide range in estimates of the cat population projected for the start of the hunting campaign highlights the inappropriateness of some of the techniques employed. The rugged nature of the terrain, the clumped distribution of the cats and the very few cats seen during the day make stratified sampling impracticable. Although stratified sampling based on day sightings within a well-defined area was satisfactory in the past as an index of density which would illustrate population trends (e.g. Van Aarde 1979, 1983; Van Rensburg *et al.* 1987) its relationship to actual population size is unknown. The duration and intensity of stratified sampling in the present study was inadequate, but in the absence of a method to reliably identify individual cats (and therefore exclude resights of individuals), an increase in the duration and intensity of sampling would simply result in an increase in the population estimate. The similarity between the mean of the higher estimates (stratified sampling excluded) in season one (657) and that of Van Rensburg *et al.* (1987) in 1982 based on stratified sampling (615 $\pm$ 107) is considered to be purely fortuitous.

The weakness of the retrospective estimate lies in the difficulty of estimating the number of surviving cats. Only 40 cats were seen in the last month of hunting in season three, but it was impossible to know if all cats present were seen, how many were seen more than once and, of the cats present, how many were old enough to have been on the island at the start of the campaign.

The accuracy of any estimate based on the manipulation of a density index (i.e. cats seen per hour of hunting) is dependent on the population being closed during the period of removal (Caughley 1977). Because the index was measured over ten months, births and natural deaths would obviously have violated this requirement.

The nature of the hunting programme has made accurate estimates of the number of cats present on the island practically impossible. The means of collecting data used for estimating population size were not appropriate for all of the methods described, and the continuous removal of cats further compounded the problem. Any effort to try and accurately estimate the number of cats on Marion Island is therefore a waste of valuable time. Lynx, *Lynx canadensis*, which have also proved practically impossible to census, are often monitored solely by trends in hunting returns (Quinn & Thompson 1987). The higher population estimates are probably most accurate, but the only real indication of the reduction in cat density was the marked increase in the number of hours hunted at night per cat sighted from 1.3 hours per sighting at the start of the first season to 8.3 by the end of the third.

CHAPTER 5: DIET OF THE DECLINING CAT POPULATION

INTRODUCTION

Feral cats have been shown to be opportunistic predators, and that differences in their diets reflect availability rather than selection of prey (Derenne & Mougin 1976; Jones 1977; Dilks 1979; Pascal 1980; Van Aarde 1980; Brothers 1984; Van Rensburg 1985; Weimerskirch *et al.* 1988). On most sub-Antarctic islands birds form the greatest part of the diet, but on those islands where other prey is available, such as rabbits *Oryctolagus cuniculus* on Macquarie Island (Jones 1977) and rats *Rattus norvegicus* on Campbell Island (Dilks 1979), such prey features prominantly in the diet.

Van Rensburg (1985) found a significant change in the diet of cats on Marion Island between 1975 and 1982, with an apparent shift from birds to mice. A suggested reason for this shift was a decline in the availability of birds as a result of cat depredation. As the present study was not intended to be a detailed study of the diet of cat population on the island, diet analysis was undertaken only to describe the composition of the diet and to determine if the shift in the diet was still apparent.

MATERIALS AND METHODS

Between September 1986 and May 1989 623 stomachs were collected from 857 cats killed during the first three summer seasons of the hunting programme. In the field stomachs were usually placed in 5% formalin and once at the base station frozen until examination. The contents of each stomach were rinsed in running water on a 1 mm mesh sieve to loosen and wash the food mass and then macroscopically identified. Prey remains were identified as far as possible against reference material collected from dead birds found in the field. Identification of bird remains was based on the colour, size and structure of feathers and when present on the colour, size and shape of beaks or legs and feet. As it was often difficult to distinguish between the feathers of Salvin's prions *Pachyptila salvini* and blue petrels *Halobaena caerulea*, a prion/blue petrel category was established for remains definitely belonging to one or the other. A category combining all burrowing petrels (Procellariidae) was established because it was considered that these form a functional prey type. Petrel chicks were easily recognised as such by small, sometimes poorly developed beaks and feet, or by wings covered in down or developing feathers. Salvin's prion and blue petrel chicks were difficult to tell apart and were therefore grouped together into a prion/blue petrel chick category. Remains of mice *Mus musculus* were identified with certainty.

All analyses are based on stomachs containing food (n = 587). Thirty-four empty stomachs and two collected from suckling kittens (only white granules present) were excluded. Analyses of stomach contents are summarised as frequency of occurrence i.e. the percentage of the total number of stomachs which contained a particular food item. Percentages exceed 100% due to the fact that more than one food type was usually found in any one stomach. Presence of chicks in the diet is given as the percentage of the total number of birds present. For the calculation of predation on chicks only those stomachs collected during the period from hatching to fledging of Salvin's prions and blue petrels, i.e. from November to March, were used (Berruti & Hunter 1986; Fugler *et al.* 1987), while for white-chinned petrels *Procellaria aequinoctialis* only stomachs collected during those months in which chicks were found (January to April; see discussion) were used. Data on chick presence in stomach contents from all three seasons were combined to obtain as large a sample

Table 7. Frequency of occurrence of prey items in the stomachs of cats on Marion Island from 1986 to 1989.

Prey item	1986-87 n = 304			1987-88 n = 167			1988-89 n = 116		
	Number stomachs	% stomachs	Number items	Number stomachs	% stomachs	Number items	Number stomachs	% stomachs	Number items
Chionis minor	-	-	-	1	0.6	1	-	-	-
Diomedea chrysostoma	-	-	-	1	0.6	1	-	-	-
Halobaena caerulea	31	10.2	31	23	13.9	23	17	14.7	17
Pachyptila salvini	89	29.3	117	62	37.1	71	28	24.1	32
Pelecanoides georgicus	2	0.7	2	2	1.2	2	-	-	-
Procellaria aequinoctialis	24	7.9	27	13	7.8	14	10	8.6	10
P. aequinoctialis chicks	7	2.3	9	3	1.8	4	1	0.9	1
Pterodroma macroptera	-	-	-	-	-	-	2	1.7	2
P. macroptera chicks	-	-	-	-	-	-	1	0.9	1
Pterodroma mollis	6	2.0	6	-	-	-	2	1.7	2
Procellariidae	244	80.3	285	111	66.5	135	70	60.3	84
Spheniscidae	32	10.5	32	13	7.8	14	9	7.8	9
Prion/blue petrel	74	24.3	78	5	3.0	5	12	10.3	14
Prion/blue petrel chicks	29	9.5	50	10	5.6	12	12	10.3	16
Mus musculus	148	48.7	369	106	63.5	239	70	60.3	199
Felis catus	-	-	-	-	-	-	1	0.9	1
Egg shell	2	0.7	2	5	3.0	5	2	1.7	2
Limpet shell	-	-	-	-	-	-	1	0.9	1
Plant material	67	22.0	67	51	30.5	51	11	9.5	11

Seasonal occurrence of prey in the diet

Seasonal changes in the occurrence of certain prey items in stomachs of cats are presented in Figure 9. Since there were no significant differences in the seasonal occurrence of prey items between the three years the data were combined. Salvin's prions were taken throughout the study period, with most occurring during the summer months. Mice were most frequent at the beginning and end of summer. Blue petrels were always present, but showed peaks of occurrence in December and May. White-chinned petrels were only present during the summer months with a slight increase in midsummer. Penguins were found most frequently at the end of winter, decreasing steadily throughout the summer.

White-chinned petrel chicks were easily identified by their beak structure and large size. The one great-winged petrel chick found in November was identified from its breeding season, being found two months before white-chinned petrel chicks hatch (Van Rensburg & Bester 1988*a*). The percentages of prion/blue petrel and white-chinned petrels which were chicks are presented in Figure 10. The first prion/blue petrel chicks appeared in November and the last were found in March. White-chinned petrel chicks were found between January and April. A peak of 77.4% in prion/blue petrel chicks occurred in January, while white-chinned petrels chicks showed a peak of 91.7% in January. Twenty-three percent of all white-chinned petrels taken were chicks, compared to 15% of the prion/blue petrel category. Most egg shell appeared in stomachs between October and January, but one stomach collected in April also contained egg shell.

Changes in the diet since 1975

The frequency of occurrence of the three major food categories in the diet of cats (Procellariidae, *Mus musculus* and Spheniscidae) for the years 1975 to 1989 are given in Table 8. There has been a significant

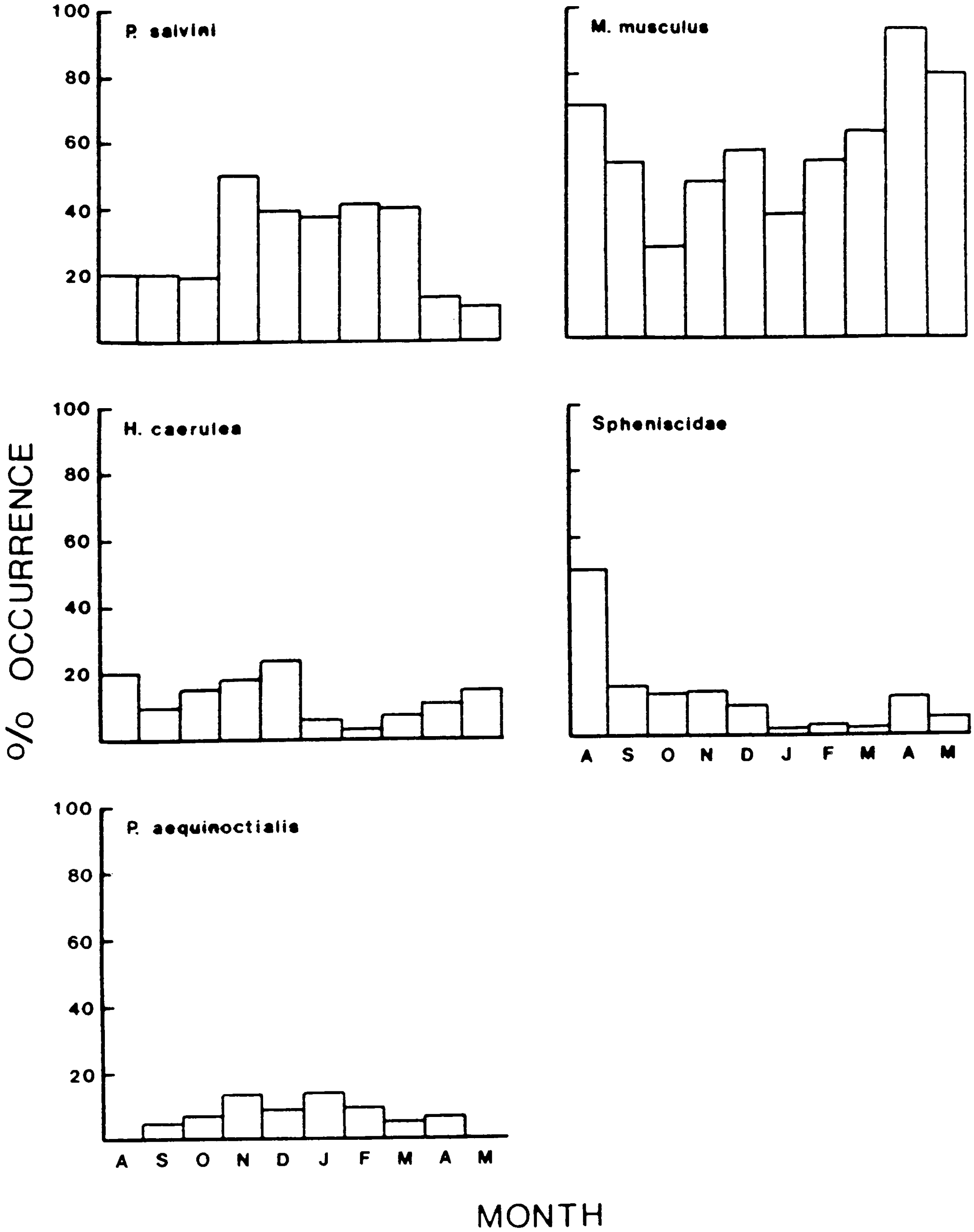

Figure 9: Seasonal patterns in the frequency of occurrence of prey items in the diet of cats on Marion Island.

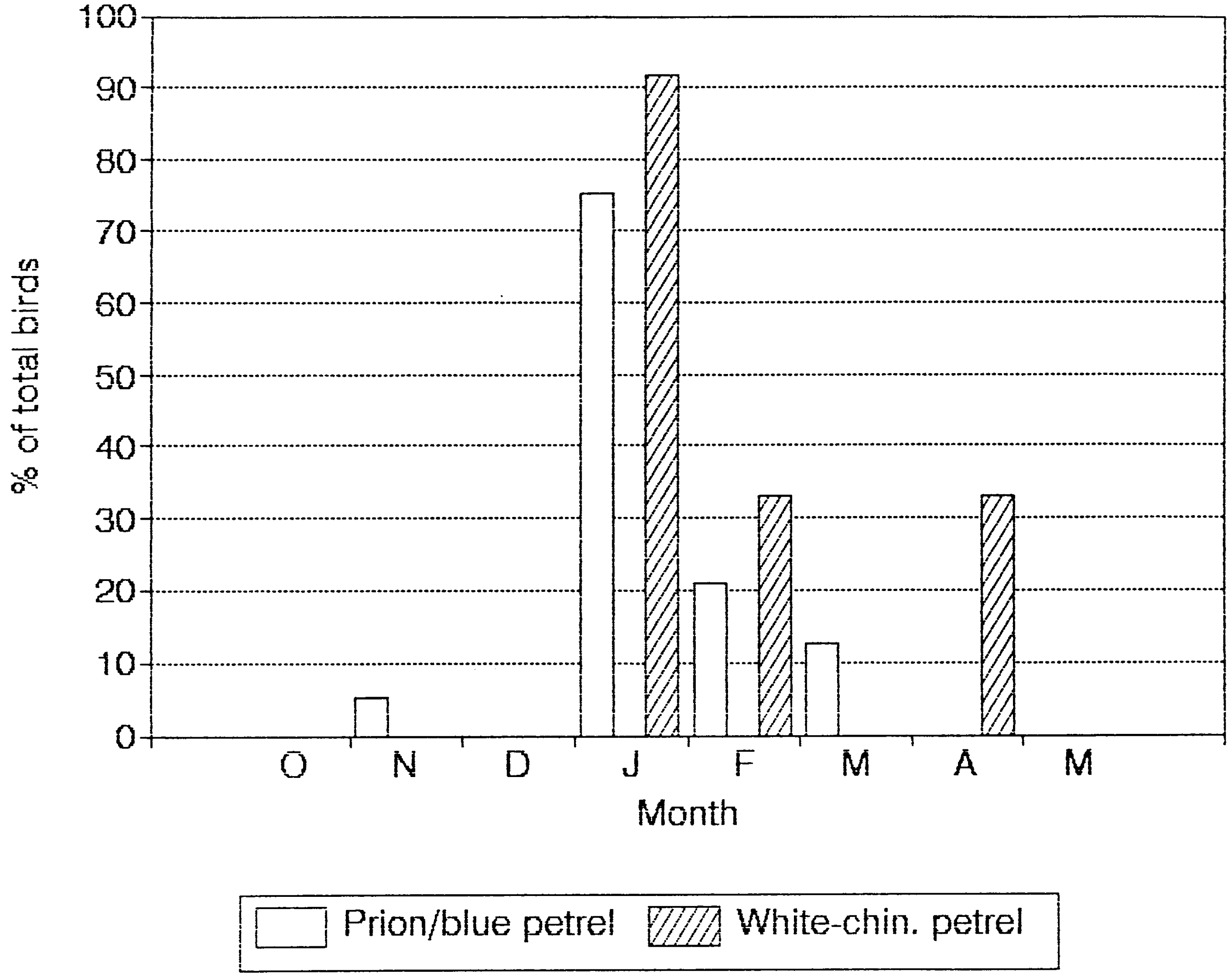

Figure 10: Presence of prion/blue petrel and white-chinned petrel chicks, expressed as the proportion of total birds, in the diet of cats on Marion Island.

Table 8. Percentage occurrence of the three major food categories in the diet of cats on Marion Island in 1975, 1982 and from 1986 to 1989.

	Year				
Prey category	1975*	1982**	1986-87	1987-88	1988-89
Procellariidae	97.4	83.9	80.3	66.5	60.3
Mus musculus	16.4	41.3	48.7	63.5	60.3
Spheniscidae	6.9	4.9	10.5	7.8	7.8

* Van Aarde (1980)
** Van Rensburg (1985)

decrease in the occurrence of birds ($\chi^2_4 = 62.86$; $p < 0.001$) and a significant increase in the frequency of mice ($\chi^2_4 = 72.15$; $p < 0.001$). Penguins have not changed significantly in the diet ($\chi^2_4 = 4.66$; $p > 0.05$). Differences between years for the other species could not be tested due to their very low frequencies of occurrence.

DISCUSSION

Analysis of the frequency of occurrence of prey items is valuable in that it gives an indication of what and how many prey are eaten. It can indicate the impact of predation on prey populations and changes in the diet with time. A disadvantage of the technique is that the importance of small food items tends to be overemphasised and all items in the diet are counted as being equally important, for example a piece of grass is as important as a bird. It does not give a good indication of the importance of individual food types. It has been suggested that food items taken by many individuals must be considered more important food sources than those items found less frequently (Ferguson 1988). It should be also be realised that a food item need not only be important from a nutritional point of view, but nevertheless be necessary in the diet, for example grass may aid in digestion. The merits of frequency and volumetric analyses have been much debated, but it is generally agreed that both are useful and necessary in a study of feeding habits. However, a volumetric analysis was discounted for this study, particularly in view of the fact that a large proportion of the diet was made up of similar birds. The reasons for this decision, despite the resulting limitations of the data, were that the volume of feathers in a stomach (generally all that is found unless the bird was recently eaten) is useless information because feathers are only the waste remains of prey eaten, where two beaks are found it is impossible to separate the contributions of the two individuals, and if a mouse tail or hair is present the volume of the eaten body is not taken into consideration. Finally, because it is impossible to determine what proportion of a particular prey animal was eaten, one cannot calculate the amount of food actually consumed. Diet studies from stomach contents are also confounded by regurgitation of indigestible food items, which influences what is found in the stomach. Furthermore, if there are only a few remains of other birds in amongst a large bulk of feathers in the stomach they are not found unless those feathers are very distinctive. Some species have similar feathers on different parts of the body, and for this reason the prion/blue petrel category was included. The number of prey items counted in a stomach is also of necessity a minimum.

Salvin's prions are present on the island throughout the year but occur most frequently in the diet when the birds are most abundant and accessible during their summer breeding season (Berruti & Hunter 1986). Blue petrel numbers peak on the island during November/December and March/April (Fugler *et al.* 1987) and this is reflected by the two peaks in their occurrence in stomachs. Great-winged petrels are winter breeders and adults were found in stomachs at the end of one hunting season when winter was beginning and one unfledged chick in early November. Van Aarde (1980) found them only in winter. The low frequency of white-chinned petrels is perhaps due to size selection by cats; adults are large and aggressive but during the breeding season a high proportion of smaller and more vulnerable chicks are killed. The larger individuals which were found may have been younger birds or scavenged skua *Catharacta antarctica* kills. Van Aarde (1980) found only chicks of white-chinned petrels in stomachs. Mice are present in large numbers throughout the year, but fewer are eaten in the summer months despite a peak in numbers at that time (Gleeson 1981). This is probably due to the availability of the preferred bird prey resulting in fewer mice being taken. Mice were eaten most frequently during April/May when most prions are absent after the chicks had fledged (Van Aarde 1980), and appeared to be most important during the winter months. Prey items were therefore found most frequently in stomachs of cats when that prey species was most abundant, as was the case in previous years. The foregoing suggests that prey presence in stomachs is generally a function of availability rather than preference, except for mice and prions in summer. Here both are available and abundant but of the two birds are preferred.

Prion/blue petrel chicks were first found in stomachs when blue petrels started hatching in November and reached a peak when prions began hatching in January. Blue petrels fledge in February and prions in March, resulting in the absence of chicks in stomachs after March. Few adult white-chinned petrels were taken by cats, while the smaller, less aggressive chicks were found more frequently. White-chinned petrel chicks disappeared from stomachs four months before they fledge in August, their increased size and aggressiveness possibly deterring cats even before they reach fledging size. The presence of egg shell in stomachs is probably the result of eggs preyed on in the nest. Most egg shell was found when most species were breeding in the summer, while egg shell found in April was possibly that of a grey petrel *Procellaria cinerea*, which hatch in early May (Newton & Fugler 1989). The high proportions of chicks in stomachs during the breeding season of the various birds illustrate cat utilisation of vulnerable chicks.

Van Rensburg (1985) suggested that the increase in percentage occurrence of mice and decrease in birds in the diet of cats reflect a decrease in the abundance of birds due to cat predation, which was borne out by his work on changes in the diet of skuas. The present study shows this trend to be continuing, despite the removal of a large number of cats. There are however also indications that mouse numbers may have increased substantially over the past 20 years (Steenkamp 1991), and the increase in mice in the diet of cats possibly reflects an increased availability of mice.

The presence of penguins in the diet is ascribed to scavenging; the higher frequency at the end of winter indicating that penguin carcasses are available as a supplement to the winter food supply. Van Aarde (1980) and Jones (1977) found that penguin remains were scavenged chiefly during winter on Marion and Macquarie Islands respectively. The greyheaded albatross and lesser sheathbill were undoubtedly scavenged, as were limpets. Jones (1977) reported similar scavenging of goose barnacles (*Lepas* sp.) on driftwood on Maquarie Island. The remains of a kitten in the stomach of a lactating female confirms cannibalism, as has previously been described by Van Aarde (1977) and Jones (1977).

The high frequency of plant material in stomachs suggests that this is deliberately eaten, although some may be taken in during feeding or grooming. Jones (1977) and Jones & Coman (1981) suggest that plant material forms an important part of the diet, aiding in digestion. Domestic cats often vomit after eating grass, and this behaviour may therefore be important in aiding the regurgitation of indigestible food items.

On Macquarie Island rabbits are a more important food item than either birds or mice and rats (Jones 1977). Small rabbits and birds are abundant during the summer, but during winter the birds are gone and rabbits of the preferred size are not present. Old, debilitated cats on the one hand and young cats on the other may be unable to capture large rabbits and the population is therefore limited by its winter food supply. Cats on Marion Island however do not appear to be limited by food in winter because some prions and blue petrels remain on the island, great-winged and grey petrels are breeding and large numbers of mice and penguin carcasses are always present.

CHAPTER 6: EFFECTS OF CAT PREDATION ON BIRD POPULATIONS

INTRODUCTION

Van Aarde (1978) estimated that by 1975 approximately 450 000 burrowing petrels were being killed by cats on Marion Island each year. Williams (1984) suggested that cat predation had caused the extinction of the common diving petrel, and breeding success of other species was declining alarmingly (Schramm 1986; Van Rensburg & Bester 1988*a*; Newton & Fugler 1989). The cat eradication programme was initiated to stop this depredation of bird populations and allow the recovery or recolonisation of affected populations.

Breeding success of white-chinned petrels *Procellaria aequinoctialis* and Salvin's prions *Pachyptila salvini* was monitored during each hunting season to determine if breeding success of these burrowing birds was increasing in response to lowered cat numbers.

MATERIALS AND METHODS

Initially both Salvin's prions and white-chinned petrels were included in this study. However, monitoring of Salvin's prions was abandoned after the second season because at the start of that breeding season only 21% of the 141 marked nests were occupied. Therefore only the breeding success of white-chinned petrels was monitored. Incubation and feeding visits by birds to nests were monitored for the duration of three breeding seasons from 1986 to 1989 on Junior's Kop and in Nellie Humps, both situated close to the base station, using the methods of Van Rensburg & Bester (1988*a*). Only nests occupied at the start of each season were monitored; 71, 66 and 91 respectively in each of the three seasons. Nests were inspected on alternate days for the last two weeks of

December, January, February and March. Visits to nests were detected by planting a row of matchsticks upright in the burrow entrances. Matchsticks were soaked in formalin to discourage mice from disturbing or removing them. Disturbed matchsticks were taken to indicate that a bird had entered or left the burrow and was therefore still breeding. This method, in conjunction with indirect methods such as calls from within burrows, signs of recent burrowing activity, recent scratch marks and newly discarded feathers, is considered to be a reliable indicator of whether the burrow was still occupied. The absence of nest visits during the second half of any inspection period was considered indicative of breeding failure. Breeding success was taken to be the percentage of the total number of nests occupied at the start of the breeding season that were still active at the end of the season. These birds were assumed to have successfully fledged young. Results were compared with those obtained by Van Rensburg & Bester (1988*a*) outside two fenced areas from which cats had been removed.

RESULTS

Breeding success data for white-chinned petrels in 1982 and in each of the three seasons are presented in Table 9. The percentage of burrows still in use at the end of the breeding season (i.e. birds assumed to have bred successfully) increased by nearly 7% over the three seasons, although not significantly ($\chi^2_2 = 0.93$; $p > 0.5$). Between 1982 and 1986-87 breeding success increased by 13%, also not significantly ($\chi^2_1 = 1.52$; $p > 0.05$), but there was a significant increase of 20% between 1982 and 1988-89 ($\chi^2_1 = 4.12$; $p < 0.05$).

Table 9. Percentage of white-chinned petrel *Procellaria aequinoctialis* nests active per month in corresponding study areas on Marion Island in 1982 and from 1986 to 1989.

Year/Month	December	January	February	March
1982*	100	100	81.5	55.6
86-87	100	97.2	91.6	69.0
87-88	100	97.0	91.0	72.8
88-89	100	97.8	97.8	75.8

* Van Rensburg & Bester (1988*a*)

Table 10. Breeding success of great-winged petrels *Pterodroma macroptera* on Marion Island from 1979 to 1990.

Year	Breeding success (%)	Reference
1979	0	Schramm (1983)
1980	0	Schramm (1983)
1982	20.5	Newton & Fugler (1989)
1982	0 (outside cat exclosure) 50 (inside cat exclosure)	Van Rensburg & Bester (1988*a*)
1984	0	Newton & Fugler (1989)
1990	59.6	Cooper & Fourie (1991)

DISCUSSION

The assumptions on which this method of determining breeding success are based are that an occupied burrow was indeed being used for breeding, that a burrow was abandoned soon after a breeding failure, that only one pair of birds used a burrow for breeding and that a burrow had no other occupants (Van Rensburg & Bester 1988*a*). Although these assumptions may not always hold true, the authors were of the opinion that the method was useful for comparative purposes.

The increase in breeding success of white-chinned petrels between 1982 and 1986-87, and over the three hunting seasons, may be due to reduced predation by cats, or can merely be the result of natural fluctuations in breeding success caused by external factors such as food availability. However, the steady increase from 1982 to 1989, concomitant with the sustained decrease in cat numbers, suggests that breeding success is increasing due to lowered cat predation. Similarly, a summary of published reports of breeding success of winter-breeding great-winged petrels *Pterodroma macroptera* between 1979 and 1990 (Table 11) demonstrates improved breeding success with the progression of the eradication programme. Between 1979 and 1984 breeding success was largely zero, and this was considered to be the result of cat predation (Schramm 1983; Newton & Fugler 1989). In an experiment in 1982 Van Rensburg & Bester (1988*a*) attributed significantly higher breeding success inside fenced areas from which cats had been removed to lowered predation. In 1990 breeding success was 59.6%, with zero chick mortality and no signs of cat predation (Cooper & Fourie 1991). They conclude that this increased breeding success is directly attributable to the eradication programme and is a good indication that the programme is achieving its aim. Nevertheless, recovery of bird populations is expected to be slow since burrowing petrels are K-selected species, i.e. they are slow breeders with lifelong pair bonds, lay only one egg (often only every second year) and only begin breeding at the age of five or six years (Lack 1968).

During the breeding seasons of burrowing petrels predation on chicks was particularly high (see Chapter 5). Young white-chinned petrel chicks formed nearly 92% of all white-chinned petrels taken during that time. The young of this large species are particularly susceptible to predation due to their large burrows which allow cats easy access, and nest visits by parents decrease after hatching, therefore leaving the chicks unprotected for longer periods. When the young leave the burrow to exercise their wings they are also at greater risk (Van Rensburg & Bester 1988*a*). Seventy-seven percent of Salvin's prions and blue petrels taken during the breeding season were chicks, confirming their susceptibility to predation, despite the statement of Van Rensburg & Bester (1988*a*) that prion burrows are usually too small for cats to enter and that the adults are at greatest risk. Van Aarde (1980) however reported cats entering larger prion burrows to reach the chicks, which confirms that chicks are indeed very vulnerable.

It is not known if the cat population would have reached equilibrium with prey populations on Marion Island had the eradication programme not been undertaken. In all cases where feral cat populations had not been removed from islands, however, an equilibrium state was not reached. On a number of small islands the cat populations died out after causing the extinction of all bird prey (Bell 1989). In other cases cats caused the extinction of one or more birds before switching to less common species (Taylor 1979; Imber 1987).

CHAPTER 7: CONCLUSIONS

Mechanical control of the cat population by hunting has been successful in reducing the feral cat population on Marion Island, after biological control with the viral disease feline panleucopaenia had provided the initial reduction in numbers.

It was not possible to estimate the numbers of cats present on the island, but number of cats sighted per hour of night hunting is considered to be the most reliable index of density. The number of sightings per hour decreased from 0.5 to 0.099 over the first four years of the hunting programme, indicating a marked decrease in density.

A reduction in the rate of decline of sightings per hour in successive seasons indicated that hunting was no longer removing sufficient numbers to continue significantly reducing the population. The incorporation of trapping into the campaign further reduced the population.

No single method will be successful in eradicating the population. Hunting became less effective as cat density decreased. At low cat densities, gin-trapping became a more effective method than hunting. Non-target species were trapped but in insufficient numbers to affect their populations. Together with poisoning, which was recently incorporated into the programme, mass trapping is believed to be the key to the eradication of the cat population.

A density-dependent decrease in fecundity, due largely to decreases in the proportion of female cats breeding and in the number of litters produced per female per year, is ascribed to densities being so low that females encounter males less frequently, and enhances the prospects of success of the programme.

Cat distribution appears to correspond to areas of suitable habitat for burrowing petrels, a major prey item. However, the diet of the cats has continued to change significantly, with decreases in the proportion of birds in the diet and increases in mice. This is ascribed to a possible decrease in the availability of bird prey. During the breeding seasons of the birds, chicks form a substantial proportion of the total number of birds taken.

The marked decrease in the number of cats has greatly reduced predation pressure on bird populations. The apparent increases in breeding success of two burrowing petrel species may be the result of decreased predation pressure on their young by cats. These observations suggest that bird populations may recover with the removal of the cats.

The eradication programme on Marion Island was planned in detail and executed with a great deal of effort and commitment, and has been successful in reducing the feral cat population to low levels. It is however recognised that it is essential to maintain morale and total commitment in all those involved, and that the closer complete eradication is approached, the more expensive in terms of money and effort each successive kill becomes. The South African Department of Environment Affairs intends allocating sufficient resources to achieve this and to maintain vigilance for some time after eradication is thought to be complete.

SUMMARY

A feral cat population on sub-Antarctic Marion Island, originating from five pets introduced in 1949, was seriously threatening burrowing seabird populations on the island. Biological control with the virus feline panleucopaenia was initiated in 1977, but after substantially reducing the population the disease appeared to become ineffective at low cat densities. Follow-up control by means of hunting, mainly at night with shotguns and spotlights, was started in 1986.

A total of 14 725 man-hours were hunted during 4486 hunting trips. Eight hundred and seventy two cats were shot and an additional 80 trapped. Although it has been impossible to estimate the size of the cat population, the number of cats sighted per hour of hunting at night is considered to be the most reliable index of density. The number of sightings per hour decreased from 0.5 to 0.099 over the first four years of the programme, indicating a marked decrease in density.

The reduction in the rate of decline of sightings in successive seasons indicated that hunting was no longer removing sufficient cats to continue significantly reducing their numbers. Gin trapping was therefore incorporated into the programme and proved to be an effective method at low cat densities. Non-target species were caught in gin traps, but not in sufficient numbers to affect their populations. Poisoning has recently been incorporated into the programme in conjunction with trapping on a much larger scale.

The proportion of birds in the diet of the cats decreased significantly, with a concomitant increase in mice. This is ascribed to a decrease in the availability of birds as a result of cat predation. During the birds' breeding seasons chicks form a substantial proportion of the total number of birds taken.

The breeding success of two burrowing petrel species appears to

have increased over the course of the eradication programme, indicating that predation pressure by cats on young birds may be decreasing. If this is so bird populations may recover with the removal of the cats.

OPSOMMING

'n Wildehuiskatbevolking op sub-Antarktiese Marioneiland, wat ontstaan het uit nakomelinge van vyf troeteldiere wat in 1949 na die eiland geneem is, het grawende stormvoëlbevolkings op die eiland ernstig bedreig. Biologiese beheer met die feline panleucopaeniavirus het in 1977 'n aanvang geneem, maar nadat die bevolking aansienlik verminder is blyk dit dat die siekte by lae katdigthede oneffektief geword het. Opvolgbeheer d.m.v. jag, hoofsaaklik in die nag met haelgewere en skietlampe, het in 1986 begin.

In totaal is 14 725 man-ure gejag gedurende 4487 jagtogte. Agthonderd-twee-en-sewentig katte is geskiet en 'n verdere 80 is in valle gevang. Alhoewel dit onmoontlik was om die grootte van die katbevolking te beraam, is die aantal katte waargeneem per uur van nagjag beskou as die mees betroubare indeks van digtheid. Die aantal waarnemings per uur het gedaal van 0.5 tot 0.099 oor die eerste vier jaar van die program, wat 'n drastiese afname in digtheid aantoon.

Die afname in die tempo van waarnemings per uur in opeenvolgende seisoene het aangetoon dat jag nie meer genoeg katte verwyder het om 'n betekenisvolle afname in getalle vol te hou nie. Die gebruik van slagysters is gevolglik in die program ingesluit, en is 'n effektiewe metode by lae katdigthede. Nie-teiken spesies is in slagysters gevang, maar te min om hulle bevolkings te beinvloed. Die gebruik van gif is onlangs in die program ingesluit tesame met die gebruik van slagysters op 'n baie groter skaal.

Die verhouding voëls in die dieet van die katte het betekenisvol verminder, gepaardgaande met 'n toename in muise. Dit word toegeskryf aan 'n afname in die beskikbaarheid van voëls as gevolg van katpredasie. Gedurende die voëls se broeiseisoene vorm kuikens 'n aansienlike deel van die totale aantal voëls wat gevang word.

Die broeisukses van twee grawende stormvoëlspesies het waarskynlik toegeneem met verloop van die uitwissingsprogram, wat daarop dui dat predasiedruk deur katte op jong voëls afgeneem het. In dié geval sal voëlbevolkings waarskynlik herstel.

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APPENDIX 1: EFFECTS OF CONTROL ON THE GENETIC STRUCTURE OF THE CAT POPULATION

AIM

To determine if control was selecting against certain phenotypes, and if so if this selection pressure had resulted in genotypic changes in the population.

MATERIALS AND METHODS

All cats shot were classified according to coat colour pattern, following Van Aarde & Robinson (1980). Coat colour pattern was recorded as black, or striped or blotched tabby. Presence of piebald spotting was noted. Analysis was by chi-square, based on original observations (Zar 1984), although results are presented as percentages.

RESULTS

Frequencies of coat colour phenotypes of all cats killed are presented in Table 11. The proportions of black cats in the population changed significantly over the three years ($\chi^2_2 = 19.33$; $p < 0.001$), but in no constant direction. The proportion of blotched to striped tabbies increased significantly over the three years ($\chi^2_2 = 6.36$; $p < 0.05$). There were no significant changes in the proportions of piebald spotting ($\chi^2_2 = 3.07$; $p > 0.05$).

DISCUSSION

The high proportion of black cats in the population on Marion Island has