

INTERACTIONS OF THE SOUTH AFRICAN FUR SEAL
AND FISHERIES IN THE BENGUELA ECOSYSTEM

by

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Submitted in fulfillment of the requirements for the degree of Doctor of Philosophy in the
Department of Zoology, Faculty of Science at the University of Cape Town

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DECLARATION

This thesis documents original research, carried out in the Zoology Department, University of Cape Town, between 1987 and 1989. None of it has been submitted in whole or in part for a degree at any other university. Any interpretations that are uncited are my own and any assistance I have received is fully acknowledged.

Signed by candidate

Signature removed

P. A. Wickens

9-10-1989

Date

For Geoff and my parents, Roger and Pam

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ABSTRACT

Wickens, Patti A. 1989. Interactions of the South African fur seal and fisheries in the Benguela Ecosystem. Ph.D. Thesis, Zoology Department, University of Cape Town, Rondebosch, 7700, South Africa, 288 pp.

This thesis adopts an holistic approach to evaluation of the "seal problem", which encompasses the operational and biological interactions between the South African fur seal and fisheries in the Benguela Ecosystem. The operational interactions are examined using a qualitative assessment, and speculative, single-species simulation models are developed to improve understanding of seal population dynamics, present options for seal management and explore seal-fishery interactions. The models show that the probability of a seal living longer than 20 years is 14%; that the population has increased at a rate of 5.1% p.a. since the last major census in 1983; that in 1988 there were an estimated 1.5 million seals that consumed over 2 million tons of fish; that although seal population size is usually estimated by multiplying the number of pups by a factor of 4, this factor is very variable and under different culling regimes is usually greater than 4; that historically, the mean population : pup ratio is 4.55. The most effective means of reducing the population is to cull both pups and bulls (the population decrease resulting mainly from reduced pup production caused by disturbance during bull culling). Culling pups is the least effective means of population control. Culling cows alters the population sex ratio drastically and is considered undesirable. To achieve a small or negative population growth rate, more bulls and pups need to be culled than have been taken historically. Each of the fisheries is found to be subject to operational interactions with seals, this being most severe for the purse-seine fishery. The per capita consumption of fish by seals is similar under any management regime so it is not justified to adopt a particular culling strategy to reduce overall consumption. When either seal predation or fishing mortality is reduced, the model simulates an increase in fishery yield of Cape hakes. But there is inadequate understanding of hake population dynamics at present, and depending on the interactions between species, decreased predation may result in increased or decreased fishery yields. This study shows that operational interactions are a real problem and this biases the opinion of fishermen towards seals as competitors for fish resources.

CHAPTER 1

GENERAL INTRODUCTION

THE "SEAL PROBLEM"

In 1984, the Minister of Environment Affairs introduced a management policy (Wiley, 1985) which was aimed at reducing the population of the South African (Cape) fur seal (*Arctocephalus pusillus pusillus*). The policy was an attempt to appease those commercial fishermen who claim that the seals compete with them for the common resource of fish and that seals interfere during fishing operations. The policy called for culling seals at various colonies, and for one colony, females were to be "shooed" away as they came ashore to give birth. The logic behind decreasing the population size was that this would lead to reduced predation on the fish, resulting in more fish for the fishing industry to harvest. Although the management objective was clear, the effect that a reduced seal population would have on the fish populations was unknown because the policy had no scientific basis. In response to this, an informal conference was held in 1987 (Anon, 1987) and the participants recommended that this management policy be suspended until the rationale behind it had been thoroughly examined in a scientific manner. The purpose of this thesis is to examine the consequences of culling on the seal population and the possible effects of seal culling on fish yield.

Sealing is a controversial and emotive issue. The views of the fishermen are diametrically opposed to those of the animal rights campaigners. Both of these groups are able to motivate strongly for changes in seal management policies as has been seen in South Africa in the 1980's. Originally the policy aimed at an optimal harvest of pelts for the fur market. This was stopped by a world-wide "pro-seals" conservationist lobby, which led to the collapse of the pelt market in 1983. Harvesting then focussed on the bull seals, the genitals of which are used as an aphrodisiac in the Far East. This market is also unpopular with campaigners for animal rights, but their opposition has not reached influential proportions. More recently, motivated by the "anti-seal" views of the fishermen, a policy was implemented in 1984, in which the emphasis was to control the seal population rather than optimise a harvest of seals.

At present, alternative markets are being explored for seal products and the management objective is once again being directed towards the optimal harvesting of both pups and bulls. However, the problem of the interaction between commercial fisheries and seals, which has been a cause of dissatisfaction among fishermen for many years in the Benguela Ecosystem and has formed part of the "seal problem", remains an intractable issue. Beverton (1985, p 4) believes that the "problems created by the interactions between marine mammals and fisheries, both for the decision makers and the scientists, are among the most challenging and fascinating that have arisen so far in the management of natural resources".

There is much documentation on the interactions between commercial fisheries and marine mammals. Studies and discussions of the seal-fisheries interaction have been undertaken both locally (*e.g.* Rand, 1959; Shaughnessy *et al.*, 1981; Shaughnessy, 1985; David, 1986; Oosthuizen, 1986; David, 1987a, Butterworth *et al.*, 1988) and worldwide (*e.g.* Lister-Kaye, 1979; Bonner, 1982; Furness, 1982; Northridge, 1984, 1986; Beddington & de la Mare, 1985; Bowen, 1985; DeMaster *et al.*, 1985; Harwood & Greenwood, 1985; Lowry & Frost, 1985; Swartzman & Haar, 1985; Yablokov, 1985; Gulland, 1987a, b; Harwood & Croxall, 1988), and the problems encountered are similar. Interactions between all marine mammals and fisheries are reviewed by Northridge (1984). Based on data from his summary of interactions, only the interactions of four pinniped species can be regarded as being of particular significance to either the seal population or a fishery, both in terms of operational encounters and the consumption of commercial species by seals. Two of these species are true seals (the grey seal *Halichoerus grypus* in the northwest Atlantic and the harp seal *Phoca groenlandica* in the north Atlantic), and the other two are fur seal species (the Northern fur seal *Callorhinus ursinus* in the northeast Pacific and the South African fur seal in the southeast Atlantic).

The "seal problem" involving the South African fur seal encompasses the competitive interactions between seals, the commercial fisheries and seabirds. There are two important interactions between seals and the fisheries : an operational interaction and a biological interaction. It is a major complaint of the fisheries that seals consume catches, disturb some fishing operations and damage

equipment. Furthermore, it is often maintained that the seals are consuming fish that could otherwise be harvested by the fishing industry. At the time of the last major census of the seal population in 1983, the seals were thought to have increased whereas some harvestable fish stocks such as the South African pilchard *Sardinops ocellatus* and the west coast hakes *Merluccius paradoxus* and *Merluccius capensis* had declined. This caused concern amongst the fishermen, who attributed the decrease in their potential catches to increased consumption by the seals, which were already unpopular because of interference during fishing operations. An additional interaction between other seal species and fisheries is the spread of parasites from seals to fish both of which form hosts to the parasite. This requires additional handling on the part of the fish processors to reduce the number of parasites to an acceptable level (Gulland, 1987a, b). Although parasites are found in the South African fur seal, they have not been documented as being any problem to southern African commercial fish (Shaughnessy, 1985).

In addition, a further aspect of the "seal problem" that requires investigation, but is not dealt with in this study, is seal-bird interactions which are a cause for concern amongst ornithologists. Seals compete with a number of bird species for breeding space and food, and seals have been seen eating birds. Displacement of seabirds by recolonising seals has occurred at Hollam's Bird Island, Sinclair Island, Mercury Island, Elephant Rock, Seal Island (False Bay), Quoin Rock and Seal Island (Mossel Bay) (Rand, 1952, 1963, 1972; Shaughnessy, 1980b, 1984; Brooke, 1984; Shelton *et al.*, 1984; Crawford *et al.*, 1989 and Crawford *et al.*, in prep). For example, at Mercury Island seal breeding resumed in 1983 after a break of almost a century (Crawford *et al.*, 1989). At Mercury Island there are three main bird species (jackass penguins, bank cormorants and Cape cormorants) competing for space and all are in the Red Data Book and considered endangered or scarce. Seals displace and disturb birds, mainly during the seal breeding season. Between 1978 and 1986 there was a large decrease in the population of penguins (65%), Cape cormorants (90%) and bank cormorants (approximately 70%) on Mercury Island. Although seals have been known to consume seabirds, in particular, penguins, the evidence is mostly anecdotal (*e.g.* Rand, 1959; Cooper, 1974; Shaughnessy, 1978; Rebelo, 1984; Shelton *et al.*, 1984; Bruemmer, 1988; Crawford, pers. comm.), and seals certainly do not appear to be common predators of seabirds.

Although seal-bird interactions require attention, they are localised problems and are not aspects of importance to the fisheries. Consequently they are beyond the scope of this thesis.

The "seal problem" is therefore complicated and commissions which have addressed the issue both in South Africa and elsewhere have not always been considered to have treated it adequately. For example, two recent reports (Anon, 1986b, c) in which sealing is discussed have been criticised as being both biased and essentially incorrect (Holt, 1987; Butterworth *et al.*, 1988). The Diemont Commission (Anon, 1986b) which was formed to examine the allocation of quotas for exploitation of living marine resources, recommended that the South African fur seal population be reduced. However, critical examination of the sections of the report relating to seals show that it has little scientific basis and many statements are erroneous or misleading (Butterworth *et al.*, 1988). Likewise, the Canadian Royal Commission on Seals and Sealing (Anon, 1986c) was found to have many cumulative errors which invalidated its conclusion that it was cost-beneficial to cull grey seals (Holt, 1987). Similar articles have been published in the popular press by those in favour of utilising seal products. As an example, an article published in the Fur Bulletin (Anon, 1986a) was found by David (1986) and Comrie-Greig (1986) to contain many illogical opinions and factually incorrect statements. It is implicit in the aims of this thesis, which are described below, to provide more objective treatment of the "seal problem" to serve opinion and policy development.

SCOPE AND OBJECTIVES OF THIS STUDY

The aim of this study is to focus specifically on the seal-fisheries aspect of the "seal problem". Fig. 1.1 shows the aspects of the "seal problem" schematically and highlights those that are to be evaluated by this study. There are three main objectives :

- (i) to evaluate operational interactions between seals and fisheries.
- (ii) to consider culling as a means of controlling the seal population, irrespective of the ultimate purpose of the control.
- (iii) to assess culling as a means of reducing fish consumption and, more specifically, as a means of increasing fish yield for the fisheries.

In addition to these specific objectives, the thesis aims generally to improve understanding of the seal population dynamics, both historically and as a result of the different theoretical culling schemes, to assess the potential size of the harvest under various management strategies, and to suggest directions for future research.

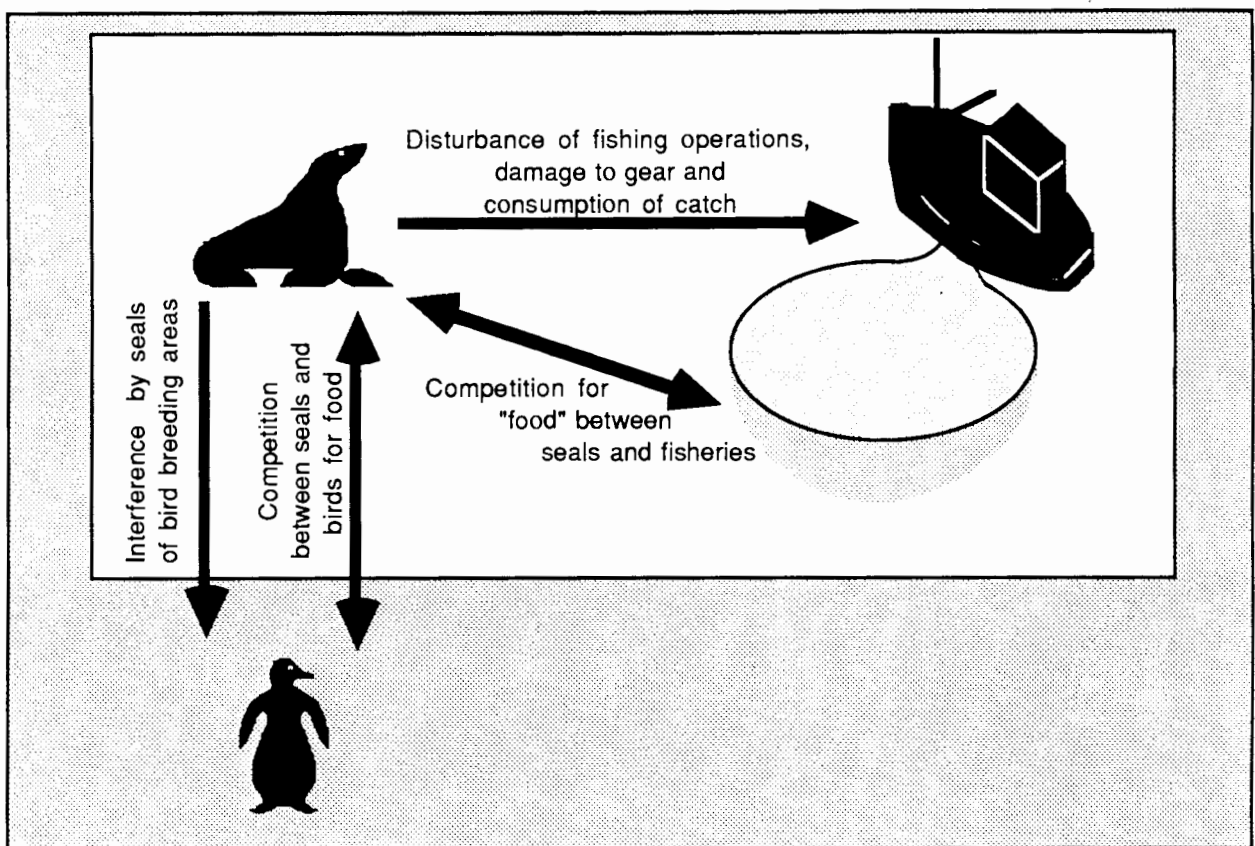


FIGURE 1.1 : Pictorial representation of the biological and operational interactions between seals, the fishery, fish and birds. Thick lines with double arrows link the competitors. The single ended arrow represents interference. The interactions to be examined in this thesis fall within the enclosed white area.

THE APPROACH TO THE PROBLEM

The approach adopted for Objective (i), evaluation of the operational interactions between seals and the fisheries, is to assess the effects in a qualitative manner through discussion with persons dealing with each of the fisheries. A quantitative evaluation is difficult because there is likely to be a large degree of bias involved if fishermen are expected to make objective observations. The remaining two objectives of the study are achieved by modelling as opposed to empirical techniques. There are many parallels between modelling and empirical techniques (Caswell, 1988); both models and experiments are "tools" used to test hypotheses. The rationale for choosing models instead of empirical techniques is because modelling creates an ersatz world in which many trials, testing different culling hypotheses, can be conducted in a short time without perturbing the system, whereas the empirical method would require a long real-time period in order to test a single culling hypothesis. The rationale behind selecting the specific modelling techniques used to explore Objectives (ii) and (iii), that of the *interactive use of speculative single-species* models, from a range of different modelling approaches that could be adopted, is outlined below.

Speculative modelling

Of the many myths that abound about modelling studies, the worst is considered by Walters (1986, p 44) to be one that states : "if models are to be useful, they must be capable of detailed and/or precise quantitative predictions". Walters (1986, p 45) believes that the "value of modelling in fields like biology has *not* been to make precise predictions, but rather to provide clear caricatures of nature against which to test and expand experience". Starfield and Bleloch (1986) also describe models as "intellectual tools" which can be built for a number of reasons. At no point in this thesis is there any intention of making precise predictions and providing "best estimates" based on the model results. The approach adopted therefore is to build parsimonious, speculative models as opposed to predictive statistical models. These models can be used to formalise thought, to improve understanding and to gain insight into the dynamics of populations under

various hypothetical scenarios. The speculative capacity of the models depends on how adequately they explain the most relevant characteristics of the populations.

A model is a subset of a larger context and the researcher decides which features should be incorporated and which disregarded. The approach to the formulation of a particular model depends on the modeller's perception of the system and choice of temporal and spatial scales. There is no defined limit to the number of assumptions one can make in a model; the boundaries for acceptability and resolution of a model are in the hands of the modeller. The design of a model is therefore a subjective process. However, the design of any study, whether experimental, field-based or modelling, has limitations and involves simplifying assumptions which are made by the researcher. Output of a model is limited by the quality of the available information that is fed in. The results of a model should be analysed and interpreted with the specific structure and data of the model in mind, and the limitations and constraints placed on the output by the model assumptions must be critically discussed. Often, counter-intuitive results are produced by a model and these can generally be explained by examining the model structure and input data carefully. The sensitivity of a model to structural or data changes often provides insight about areas in which information is sparse or requires improvement.

No single model can necessarily be expected to solve an issue completely (Caswell, 1988). Therefore numerous plausible models may exist for a particular scenario. Starfield *et al.* (1988, p 299) note that "no single model is sufficiently flexible to address the wide range of potential problems that constitute the decision environment for managers of renewable resources". Consequently, these authors advocate that a "toolbox" of models should be built. A number of different speculative models can be built for a single purpose. Cohen (1987) questions the extent to which a model is unique in describing the relationship between inputs and outputs. No single model can be considered as *the* correct one. However, there are incorrect models (those that yield implausible results) and at best we can eliminate these and in so doing reduce the set of possible models. Presumably, as more data are collected, there will be fewer models that fall into the acceptable set. Each model presented in this study provides a certain amount of insight into some

particular aspect of the "seal problem", and together these models should provide a balanced set of management strategies while furthering the understanding of the seal population.

Single- versus multi-species approach

Caughley (1981, p 362) makes the statement that "there are many single-species models of animals but there are no animals in single-species environments". This statement applies to both empirical and theoretical studies, because all species interact with one another. Most fisheries models are single-species, because most fish stocks are managed with a single-species objective in mind. The aim of the 1984 seal management policy (Wiley, 1985) was to reduce the seal population in order to reduce predation on fish which would, in theory, lead to an increase in fish populations and thus the yield of fish. A management policy which requires the culling of seals to achieve an increased yield of another species should be based on multi-species analyses. This multi-species concept of culling a stock for the benefit of another stock is therefore more interesting and intriguing than the common fisheries management problem of harvesting a population optimally, in which species influences are ignored primarily through assuming a constant rate of natural mortality. It is in this respect that the seal management problem differs from that of most fisheries management tasks in South Africa. Furthermore, the aims of multi-species models that have been formulated for other systems, have also differed from that of the South African seal-fish system. In other multi-species systems, the management objective has been the maximisation of the harvest of at least one of the species involved, and not, as for the South African seal, specifically to reduce one component (seals) to optimise the yield of another (fish).

Numerous models have been developed to examine multi-species systems for a variety of objectives (*e.g.* Anderson & Ursin, 1977; May *et al.*, 1979; Beddington & May, 1980; Beddington & Cooke, 1982; Laevastu *et al.*, 1982; Vincent & Gayek, 1982; Butterworth *et al.*, 1988) and the short-comings of these models have been discussed (*e.g.* May, 1976; Horwood, 1981; Cohen, 1987; Pikitch, 1988). The dilemma in deciding on the resolution of a model while acknowledging the limitations at either end of the complexity scale has been well-documented

(*e.g.* May *et al.*, 1979; Horwood, 1981; Starfield *et al.*, 1988; Onstad, 1988; Shelton, 1988). As a model increases in complexity and therefore in resolution, more may be explained but the ease of interpretation may decrease because model effects are more difficult to define.

Not all of the limitations and constraints of multi-species modelling are insurmountable, because certain assumptions have to be made in any model. However, some features of a population may be considered to be particularly limiting to the formulation of multi-species models, making the dynamics difficult to model. An example is opportunism in feeding. Fur seals are generally opportunistic predators, and the South African fur seal is considered to be an opportunistic feeder although Lipiński and David (in prep) speculate that some seals may have a preference for squid on the South African coast. The diet information used in this study (David, 1987a) is a synthesis of data collected between the years 1974 and 1984. However, the diet composition of an opportunistic feeder is, by definition, mutable, changing in response to the availability of the prey items. Therefore diet information is not necessarily representative of the diet for an extended period of time. The South African fur seal diet may have been changing during the ten-year period of data collection, and may have altered subsequent to 1984.

Examination of the diet, which comprises numerous species (David, 1987a) and a myriad of interactions between these species (Bergh *et al.*, 1985), provides a static view of the important components that might be studied in a model. Multi-species models which include seals and dietary species should incorporate dynamic effects but this gives rise to many complications. Firstly, the species involved in an interaction often have different temporal scales and levels of resolution in terms of the quality of their data sets. Secondly, as the relative proportions of the system components are altered, it is probable that prey switching will occur. It is often difficult to define the functional relationships between predator and prey because the nature and strength of the interactions between the species (*e.g.* competition, predation and cannibalism) and the relative densities of the different species, can profoundly affect the dynamics of a multi-species system. Some interactions may appear more important than others when the static system is examined, but in a dynamic system, the relative importance of different interactions may change and new

interactions may arise. This introduces variability, not only to the species interactions but also to the species included in a model. Populations that are excluded from a model as insignificant may become important and require inclusion.

Another limitation of multi-species modelling is the spatial heterogeneity of the diet because this results in different types of interactions in different regions within the predator's range. This complicates matters when one strategy is required to apply to the whole seal population but multi-species modelling may require that different areas be modelled separately. Thus the opportunistic feeding of the South African fur seal and the variation in diet in different areas are probably the most important limitations in formulating a meaningful multi-species model for this population. The set of possible speculative multi-species models that could be designed to explore the response of fish populations to changes in the seal population is therefore likely to be very large.

Management requires some guidelines in order to determine a policy for the South African fur seal. The best alternative to a multi-species model is to look at different aspects of the multi-species problem by means of a number of single-species models, and this approach is adopted here. The information for single-species models is more readily available than for multi-species models, although single-species models are limited in that they can be too simple and therefore omit some vital ecosystem characteristics which may be necessary to understand multi-species interactions. However, tractable single-species models with associated forcing functions can be designed to produce a selection of options for management. The management policy for seals could be directed towards single-species management. For example, a policy could be aimed merely at keeping the seal population at a particular level, since it is in no danger of extinction. In this thesis, single-species analyses are performed to improve our understanding of the seal population and to explore management strategies for the seals and thereby achieve the three main objectives. The models to be described are represented diagrammatically in Fig. 1.2, showing the model populations, forcing functions and the main output. Under different culling regimes, the changes in the seal population and the amount of food consumed by seals (which requires no

specification of the diet) are explored using various modifications of a generalised seal model. The effect of seal predation on fish yield is investigated using a single-species fish model.

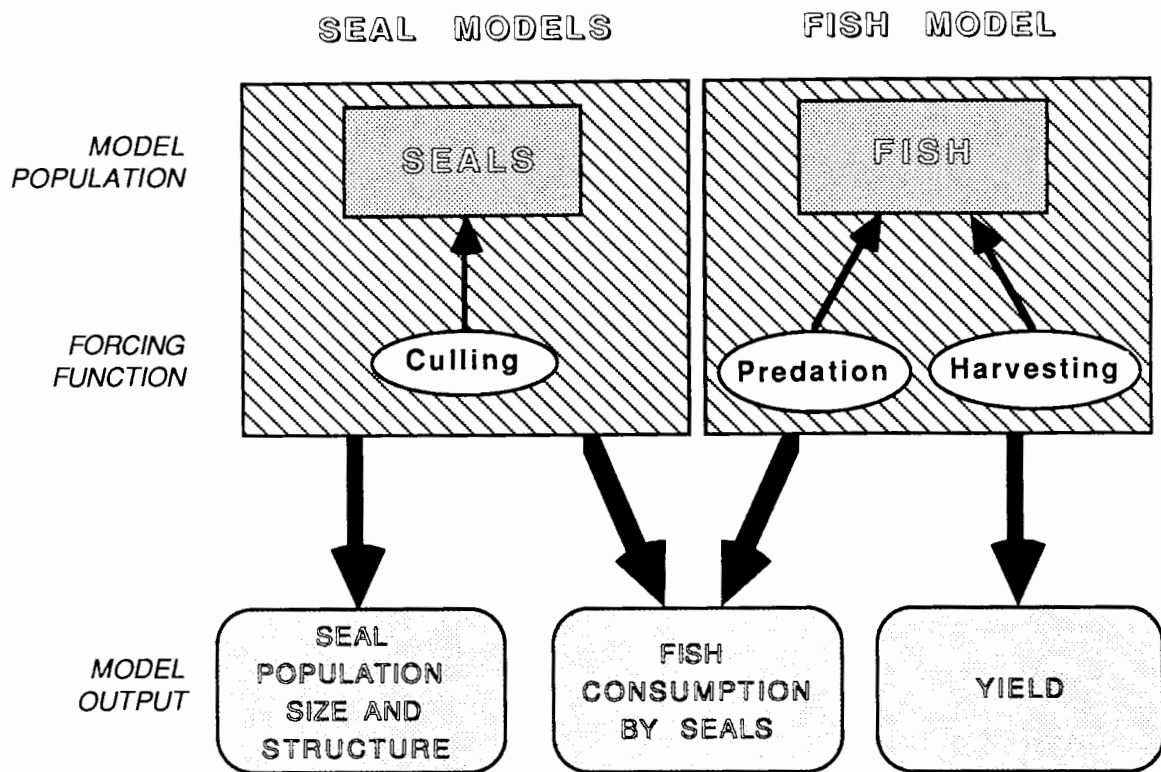


FIGURE 1.2 : The single-species models to be used to explore seal-fish-fishery interactions. Culling is considered a forcing function in the seal models, and the effects of culling are viewed in terms of seal population size, age and sex structure and consumption of fish by the seals. Predation and harvesting are forcing functions in the fish model, and the effects are examined in terms of consumption of fish by seals, and fish yield to the fishery.

Interactive process of modelling

Model-building requires input from a number of different sources; the approach adopted here involves an iterative process of improvement of the models. This is similar to one advocated by Walters (1986), in which the process of modelling involves designing the model, performing simulations, comparing the simulations with expectations and, if inconsistencies are found, repeating the process. In this study, the approach is to build a model, discuss its limitations with modellers, biologists and resource managers and then repeat the modelling process, improving the

models, assumptions and data. During this process of model building, questions arise that require answers in order to refine the model, and in this manner knowledge about the population and related effects is improved.

There are a number of reasons for strong interactions to take place between the modeller, biologists and managers. For example, not all parameters in the model can be easily measured, but biologists may be able to make educated guesses, based on their intuitive understanding or from information that would otherwise not have been available to the modeller. A modeller must know the derivation and quality of the model data to determine its applicability in the model, and this can be evaluated by biologists who collect the data. It is important to know whether the data are obtained from direct measurements, or if they are derived from other data (*e.g.* from catch data), as this may influence interpretation of the results.

In the development of models, it is important that there be continuous interaction between those producing models and the ultimate client during the conceptual, developmental and output stages of model development. Because one of the most difficult problems in ecological modelling in the fisheries context is to communicate the results of the modelling exercise to fisheries managers (Cohen, 1987), the communication task becomes easier if there has been prior input from the end-user and collaboration between the modeller and the biologists and managers.

STRUCTURE OF THE THESIS

In Chapter 2, an understanding of the life history of the South African fur seal, its geographical distribution, censusing methods, historical population trends, management, exploitation and the economics of sealing and tourism are explored. The operational interactions with the different fisheries are evaluated in Chapter 3. Various models and their output are discussed in the remaining chapters and these models are characterised according to a set of attributes based on the concept described in Starfield *et al.* (1988) although the choice of attributes differs. A speculative

simulation model of the seal population which includes options for seal culling and the disturbance influences of culling is developed in Chapter 4. The model is then modified in order to follow one seal cohort through its lifespan to compare model population longevity with literature values for other seals. The sensitivity of the models to parameter values for other fur seals is tested. In Chapter 5 this seal model, which is not scaled to realistic population size, is used to provide hypothetical scenarios on the performance of various alternative management strategies. In Chapter 6 the model is scaled with historical trends in the South African fur seal population to suggest possible future outcomes under alternative management strategies. Thereafter the amount of fish consumed by the model seal population under different management regimes is simulated and discussed in Chapter 7. In Chapter 8, a model of the hake population on the South African west coast is developed and used to assess the effect of different seal predation levels on the hake yield to the commercial fishery. Finally, in Chapter 9, a synthesis of the analyses of the seal-fishery interactions are presented and insight gained about the seal population discussed.

CHAPTER 2

BACKGROUND TO THE SOUTH AFRICAN FUR SEAL PROBLEM

LIFE HISTORY

Bulls are polygamous and arrive at the colonies to set up territories in mid-October (Shaughnessy, 1985) with the females arriving slightly later. The bulls are only present for the duration of the pupping season. Each territory comprises an aggregation of females all of whom mate with the bull. The term "harem" was previously used to describe the group of females, all of whom mated with a particular male. This was abandoned (Peterson, 1968) since the cows aggregate with each other and no evidence suggests that the females prefer specific males or are held to a territory by the male - as is implied by the term "harem". The pupping season is approximately one month long (Shaughnessy, 1979; David, 1987b) with the median pupping date in early December (David, 1987b).

Mating takes place, on average, 6 days after pupping (David & Rand, 1986) and the gestation period is almost one year, with delayed implantation of about 4 months (Shaughnessy, 1979). Each cow produces one pup which can be suckled for 12 months or longer (Shaughnessy, 1979), although they are usually fully weaned between the ages of 9 and 11 months (David & Rand, 1986). The cows remain at the colony until their pups are weaned. Pups usually start foraging at the age of 5 to 6 months (David & Rand, 1986).

Seals have terrestrial and marine predators. Only the mainland colonies are subject to the land predators in the form of the brown hyaena and the black-backed jackal (David, 1987b). The jackals tend to take only the still-born pups and placentas while the hyaenas may take live pups (personal observation). In the sea, sharks and killer whales are probably the main predators (David, 1987b).

The events that take place in a colony during a year and the various individuals present at the colony during different months are shown in Table 2.1. Only the pups remain at the colony most consistently during the year.

TABLE 2.1 : Calendar of events taking place in a seal colony. See text for references.

MONTH	INDIVIDUALS AT THE COLONY
November	Bulls arrive first to set up territories for breeding. Females arrive to pup and to mate, which takes place on average 6 days after pupping (David & Rand, 1986). Breeding starts towards end of the month.
December	Breeding period tails off near end of month.
January	Bulls leave colony.
January - July	Cows continue feeding pups and are present at the colony for about 50% of the time. Pups start foraging at 5 to 6 months old.
August - September	Some pups are weaned and can survive alone.
October	Pups all weaned by 9 to 11 months old (David & Rand, 1986). Very few individuals at the colony.

COLONY DESCRIPTION

The location of the breeding and non-breeding colonies of the South African fur seal on the southern African coast are shown in Fig 2.1. The range of this population extends from the non-breeding colony, Cape Frio, Namibia (18°S) to the breeding colony, Black Rocks, South Africa (26°E). Ten known non-breeding colonies (five on the mainland and five on islands) have been described by Oosthuizen & David (1988) and these are distinguished from breeding colonies by the absence of pups or minimal, erratic pup production. The numbers at the non-breeding colonies are increasing and the number of these colonies varies with the ongoing process of recolonisation. Generally, the term "colony" refers to a breeding colony unless otherwise specified.

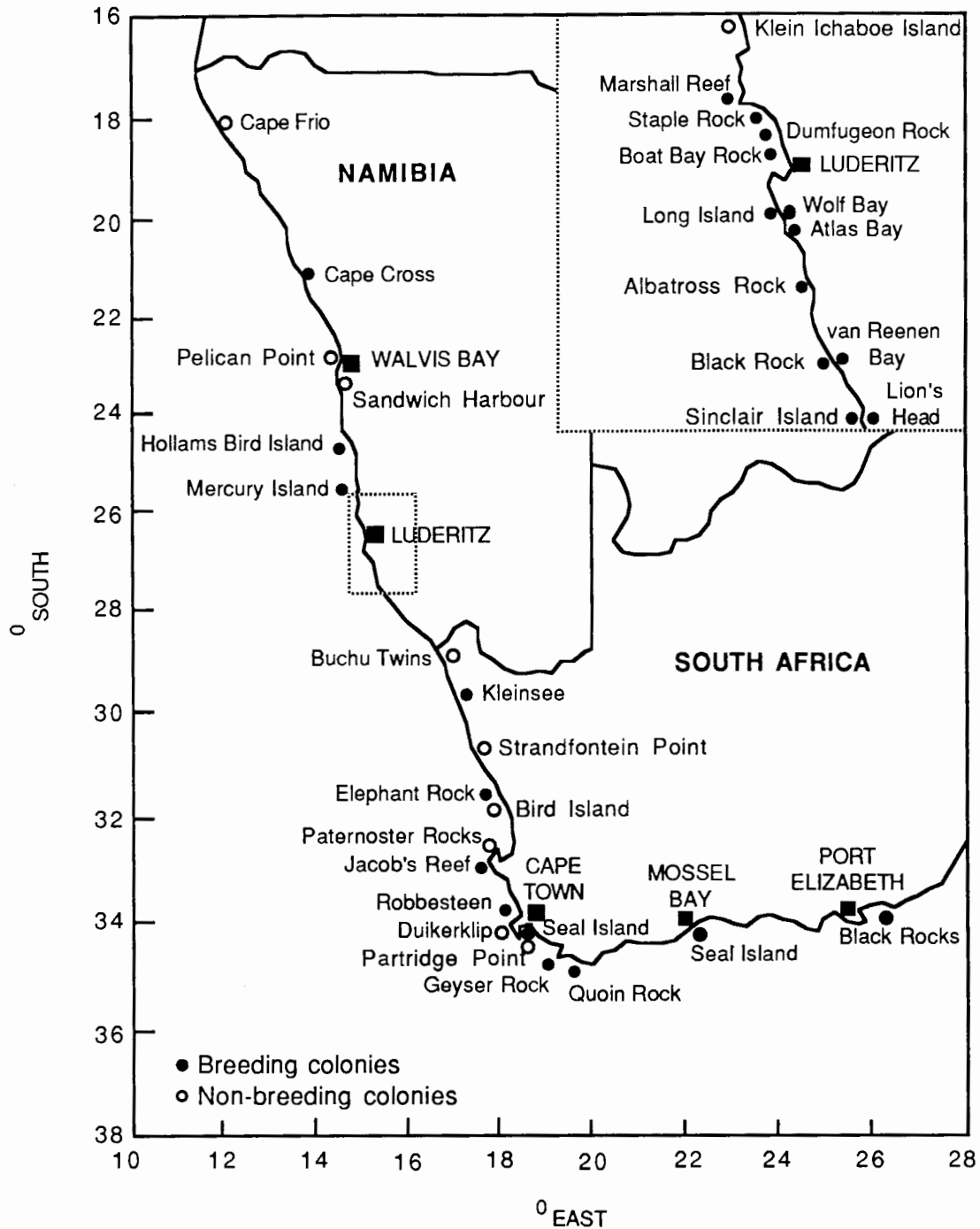


FIGURE 2.1 : Breeding and non-breeding colonies of the South African fur seal, throughout the extent of their range. The insert shows the colonies in the Luderitz area.

None of the colonies are positioned where human disturbance occurs. The island colonies are protected by their inaccessibility. Of the five mainland areas, four are in diamond-mining areas to which access is restricted and the remaining one, Cape Cross is in a nature reserve. David (1989)

suggests that Kleinsee and Atlas Bay are likely to be the largest mainland seal colonies in the world.

POPULATION CENSUSING

The method currently used to estimate seal population size is to multiply the number of pups by a figure of 4 (based on the method used for the Northern fur seal given by Johnson (1972)). The number of pups are censused using two methods : aerial censusing and tag-recapture estimation. Pups are censused since they are the only part of the population in the colony for an extended period. The other seals are either at sea feeding or are at areas other than the breeding colonies. An aerial survey is done in December after the birth season when pups are approximately three weeks old. Black-and-white photographs are taken and the number of pups on these counted. Three estimates are made from independent tag-recapture samples. Tags are attached to pups of about six weeks old. After one week, groups are surrounded and the number of tagged and untagged pups counted. Other recapture estimates are made from the ratio of tagged to untagged pups which are killed during the pup harvest later in the year (July/August). Two estimates are obtained because each sex is treated as a separate sample. Butterworth *et al.* (1987) calculate bias factors for each census method and produced estimates of the number of pups for each colony and these are given in David (1987b), for 1971 and 1983, the only two years to date, for which censusing of all colonies has been done.

POPULATION TRENDS

David (Table 2.2, 1987b) summarises the major demographic trends in the numbers of pups at all colonies from 1971, when regular censusing started. The mean number of pups at each colony in 1971 and 1983 and the annual growth over this period, taken from his table, are given in Appendix 1. The changes in the number of pups for each colony between 1971 and 1983 are also

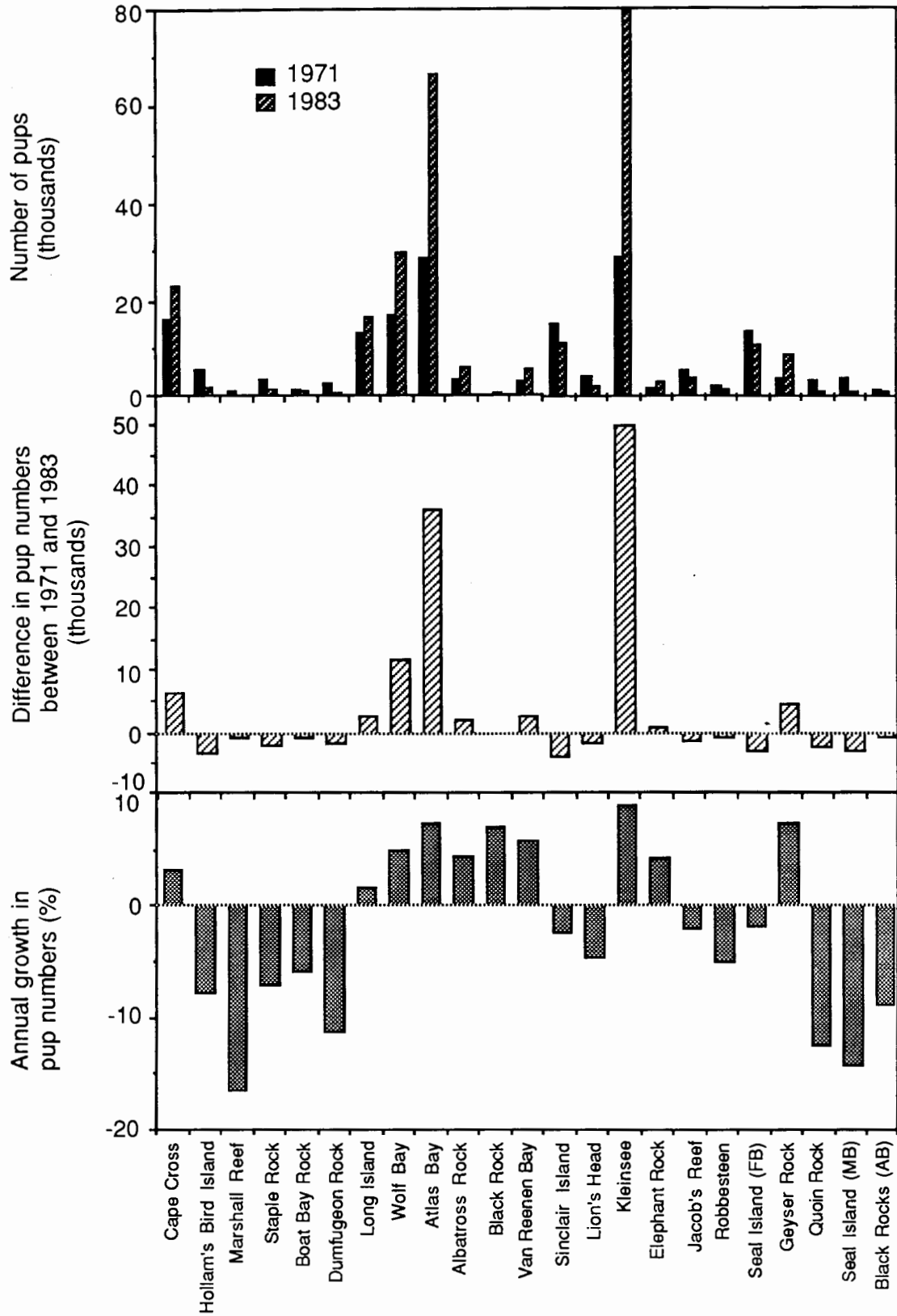


FIGURE 2.2 : Numbers of pups in 1971 and 1983, the years of major censusing; the difference in numbers between these years and the average annual growth during this period. Colonies are arranged according to long-shore geographic location. Data are taken from Appendix 1.

given. Fig. 2.2 shows graphically the relative numbers of pups at the colonies, their corresponding growth rates and the changes in numbers. Note, for example that the annual growth of Atlas Bay and Geyser Rock is similar but the change in numbers is very different. Kleinsee has shown the greatest increase, followed by Wolf Bay, Atlas Bay and then Cape Cross. In 1983, the 4 largest colonies were the mainland colonies of Kleinsee, Cape Cross and Wolf and Atlas Bays, which made up approximately three quarters of the total population. An additional breeding colony, Mercury Island was recolonised in the early 1980's and has now been added to these twenty-three. Pups have been born at Paternoster Rocks since 1985 but as yet, it is not recognised as a new breeding colony.

HISTORICAL MANAGEMENT POLICIES AND OBJECTIVES

The distinction must be made between culling for control of the population number with a minimum of effort, and harvesting which is using parts of the seal corpses for commercial value. The term "sealing" is used in this thesis to imply either culling or harvesting. The calendar of changes in sealing policy showing the transition from limitless sealing, through management for optimal harvest, then for control of the population, to the present less-well-defined policy, is documented below:

17th - 19th century : Uncontrolled international sealing in South Africa and Namibia.

1893 : First legislation which provided protection for seals came into being in the form of the "Fish Protection Act". This stated that no seals may be taken without a permit.

1909 : A limit placed on the season of sealing.

1922 : The "Sealing and Fisheries Proclamation" was formulated to control sealing in Namibia.

1949 - A second act, "Sealing and Fisheries Ordinance" to control sealing in Namibia replaced the 1922 one.

1973 - The "Sea Birds and Seals Protection Act" repealed all other acts for Namibia and South Africa. This specified the age, size and sex killed, season and localities for sealing. The policy was to exploit the fur seal at around their maximum sustainable yield level with the aim of :

- reducing the population significantly to decrease seal predation on fish stocks
- maintaining a profitable sealing industry
- conserving fur seal for the appreciation of the public (Best, 1973).

The Act prohibits anyone from pursuing, shooting, wilfully disturbing, killing or capturing seals. However, the appropriate Minister may waive these prohibitions at his discretion.

1983 - A collapse in the market for seal pelts was brought about by conservationists, no longer making the harvesting of pups commercially viable. Prior to this, quotas were set on the basis of a maximal sustainable yield of pups. The Alant Committee report (Anon, 1983) stated that "seals should not be culled if the principle objective for doing so is to attempt to make more fish available to the industry. In any event, no culling of any kind should be allowed before adequate scientific studies have been completed".

1984 - Minister Wiley (Department of Environment Affairs) formulated his policy in an attempt to reduce the seal population without scientific support. Quotas for bulls were issued but the culling was carried out during the pupping season resulting in many deaths. The rationale behind this culling programme was argued in the press and although pertinent questions regarding the Minister's reasoning for the cull were addressed to him in an open letter published in *African Wildlife* (Comrie-Greig, 1985), he declined to answer them in his reply in a later issue of *African Wildlife* (Wiley, 1985).

1985 - In this year, Minister Wiley stated that for every cow culled, a "free" bull could be taken. The Minister's rationale was to cause a reduction of the population by taking cows (which are of little financial value) while allowing the sealers to take bulls for their commercial value. His policy was that the seal population should not exceed its 1985 level.

1986 - The Diemont Commission (Anon, 1986b) which included no marine resource scientists stated that "control and reduction of the huge seal herds have become issues of major importance in the fishing industry and culling must be undertaken by the State ...". This policy of culling for population control as opposed to a harvest was accepted by the government.

Butterworth *et al.* (1988) examined the report in detail and found many statements to be "erroneous and misleading" and with no scientific basis. As part of the population reduction policy, Minister Wiley initiated a "shooing" programme at Seal Island, False Bay in which men were stationed on the island and chased seals as they tried to come ashore to breed. The result was that the pregnant females tried unsuccessfully to find other places to pup and numerous dead pups were found on the mainland beach opposite the island. This caused an uproar in the press and the "shooing programme" was debated in successive issues of African Wildlife (Yeld, 1987a, b and c; Wiley, 1987). In a press release by Minister Wiley (1986), he stated that "in addition to the 'seal disturbance' program, the seal culling programme will continue and regulations which, at present, prohibit skippers from shooting seals which interfere with their catches will be repealed".

1987 - A local informal conference was held by the Society for Prevention of Cruelty to Animals (S.P.C.A.) and was attended by biologists, an applied mathematician, a fishing industry economist, fishing company executives, a skipper and S.P.C.A. representatives. Recommendations were made that there be a 4-year moratorium on culling and that sealing take place only during August to October and only at Kleinsee, the colony accounting for most of the population increase. Quotas would be set for pups and bulls. They emphasised that "experiments" such as the "disturbance programme" undertaken by Minister Wiley should be scientifically planned and monitored as this programme had no clear long-term goal. During 1987, various simulation models and expert systems were formulated by various researchers at the University of Cape Town and the Sea Fisheries Research Institute to explore aspects of the "seal problem" and these are documented in a Benguela Ecology Programme Report by Wickens and Shelton (1988). This preliminary document forms the basis for this thesis and is given in Appendix 2.

Present - The policy is to follow the recommendations of the World Conservation Strategy, as defined by the International Union for the Conservation of Nature and Natural Resources (Anon, 1980). This states that a renewable resource can be exploited provided it is done on a rational basis with careful management of the harvest and monitoring of the population size. Currently a market for meat is being explored and the Taiwanese have developed a market for

pelt leather for bags, hats etc. Bulls continue to be harvested for the oriental aphrodisiac market and the carcasses are also usually used to produce meat and oil. So the policy is returning to one of a harvest and maximum sustainable yield for pups and bulls.

MANAGEMENT ENFORCEMENT AGENCIES

At present there are four enforcement agencies bodies, spanning two countries, and these have control over various colonies in different areas (Table 2.2). The South African island colonies do not lie only off the South African coast; Hollam's Bird Island, Mercury Island, Long Island, Albatross Rock and Sinclair Island are also claimed as South African islands. There is therefore no logical spatial or biological context to the grouping of the colonies under the control of different enforcement agencies.

TABLE 2.2 : Enforcement agencies that have control over different groups of colonies.

ENFORCEMENT AGENCIES	COLONIES
Nature Conservation, Namibia Directorate of Sea Fisheries, Namibia Sea Fisheries Research Institute Cape Department of Nature and Environmental Conservation	Cape Cross Namibian colonies excluding Cape Cross Kleinsee South African island colonies

SEALING METHODS

The methods of killing are the "stick-and-stun" (clubbing) method for pups while bulls and cows are shot in the head. The "stick-and-stun" method involves a group containing mainly yearlings being separated from the rest; clubbers form two parallel lines down towards the sea; the seals are

released from the group and move between the clubbers; under- and over-sized animals, cows and juveniles are allowed to pass through while the pups are hit on the head with a club; the unconscious animals are tossed back to the stickers who insert a knife into the heart and pierce the main blood vessels; the carcasses are then stacked behind and the skinning only commences once all the animals have been killed. Clubbing is overseen by an inspector of the Marine Development Directorate of the Department of Environment Affairs and by a representative of the S.P.C.A.. Adult seals are shot using a rifle with telescopic sights and a silencer from a range of about 30m.

The sealing seasons differ depending on which age or sex are being taken. The pup harvest takes place around July/August when the pups are approximately 8 months old. Early November is best for bulls, this being prior to the arrival of the cows. The 1985 cow cull took place during November and they were shot along with the bulls. In 1988, the cow season extended from August (with the pup harvest) to November (with the bull harvest). In this year they were clubbed.

OPINIONS REGARDING SEALING

Until fairly recently, humane societies were concerned that clubbing was inhumane and caused suffering to the pups. C. Platt (1977) from the International Society for the Protection of Animals witnessed clubbing operations on the South African fur seal and concluded that the method was generally efficient although as fatigue set in, clubbing did become less accurate and some pups required repeated blows to stun them. The opinions of some well-known animal rights campaigners and ardent conservationists were obtained :

"From what I have read, clubbing and shooting appear to be the best means available to despatch these animals." - N. Rice (Conservationist, pers. comm., 13-06-1988).

"Clubbing the sub-adults is probably the most humane yet the goriest method of killing the animals. I am totally opposed to shooting because of inaccuracy. Seals are wild animals and the presence of humans clubbing and shooting MUST cause the remaining animals considerable trauma" - C. Berry (Managing Trustee of "Beauty Without Cruelty", pers. comm., 11-06-1988).

K. Goudie (Secretary of the S.P.C.A., pers. comm., 12-07-1988) who has witnessed a sealing operation says that both the methods for killing seals are relatively humane and quick and not unlike abattoir methods but it is dependent on the skill of the sealers. However, he suggests that the remaining animals may be disturbed during a cull, particularly a bull cull, and this may be a problem.

The opinions are that if sealing is to be carried out, the current method of "pup clubbing" is acceptable. The shooting of bulls is also accepted but there is fear that the disturbance of this has a detrimental effect on the other seals. However, the basic acceptance of the methods by any of these persons does not mean they condone sealing.

The conservationist, Thomson (1986), attributes the anti-harvesting campaigns to the fact that the "main objection to the harvest is the practice of clubbing the seal pups to death". He suggests that the basis for stopping sealing is irrational and that since seals are not in danger of extinction and there is a market for the products the harvest should continue. This opinion appears to be incorrect in that it is generally not the method of sealing that causes objection (see above), although the disturbance caused by shooting bulls does cause concern. The reasons for the anti-sealing movements are based mainly on ethical and moral grounds regarding the non-essential use of seal products; their argument is not that the methods are cruel. This is confirmed by two animal rights campaigners :

"There is absolutely no necessity to kill seals as we do not need seal by-products for survival so to try and create markets for the products purely as a commercial operation is morally unjustifiable

and would be regarded as such by the public" - C. Berry (Managing Trustee of "Beauty Without Cruelty", pers. comm., 11-06-1988).

"If the authorities persist in maintaining that seals should be killed to appease the whims of the fishermen (and often the reasons for this are political) then obviously I would agree that meat from the carcasses should not be wasted. However, I am totally against genital organs being sold to buyers in the east to be used as aphrodisiacs etc. This is ethically wrong and is not fostering correct attitudes or correct awareness." - N. Rice (Conservationist, pers. comm., 13-06-88).

HISTORICAL SEALING TRENDS

Of the nine fur seal species, only the South American seal in Uruguay and the South African fur seal are still harvested (Information extracted from the "Species Summaries", Croxall & Gentry, 1987). Appendix 3 summarises the number of seals killed annually at the different colonies from 1900. Fig. 2.3 shows these sealing figures graphically, as a total and separated into pups and bulls. Two-and-a-half million pups, almost two hundred thousand bulls and approximately ten thousand cows have been killed this century. There is a period in the early 1930's during which few seals were taken and David (pers. comm.) attributes this to the economic depression of the time. The number killed increased dramatically from the 1930's and levelled off in the late sixties. The recent decline in pups harvested, since 1983, is a result of the collapse of the fur market. The number of bulls taken has been fairly irregular but in recent years greater numbers have been harvested for the oriental aphrodisiac market which has replaced the pelt industry.

Analysis of the years following the introduction of the "Sea Birds and Seals Protection Act" in 1973, with its stricter regulation of quotas for different colonies, is more detailed. Fig. 2.4 gives a breakdown of the relative numbers of pups, bulls and cows killed showing that pups are the largest contributor to the harvests, other than in the last two years. Cows have only been harvested twice. In 1985 they were killed as part of the population reduction policy, whereas in 1988 a

global quota of seal was given mainly for producing meat and oil, and cows were killed amongst the pups and bulls.

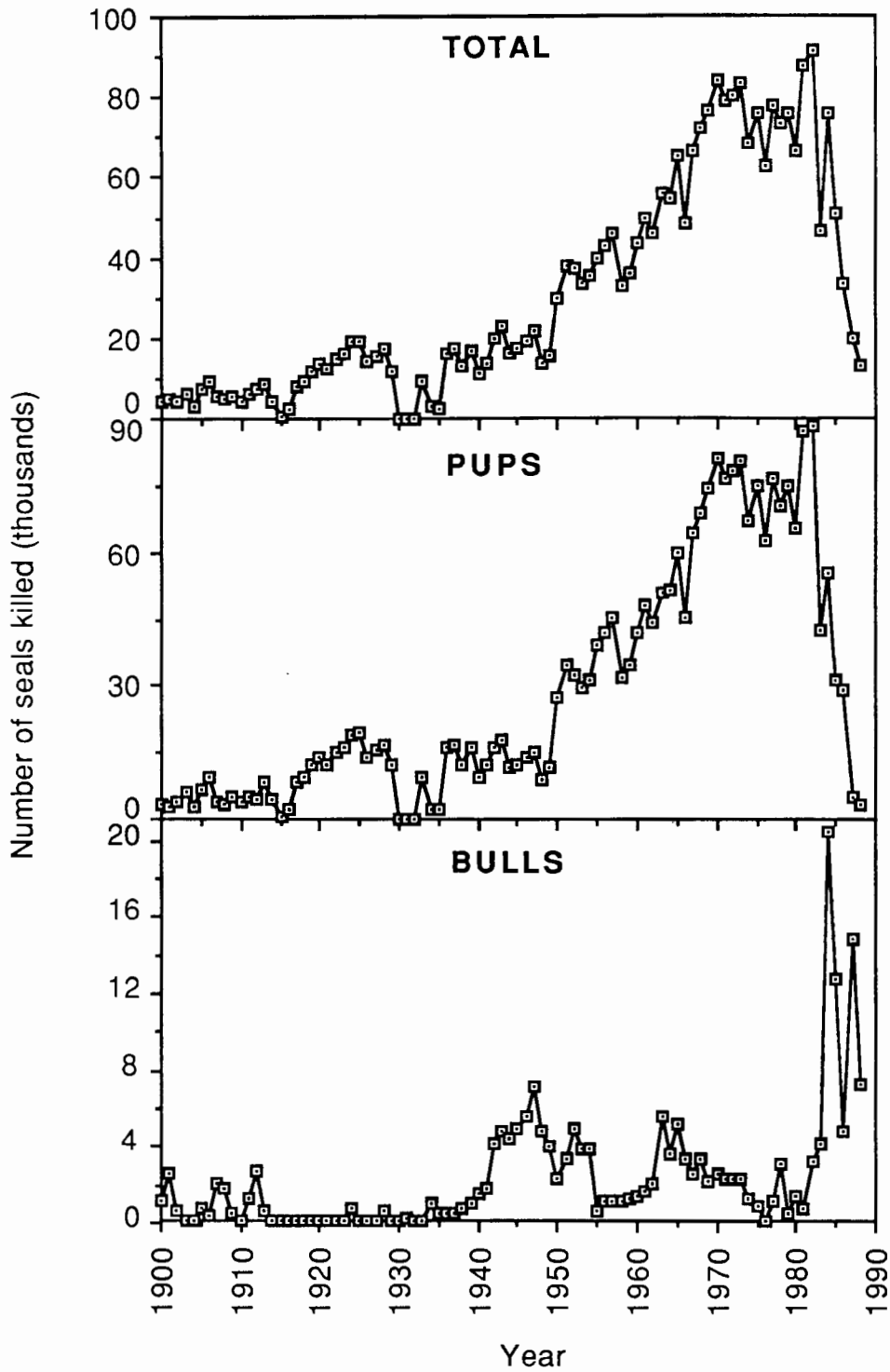


FIGURE 2.3 : Number of seals killed since 1900 presented as a total and separated into pups and bulls. To date cows have only been taken in 1985 and in 1988.

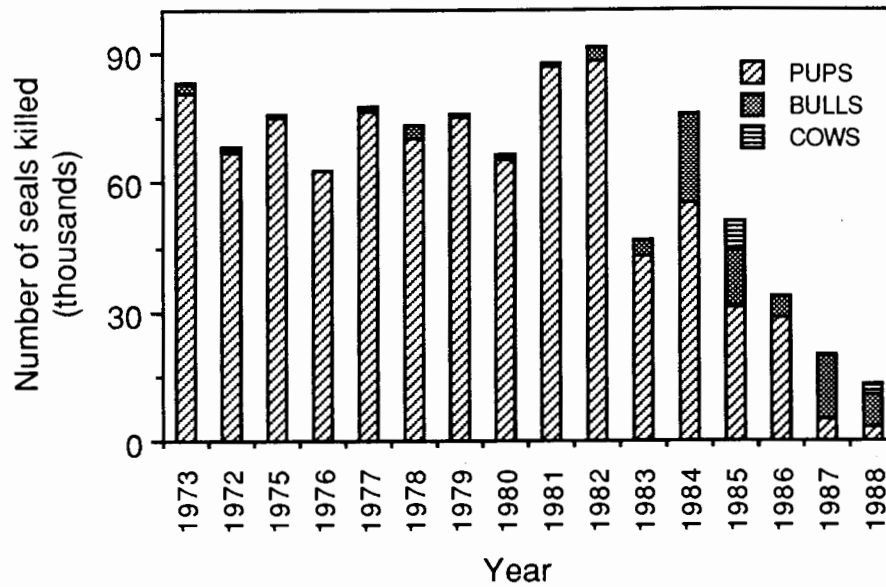


FIGURE 2.4 : The breakdown of harvests into pups, bulls and cows since 1973, the year in which the "Sea Birds and Seals Protection Act" was introduced.

The largest numbers of seals are taken from Namibia (Fig. 2.5). Accessibility for sealing operations, transport and processing of the dead seals influence the choice of colonies to be sealed. This results in the major mainland colonies, Wolf and Atlas Bay (combined because they are in close proximity and one quota is set for the two colonies), Kleinsee and Cape Cross forming the largest percentage of the harvests (Fig. 2.6). Fig. 2.7 also presents the harvests of these three areas and shows that other than in the last two years, the harvest at Wolf/Atlas Bay is the largest.

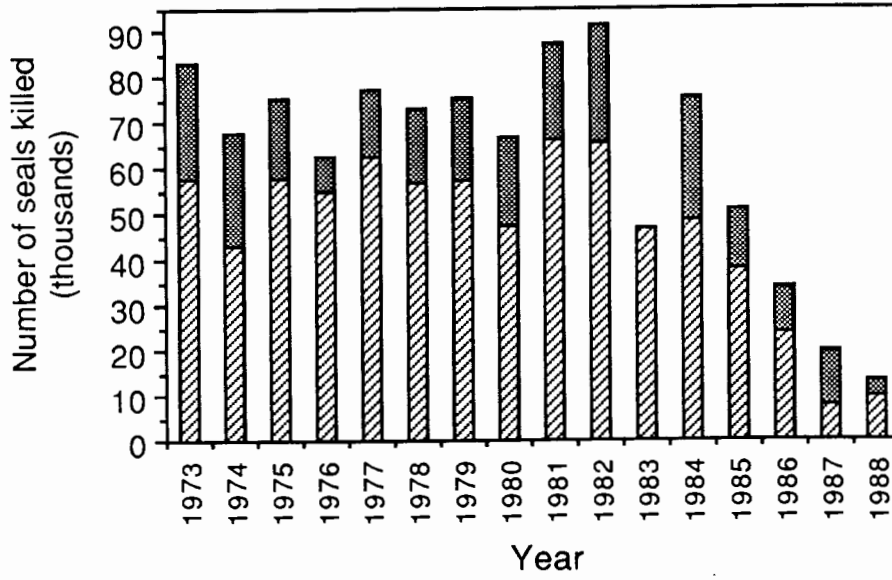


FIGURE 2.5 : Comparison of the number of seals killed in Namibian (▨) and South African (▩) colonies.

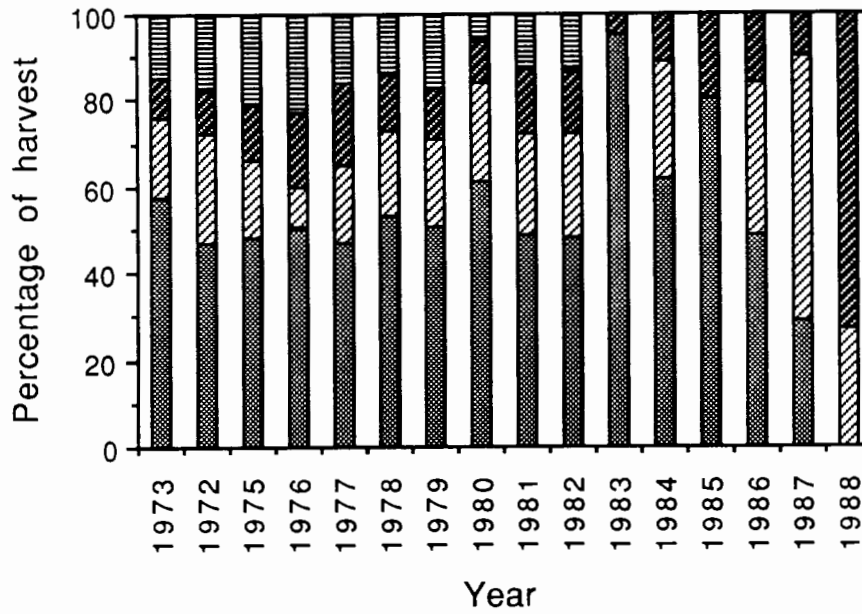


FIGURE 2.6 : Breakdown of the total annual harvest since 1973 into the three major harvested colonies, Wolf/Atlas Bay (▩), Kleinsee (▨) and Cape Cross (■) and all other colonies combined (▧).

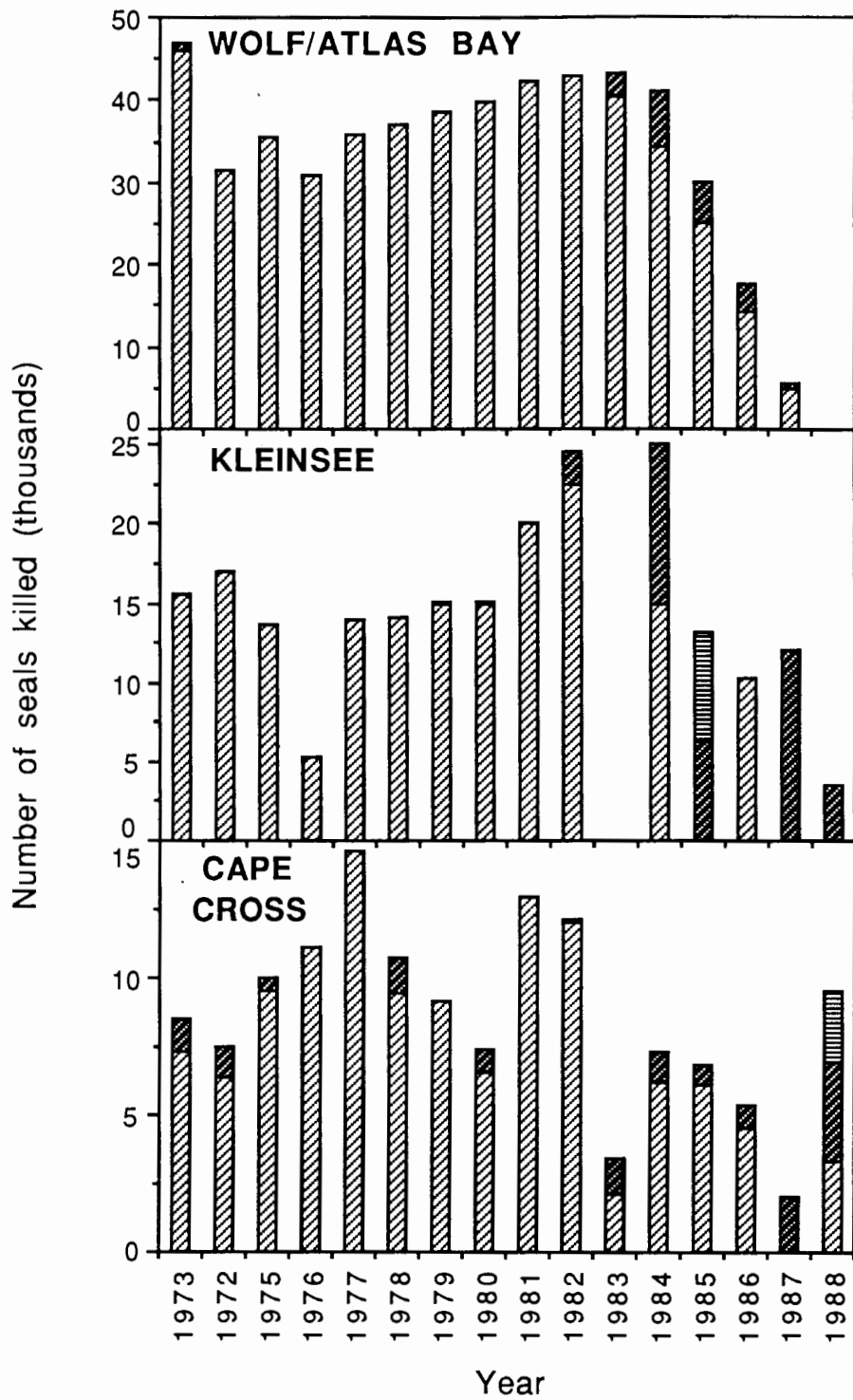


FIGURE 2.7 : Harvests of pups (▨), bulls (■) and cows (▤) at the three major harvested colonies.

ECONOMICS OF SEALING AND TOURISM

The relative importance of the different products obtained from seals in the form of pup pelts, bull genitals, oil and meat have varied in the past decade (Fig. 2.8). The number of pelts has decreased. The number of genitals was low until 1983 and has since shown some fluctuation. The market price for both of these products has decreased. In the early seventies, the local price for skins was approximately R25 per pelt (Rand, 1973) while currently it is the region of R4 to R5 per skin (Ball, pers. comm.). The price of dried genitalia was as high as US \$280.kg⁻¹ but is currently at approximately US \$130.kg⁻¹ (Ball, pers. comm.).

The amount of oil produced has declined, but showed a slight increase in 1988. The oil produced from sealing is marketed at the same price as fish oil at around R600 per ton (Ball, pers. comm.). The production of meat, all of which was processed into meat meal, was increasing until 1986. In 1987 fresh meat was used for canning and in 1988, both fresh meat and meat meal were produced. The meat can apparently be utilised as an additive in pet food (Ball, pers. comm.) but there is no way it can be marketed as such because this would be extremely unpopular with the animal-loving public. Seal meat is not an easily marketable product and currently costs more to transport than it can be sold for.

The past trends in the economic value of seal products would be interesting to observe. However, not all of the data are available and they appear to vary depending on their source. Some information, for South Africa only, was obtained from the Economic Division of the Sea Fisheries Research Institute. In 1982, the wholesale value was R432 000, followed by a zero return in 1983. Since then the annual wholesale value from all products of sealing has not exceeded R150 000 and was generally much less than this. This is only a fraction of a percent of the wholesale value of the demersal catch which is the most valuable fishery.

Live seals provide revenue. For example, 34 seals are held in captivity in seven different zoos and aquaria in South Africa and are partly responsible for the revenue received from entrance to these

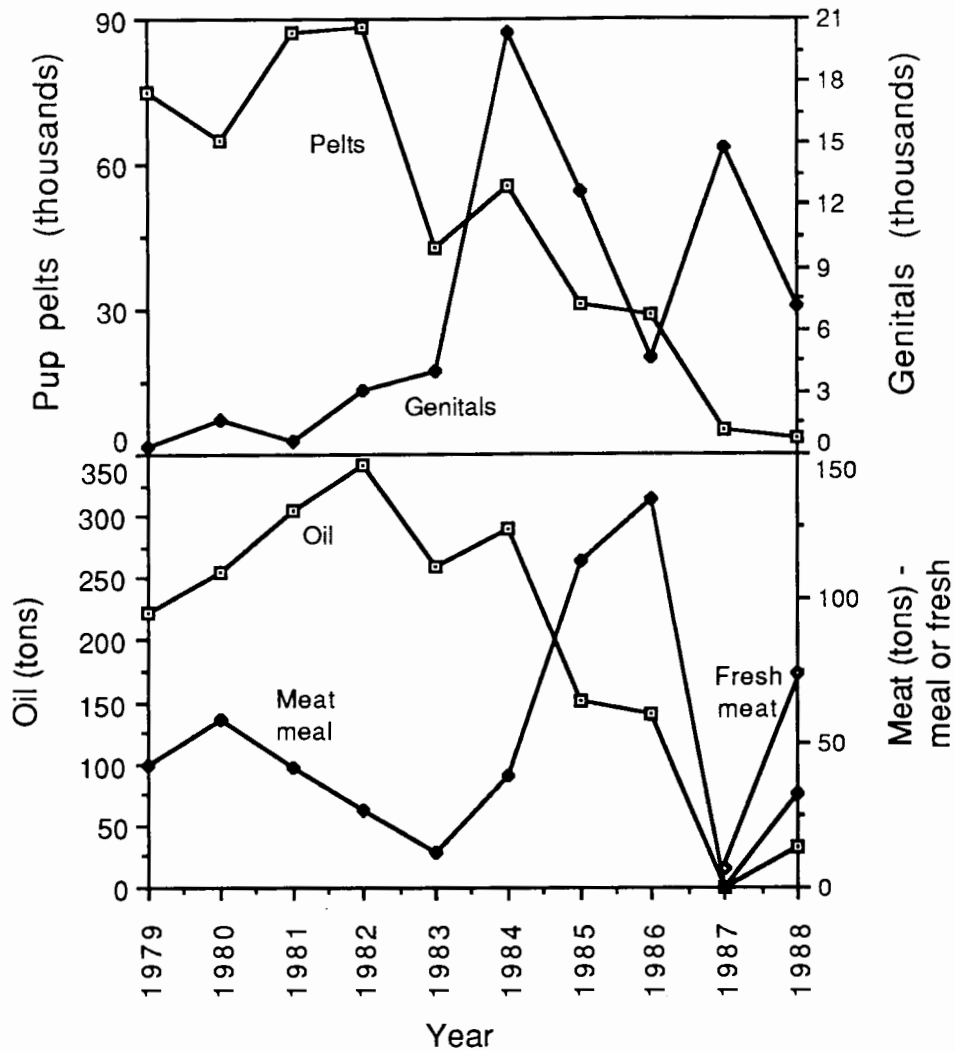


FIGURE 2.8 : Products from the seal harvests in the past decade (1979 to 1988). Prior to 1987, the meat was all in the form of meat meal. In 1988, only the meat was used for canning, and in 1989, both meat meal and fresh meat were produced.

places. In addition, tourist trips are taken to the non-breeding colony, Duikerklip in Cape Town and to Seal Island, Mossel Bay. The Cape Cross colony is a nature reserve which is open to the public and the harvesting/culling at this colony does not interfere with tourist viewing. Revenue figures could only be obtained for admission fees to Cape Cross (Department of Agriculture & Nature Conservation, Namibia, unpublished data). This amounted to R25 484 in 1987 (as compared to the wholesale value of R43 000 from sealing in South Africa) and R42 704 in 1988.

CHAPTER 3

OPERATIONAL INTERACTIONS BETWEEN THE SOUTH AFRICAN FUR SEAL AND DIFFERENT FISHERIES

ABSTRACT

A qualitative assessment is made of seal-fisheries operational interactions that are detrimental to either the fisheries or the South African fur seal. No successful method of deterring seals from fishing operations has been found so seals are often shot. Mortality of seals as a result of fishing operations is small. All fisheries are subject to some form of operational interaction by seals. It is most severe for the purse-seine fishery, particularly in that the actual fishing operations are disrupted and they lose fish from the catch to the seals. The long-line, handline and drift-net fisheries also lose fish in the catches. In the drift-net fishery, fishing gear is damaged whereas fishing operations are often disturbed in the tunny-poling fishery. The operational interactions are localised and are unlikely to be solved by reducing the whole seal population, unless the reduction is substantial.

INTRODUCTION

A major cause for complaint amongst fishermen is the interaction between South African fur seals and the operation of fishing. These interactions were evaluated briefly by Rand (1959), Shaughnessy (1985) and David (1987a) and were discussed at an informal conference held by the Society for Prevention of Cruelty to Animals (Anon, 1987). The conclusions were that a variety of problems were found in some of the fisheries but proper assessments should be carried out to examine the extent of these interactions. The objective of this analysis is to investigate the types of interactions that occur between seals and each fishery, which may be detrimental to either seals or the fisheries, and then make an overall assessment of the interactions.

INTERACTIONS DETRIMENTAL TO THE FISHERIES

The approach to investigating operational interactions between seals and different fisheries was to adopt a qualitative evaluation. Because fishermen are antagonised by interference by the seals during fishing operations, they cannot be expected to make an objective assessment of the true magnitude of the interaction. Discussion with Sea Fisheries Research Institute researchers who are associated with each of the different fisheries allowed for an objective, but non-quantitative assessment. Three types of interactions are identified - disturbance of operations, consumption of the catches and damage to gear. For each fishery, the target species, the operational method, the interactions of the seals in each of the interaction categories and the problem area and problem season are discussed.

Purse-seining (F. Kriel, pers. comm.)

Target species - Anchovy.

Operational method - A purse-seine net is set around a shoal using a sea anchor. Once the shoal has been encircled, the net is then pursed (pulled together from the bottom). While the net is still in the water, the fish are pumped aboard.

Disturbance of operations - If the seals enter the net before it is pursed, they can cause the shoal to be chased out of the bottom of the net. The seals get to know the fishing operations and react to the net being set by converging on the boat making a throw. This is the biggest problem in the fishery as the seal concentrations are sometimes so high that 250 or more seals enter a net and disrupt the fishing operations. When concentrations reach such proportions, the chances of a successful haul are small.

Consumption of catches - The seals move over the cork-line into the net to start feeding on the fish before the net is pursed and continue to do so until all the fish are pumped aboard.

Damage to equipment - This is minimal as the seals are able to move in and out of the net as they please. Sometimes, however, seals are trapped in the bag of the net when the shoal of fish has been pursed dry and ready for pumping. Some of the seals then become entangled in the net and have to be cut loose once the net has been pulled on board. Seals that have not drowned are often killed and dumped overboard.

Problem area and season - The problem occurs on the South African west coast and off Namibia with the seals concentrating on areas where the fishing intensity is the greatest. This happens all through the year when the number of seals is large (20 or more in the net).

Trawling (B. Rose, pers. comm.)

Target species - Hake.

Operational method - Two types of trawlers are used : stern trawlers and side trawlers although the latter is being phased out. In both, a net is sent to the sea bottom, pulled along for a period of time and then hauled to the surface and onto the trawler.

Disturbance of operations - None.

Consumption of catch - In stern trawling there is little time for the seals to consume the catch. On a side trawler, however, the net is on the surface for some time so there can be a problem with seals taking the catch.

Damage to gear - Negligible.

Problem area and season - The problem occurs all year round on the South African west coast where most trawlers are accompanied by 20 or more seals.

Trap and hoop-netting (P. Goosen, pers. comm.)

Target species - Rock-lobster.

Operational method - Two types of gear are used to capture rock-lobster. Rectangular traps are used from motor vessels in deep water (down to 110m) and are left there for approximately 24 hours. Hoopnets are set from dinghys in shallow water of less than 30m and are left for between 30 minutes and an hour.

Disturbance of operations - The only problem is that seals sometimes take the bait from the hoopnets.

Consumption of catch - None.

Damage to gear - None.

Problem area and season - The problem occurs in shallow water areas on the S.A. west coast and Namibia mainly in summer.

Long-lining (D. Japp, pers. comm.)

Target species - Hake and kingklip.

Operational method - The lines, which can be up to 20km long and have on average, 11 000 hooks on them are set in the early evening - a process that takes about an hour and a half. The lines are left overnight for 10 to 12 hours. Hauling in the lines is a slow process which may take up to 10 hours and is always done during the day. While the lines are being brought in, the fish are exposed and vulnerable to be taken by seals prior to the catch being hauled aboard.

Disturbance of operations - None, except that it necessitates having a boat in the water at all times to recover the fish discarded by the seals.

Consumption of catch - When the lines are being brought in, the seals are a problem, taking fish from the lines. In the early morning, seals take whole fish but later, as they become satiated they tend to pick at the fish, taking soft parts, especially the livers. On average there are 5 to 10 seals near a boat but up to 50 have been seen. A process of adaptation in the behaviour of the seals seems to have taken place. Previously, they fed on the lines next to the boat but now they move

approximately 200m from the boat, dive down and take fish. This appears to be a response to the fishermen using various means to deter the seals close to the boat. A small boat launched from the main boat collects discarded fish where possible but a lot is lost because damaged fish cannot be used. The seals prefer kingklip but will take other species if hungry. The problem is severe.

Damage to gear - None.

Problem area and season - The main problem areas seem to be west of Saldanha Bay (in winter mostly) and off Cape Point (all year round) when the target is hake. The problem occurs off Mossel Bay/Port Elizabeth in the spring when they are targeting for kingklip. Generally there seem to be more seals inshore, but it is quite common to see up to 20 seals per vessel as far south as the southern most tip of the Agulhas Bank. The further offshore the boats are, the less the interference.

Hand-lining (A. Penney, pers. comm.)

Target species - Mainly snoek (90%) but also hottentot.

Operational method - Hand-lines are cast from a boat.

Disturbance of operations - Fishing on concentrated snoek shoals is fast and hectic, the size of the catch being dependent on the speed with which tackle can be returned to the water. When seals are present, numbers of hooks and lengths of line are regularly lost. Catches are then lost due to

- time taken to replace the lost tackle
- time taken to redetermine the depth of the shoal (this can be very important as lines are usually accurately measured and marked when a shoal is located).

Sudden or concentrated appearance of seals also disperses the shoal from under the boat.

Consumption of catch - Seals are attracted by the activity, particularly if there are a large number of boats. They take many fish from the lines, often taking only parts of the fish, excluding the head.

Damage to gear - Seals may take or break hooks and lengths of handlines.

Problem area and season - The problem is restricted to the west coast during the snoek season, which is usually in winter. No interference has been reported on the south coast.

Jigging (J. Augustyn, pers.comm.)

Target species - Squid.

Operational method - Jigs are operated by hand from small boats. The jig is essentially a line comprising a plastic body and two rings of barbless hooks. The jigs are dropped to the sea bottom or close to it and then jerked to the surface.

Disturbance of operations - The only incidences reported have been of the seals scaring the squid away.

Consumption of catch - Negligible.

Damage to gear - Negligible.

Problem area and season - There have been incidences on the Agulhas Bank during summer, but the main fishing area is between Plettenberg Bay and Port Alfred resulting in little overlap between the seal distribution and that of the fishery.

Drift-netting (F. Kriel, pers. comm.)

Target species - Haarders and St Josephs sharks.

Operational method - Gill nets are laid and are left, on average, for a couple of hours at a time before being pulled up and the fish removed.

Disturbance of operations - None.

Consumption of catches - Seals take fish from the net, often only taking the stomach portion from the fish and leaving the rest.

Damage to gear - The damage to haarder nets is extensive and the repair and maintenance costly. In bad periods the nets have to be replaced every 4 to 5 weeks. In the St Josephs shark fishery the nets are more extensively damaged as the spines of the sharks snag in the nets as they are pulled out by the seals.

Problem area and season - The problem becomes worse at the end of the purse-seining season (towards the end of the year) when seals turn their attention to the drift-netting fishery on the S.A. west coast.

Poling (B. Rose, pers. comm.)

Target species - Tunny.

Operational method - Once a shoal has been located, live or dead bait is thrown into the water or water is sprayed from the boat to attract the tunny. This entices the tunny to come to the surface to feed and they are then hooked and lifted on board.

Disturbance of operations - Seals are attracted by the bait which they feed on and in doing so they disrupt the tunny.

Consumption of catch - None.

Damage to gear - None.

Problem area and season - The problem occurs throughout the year but is only important when they are poling in the trawl grounds, on the west coast.

INTERACTIONS DETRIMENTAL TO THE SEALS

The shooting or maiming of seals if they come on board fishing vessels is an ongoing illegal practice by fishermen in any of the fisheries that have problems with seals. Many of the purse-seine boats have fire-arms on board and hundreds if not thousands of seals are shot each year. The factories may even be supplying ammunition to some of the boats. In the hand-line-fishery, the fishermen also shoot seals causing serious danger to nearby boats when the fleet is concentrated, such as during a snoek run. Although the shooting of seals is illegal, in the past no action has been taken against offenders and the late Minister of Environment Affairs was not prepared to enforce any rules regarding this until alternative methods of deterring seals had been found (Wiley, 1983, 1986). The fishermen also use other methods to deter the seals such as throwing objects at them. In the long-line fishery, seals are also deterred by various means although the seals have adopted a method of taking fish from the lines which avoids this.

A number of attempts have been made to find more efficient and humane methods of deterring seals from fishing operations. No single method has proved particularly successful for all

fisheries. Experiments were done in the early 1970's using explosive crackers to deter seals (Anon, 1972). This method was used between 1973 and 1976 but while they seemed to work for the seals, they were also thought to disturb the fish. At the informal conference held by the Society for the Prevention of Cruelty to Animals (Anon, 1987), it was suggested that the crackers be re-introduced after more experimentation so there must be some faith in this method. However, the purse-seine skippers are of the opinion that crackers chase the fish away (F. Kriel, pers. comm.).

A number of experiments using acoustic methods have been carried out. Electronic pulses and air guns had no lasting effects (Anon, 1975) and sounds of killer whales and of shots fired into the water (Anon, 1977) were also not successful. A transducer producing compression and sound levels similar to those of firecrackers and fired shots was built. This deterred seals from the cod-end of a trawl net but had no effect on seals at a purse-seine net (Shaughnessy *et al.*, 1981).

Shaughnessy (1980a) investigated the numbers of seals that become entangled in fishing debris. He found that the percentage of harvested seals from various colonies that were entangled was 0.11 to 0.12% (1978 and 1977 respectively). There was a high incidence on entanglement (0.56 to 0.66% between 1977 and 1979) at Cape Cross which is near to an important fishing ground. He suggested that a recommendation be made that net fragments and other debris not be discarded at sea because of the possibility of entangling seals. Shaughnessy and Payne (1979) noted that some seals are often seen in the trawl net but escape before it is hauled aboard. Some inadvertently enter the net at the beginning of a trawl and drown. They estimate that the percentage of the population that become entrapped or that are killed (either drowned in the net or deliberately killed by the fishermen if they come aboard in the net) is 2.3% and 1.3% per annum, respectively. Seals are often shot but this has not been quantified.

EVALUATION

Of the three major fisheries, the pelagic (purse-seine), demersal (trawl) and rock-lobster (trap- and hoop-netting) fisheries, only the pelagic fishery is subject to serious interference by seals. As an indication of the types of problems encountered by these purse-seine fishermen, comments made by skippers on their catch records for the year 1988 were extracted (listed in Appendix 4). For the most part, the skippers merely noted that many seals were in the vicinity of their fishing operations. The more serious comments were that they obstructed fishing by scattering the fish or causing them to move downwards, out of the net. When the fishermen are severely frustrated by the presence of the seals this is reflected by the exaggeration in their comments.

For each month, the number of comments is divided by the number of hauls (Sea Fisheries Research Institute, unpublished data), an indication of fishing intensity, to discount for a possible correlation between the two. The monthly trends in the number of comments per unit of fishing intensity shows the periods of the year during which interference between seals and purse-seining operations is most severe (Fig 3.1). The worst period seems to be in the middle of the year, especially during April and May. In May, there were a total of 124 comments made on 27 days of the month. The following explanation is speculation as to the reason for this trend in interference. At the beginning of the year, cows are colony-bound for long periods because they are suckling their young. They are therefore likely to spend less time foraging and will be foraging closer inshore, so will not come into contact with the boats as often. By May, the pups are approximately 5 to 6 months old, about which time they start foraging (David & Rand, 1986). As a result, the cows are able to spend more time at sea and, therefore have an increased chance of interfering with the purse-seining operations. The decline in the trend from June when more seals are likely to be out foraging, is a result of the increase in fishing intensity so there are relatively fewer comments. The very low interference later in the year is simply due to low fishing intensity. There are likely to be many other factors influencing the trends in interference, but this is one possible explanation.

This analysis of seal interference is merely a qualitative indication, firstly, of the types of problems encountered and secondly, of period when the fishermen are most frustrated by the presence of the seals. It is difficult to assess such comments in an objective manner when the fishermen are antagonistic towards the seals, making it an emotive issue. Such biases are complex to quantify.

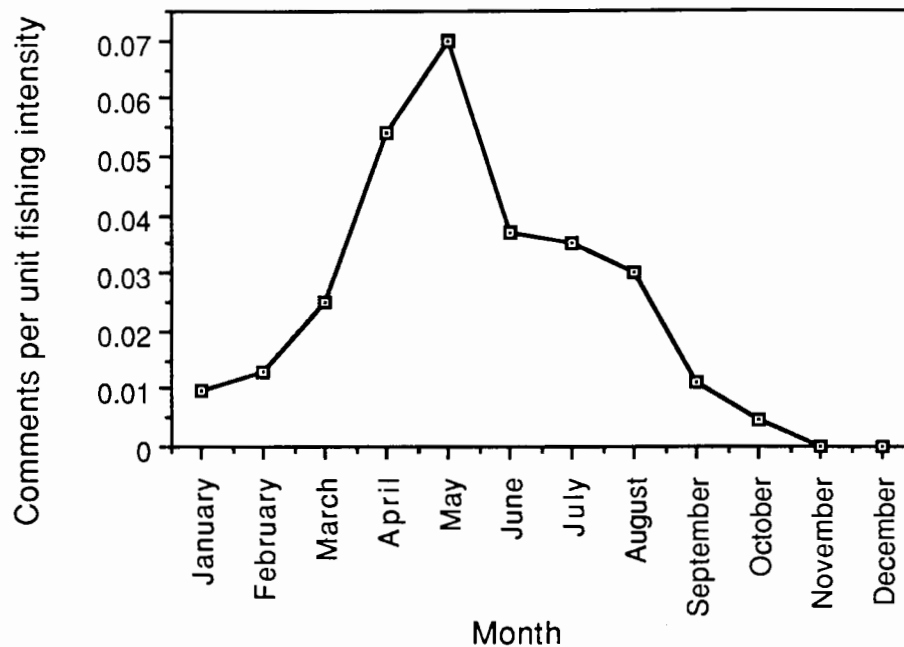


FIGURE 3.1 : Analysis of the number of comments regarding seals made by purse-seine skippers, divided by the number of hauls (as an indication of fishing intensity) during each month in the year 1988.

The operational interactions between seals and fisheries are more detrimental to the fisheries than to the seals. The mortality of seals as a result of fishing operations and discarded fishing gear is low whereas the interference between seals and different fisheries is a severe problem during some of the fishing operations. Fig. 3.2 shows a summary the three types of operational interaction that occur in each of the fisheries.

FISHERY	DISTURBANCE OF OPERATIONS	CONSUMPTION OF CATCHES	DAMAGE TO GEAR
PURSE-SEINE	●	●	◐
TRAWL	○	◐	○
TRAP & HOOP-NET	◐	○	○
LONG-LINE	○	●	○
HAND-LINE	◐	●	◐
JIGGING	◐	○	○
DRIFT-NET	○	●	●
POLING	●	○	○

KEY:

- Seals are a major problem
- No interference
- ◐ Seals are sometimes a problem or it is only a minor problem

FIGURE 3.2 : Summary of the extent to which various types of operational interactions occur in each of the fisheries.

Substantial disturbance of operations occurs only in the purse-seine and tunny-poling fisheries. In the purse-seine fishery, the problem is serious in that shoals can be disrupted while in the poling fishery, bait-taking is a problem. Seals can also disturb the operations of the trap and hoop-net fishery by taking bait; the hand-line fishery because they break tackle and scatter shoals; and the jigging fishery because they chase the squid away.

Serious consumption of catches occurs in the purse-seine, long-line, hand-line and drift-net fisheries. During purse-seining operations, whole fish are taken whereas in the other fisheries, fish are often wasted because seals only eat parts of the fish. In the case of the trawling industry, it is only when side-trawlers are being used that seals have time to take fish from the catch before the net is hauled aboard. This problem is being reduced because these vessels are being replaced by stern-trawlers on which the net is brought aboard quickly.

Damage to gear does not seem to be a major problem other than in the drift-netting industry. However, seals can be a problem causing damage to gear in the purse-seine fishery by becoming entangled in the net and having to be cut loose and in the hand-line fishery by breaking line and taking hooks.

The interference problems are localised and seasonal and the fishermen deal with this accordingly by deterring the seals either by shooting or using other methods when the seals are a problem. All interference by seals results in a financial loss to the fishermen, whether directly, in that fishing equipment becomes damaged, or indirectly, through the fishermen losing time in obtaining their catches. It is unlikely that the problem would be solved by a reduction in the seal population, unless there were a drastic decrease in the number of seals.

CHAPTER 4

DEVELOPMENT OF A GENERALISED SEAL POPULATION MODEL WITH OPTIONS FOR CULLING

ABSTRACT

Attempts are made to estimate a density-dependent function for a simulation model of the South African fur seal, but there are insufficient data to show density-dependent effects. A density-independent simulation model, the "Seal Model", which includes options for culling and the disturbance effects of culling, is designed using an iterative process of model design, discussion and improvement of model structure and data. An adaptation of this, the "Seal Age Model", is used to estimate the probability of a seal of either sex reaching particular ages. The model estimates that the probability of a South African fur seal exceeding 20 years is 14% and of reaching an age older than 30 years is only 5%. The sensitivity of the models is tested.

INTRODUCTION

Numerous models of seal populations have been built for different purposes (*e.g.* Chapman, 1961; Allen, 1975; Lett & Benjaminsen, 1977; Capstick & Ronald, 1980; DeMaster, 1981; Eberhardt, 1981; Lett *et al.*, 1981; Smith & Polacheck, 1981; York & Hartley, 1981; Frisman *et al.*, 1982). Two simulation models have previously been constructed for the South African fur seal. Shaughnessy and Best (1980) designed a model of the female seals of this species to determine the maximum sustainable yield of pups. Butterworth *et al.* (1987) also modelled female South African fur seals, with the aim of estimating probability distributions for various demographic parameters. Since the formulation of these models, large bull harvests have added new assumptions to the functioning of the seal population. Bull harvests cause disturbance of the females in the colony resulting in decreased pup production. This disturbance factor may have been present before but was less noticeable because the bull harvests were smaller. Rand (1955) notes that careless or uncontrolled bull sealing could affect the breeding success of the cows through the disturbance around the time of parturition or conception. In addition, there is disturbance at a cow cull which was not previously accounted for. It is now necessary to incorporate males into the model and insert assumptions about the disturbance of bull and cow culling into a model.

Catastrophic events may perturb natural systems; the frequency, magnitude and duration of these events are unpredictable and not realistically possible to account for in a model. Examples of such perturbations which have been detrimental to seal populations have been recorded. The 1982/1983 El Niño event in the Galápagos resulted in a massive mortality of the Galápagos fur seal (Limberger, 1985; Robinson, 1987). Roux (*pers. comm.*) believes that the warmer than average sea water temperature in the Luderitz area of Namibia during 1988 has had a similar effect of causing a food shortage, resulting in a mortality rate of over 90% of South African fur seal pups in that region. In 1949, for an unknown reason, the majority of adult seals left Seal Island, False Bay, leaving hundreds of pups to starve (Davies, 1950). Another example is the epidemic distemper virus which caused thousands of deaths amongst the common seal in the North Sea in

1988 (Anon, 1988). At best one can attempt to produce conservative management strategies for the times between such events, allowing safety factors to guard against accidental overexploitation, thereby minimising the possibility of environmental events being disastrous to the population.

The aim of this chapter is first, to explore methods of defining a density-dependent population regulation mechanism. A simulation model of the population dynamics of the South African fur seal is then developed and includes culling and the disturbance effects of culling, and consumption rates for estimating population consumption. This model is to be used as a tool to explore the effects of alternative management strategies, the results of which are discussed in Chapters 5 and 7, and this generalised model is modified for a more specific task in Chapter 6. A sensitivity analysis of the model is carried out to gain understanding of the functioning of the model prior to using it to simulate various scenarios in future chapters.

Dental ageing analysis of seal cows only has been done and it is at present only possible to identify ages of up to 14 years (Oosthuizen, pers. comm.). Other than estimates of ages of seals held in captivity, there are no existing longevity estimates and age-frequency distributions of the South African fur seal population which can be used as a reference for comparison. A simplified version of the seal model is also developed in this chapter to estimate longevity of seals and compare this to maximum ages reported in the literature and of seals held in captivity in South Africa. The sensitivity of the model output to changes in parameter values is examined to indicate the influence of parameters on maximum seal age.

ESTIMATING DENSITY-DEPENDENT POPULATION REGULATION

There are various factors affecting the size of populations and these may be density-dependent (intrinsic) or -independent (extrinsic). While it is acknowledged that some form of regulation does occur, there are no data for the South African fur seal to indicate how this control may take place.

These seals breed on island and mainland colonies, each of which have different carrying capacities and are subject to different influences. Seals are spatially limited on the islands (David, 1987b) whereas they are subject to terrestrial predation on the mainland colonies. As a whole, the population would not appear to be limited spatially at present because there are large areas of mainland, particularly in Namibia, in which there is little human interference because of restricted public access, and these areas are still available for colonisation by seals.

Density-dependent influences can be estimated from data with sufficient contrast. For example, fecundity or pup survival may be reduced at elevated population sizes. By counting the number of pups versus the total number of seals in a colony, the relative number of pups per seal at different population sizes can be calculated and this can give one indication of density-dependence. This could be done for a typical mainland and typical island. However, the number of seals in a colony varies considerably both seasonally and daily (David & Rand, 1986 and personal observation). It is only during November and December that bulls, cows, juveniles and pups are all present at a colony. The length of the birth season and the median pupping date (when half of the pups have been born) vary among colonies (David, 1987b). During the breeding season, different age and sex classes move between the sea and land at different times of the day. Thus the times of year and day that censusing is carried out are crucial. In addition, there are areas where a number of the immature seals from the different breeding colonies come ashore and the variation in the number of these individuals would not be accounted for by counting specific colonies.

It is not feasible to count all seals in a colony over a long period of time. Therefore two possible methods are considered for analysing density-dependent effects, bearing in mind the limitations on censusing presented above. Both possibilities rely on the likelihood that a change in the ratio between the total population and the number of pups is an indication of a density-dependent effect. If a density-dependent response occurs, the trend in the number of pups per seal should decrease as the density of seals increases. This is a simplification because the influence of sealing at different colonies also affects this ratio (discussed in detail in Chapter 5).

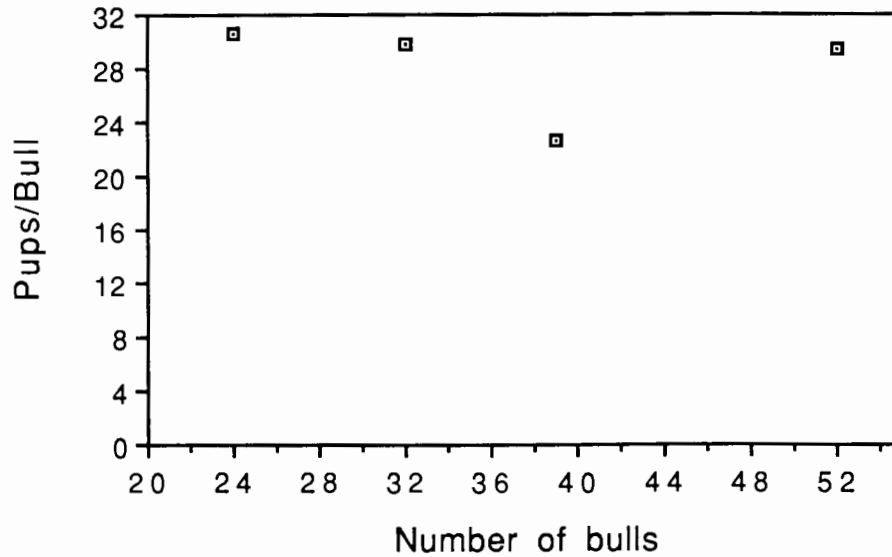


FIGURE 4.1 : The ratio of the number of pups to bulls in 4 different areas of the Cape Cross colony, photographed in 1976 (Sea Fisheries Research Institute, unpublished data).

The first method is to count the number of territorial bulls and pups on aerial photographs, assuming bulls to be indicative of population size. The bulls and newborn pups are most consistently at the colony throughout the day whereas the cows and yearlings often leave the colony for the sea. However, the bulls are difficult to distinguish in black-and-white photographs and since they are few in number in comparison to the pups, a small numerical error will make a large difference to the ratio. Some counts have been made in certain areas of the Cape Cross colony (Sea Fisheries Research Institute, unpublished data), but the data are too few and too variable for any trend to be seen (Fig. 4.1).

The second method is to examine areas that have recently been colonised and are unsealed, and where direct counts of both pups and older seals have been made because the population is small. A comparison of the annual number of pups per seal indicates how this changes in an increasing population. Three such sets of data exist - for the recolonised Sinclair Island (Shaughnessy, 1980b) and Mercury Island (Sea Fisheries Research Institute, unpublished data), and the newly colonised Paternoster Rocks (Sea Fisheries Research Institute, unpublished data). Seals have been landing on Paternoster Rocks prior to 1972 (Rand, 1972), but pups were only seen in 1985

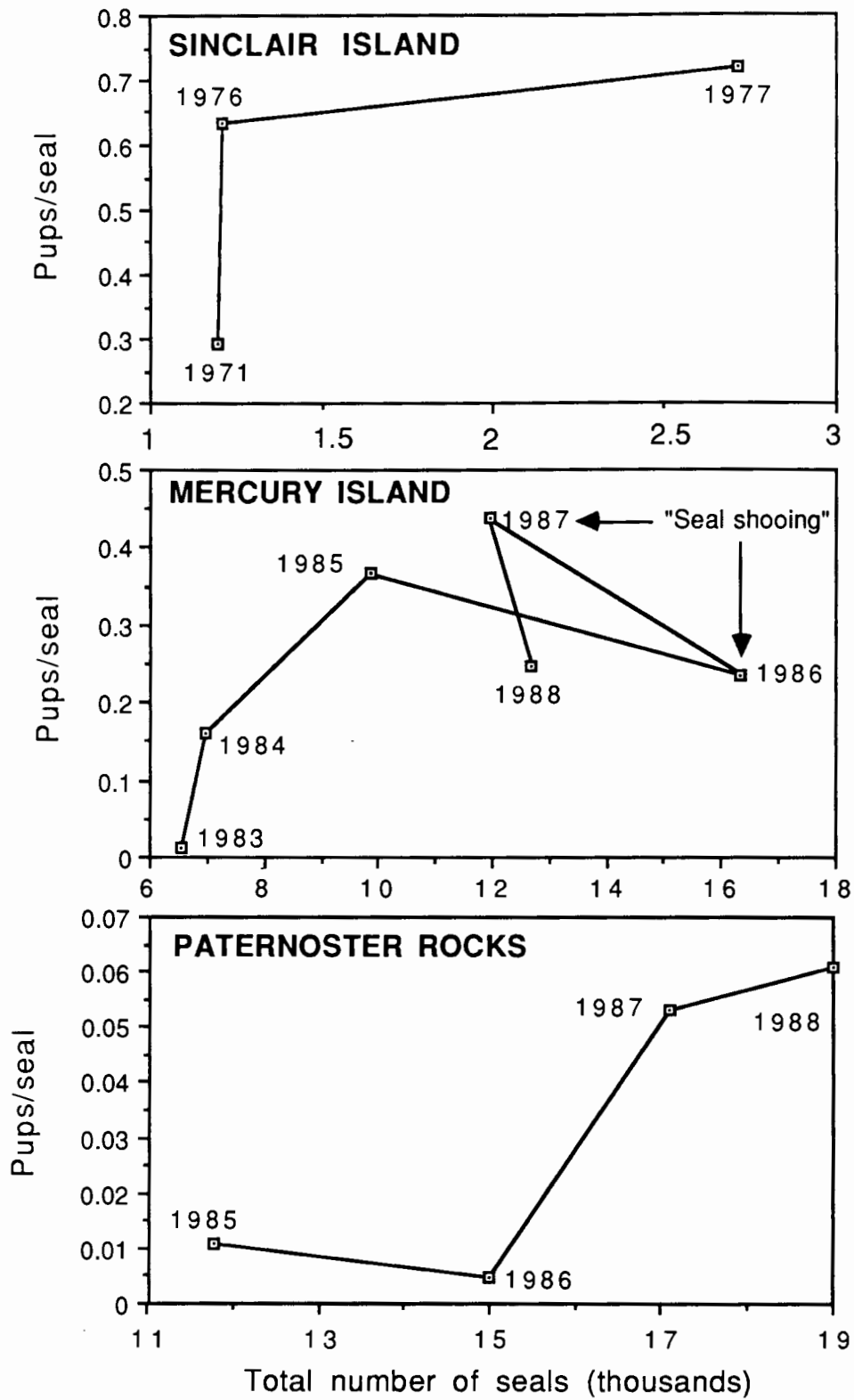


FIGURE 4.2 : Colonisation data for three areas showing the relationship between the number of pups per seal and total number of seals.

(Oosthuizen & David, 1988) and this area is not yet considered as a new breeding colony because the numbers of pups is small. The number of pups per seal is plotted against the total number of seals for each of these areas (Fig. 4.2). A confounding factor at Mercury Island is the fact that "seal shooping" took place during 1986 and 1987. This entailed people chasing the cows off the island in an attempt to limit the cows from breeding there. This is a disturbance to the natural cycle of events and therefore invalidates these years and the year following the disturbance, from the data set.

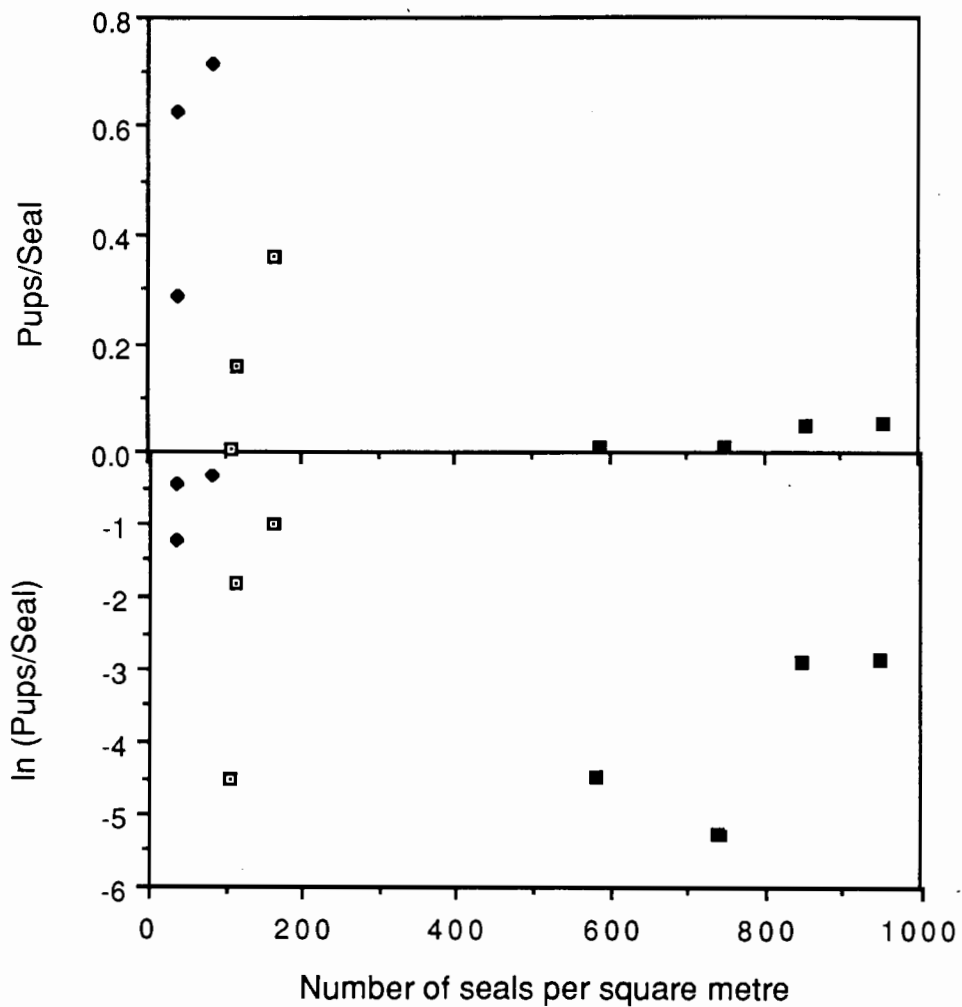
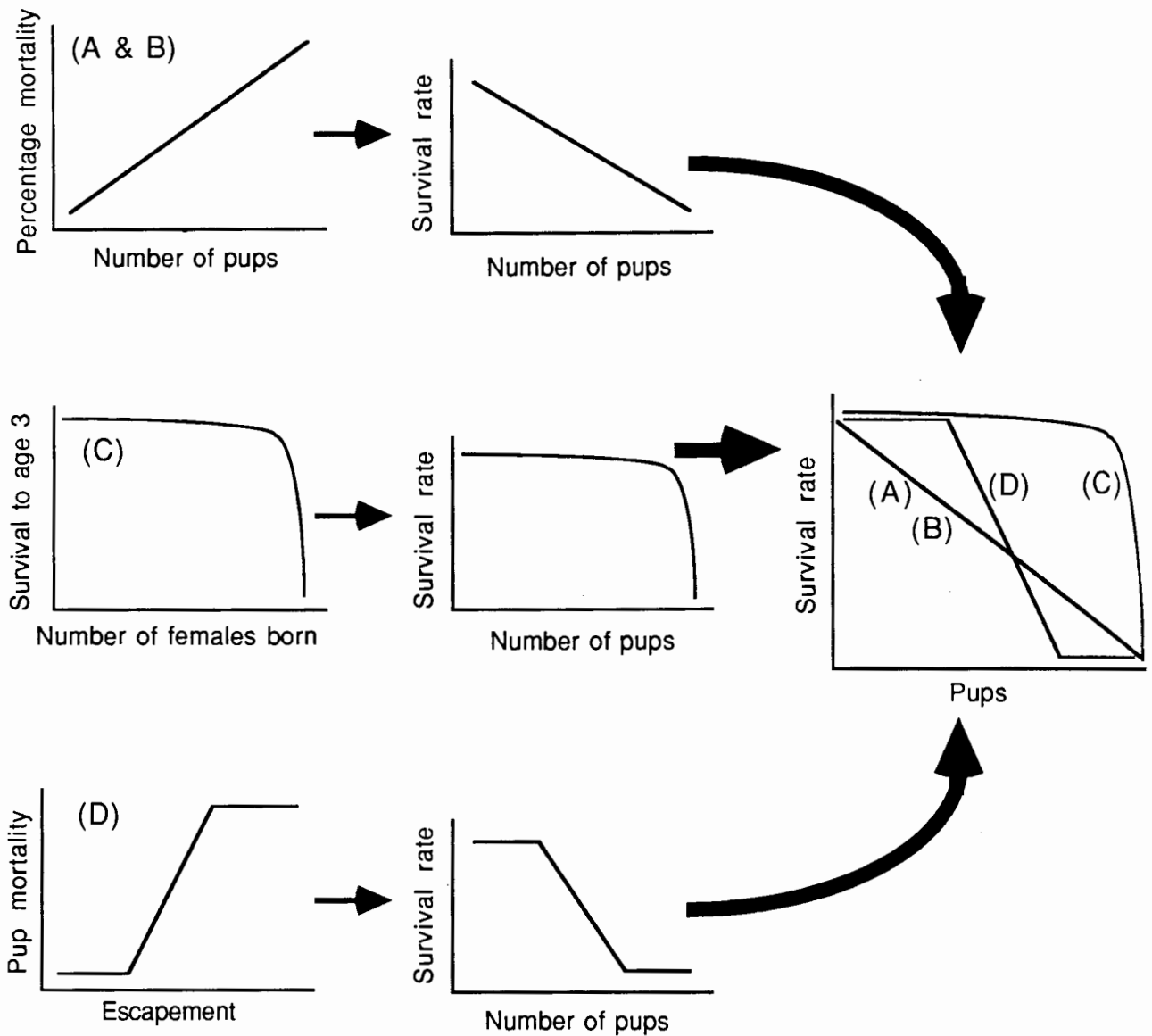


FIGURE 4.3 : Number of pups per seal and the natural logarithm of the number of pups per seal at different seal densities. The data points are taken from the recolonised areas of Sinclair Island (◆) and Mercury Island (◻) and the newly colonised, Paternoster Rocks (■).

Roux (1987a) suggests that breeding success in the early stages of recolonisation may be low because of a non-optimal social structure but that as the population density increases, breeding success may improve to an optimum before it is reduced as a result of high population densities. In each of the figures (Fig. 4.2), the main trend in the number of pups per seal is an increasing one with an increase in density and this could represent the early phase suggested by Roux (1987a). These islands are subject to different influences which can limit breeding success. For example, at Paternoster Rocks, there is heavy wave action washing over the low-lying rocks so Oosthuizen and David (1988) suggest that pup survival is low, whereas the steeper, Mercury Island has many areas that are not subject to wave action. Although there are different influences, the three sets of data are converted to the number of pups per seal as a function of seal density (Appendix 5) and are combined in Fig. 4.3. David (pers. comm.) confirmed that the relative densities of the three areas appear to be correct with Sinclair Island having the lowest density and Paternoster Rocks the greatest, the latter being typical of a non-breeding colony. If a negative correlation between the two could be found, this would indicate a density-dependent influence. However, neither a linear nor an exponential function fitted to these points is significant ($P > 0.05$, $n = 10$), so these data do not indicate statistically that there is reduced breeding success at elevated density levels. As with the first method, the limitation is, therefore, that there are insufficient valid data at present for any trends to be discerned.

Various functional forms describing density-dependent influences have been defined for other seal species. Examples can be found for grey seals (Bonner, 1975), Northern fur seals (Chapman, 1961; Eberhardt, 1977; Shaughnessy and Best, 1980; Smith & Polacheck, 1981), harp seals (Capstick & Ronald, 1980; Lett *et al.*, 1981), Subantarctic fur seals (Roux, 1987a) and the Antarctic fur seal (Doidge *et al.*, 1984). These relate parameters such as survival rate, breeding success or sexual maturity to an estimate of population size, usually presented in the form of pup numbers. Fig. 4.4 shows a few examples of the different variables used for other species and the number of functional forms that are defined for relating survival/mortality rate to the number of pups. But there is no particular reason to accept any one of these curves as representative of the South African fur seal population dynamics.



KEY:

- (A) : Grey seals (*Halichoerus grypus*) - Bonner (1975)
- (B) : Pribilof Northern fur seal (*Callorhinus ursinus*) - Shaughnessy & Best (1980)
- (C) : Pribilof seals (*Callorhinus ursinus*) - Eberhardt (1977)
- (D) : Northwestern Atlantic harp seal (*Pagophilus groenlandicus*) - Lett *et al.* (1981)

FIGURE 4.4 : Examples of density-dependent relationships between survival/mortality and an estimate of the number of pups for different seal species from the literature. These are standardised in a combined graph, showing the trend between survival rate against number of pups for comparison among the different relationships.

All animal species suffer reduced population growth if they are densely populated. Inclusion of a density-dependent function in a model requires estimating where the population size is in relation to a carrying capacity level (which is difficult to estimate and unlikely to be constant) and how the population parameters respond as the population increases. This increases the number of parameters and assumptions in a model. Following the near decimation of the seals prior to 1900, the population appears to be growing exponentially without signs of density limitation at present. The population does not appear to be limited spatially and, since the seal population has been increasing even with increased fishing, food does not seem to be limited as yet (David, 1987b, 1989). Making the assumption that the population is not near carrying capacity and excluding a density-dependent function seems less limiting than attempting to define a function. Shaughnessy and Best (1980) use density-dependent pregnancy and survival rates in a model of the South African fur seal, based on data from the northern fur seal, *Callorhinus ursinus*. But Butterworth *et al.* (1987) consider a density-dependent relationship inappropriate in their model of the South African fur seal. Similarly, no density-dependent mechanism for population regulation is used in the model to be developed here.

THE SEAL MODEL

Attributes

A simulation model of the South African fur seal population, the Seal Model, is developed according to the following attributes. Appendix 6 gives the documentation and listing of the computer program used to run the model.

Purpose : The purpose is to build a simulation model representing the South African fur seal population dynamics in order to use it to explore the effects of culling and the disturbance effects of culling on the dynamics and consumption of the population.

Brief description : This discrete single-species model is deterministic, excludes a density-dependent population regulation mechanism and includes variable pup production which is dependent on the fecundity of the females in the population and on the disturbance effects of culling. The model has separate sexes and a partial age-structure, sufficient to account for the known variability in parameter values. The model includes options for culling and for estimating consumption by the population.

State variables : Eight age classes of each sex (0, 1, ..., 6, 7+ years) in which the last age class contains an accumulation of that age and older.

Units : Number of seals and mass of fish consumed.

Time step : 1 year.

Time horizon : 5 to 20 years.

Calendar of events : Fig. 4.5 shows the sequence of events occurring at a colony during one year and the associated order of the sets of equations in the model. The results, in terms of population size and consumption of fish by the population, are output when the population is at its maximum size (after recruitment).

Assumptions and constraints

No density-dependent function for the South African fur seal is included, thus all parameters are assumed to be independent of seal population size. The model is therefore an exponential population growth model of the form, $N_t = N_0 e^{rt}$, where r is determined by the age- and sex-specific mortality and fecundity rates.

All the colonies are regarded as one cohesive population and colony-specific effects are disregarded, such as differential culling at only some of the colonies.

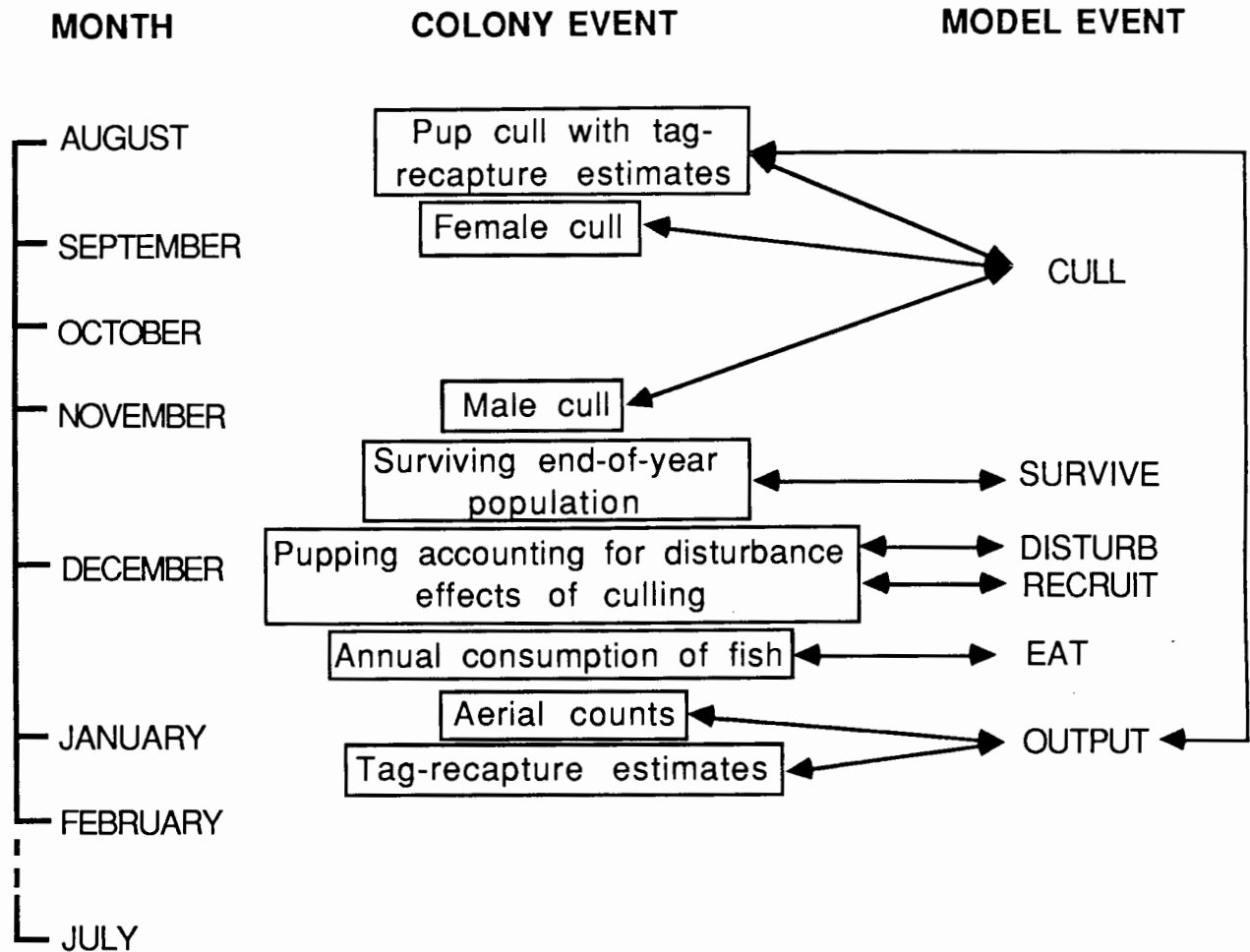


FIGURE 4.5 : Temporal sequence of events at a colony and the corresponding sequence in the Seal Model.

All seals older than 7 years are combined into the 7th age class. This is not a limitation because parameter values for older age classes are not available in either a published or unpublished form, other than the mortality rate of territorial bulls, and this is accounted for by the equations.

The two forms of mortality of seals, natural mortality and culling, operate independently with the culling being done first. The same proportion of the seals that remain after culling are subject to the natural mortality rate. If there is any bias because of the sequence of mortalities that is chosen, it is towards an underestimation of both the number of seals culled and the effect thereof, because some of the percentage of seals that were culled would have died naturally.

The model does not include a function whereby pup production is reduced when there is a scarcity of breeding bulls. As a consequence, no culling rates are explored over 80% of any particular subset of the population.

Some assumptions are made about culling :

- Only males of 7 years and older are culled. This follows from the harvest data which indicates that bulls of 150cm and larger are taken (corresponding to animals that are approximately 7 years of age and older) (David, pers. comm.).
- Only breeding females are culled because it is these females that come onto land to pup and are accessible for culling.
- Either sex of pups (seals under the age of 1 year) are culled.

The assumptions regarding the disturbance effects of culling are based on less factual information but from discussions, mainly with David (pers. comm.). In Appendix 2 different versions of a seal culling model are described and these show a progression from having no disturbance effects through to the inclusion of the influence of disturbance. The magnitude of the disturbance effects is partly determined by the skill of those culling the seals, and the season during which culling takes place (for example, culling during the breeding season causes more disturbance than at other times of the year). The types of disturbance finally chosen for incorporation into this model are described below and these disturbance functions are shown graphically in Fig 4.6 :

- After the large bull harvest of over 10 000 animals at Kleinsee in 1984, pup production at the colony was reduced somewhat that year, and by approximately half the following year. In the model, bull cull disturbance causes pup production of the same year to be reduced by an amount equivalent to the culling rate, up to a maximum of 15%. This reduction in pup production is a result of the trauma caused by the culling operation reducing pup survival. The same disturbance causes pup production of the following year to be reduced by an amount determined by a linearly increasing function of the culling rate, up to a maximum of 50%. This function is calculated from the ratio between the number culled and the bull population size at Kleinsee in 1984 and provides a linear decline in the loss in pup production from 50% to 0% at low culling

rates (<20%). This is a result of lowered pregnancy rates caused by the disturbance during the breeding season the previous year (because the gestation period is almost one year).

- The disturbance of a cow cull is assumed to reduce pup production by 15% in that year.

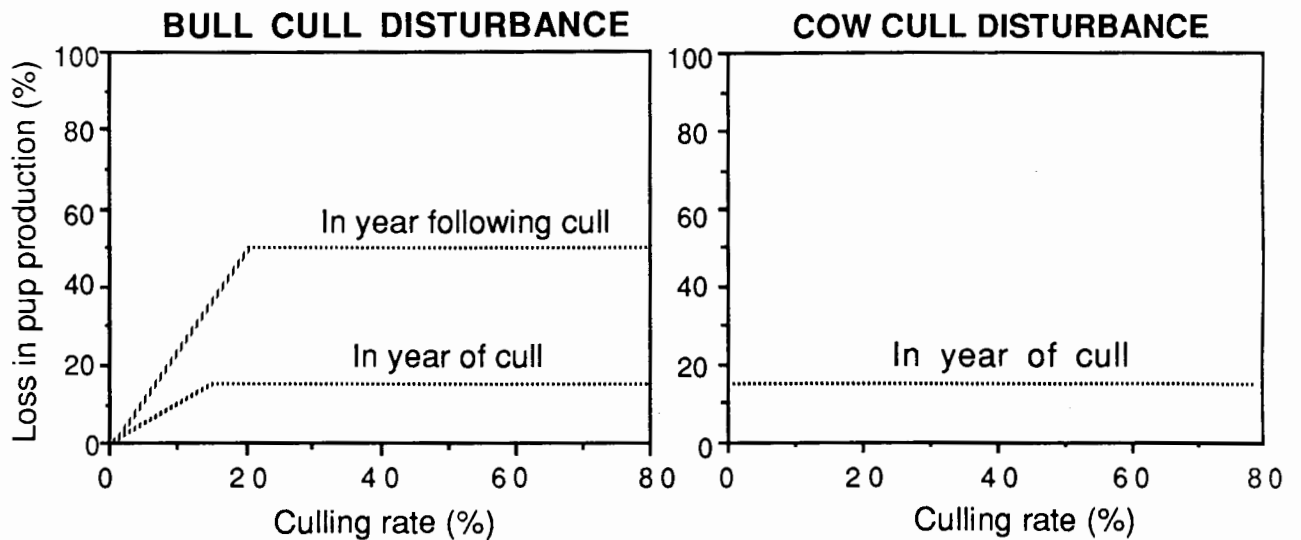


FIGURE 4.6 : Functions describing the effect of disturbance during bull and cow culling operations on pup production (based on discussions with David, pers. comm.).

Equations

Cull : The number of male pups (S_{m0}) is reduced by the culling rate of pups (C_p), accounting for the proportion of males in a pup cull (K_m) and the remaining proportion of pups in the cull are removed from the number of female pups (S_{f0}). The number of males in the last age class (S_{m7}) is reduced by the bull culling rate (C_b). The number cows of each age (S_{fi}) that are pregnant (P_i) is reduced by the cow culling rate (C_c).

$$S_{m0} = S_{m0} - (S_{m0} + S_{f0}) C_p K_m$$

$$S_{f0} = S_{f0} - (S_{m0} + S_{f0}) C_p (1 - K_m)$$

$$S_{m7} = S_{m7} (1 - C_b)$$

$$S_{fi} = S_{fi} (1 - P_i C_c)$$

Survive : The number of males that are territorial (S_T) is calculated by estimating the number of breeding cows, which is the sum of the breeding proportion (P_i) of females (S_{fi}) in each age class, and dividing by female aggregation size (A). In order to account for the mortality of territorial males (M_T), the mortality rate of the males in age class 7 (M_{m7}) is estimated by apportioning territorial mortality and other natural mortality (M_i) to the number of territorial males, and other males aged 7 and older (S_{m7}), respectively. The number of seals of each age and sex (S_i) grows into the next age class, once it has been reduced by natural mortality.

$$S_T = \left(\sum_{i=3}^7 (P_i S_{fi}) \right) / A$$

$$M_{m7} = \left((S_{m7} - S_T) (1 - M_7) + S_T (1 - M_T) \right) / S_{m7}$$

$$S_7 = (S_6 (1 - M_6)) + (S_7 (1 - M_7))$$

$$S_i = S_{(i-1)} (1 - M_{(i-1)}) \quad \text{for } i = 1 \text{ to } 6$$

Disturb : The disturbance factors in the current year (D_{bt}) and in the following year (D_{bn}) from culling bulls and the disturbance during the culling of cows (D_c) are determined by the functions presented in Fig. 4.6 and depend on the culling rates of bulls (C_b) and cows (C_c). This determines the proportion of potential number of pups not recruited due to disturbance.

$$\text{If } C_c > 0 \text{ then } D_c = 0.15$$

$$\text{If } C_b > 0.15 \text{ then if } D_{bt} = 0 \text{ then } D_{bt} = 0.15$$

$$\text{else } D_{bt} = 1 - (1 - D_{bt}) (1 - 0.15)$$

$$\text{else if } D_{bt} = 0 \text{ then } D_{bt} = C_b$$

$$\text{else } D_{bt} = 1 - (1 - D_{bt}) (1 - C_b)$$

$$\text{If } C_b < 0.2 \text{ then } D_{bn} = (0.5/0.2) C_b$$

$$\text{else } D_{bn} = 0.5$$

Recruit : The number of male pups (S_{m0}) is estimated by the sum of the number of females (S_i) that are pregnant (P_i) (because each only produces one pup), multiplied by the proportion of pups that are born male (B_m) and accounting for reduction in pup production as a result of disturbance. The number of female pups (S_{f0}) is calculated similarly but is multiplied by the remaining proportion of pups that are female.

$$S_{m0} = \sum_{i=3}^7 (P_i S_{fi}) B_m (1 - D_{bt}) (1 - D_c)$$

$$S_{f0} = \sum_{i=3}^7 (P_i S_{fi}) (1 - B_m) (1 - D_{bt}) (1 - D_c)$$

Eat : The total amount of fish consumed (E) is calculated as the sum for each age and sex class of the product of the mean mass of a seal of age i (W_i) and the percentage (R_i) of this body mass that a seal consumes per year, multiplied by the number of seals (S_i).

$$E = \sum_{i=1}^7 (S_i W_i R_i)$$

Input

The parameters are age-specific pregnancy rate, age- and sex-specific annual natural mortality rate, and the proportion of pups born male, female aggregation size, the sex ratio of a harvest, age- and sex-specific body mass and age- and sex-specific consumption rates. The values for these model parameters are given in Table 4.1.

Values of 74% (Best, 1973) and 78% (David, 1987b) for average female pregnancy rate of the South African fur seal population are available in the literature but no age-specific figures have been published. The age-specific pregnancy rate values are estimated by Oosthuizen (pers. comm.). Butterworth *et al.* (1987) calculate pup survival to be less than 92% (or a mortality rate of more than 8%). Their population model requires this figure in order to achieve the growth rates found at Kleinsee and Atlas Bay. Immigration is thought to play a role in causing the fast growth

rates and this is incorporated into their survival rate figure. In this model the whole population is being modelled so immigration/emigration are not factors that need to be taken into account. David (1987b) suggested that pup mortality is variable but may be as high as 20% in the first 50 days of life so this figure is used for pup mortality. The other mortality rates used in this model are the figures calculated by Butterworth *et al.* (1987). The mortality of territorial bulls is calculated by Butterworth *et al.* (1988) based on the information for the Northern fur seal which suggests a 3.5-fold increase in natural mortality as territorial status is achieved (Johnson, 1968). Female aggregation size is variable, probably in the range of between 10 and 30 females per male, and averaging approximately 21 (David, pers. comm.). This range includes the published figure of 28 females per male (Rand, 1967). The sex ratio of a harvest is estimated independently by two sources (Roux, pers. comm. & Sea Fisheries Research Institute, unpublished data) as the same figure. This sex selection during a pup harvest is a consequence of the sealers favouring the larger pups. Sexual dimorphism results in the larger pups being males.

In the literature, body mass data are presented as mean values for various subsets of the population or for the whole population. David (1987b) gives a mean of 247 kg for breeding bulls, the largest individuals in a colony, and 57 kg for females. The mean mass of foraging animals (which excludes pups) is estimated at 60 kg (David, 1987a), whereas Butterworth *et al.* (1988) suggest a figure of 72 kg. The age- and sex-specific body mass values used in the model are estimated by David (pers. comm.) for seals up to 6 years of age and the mass of a seven year-old is extrapolated from these figures. Shaughnessy (1985) and David (1987a) use a consumption rate of 8% of body mass consumed per day, whereas Butterworth *et al.* (1988) suggests that a range between 5% and 20% for the population is likely. The range suggested by Butterworth *et al.* (1988) is used and an assumption is made for the model that the youngest age class consumes 20% of its body mass and the oldest age class consumes 5%, with a linear increase in percentage between them.

To set up an initial population in the model, a number of pups is input. The number in this initial cohort surviving each age with no culling produces the number in each age class.

Output

Model output occurs at the time when the population is at its maximum, directly after recruitment. The number of pups, total population size, number of animals killed, the sex ratio of the population and the mass of fish consumed are output. Only relative changes under different scenarios are being investigated, so quantification of actual population size is unnecessary at this stage.

TABLE 4.1 : Data values for parameters of the Seal Model.

PARAMETER	VALUE	SOURCE
<i>Annual pregnancy rate (%)</i>		
3 year-old	10	Oosthuizen (pers. comm.)
4 & 5 year-olds	68	" " "
6+ year-olds	81	" " "
<i>Annual natural mortality rate (%)</i>		
Pups	20	David (1987b)
1, 2 & 3 year-olds	14	Butterworth <i>et al.</i> (1987)
4+ year-olds	8	Butterworth <i>et al.</i> (1987)
Territorial bulls	29	Butterworth <i>et al.</i> (1988)
<i>Percentage born male (%)</i>	55	Butterworth <i>et al.</i> (1987)
<i>Female aggregation size</i>	21	David (pers. comm.)
<i>Male percentage of pup harvest (%)</i>	65	Sea Fisheries Research Institute (unpubl. data) & Roux (pers. comm.)
<i>Average mass (kg)</i>		
1 year-old	20	David (pers. comm.)
2 year-old	25	" " "
3 year-old	32	" " "
4 year-old (female/male)	40/52	" " "
5 year-old (female/male)	50/75	" " "
6 year-old (female/male)	60/90	" " "
7+ year-olds (female/male)	70/117	Estimate
<i>Body mass consumed daily (%)</i>		
1 year-old	20	Assumed from range given by Butterworth <i>et al.</i> (1988)
2 year-old	17.5	" " "
3 year-old	15	" " "
4 year-old	12.5	" " "
5 year-old	10	" " "
6 year-old	7.5	" " "
7 year-old	5	" " "

THE SEAL AGE MODEL

Attributes

Appendix 7 gives the documentation and listing of the computer program used to run this Seal Age Model, which is a simplified version of the Seal Model. The model is defined according to the following set of attributes with only the time step and the units remaining the same as in the Seal Model.

Purpose : The purpose of this simulation model is to follow single male and female cohorts through their lifespan to estimate the percentage probability of reaching particular ages with no culling, and to explore the variability in this by using different parameter values that are applicable to other fur seal species.

Brief description : This model is a simplified version of the Seal Model in which only the basic description, the units and time step are the same, and differing essentially only in that it has an unlimited number of age classes.

State variables : Age classes of seals of each sex from age 0.

Units : Number of seals.

Time step : 1 year.

Time horizon : When the number of seals in an age class is less than 1%, this is taken as the oldest age.

Calendar of events : No culling is included in estimation of the probability of a seal reaching certain ages in a virgin model seal population, so the sequence of events is to input a number of recruits and then each year to calculate the number surviving to the following age class.

Assumptions and constraints

The same assumption as in the Seal Model is maintained, that of omitting a density-dependent influence.

Equations

Initially, one hundred pups of each sex is used as a starting point in the model and these cohorts then grow through each age class, being reduced by natural mortality (M_i) each year.

$$S_i = S_{(i-1)} (1 - M_{(i-1)}) \quad \text{for } i = 1 \text{ to oldest}$$

To account for the mortality of territorial males, an estimate of the number of territorial bulls is then made by calculating the number of breeding females in all age classes and dividing by female aggregation size as in the Seal Model equations, and the number of seals in age classes 7 and older is adjusted to account for territorial mortality, where S_{m7+} is the total number of seals over the age of 6 years.

$$S_T = \left(\sum_{i=3}^{\text{oldest}} (P_i S_{fi}) \right) / A$$
$$S_{mi} = S_{mi} \left(1 - \left((S_{mi} - S_T) (1 - M_6) + S_T (1 - M_T) \right) / S_{m7+} \right) \quad \text{for } i = 7 \text{ to oldest}$$

Input

To start the simulation, one hundred pups is entered so that the number of seals in each age class is equivalent to the percentage of pups reaching each age.

Output

Output is in the form of the percentage of male or female seals in each age class which is, in effect, the percentage probability of a seal reaching each age.

MODEL OUTPUT AND DISCUSSION

Probability of attaining various ages as estimated by the Seal Age Model

The results of the Seal Age Model show the probabilities of a male and female seal reaching particular ages (Fig. 4.7), estimated by following single cohorts and subjecting them to natural mortality annually. The only difference between the male and female parameters is that territorial bulls have increased mortality so the probabilities only differ from the age of 7 years. This territorial mortality decreases the average lifespan of males, making it shorter than that of the females. The model shows that 45% of the population is 7 years of age and older and this percentage of all seals is combined into the age class 7, the oldest age class in the Seal Model.

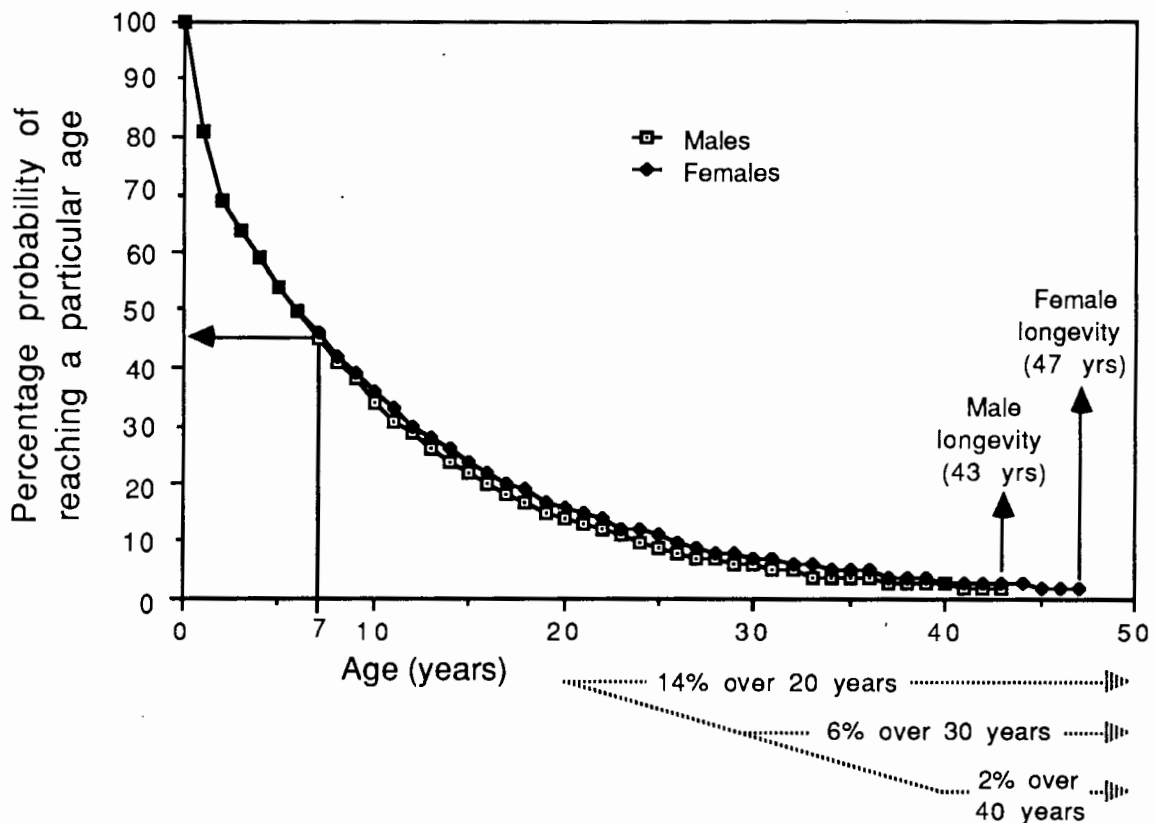


FIGURE 4.7 : The percentage probability of male and female seals reaching each age, as simulated by the Seal Age Model. Males and females have different probabilities of surviving to various ages as a result of increased natural mortality of territorial males.

TABLE 4.2 : Some recorded and estimated maximum ages of various seal species, with the estimates of the captive South African fur seals (*A. pusillus pusillus*) given in bold.

SPECIES	AGE	SOURCE
Males		
<i>A. pusillus pusillus</i>	17	Appendix 8
<i>A. pusillus doriferus</i>	18	Shaughnessy & Warneke (1987)
<i>A. australis</i>	21	Vaz-Ferreira & Ponce de Leon (1987)
<i>A. tropicalis</i>	18+	Bester (1987)
<i>A. forsteri</i>	15+	Mattlin (1987)
<i>Halichoerus grypus</i>	41	Hewer (1964)
<i>Halichoerus grypus</i>	25 (estimated max)	Anon (1988)
<i>Phoca vitulina</i>	20 (estimated max)	Anon (1988)
Females		
<i>A. pusillus pusillus</i>	16	Appendix 8
<i>A. pusillus doriferus</i>	21	Shaughnessy & Warneke (1987)
<i>A. tropicalis</i>	23+	Bester (1987)
<i>A. forsteri</i>	14+	Mattlin (1987)
<i>Halichoerus grypus</i>	46	Anon (1988)
<i>Halichoerus grypus</i>	35 (estimated max)	Anon (1988)
<i>Phoca vitulina</i>	25 (estimated max)	Anon (1988)

Maximum ages (percentage probability < 1%) are estimated to be 43 years for males and 47 years for females. Appendix 8 lists all seals held in zoos and aquaria in South Africa and the estimated ages of these seals. The oldest recorded ages are of a male which died at 17 years and a female which died at the age of 18 years. Most maximum age estimates for other species are less than 40 years (Table 4.2). The model estimates for the South African fur seal are comparable with the oldest recorded males and females of the true seal *Halichoerus grypus* (Table 4.2). Although this age is relatively old there are a few explanations for this. Firstly, the model population is a virgin (unsealed) stock and so is not subject to man-induced mortality which reduces the number of seals likely to survive. Secondly, it is likely that seals nearing the end of their lifespan have increased natural mortality although this has not been measured and is not included in the model. The model

accounts for all seals in the population whereas in the field, one is less likely to sample the extreme examples of age. In addition, the probability of the model seal reaching this maximum age is only 1%. The probabilities of seals exceeding certain ages are more meaningful than a single estimate of longevity for which a cut-off point at the "tail" end of the graph is less easy to define. The probability of either sex being over 20 years is approximately 14% whereas the probability of being over 30 years is approximately 5% and only 2% of seals are estimated to exceed 40 years of age. The probability of a male exceeding 17 years or of a female being over 18 years (such as those recorded in captivity) is 17% and 18%, respectively.

Sensitivity analyses

In order to conduct sensitivity analyses on the two seal models, ranges of possible parameter values are tested, based on data for other fur seal species (Table 4.3). The sensitivity analyses are carried out by inputting a range of small and large rates for pregnancy, natural mortality and consumption and comparing the output to that of simulations in which the values are used from Table 4.1 for the South African fur seal.

The effects of mortality and pregnancy rate on population size and the effect of consumption rates on fish consumption are explored after 20 years of simulation using the Seal Model (Fig. 4.8). Low mortality rates result in an elevated population size and vice versa for large mortality rates. The population sizes attained using low mortality values differ more from the population sizes simulated using the South African fur seal data than the output obtained when using high mortality rates. This indicates that the mortality rates defined for this species are in the upper part of the range for fur seal species.

TABLE 4.3 : Some annual rates of natural mortality (%), pregnancy (%) and consumption (% body mass per day) of different fur seal species as compared to those used in the models (shown in bold) for the South African fur seal.

SPECIES	PUP MORTALITY	DAYS	SOURCE
<i>A. pusillus pusillus</i>	20	50	Model
<i>A. pusillus doriferus</i>	15+	60	Shaughnessy & Warneke (1987)
<i>A. forsteri</i>	40	365	Mattlin (1987)
<i>A. gazella</i>	24	365	Payne (1977)
<i>A. australis</i>	10-20	60	Vaz-Ferreira & Ponce de Leon (1987)
<i>A. tropicalis</i>	15	84	Roux (1987b)
<i>A. tropicalis</i>	24	365	Bester (1980)
<i>A. tropicalis</i>	10+	86	Kerley (1987)
<i>A. galápaguensis</i>	9-15	30	Trillmich (1987)
SPECIES	POST-PUP MORTALITY	AGE (Years)	SOURCE
<i>A. pusillus pusillus</i>	14	Age 1, 2 & 3	Model
<i>A. pusillus pusillus</i>	8	Age 4+	Model
<i>A. gazella</i>	5	Age 2	Payne (1977)
<i>A. gazella</i>	8	Breeding females	Payne (1977)
<i>A. gazella</i>	8	Males ≤ 7 years	Payne (1977)
<i>A. galápaguensis</i>	15	Adult females with pups	Trillmich (1987)
<i>A. pusillus pusillus</i>	29	Territorial males	Model
<i>A. gazella</i>	30	Territorial males	Payne (1977)
<i>A. galápaguensis</i>	32	Territorial males	Trillmich (1987)
SPECIES	FECUNDITY	AGE (Years)	SOURCE
<i>A. pusillus pusillus</i>	10	Age 3	Model
<i>A. pusillus pusillus</i>	68	Age 4 and 5	Model
<i>A. pusillus pusillus</i>	81	Age 6 and 7	Model
<i>A. pusillus pusillus</i>	74	All mature females	Best (1973)
<i>A. pusillus pusillus</i>	78	All mature females	David (1987b)
<i>A. pusillus doriferus</i>	73	All mature females	Shaughnessy & Warneke (1987)
<i>A. tropicalis</i>	84	All mature females	Hes & Roux (1983)
<i>A. tropicalis</i>	86	All mature females	Bester (1980)
<i>A. gazella</i>	55, 75, 85, 90	Age 3, 4, 5, 6+	Payne (1977)
SPECIES	CONSUMPTION	AGE (Years)	SOURCE
<i>A. pusillus pusillus</i>	5 to 20	Age 7 to 1	Model
<i>A. pusillus pusillus</i>	8	All ages	Shaughnessy (1985) & David (1987a)
<i>A. pusillus pusillus</i>	5-20	All ages	Butterworth <i>et al.</i> (1988)
<i>A. tropicalis</i>	6	All ages	Condy (1981)
<i>A. gazella</i>	6	All ages	Condy (1981)
<i>C. ursinus</i>	6	All ages	Laws (1977)
<i>C. ursinus</i>	6-10	All ages	Keyes (1968)
<i>C. ursinus</i>	27	Adults	Bonner (1982)
<i>C. ursinus</i>	4-13	Adult females	Spotte & Adams (1981)
<i>C. ursinus</i>	20	Lactating females	Costa & Gentry (1986)

The low and high pregnancy rates, which are averages for all mature females, produce population sizes that are larger than the population size attained using the rates for the South African fur seal. The age-specific pregnancy rates given for *A. gazella* by Payne (1977) from Table 4.3 produce a population size that falls intermediate between the low and high average values (not presented). Although all of the South African fur seals of age 6 and older have a higher pregnancy rate (81%) than the average low rate of 74%, a lower population size is simulated than that obtained using the low rate for other fur seals. The use of this figure of 74% must therefore have a large influence when used for ages 3 to 5 years for which the South African fur seal has lower pregnancy rates and this results in the population size being 25% higher. This indicates that the fecundity rates are low compared to those for other fur seal species and that pup production is influenced to a large extent by the females of ages 3, 4 and 5 years.

The model consumption data for the South African fur seal is a range of between 20 and 5 percent of body mass eaten per day between the ages of 2 and 7+ years, respectively. Literature values for other fur seals range between 4% and 27% and the results show, as is expected, that the amount of food consumed lies between these limits for other seals. The amount of fish consumed by the South African fur seal is closer to that simulated using low consumption rates as opposed to high rates. This is most likely a result of the majority of older, heavier South African fur seals (7+ years of age) consuming 5% of their body mass which is far more similar to 4% (low) than 27% (high). The high consumption rate is large compared to consumption rates for other pinnipeds which are mainly in the range 6% to 10% (e.g. Laws, 1977; Øritsland, 1977; Naumov & Chekunova, 1980; Innes *et al.*, 1987).

The data for the South African fur seal appear to be more closely aligned with producing smaller population sizes because it tends towards the high end of the range in terms of mortality rates and is below the low estimates for fecundity for other species.

INPUT

	MORTALITY Annual (%)			FECUNDITY Annual (%)		
	S.A. fur seal	Low	High	S.A. fur seal	Low	High
Pups	20	9	40	Age 3	10	
Age 1-3	14	5	15	Age 4&5	68	
Age 4+	8	5	15	Age 6+	81	
Territorial bulls	29	30	32	Average		74 84

CONSUMPTION % Body mass/day			
	S.A. fur seal	Low	High
Age 2-7+ Average	20 to 5	4	27

OUTPUT

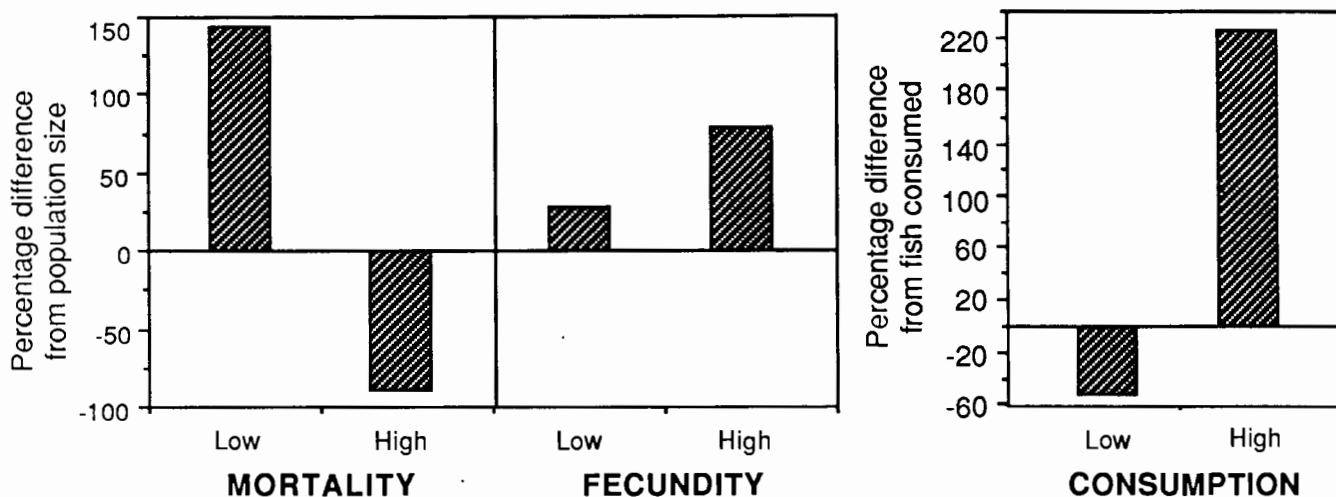


FIGURE 4.8 : Sensitivity analysis of the Seal Model showing changes in population size and fish consumption by the South African fur seal after 20 years under parameter values based on the information for other fur seals in Table 4.3.

A sensitivity analysis is undertaken with the Seal Age Model using the range of parameter values for fur seals (Table 4.3) to compare the smallest and largest maximum ages obtained (Fig. 4.9). For females, the high and low mortality rates are used as input and they produce longevity estimates of 23 and 81 years respectively. When low mortality rates are used, the probability of a female exceeding 20 years is 34%, which is high when compared to an equivalent 15% for the South African fur seal and 3%, using high mortality rates as input.

The number of territorial bulls is influenced by the number of breeding females; therefore the higher the pregnancy rate, the more breeding females there are, and the greater the number of bulls that are subject to the elevated territorial bull mortality, and vice versa. Fig 4.8 and Table 4.3 show that the pregnancy rates of the South African fur seal are among the lowest of fur seals so these rates are taken as the low end of the range. A simulation in which a high pregnancy rate and high mortality is input produces a maximum age for males of 22 years, whereas a maximum age of 67 years is obtained when low mortality rates and the South African fur seal pregnancy rates are input. As with the females, the maximum age achieved under conditions of low mortality is very old. The probability of exceeding 20 years is 29% (low mortality) and only 2% (high mortality) as compared to the 13% in the South African fur seal. It seems unlikely that the latter maximum age would be achieved, so a combination of low mortality in all age classes is unlikely to occur for an extended period.

The sensitivity analysis shows that there are no unexpected results in the behaviour of the models. The Seal Model is to be used to explore comparative output under different management strategies by examining the output when different culling rates are used on different age and sex classes of the population. Different mortality rates, and to some extent, fecundity rates, change the percentages of seals in each age class for each sex and this will influence the output under different culling regimes. But since the results are only being explored comparatively, the trends should remain largely unchanged.

INPUT	MORTALITY Annual (%)			FECUNDITY Annual (%)		
	S.A. fur seal	Low	High	S.A. fur seal	High	
Pups	20	9	40	Age 3	10	
Age 1-3	14	5	15	Age 4&5	68	
Age 4+	8	5	15	Age 6+	81	
Territorial bulls	29	30	32	Average		84

OUTPUT

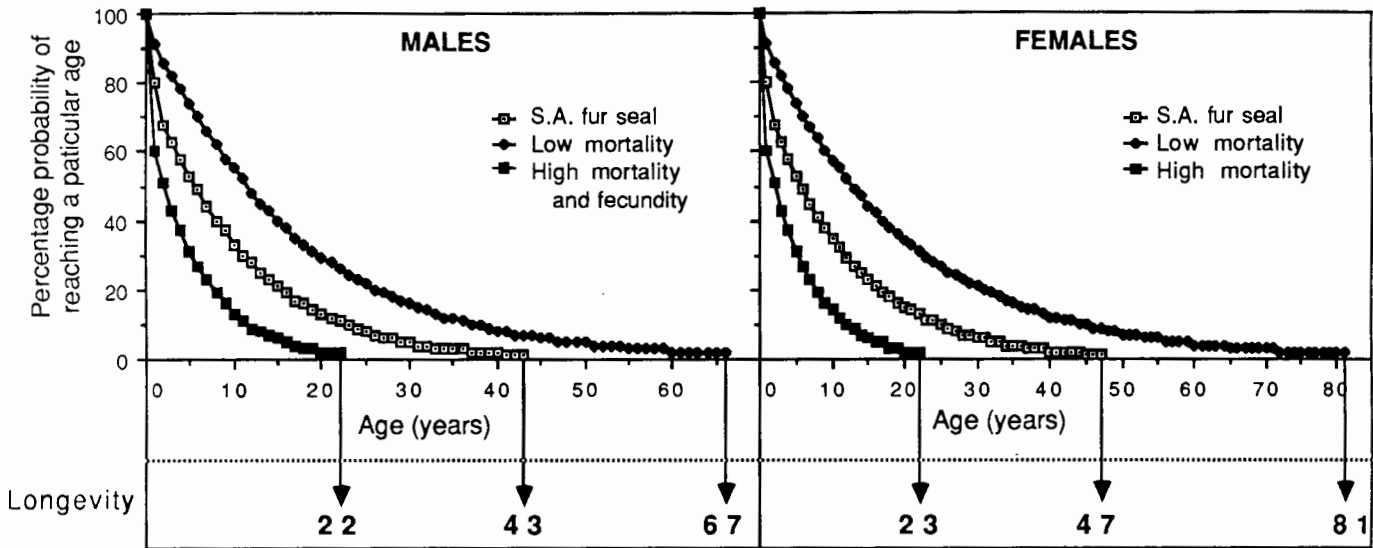


FIGURE 4.9 : Sensitivity analysis of the Seal Age Model showing changes in probability of male and female seals reaching each age under different parameter values (based on the information for other fur seals in Table 4.3). Low and high mortality rates are used, and for estimating the probabilities of males reaching each age, the consequence of large pregnancy rates are also tested because this affects the number of territorial bulls which have elevated mortality levels.

CONCLUSIONS

The formulation of the Seal Model entailed repetition of a succession of processes involving model building, discussion with seal biologists, followed by model improvement. This method of iterative refinement of model structure and data produced the version of the model, which is regarded as a robust model of the South African fur seal population. The most important structural differences between this and previous models built for the South African fur seal (Shaughnessy & Best, 1980 & Butterworth *et al.*, 1987) are the incorporation of males into the model population and the inclusion of disturbance influences of culling. The decision to exclude a density-dependent function was taken because no significant functional response has been observed. Estimation of such a function would require more assumptions being made than assuming that the South African fur seal is at a population level at which such influences are negligible. From the simple Seal Age Model, the longevity of male South African fur seals is estimated to be 43 years and of females, 47 years although the percentage probability of an individual exceeding 20 years, which is approximately the maximum age recorded for other seals, is only 14%. The sensitivity analyses on the two models show the variation in the results when data for other fur seal species are used as input. The models are not particularly sensitive to any parameter values although the younger females seem to have an important influence on the the overall population size. The Seal Model is used as a tool for further simulations regarding the seal population (Chapter 5) and fish consumption (Chapter 7). The Seal Model is modified and scaled to historical population sizes to conduct various other speculative analyses such as exploring historical population dynamics (Chapter 6) and examining fish consumption by the seal population (Chapter 7).

CHAPTER 5

SEAL CULLING : ALTERNATIVE MANAGEMENT SCHEMES AND POPULATION DYNAMICS

ABSTRACT

The "Seal Model" (Chapter 4), which is not scaled to realistic population size, is used to evaluate culling as a means of seal population control and the consequences of different culling regimes. The effects of the incorporation of reduced pup production as a result of disturbance during a cull are explored and, in the case of disturbance during a bull cull, this makes a substantial difference to the population. The model shows that the most effective means of reducing the population is to cull pups and bulls. In this case, the decrease in population size is brought about mainly by a reduction in pup production (fewer births and decreased pup survival) which is caused by the disturbance during a bull cull. Culling pups is the least effective means of population control, and consequently, for any particular culling rate, the harvest of pups is the greatest. Culling cows alters the population age and sex structure severely and is therefore considered unsuitable. Although the current method of estimating the population size of the South African fur seal is by multiplying the censused number of pups by 4, the model shows that the ratio of the whole population to number of pups is variable and, under most culling regimes, is greater than 4.

INTRODUCTION

The fishing community has two main complaints regarding the interactions between the South African fur seal and the fishing industry. The first is that seals interfere with their fishing operations. The second is that they compete with the industry for the same resource *i.e.* commercial fish species. Many in the fishing industry claim that culling seals will reduce the seal population, thereby both lessening operational interferences and making more fish available for them to harvest. These assumptions are simplistic when applied to a complex ecosystem. However, a speculative model can be used to simulate the possible changes to the seal population when seals are culled. The sealers may wish to maximise the harvest of seals so the same model can also be used to simulate the possible effects of harvesting different subsets of the population. It is important to investigate these effects in both the short- and long-term. The parties involved in influencing management policy may wish to see the short-term results of different management strategies. However the long-term effects should also be considered if a management policy is to be enforced for an extended period.

The distinction must be made between culling (for control of the population with a minimum of effort) and harvesting (killing for economic benefit). Different sealing strategies may be implemented for a cull or a harvest. A cull is more interesting than the common problem in fisheries biology of selecting optimal harvesting strategies because this may imply the control of one population for some indirect benefit (such as in the seal-fishery problem). The term "cull" is used in reference to man-induced mortality for situations in which both direct and indirect benefits are the objectives and the effects of both are discussed.

The "Seal Model", described in Chapter 4, will be used as a tool for various analyses. In a density-independent model, such as the Seal Model, a maximum sustainable yield (MSY) is not output because this only applies to models which have some form of intrinsic population control built into them. In addition maximum sustainable yield is a concept only useful for populations that do not interact strongly and which can be viewed as isolated populations (May *et al.*, 1979) but

this is not the case with the seal population. The short- and long-term effects of different management regimes will be investigated in terms of the number of seals culled (to estimate harvest size), seal population size, sex ratio of the population, annual population growth rate, annual trends in the population and the population : pup ratio.

METHODS

The Seal Model and the data from Table 4.1 are used to simulate the effects of different culling regimes. Four culling regimes are chosen : that of culling pups, cows, bulls and a combination of pups and bulls (both of which are culled at the same rate). The influence of culling disturbance is explored. These effects are viewed in terms of the number culled and resultant population size, sex ratio of population, annual population growth rate and population trends in both the short- (5 years) and long-term (20 years). A figure of half a million pups was input into the model to set up the initial population, which is calculated by following a cohort through all ages. In this model, the population is not scaled to a realistic size because only the relative changes between different culling regimes are being investigated. The output for the two time periods is presented on the graphs using the same scaling units so that they that are directly comparable.

The average annual growth rate (r) is calculated as the average growth in number of seals (S) over the 15 years between the fifth and twentieth simulated year. This relationship has been used to estimate seal population growth of various species (*e.g.* Payne, 1977; Condy, 1978; Bester, 1980; Hes & Roux, 1983; Kerley, 1983b).

$$r = \left(\sqrt[15]{\frac{S_{20}}{S_5}} - 1 \right) 100$$

RESULTS AND DISCUSSION

Number culled

The relative numbers culled under each of the four culling regimes in both the short- and long-term time are presented in Fig. 5.1. This provides information as to the size of the harvest that could be expected from different management strategies. In the short-term, at low cull rates (<20%), the number of seals culled is similar under all of the four management schemes. Above this the number of bulls and cows culled is the smallest, the number of pups culled the greatest, while the "pup and bull" culling regime results in an intermediate number being killed.

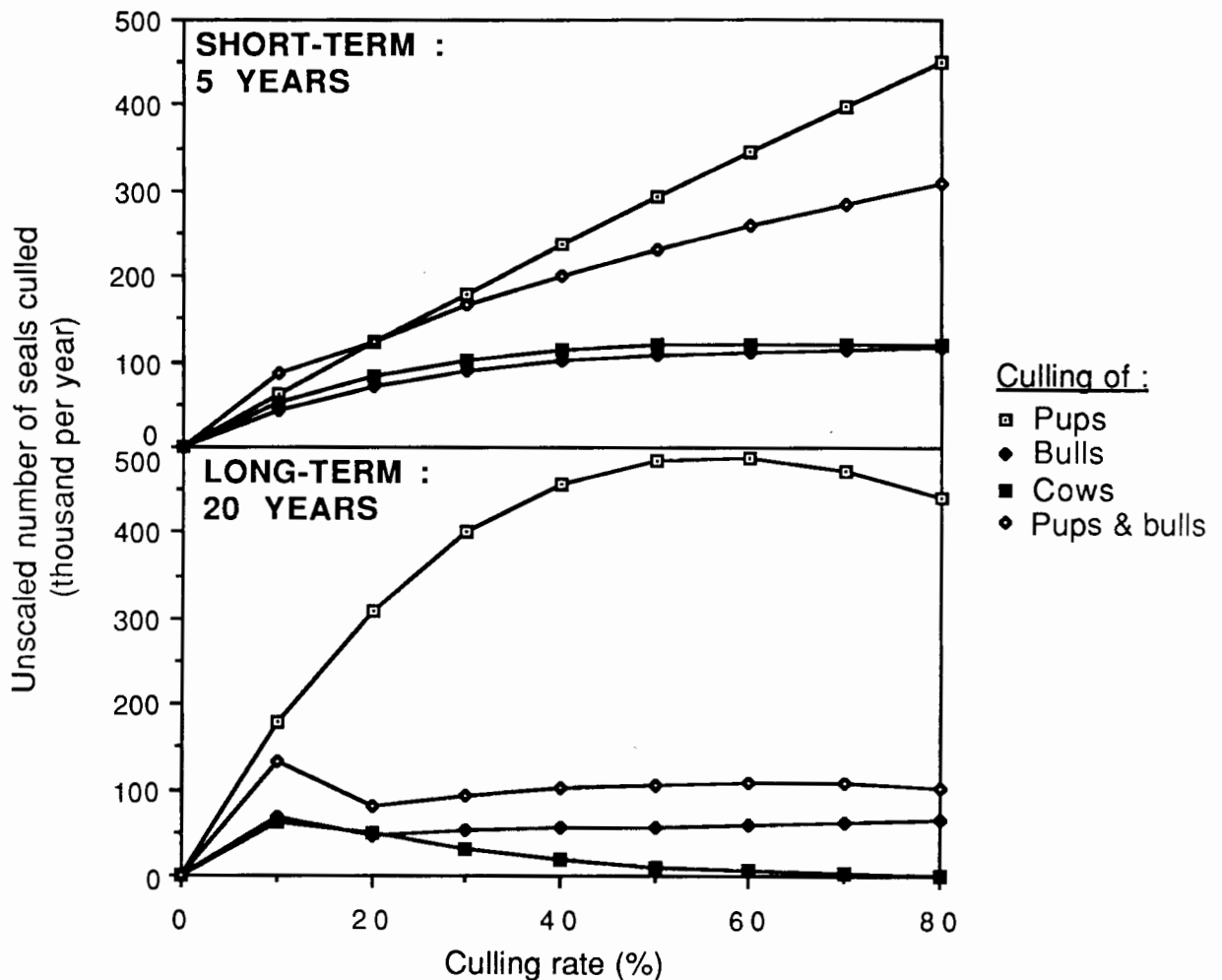


FIGURE 5. 1 : The number of seals culled annually under different culling regimes as simulated by the Seal Model, using a starting figure of half a million pups.

In the long-term, the trends in the number of seals culled differs from that in the short-term. The pattern in the number of seals culled between culling rates of 0% and 20% under each of the culling regimes, excluding the pups-only cull, is explained by the disturbance effects of culling. At low culling rates, disturbance is variable but above 20%, the model assumes a constant disturbance effect. The decline in numbers culled between 10% and 20% is a direct consequence of there being lower recruitment due to disturbance and therefore fewer animals overall from which the percentage culled is calculated. After 20 years, it is only with the culling of pups alone, that a point of inflection is reached, above which additional culling has a reduced impact. This point occurs at a culling rate of approximately 60%. This is a result of the fact that under a high culling rate, the population is reduced after 20 years so that although the same percentage of pups is taken, it is a percentage of a smaller number of pups. Under the other culling regimes, the number culled is somewhat fewer. When cows are being taken, the number culled is very small, decreasing to almost zero at high rates because recruitment has been severely reduced and this has had time to filter up through the age classes, leaving a very low population size.

Population size

Under each of the management regimes, the trends in population size are similar in both the short- and long-term. But the relative population sizes are, as would be expected, much smaller in the long-term (Fig. 5.2). The population size that results from the pup cull is the largest of all the management schemes. At low cull rates, the population size under each of the other culling regimes is similar. The cow and the "pup and bull" culling regimes show similar decreases in the population with increasing culling rate. When bulls are culled, the population size remains fairly constant above a culling rate of 20%. The initial decrease in population size under all culling regimes, excluding that of pups alone, is a result of the disturbance effects, which vary as a function of the culling rate of bulls or cows, reducing pup production. The magnitude of the disturbance effects depend on the culling rate if it is below 20%; above this, the disturbance effect on pup production is constant.

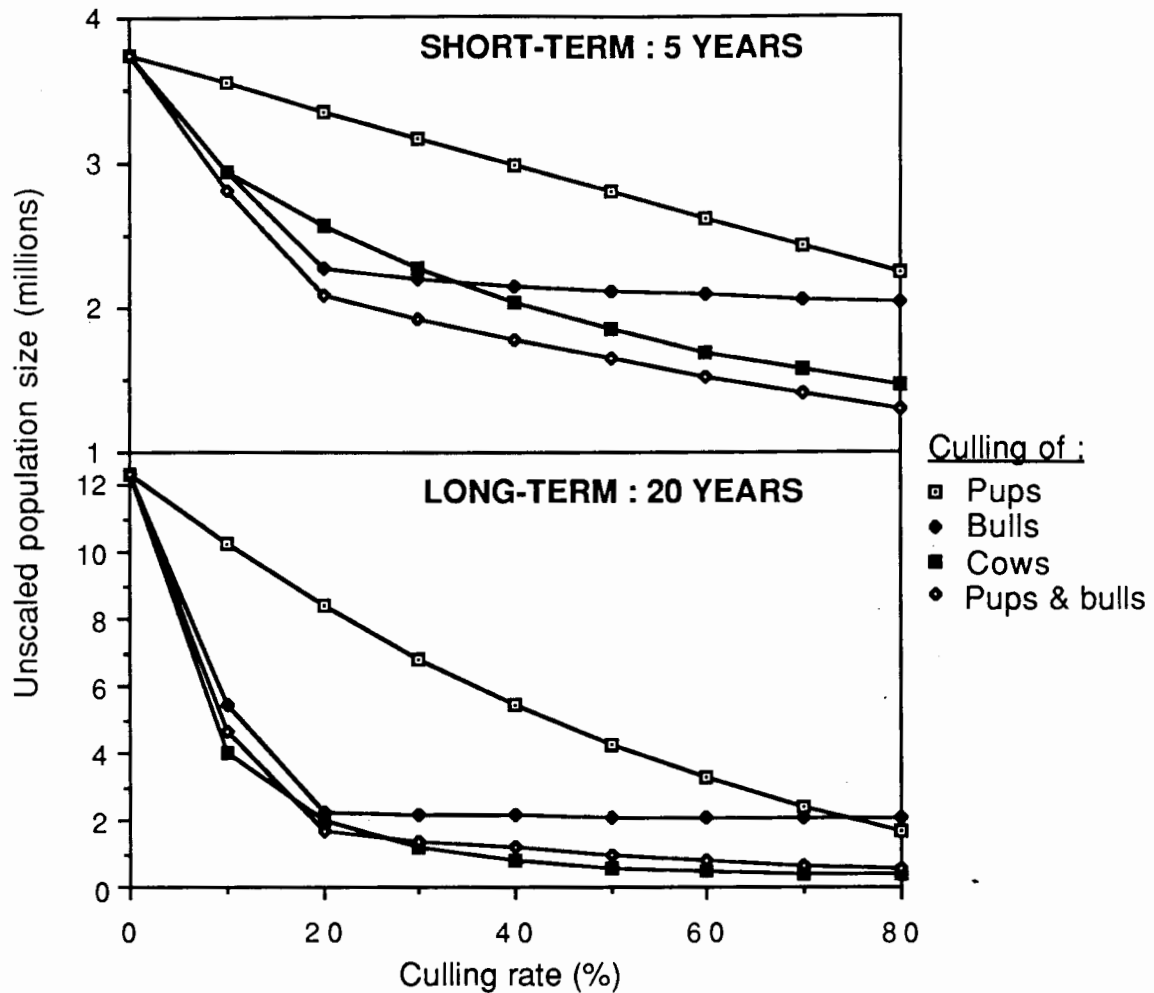


FIGURE 5.2 : The population size under different culling regimes as simulated by the Seal Model, using a starting figure of half a million pups.

The effects of model assumptions regarding culling

Various assumptions regarding culling and the disturbance effects of culling are made in the Seal Model, some of which are more firmly based (being supported by better data) than others. Since the objective of the simulations is to explore the effects of different culling regimes on the seal population, the "grey" areas in the output which may result from the model assumptions require investigation. The assumptions that only males older than 7 years and only breeding females are culled, and the information that male pups are taken preferentially to female pups, are based on evidence from harvests and therefore can be considered as forming part of the firmly based model structure.

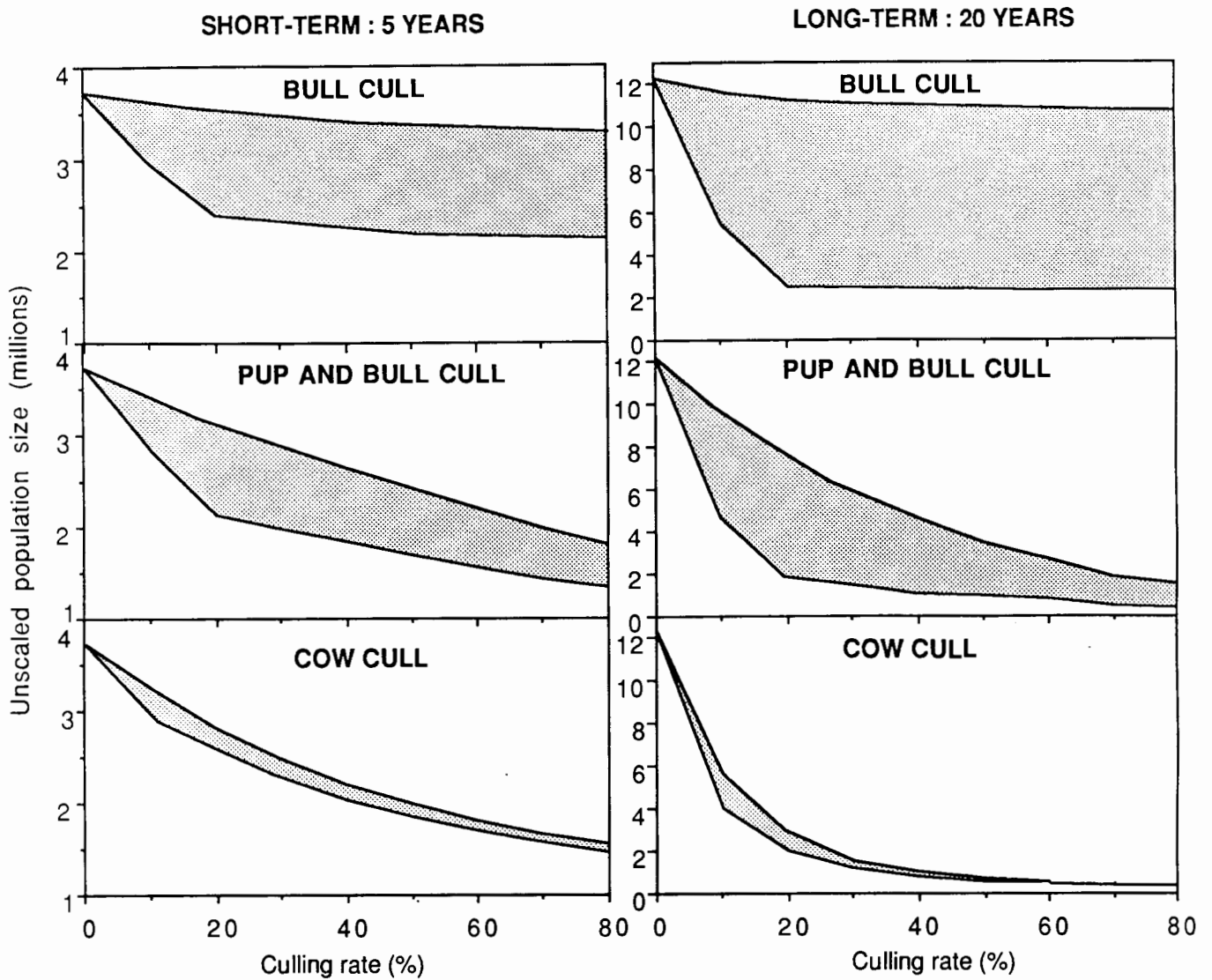


FIGURE 5.3 : Population size under different culling regimes, showing the difference between no disturbance effects (the upper limit of each shaded area) and the inclusion of disturbance effects that are thought to occur, as simulated by the Seal Model, using a starting figure of half a million pups.

The assumptions regarding the disturbance effects of culling, which result from bull and cow culls only, are based on fewer data. During the process of building the Seal Model, a number of versions were produced and then improved after discussion. The results of different preliminary versions which range from those which incorporate no disturbance effects to those with different amounts of disturbance influencing pup production (fewer births and reduced pup survival) are discussed in Appendix 2. Therefore, although the disturbance effects included in the Seal Model (Chapter 4) are not based on hard data, they are what is currently regarded as most likely to influence pup production based on our knowledge at present. The effects caused by the

disturbance are examined (Fig. 5.3). The ranges in population size show the results if disturbance factors are accepted (at the low end of the range *i.e.* maximum disturbance and greatest reduction in pup production) and the top of the range indicates the population sizes resulting from the exclusion of disturbance factors. There is no substantial difference between excluding disturbance effects of a cow cull and incorporating it. There is a marked effect caused by disturbance during a bull cull which affects pup production both in the year of the cull and in the following year. If disturbance is excluded from the model, bull culling has very little effect on the population size, showing minimal change in population size during a bull only cull and only a marginal difference from the population size resulting from a pups only cull when bulls and pups are culled together (Appendix 2). This assumption of the disturbance effects of bull culling therefore has important consequences for a comparison of the results of different culling regimes and must be borne in mind.

Sex ratios

It is important to investigate the population sex ratio under different hypothetical culling regimes. If there is a large change in the sex ratio of the population, responses by the population, such as reduced fecundity and/or pup survival, which may be undesirable could occur, and these are responses not accounted for by the model. Fig. 5.4 shows the percentage of males in the population under different culling regimes. When no seals are being culled, the male : female ratio is 55 : 45 (see Table 4.1). The difference between the short- and long-term results is simply that the change in percentage of males is amplified after 20 years because of the effects being realised through more of the population. The sex ratio of the population changes most drastically in favour of the males under a cow culling regime. After 20 years of a cow culling regime, the male proportion reaches almost 100% but the population is in fact close to zero. This change to the structure of the population may lead to responses in the population that are not accounted for by the model. As the pup culling rate increases the proportion of males decreases because males are culled preferentially in the ratio 65 : 35 (see Table 4.1). When both pups and bulls are being culled, the effect is most severe in terms of the reduction in number of males in the population both in the short- and long-term as a consequence of adult males and male pups being taken.

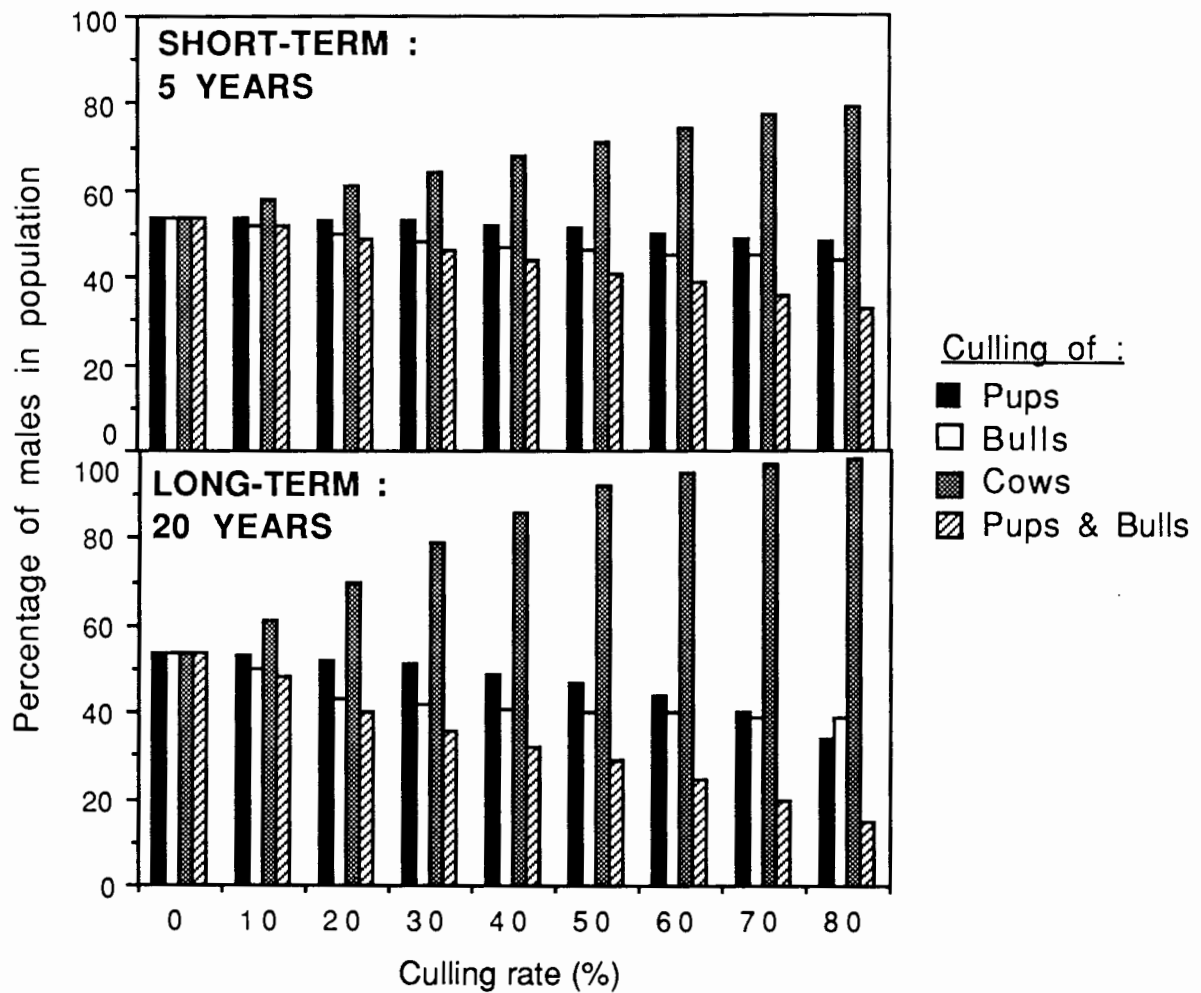


FIGURE 5.4 : Percentage of males in the population under different culling regimes as simulated by the Seal Model.

Annual population growth rate and trends

The model estimates of the average annual growth rates for the seal population under each culling regime are presented in Fig. 5.5. If the population is to remain fairly constant, culling rates of approximately 70% for pups, over 20% for bulls, and between 10% and 20% for cows or pups and bulls would need to be enforced. Above these culling rates, the population would decline and below these the population would increase. The annual growth rate trend under bull culling schemes differs in that it is relatively constant, perhaps increasing slightly at higher rates. The reason for this was discussed earlier in terms of the constant population size at higher culling rates

resulting from a constant disturbance effect (see Fig 5.2). Considering the "grey" area of the consequence of disturbance effects of bull culling (see Fig. 5.3), the growth rate under both bull and pup culling regimes could be much higher. If disturbance were excluded, a marginal decrease from the growth rate found under a regime of no culling, would be seen at all bull culling rates. If no disturbance effects were included in a "pup and bull" cull, the annual growth would be similar to a pups-only cull.

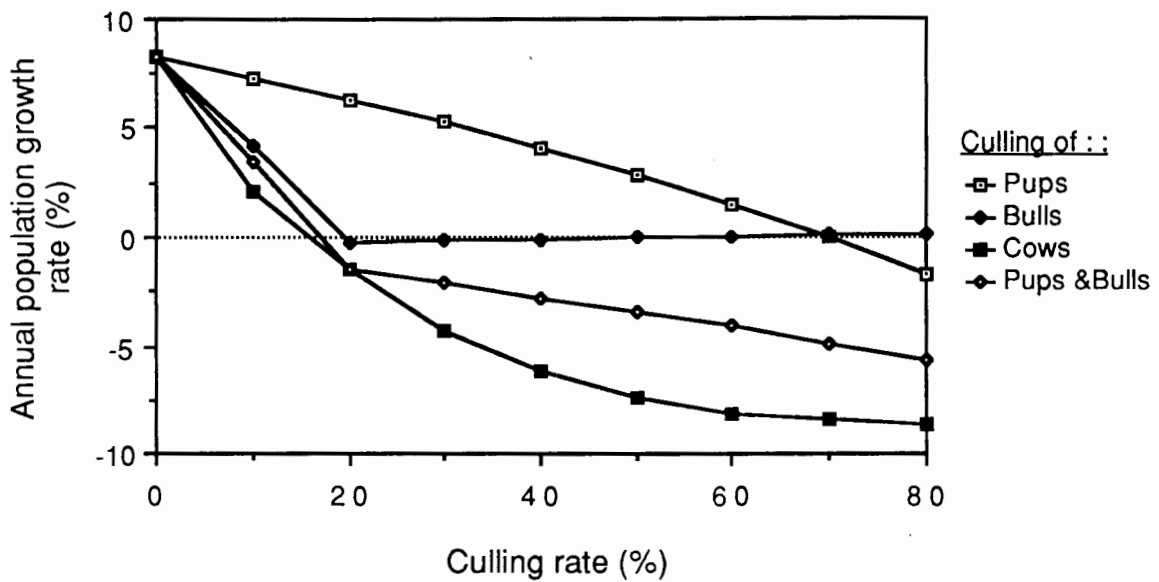


FIGURE 5.5 : Average annual growth rate under different culling schemes as simulated by the Seal Model.

Based on the annual growth rate trends at different culling rates (see Fig. 5.5), the change in the seal population size is shown over a period of 20 years under selected culling regimes (Fig. 5.6). For each subset being culled, culling rates are shown that represent the changeover from an increasing to a decreasing population. Since a bull cull does not show a decreasing population under any culling rate, the maximum culling rate is also presented. For pups, the trends are also shown under culling rates which result in an approximately static population size. A large percentage of pups (over 70%) needs to be culled to produce a decreasing population while for the cow and "pup and bull" culling regimes, 20% is sufficient.

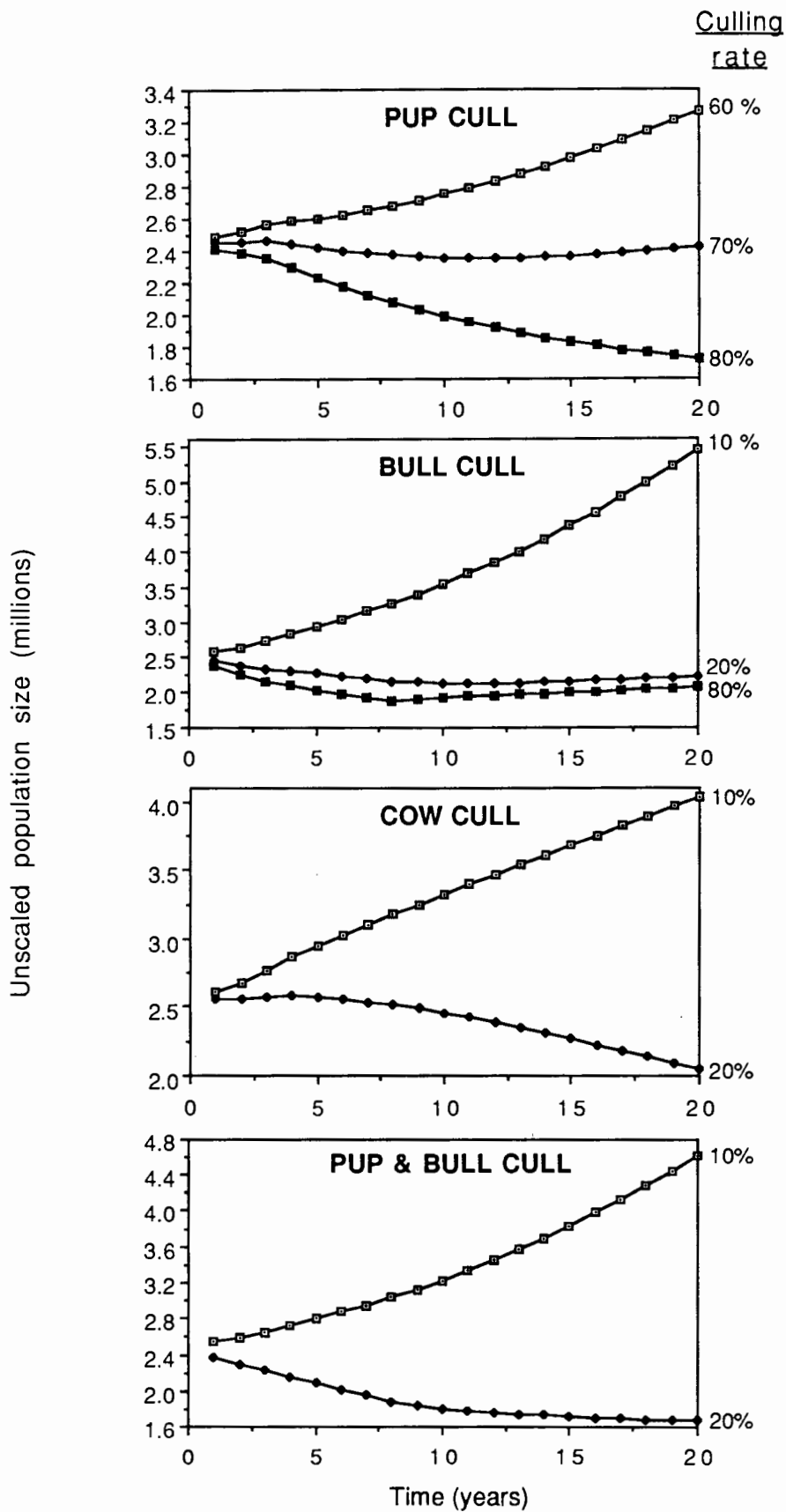


FIGURE 5.6 : Annual population trends under different culling regimes at the culling rates which cause increasing, static or decreasing population sizes, when simulated by the Seal Model, using a starting figure of half a million pups.

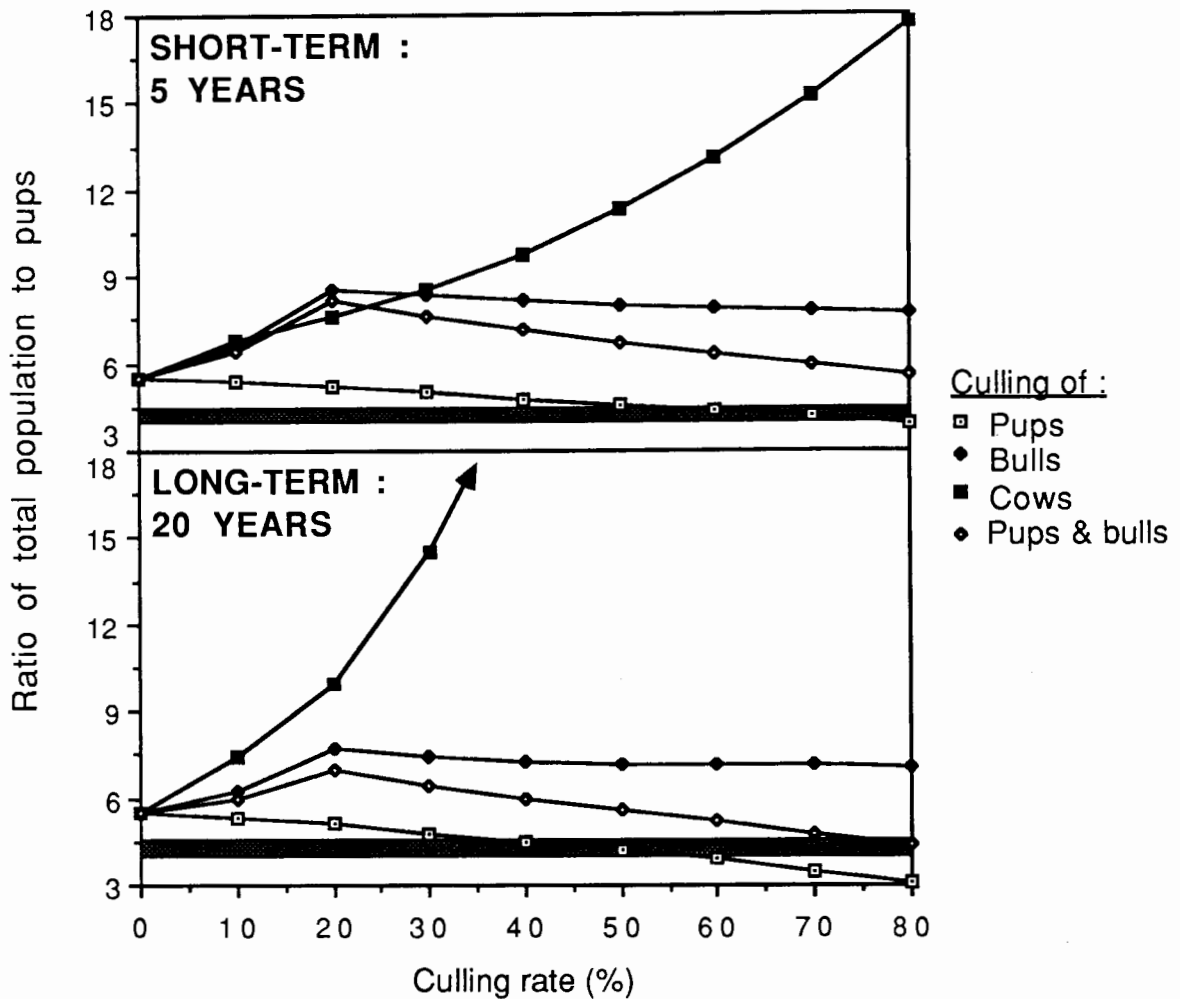


FIGURE 5.7 : The ratio between the the number of pups and total population sizes for the short- and long-term as simulated by the Seal Model under different culling regimes. The horizontal band on the graphs represents the range of ratios between 4 (Johnson, 1972) and 4.49 (Butterworth *et al.*, 1988).

Population : pup ratios

The method used to estimate total population size of the South African fur seal is to multiply the number of pups (which are counted by the census methods described in Chapter 2) by a factor, assumed to be the ratio between pup numbers and the total population. Johnson (1972) suggested a ratio of 4 for Northern fur seals and this is currently used to estimate the population size of the South African fur seal. Butterworth *et al.* (1988) estimate this ratio as 4.49. The model is used to estimate the ratios under different management scenarios enforced over the different time periods

(after 5 and 20 years) (Fig. 5.7). The most important point to note is that the ratios presented are all higher in both the short- and long-term than the ratio currently used (Johnson, 1972) and that suggested by Butterworth *et al.* (1988). At low culling rates, the ratios are above any current estimates. Only when pups are being culled does the ratio between the population and pups drop into the suggested range. A cow cull causes very high ratios even at very low culling rates.

If no disturbance effects of a bull cull were included in the model, the ratios under any bull culling regime would be slightly lower than the ratio of 5.5 (when no culling takes place). Under the same conditions, the ratios under a pup and bull culling regime would be slightly lower than if a pups-only culling strategy were adopted. In the latter case, the population : pup ratio is more in line with the suggested ratios of Johnson (1972) and Butterworth *et al.* (1988).

CONCLUSIONS

The consequences of age and sex-selective culling are explored by the Seal Model, a model which in addition to including culling as a variable form of mortality also incorporates a second-order effect of culling, that of reduced pup production as a result of disturbance at the colony. The impact of this disturbance is not based on specifically measured data. The effects finally included in the model are derived from an iterative process involving a series of models, the results of which were examined (Appendix 2) until the effects which were considered to be the most realistic disturbance effects of culling were accepted and included. In particular the disturbance effects of bull culling have the most marked consequences because bull culling in itself would have little effect, whereas the reduction in pup production makes substantial changes to the population size. The results of the different culling regimes are examined in the light of the "grey" areas in the model assumptions, caused by the disturbance effects of culling.

The model output of the long-term simulations over 20 years must be considered in view of the fact that no density-dependent regulation mechanism is incorporated into the model. If such a mechanism were to come into play within 20 years the consequences to the model results would most likely be that the number of pups, in particular, would be overestimated because this age class of the population is likely to be most reduced by an intrinsic density-dependent regulatory mechanism. Resulting from this, the population size and growth rate and the number of seals culled, particularly the number of pups culled would be overestimated and the population : pup ratio would be underestimated. However, this should make little difference to the output which is being examined in a comparative way between different culling strategies.

From the results of the Seal Model, it is speculated that culling a combination of pups and bulls is the most effective means of reducing the South African fur seal population. At culling rates of 20% and more, a negative growth rate of the population is achieved. The main cause for the population reduction would be by disturbance during bull culling operations resulting in reduced pup production, and not from the removal of the bulls and pups. Pup culling is the least effective means of reducing the seal population. Only at very high pup culling rates (> 70%) would a static or negative growth rate be achieved. A management strategy which allows for population control, while making the procedure economically viable in terms of a harvest, may need to be considered. The manager would then be interested in the size of a harvest that may result from a culling operation. The model shows that for any particular culling rate, the number of seals taken is greatest when pups alone are being culled, as opposed to any other age or sex classes of the population. When pups and bulls are culled together, the harvest is not as great because pup production is reduced by disturbance during the bull cull.

Culling cows has a dramatic effect on the population both in terms of population numbers and in altering the sex ratio. It may, therefore, be undesirable to kill cows, except at low culling rates, because severely altered sex ratios have not been observed in the seal population, and this may have unforeseen consequences. The harvest gained from cow culling is low but at present this

would not be important since there is little financial incentive to kill cows. There is no specific marketable product taken from the cows other than using them for meat and oil.

In Chapter 4, the number of pups per seal is viewed against the density of seals in an attempt to find a negative correlation between the two and thereby define a density-dependent influence. To show a density-dependent influence, the method relies on the fact that the ratio between the population and the number of pups changes as density increases. However culling, which is density-independent, is explored using the Seal Model and the results show that this ratio is very variable. The data for any method that relies on a change in this ratio should therefore only be taken from unsealed populations because of the influence that sealing has on the ratio.

The total population size of the South African fur seal is, at present, estimated by multiplying the number of pups, which are counted during surveys, by a factor of 4. However, the model shows great variability in this ratio under different management regimes. In most cases, the model population : pup ratio is above the figure of 4 presently used, and this current method of estimating population size is therefore likely to produce underestimates.

CHAPTER 6

HISTORICAL POPULATION DYNAMICS AND FUTURE MANAGEMENT SCHEMES FOR THE SOUTH AFRICAN FUR SEAL

ABSTRACT

The "Seal Model" (Chapter 4) is scaled according to historical population sizes of the South African fur seal using historical culling data as input, and this "Scaled Seal Model" is used to explore seal demography and culling. Although the numbers of pups have undergone some fluctuation in the recent years and have shown negative growth on average, these fluctuations are not as evident in the total population trend, which is estimated to have increased at an annual rate of 5.1% since the last major census in 1983. The model is used to estimate that the population was approximately one-and-a-half million seals in 1988. Historical harvesting is thought to have influenced the trends in population size significantly. Since 1900, the mean ratio between pups and total population size is estimated at 4.55, as opposed to the figure of 4 currently used to estimate population size from pup numbers. A comparison is made between annual model population sizes and the population estimated by multiplying the number of pups by a population : pup ratio, and shows the drawbacks of this method. To achieve a small or negative growth rate in the population, more bulls and pups would need to be culled than have been taken annually this century.

INTRODUCTION

One test of the validity of the theoretical "Seal Model," developed in Chapter 4, lies in its ability to simulate the historical dynamics of the South African seal population. If this can be achieved, it is further verification of the validity of the model, showing that the basic model and its parameter values cannot be eliminated from the set of speculative models for the South African fur seal, based on the present data. This procedure is not carried out in order to be able to make precise predictions from the model results, it merely allows the model to be used further in the speculative realm to examine various scenarios. By inputting historical harvesting data and attempting to fit the model to historical population sizes, the usefulness and plausibility of the model is enhanced. The model output then becomes more understandable to the user because it is closer to reality.

The objective here is to use historical harvest figures as input into an adapted version of the Seal Model, called the Scaled Seal Model and attempt to attain the population size estimates given by David (1987b) and shown in Appendix 1. If it is possible to simulate historical trends of the whole population, it will be useful to see if the same model can simulate groups of colonies or individual colonies. Features and influences of the historical population trends can be examined and the effects of selected future management regimes explored.

THE SCALED SEAL MODEL

Attributes

The documentation and listing of the computer program used to run the Scaled Seal Model, which is a modification of the Seal Model, scaled to realistic population size, is given in Appendix 9. The attributes of the Scaled Seal Model, other than the time horizon, remain the same as in the Seal Model.

Purpose : The purpose of scaling the Seal Model (Chapter 4) to historical (1900 - 1988) numbers of pups, and including historical harvest data, is to make the model numerically understandable and applicable in real terms in order to observe historical trends and explore future (1989 - 2000) effects under selected theoretical management schemes.

Time Horizon : The simulation period for which historical harvesting data are available for input into the model is from 1900 to 1988 or any subset thereof. The whole population is simulated from 1900 and includes all the harvesting data. Prior to 1973, the bull harvest data were only recorded as an annual total; the number of bulls taken from different colonies was not specified (see Appendix 3). Consequently, in simulating certain areas of the whole population, these bull harvests cannot be accounted for. Since the first year that can be used for comparison between the estimated number of pups (David, 1987b) and the number of pups simulated by the model is 1971, this year must be included in a simulation. Simulations for each subarea of the population are done from 1965, which is 7 years prior to 1971, to allow at least one set of the 7 model age classes to grow, before the numbers of pups in 1971 are output for comparison. Since the bull harvests between 1965 and 1973 are excluded from the model simulations of subareas, it should be borne in mind that the model population sizes are overestimates. This should affect the model estimates for both years, if at all, and not bias one of the estimates. Between 1989 and the year 2000, theoretical culling rates can be input to test the effect of alternative management schemes.

Assumptions and constraints

All those of the Seal Model apply to this model.

Equations

The number of animals that have been killed each year up to, and including, 1988 are input into the model. Prior to execution of the culling equations, the annual historical harvest figures (H_i) for either pups, bulls or cows are converted to annual rates (C_i) by dividing by the number of seals of the particular age or sex classes (S_i) in the population for each year, using the following equation :

$$C_i = \frac{H_i}{S_i}$$

Input

All input values remain the same as in the Seal Model (see Table 4.1). In addition, the numbers of pups, cows and bulls killed each year prior to 1988 form part of the data set (extracted from Appendix 3). Theoretical culling rates can be input from 1989 onwards to forecast the results of alternative future management schemes. To start a simulation, an initial number of pups is input in 1900 (for simulating the whole population) or in 1965 (for simulation of subsets of the population) and the magnitude of this is used to scale the output.

Output

The number of pups, harvesting rate, degree of disturbance, sex ratio and the number of seals killed are output annually. The total population size during one year has a maximum and a minimum size. Immediately after the pupping season, the population is at its maximum, having received the new recruits. Just prior to pupping, the population is at a minimum. The average population during one year is a figure somewhere between these two values. The minimum and maximum annual population sizes are therefore output to present a range.

METHODS

Only two estimates of the number of pups, those for 1971 and 1983, are available for all colonies (David, 1987b). The estimates in David (1987b) are refined from those in Butterworth *et al.* (1987) using a density-dependent model of the population and incorporating census data from these two years when full censuses of each colony were done, and census data from specific colonies for all the years between 1971 and 1983. These estimates are therefore unlikely to represent unusual numbers of pups in these two years because the different censuses are taken into account. In addition it was only after 1983 that large changes to the sealing trends took place

which could influence the number of pups each year. These two estimates of number of pups are used for comparison with the simulated ones. An initial number of pups is adjusted until the simulated number of pups resemble the estimated number. The "best estimate" is chosen once the residual mean square between the model and the estimate for each year is minimised. A model simulation is considered as representative of the estimated number of pups if the number of pups in the two years falls within one standard deviation of the mean.

The average annual growth rate (r) in number of seals (S) during a time period between years, t_1 and t_2 is calculated as follows :

$$r(\%) = \left(\sqrt{(t_2 - t_1)} \frac{S_{t_2}}{S_{t_1}} - 1 \right) 100$$

MODEL OUTPUT AND DISCUSSION

Simulating the whole population and subareas

Attempts are made to simulate the entire population and different subsets of the population. These subsets include major colonies and subareas. The colonies chosen are Kleinsee, Cape Cross and Wolf/Atlas Bay which are the largest in number of seals and are the main areas of seal harvesting (see Figs 2.6 and 2.7). Wolf and Atlas bays are combined because they are in close proximity and one harvest quota is set for both areas. Two sets of subareas are chosen according to biological (diet) and spatial (mainland/island) criteria, which are thought to form logical boundaries in the whole population (Fig. 6.1). The three dietary areas are those identified by David (1987a) as distinct regions : Namibia, S.A. west coast and S.A. south coast. The mainland colonies are Cape Cross, Wolf Bay, Atlas Bay, van Reenen Bay, Lion's Head and Kleinsee and all the remaining colonies are islands.

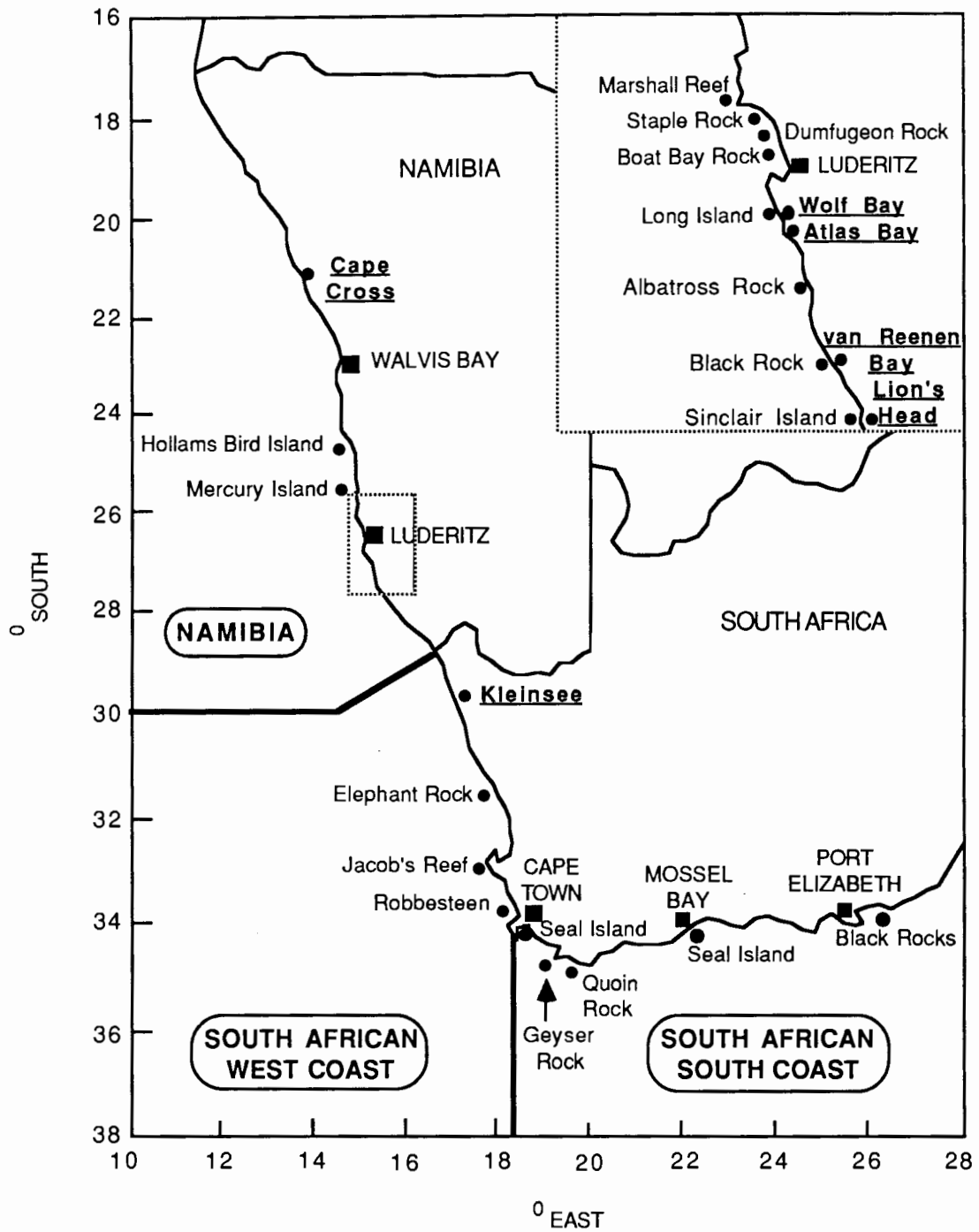


FIGURE 6.1 : Breeding colonies of the South African fur seal showing the island/mainland colonies (the mainland colonies are underlined and in bold) and the three dietary areas, demarcated by the heavy lines.

Fig. 6.2. shows the estimated number of pups in 1971 and 1983 (David, 1987b) with one standard deviation and the closest model output obtained. When the number of pups in the entire population is modelled, the model estimates are considered to be similar enough to the number of pups estimated to be representative of the whole population. However, when subsets of the population are modelled, reasonable representation cannot always be achieved. Of the three dietary areas, the Namibian colonies which account for 60% of the number of pups, can be reasonably represented by model simulation. The fast growth in the number of pups on the South African west coast (33% of the total), and the negative growth of the South African south coast colonies, which form 7% of the total number of pups, cannot be achieved with the model structure and parameters. Between 1971 and 1983, the number of pups from the mainland colonies showed a faster growth rate (6.5%) than that for the whole population (3.7%), whereas pup numbers of the island colonies showed a decrease (-1.5%). For the mainland colonies, the fast growth rate cannot be reproduced by the model and its current parameters. The opposite effect occurs when the islands are simulated in that a negative growth rate cannot be attained. Likewise, the faster than average growth in pup numbers of the Wolf and Atlas Bays (6.4%) and Kleinsee (8.9%) colonies cannot be achieved with these model parameters. Butterworth *et al.* (1987) found that the fast growth rates of these colonies could only be attained using better than average pup survival. The pup numbers of the Cape Cross colony which showed a 3.1% increase can be simulated representatively. Two possibilities are presented here that could account for the inability of the model to simulate subsets of the population :

Migration : The South African fur seal is not a migratory species (David & Rand, 1986) although individuals have been found as far south as subantarctic Marion Island (Kerley, 1983a). There is, however, some migration between colonies which is not accounted for in the model. It may be possible to include a function which allows a proportion of the population to be lost/gained as a representation of immigration/emigration from the simulated area. However, at present there are not sufficient data on the age and sex classes of the population that are likely to migrate between colonies.

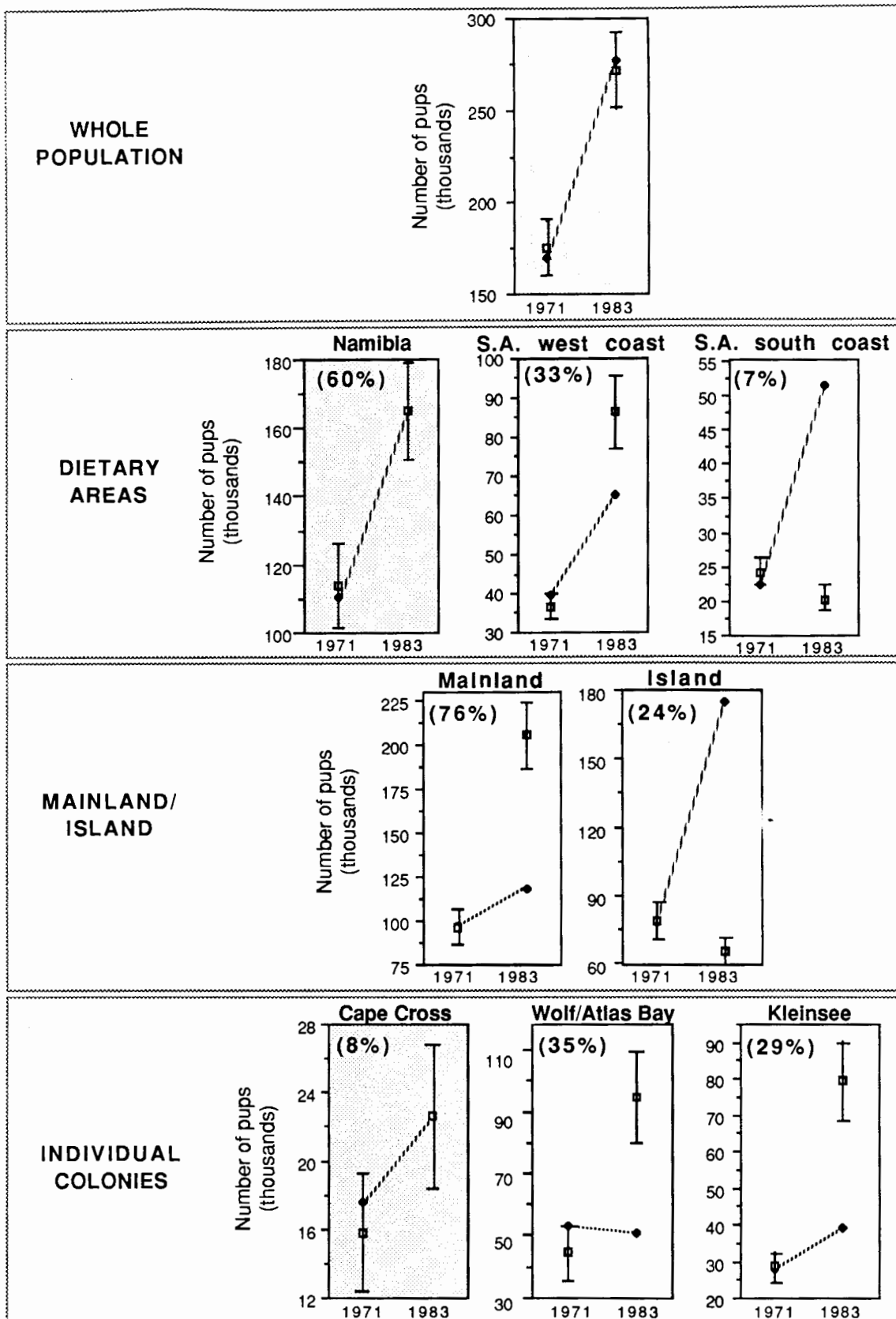


FIGURE 6.2 : The number of pups simulated by the Scaled Seal Model (◆) for the whole population and subareas thereof, compared to the mean number of pups (□), ± 1 standard deviation, as estimated by David (1987b). In each case, the model is scaled to give a trend as close as possible to the observed data. The shaded graphs show simulations that are considered to be representative (if the model estimates fall within one standard deviation of the mean) of the estimated number of pups.

If a migration flux is to account for the inability of the model to simulate the various groupings, then one anticipates that the number of seals moving from one colony group will be approximately equal to the number immigrating to another group. The colonies of the Namibian and South African west coast have increased to a similar degree, whereas the small south coast population has decreased. From Figs 1 and 2 of Butterworth *et al.* (1988) it appears that seals in Namibia tend to migrate mainly northwards. Animals on the South African west coast also seem to move mainly to the north, as far as northern Namibia. The seals tagged on the western boundary of the south coast moved eastwards. From this small data set, seals appear not to move *out* of this area. The population decrease on the south coast is therefore probably due to another factor.

Mainland colonies increased between 1971 and 1983, whereas the island populations decreased (David, 1987b). The increase in the mainland colonies is far greater than the loss of seals from the islands. Therefore this cannot be due solely, if at all, to migration from the islands to the mainland. It is probably due to the fact that there is more room for expansion on the mainland colonies, whereas on the islands, the seals can be spatially limited. The reason for the decrease in the island populations is not clear. It appears, therefore, that migration cannot account for the difference between groups of colonies.

Colony-specific features : The model is run using the parameter values from Table 4.1 which are considered to be representative of the whole seal population. In reality, each parameter has a range of possible values and specific colonies, or groups thereof, may have parameter values at the extremes of these ranges. Consequently, some subareas and individual colonies cannot be represented adequately by the current model parameters. Thus the spatial variability in parameter values between colonies appears to exclude individual colonies and smaller groups from true representation. When the entire population is being modelled, the colony-specific effects are averaged and become insignificant. The subsets of the population or individual colonies, could be simulated using different parameter values but there are many parameters, including age-dependent mortality and fecundity, which could be altered with no particular reason for changing any (one or many) and thereby drawing conclusions from the exercise.

It is understandable that the Scaled Seal Model, cannot therefore be fitted to subareas of the population because it is sensitive to colony-specific changes. Its ability to simulate the whole population provides a further check of its plausibility as a model within the speculative set that can be formulated for the South African fur seal population.

Annual sex ratios, population trends and growth rate

Since 1900 there has been very little fluctuation in the sex ratio of the model population. The mean percentage of males in the population is 47.9 with a standard deviation of 1.9. So, on average, the sex ratio has been marginally in favour of the females.

The steady increase in the number of pups between 1900 and the early 1980's seems to have ended (Fig. 6.3 and Appendix 10) and pup numbers since then have been more erratic with the variation in management strategy. The increase in the total model population size (presented as a range between maximum and a minimum figures for each year) since 1900 is also shown. According to the model, the population is still increasing, but the fluctuations evident in the number of pups are dampened in the total population trend. Shaughnessy and Butterworth (1981) used the model developed by Shaughnessy and Best (1980) to explore population levels prior to the extirpation of seals from 23 localities as a result of overharvesting before the 20th century. They suggest that probably between 260 000 and 825 000 pups were born annually before harvesting began. The Scaled Seal Model estimates pup production in 1988 at 260 456, suggesting that the seal population may be reaching only the most conservative estimate of pup production prior to harvesting. The great increase in numbers this century is attributed to the normal recovery response of a species recovering from overexploitation (David, 1989). This would suggest that the population has probably not reached carrying capacity. The model estimates that the total population size in 1988 was approximately one-and-a-half million seals.

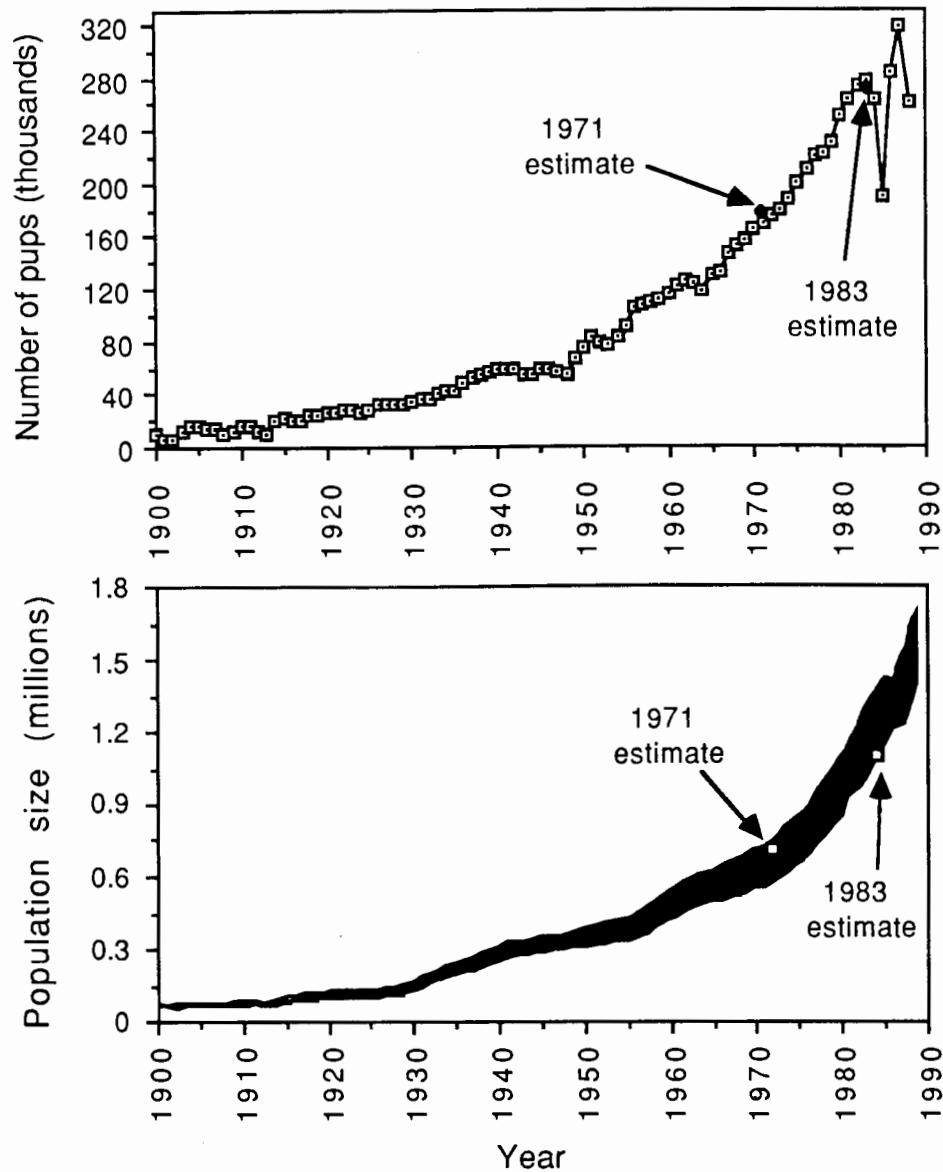


FIGURE 6.3 : The number of pups and the total population size (annual range between minimum and maximum total in one year) of the South African fur seal since 1900 as simulated by the Scaled Seal Model. The estimates given by David (1987b) for the years 1971 and 1983 are also shown.

The average annual growth rate in the number of pups since 1900 is estimated by the model as 3.7%, whereas that between 1971 and 1983 is 4.2%, as compared to the figure for average annual growth rate of pups of 3.7% estimated by David (1987b) for this 12 year period. The average annual growth rate of the whole population from 1900 to 1988 is estimated by the model as the same as that of the growth in pup numbers at 3.7%, whereas between 1971 and 1983 the whole population has grown on average at 5.4% per year which is faster than the growth rate of the

pups. Since 1983, the model estimates that the annual growth rate of pups has varied considerably and shows an overall decrease (-1.2% annual growth), whereas that of the whole population is more consistent at 5.1% increase per year (Fig. 6.4).

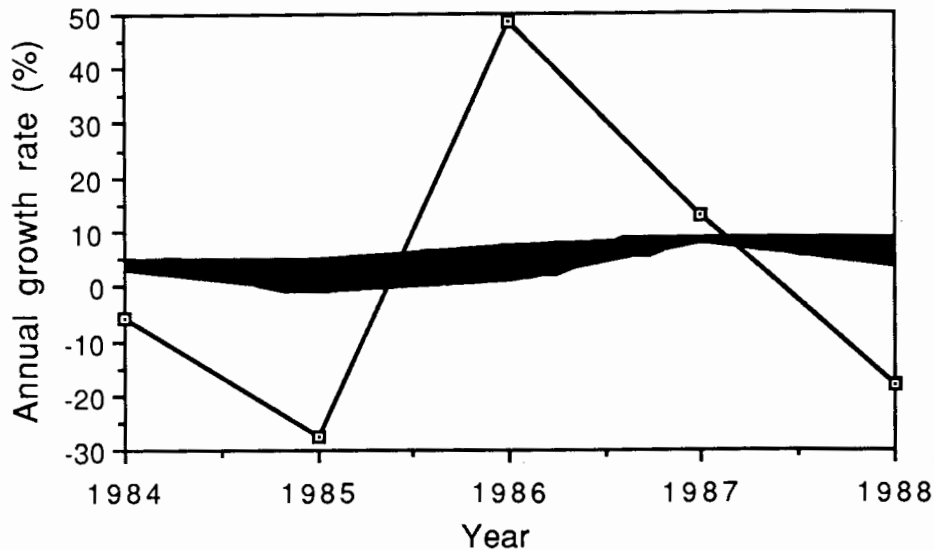


FIGURE 6.4 : Annual growth rate of pup numbers (□) and the total population (presented as the range between minimum and maximum total in one year) since 1984.

As there is no density-dependent influence in the model, the population grows at an exponential rate being varied and deviating from a true exponential curve by the effects of harvesting and the disturbance it causes. Although the model population varies according to sex and age specific parameters (birth, death and harvesting rates), this population can be represented by a single exponential curve. A curve such as this was fitted to the annual model estimates of mean population size (mean of the annual maximum and minimum population sizes between 1900 and 1988) :

$$\text{Population size in year } t = 48\,484 e^{0.038t} \quad r^2 = 0.99$$

where $t = 0$ to 88, corresponding to the years 1900 to 1988. The figure of 0.038 in the exponent is an estimate of annual growth rate (3.8%) which is not dissimilar from the figure of 3.7%

calculated from the model estimates. Fig. 6.5 shows the exponential curve and the model population size estimates to which it was fitted. The exponent of 0.038 is one figure representing average mortality (both natural and man-induced) and fecundity rates for all age and sex classes. If an age- and sex-structured model were not necessary in order to explore the effects of culling pups, breeding cows and bulls over the age of 7 years, a simple exponential model such as this would be adequate.

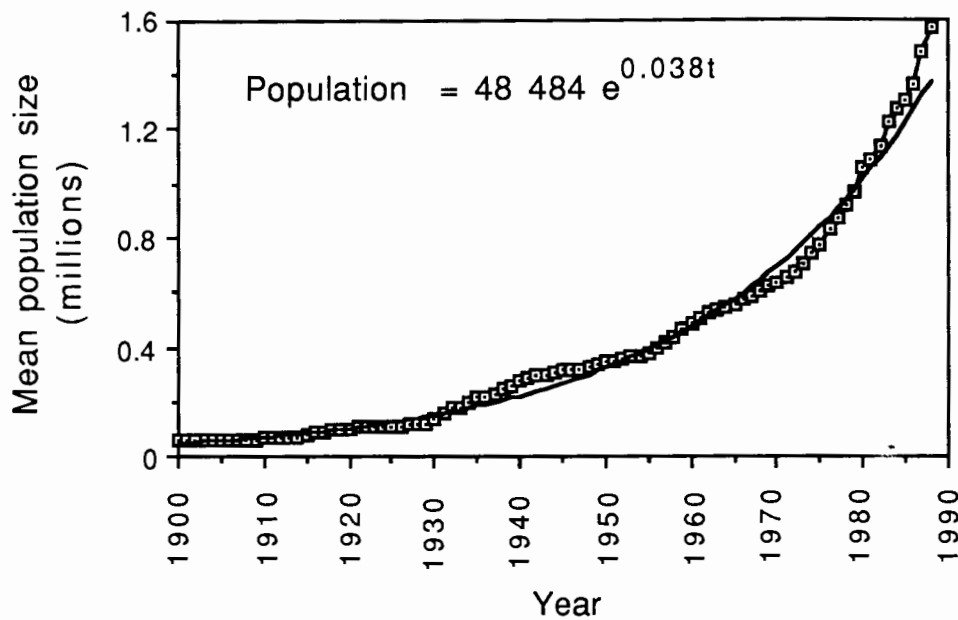


FIGURE 6.5 : An exponential curve fitted to the data points for annual population size between 1900 and 1988. The variable, t , in the equations has a range from 0 to 88, corresponding to the years, 1900 to 1988.

Influence of historical harvesting rates and harvesting disturbance

During the harvesting of bulls and cows, the colony is subject to disturbance which affects the survival of pups in that year, and results in fewer births the following year (see Fig 4.6). The simulated harvesting rates and corresponding disturbance factors between the years, 1900 and 1988 are estimated by the model from the number harvested and the model population each year (Fig. 6.6). The harvesting rate of bulls was much lower than that of pups until very recently. Shaughnessy and Best (1980) predict from their model of the South African fur seal (represented

by the females only), that a maximum sustainable yield of pups is obtained when 33% of pups are taken although 50% may be a tolerable rate. In terms of the model presented here, the average harvesting rate on pups between 1973, when the Sea Birds and Seals Protection Act came into being, and 1982, prior to the 1983 crash in the pup pelt market is $35 \pm 5\%$. Since the rate at which harvesting is being carried out can only be determined in retrospect because the population size is unknown, it is interesting to note that the model rate is close to that which the managers were attempting to achieve. The model results show that there are three times this century that the loss in pup production due to disturbance has been large, corresponding to times when bull harvesting levels have also been elevated. The changes in the harvesting rates of both pups and bulls after 1983 follow accountable differences in policy away from a maximum sustainable yield on pups, to an increased market for bulls. The disturbance caused by the elevated bull harvesting rates, is evident since the early 1980's. Likewise, disturbance effects are large in the 1940's and 1950's, following the elevated bull harvesting rates during that time.

Fig 6.7 shows three simulations : a simulation of the population with harvesting and disturbance, one with no disturbance effects, and a simulation in which no historical harvesting is included. When historical harvests are included but with no disturbance influence, the estimated numbers of pups can be reproduced by the model. It appears therefore that culling disturbance has not been an influential factor in shaping the historical trend in the South African fur seal population. When no disturbance is included the average annual growth rate in the model number of pups (4.1%) and the whole model population (4.0%) is marginally higher as opposed to the annual growth rate of 3.7% in both pup numbers and the whole population when the model includes disturbance. When no historical harvests are included in a simulation of the whole population, the model number of pups does not fall within one standard deviation of the estimated mean numbers of pups in 1971 and 1983 (David, 1987b) and is therefore not considered as representative of the population. According to this model, the annual harvests that have taken place since 1900 therefore appear to have significantly influenced the trend in numbers of pups this century.

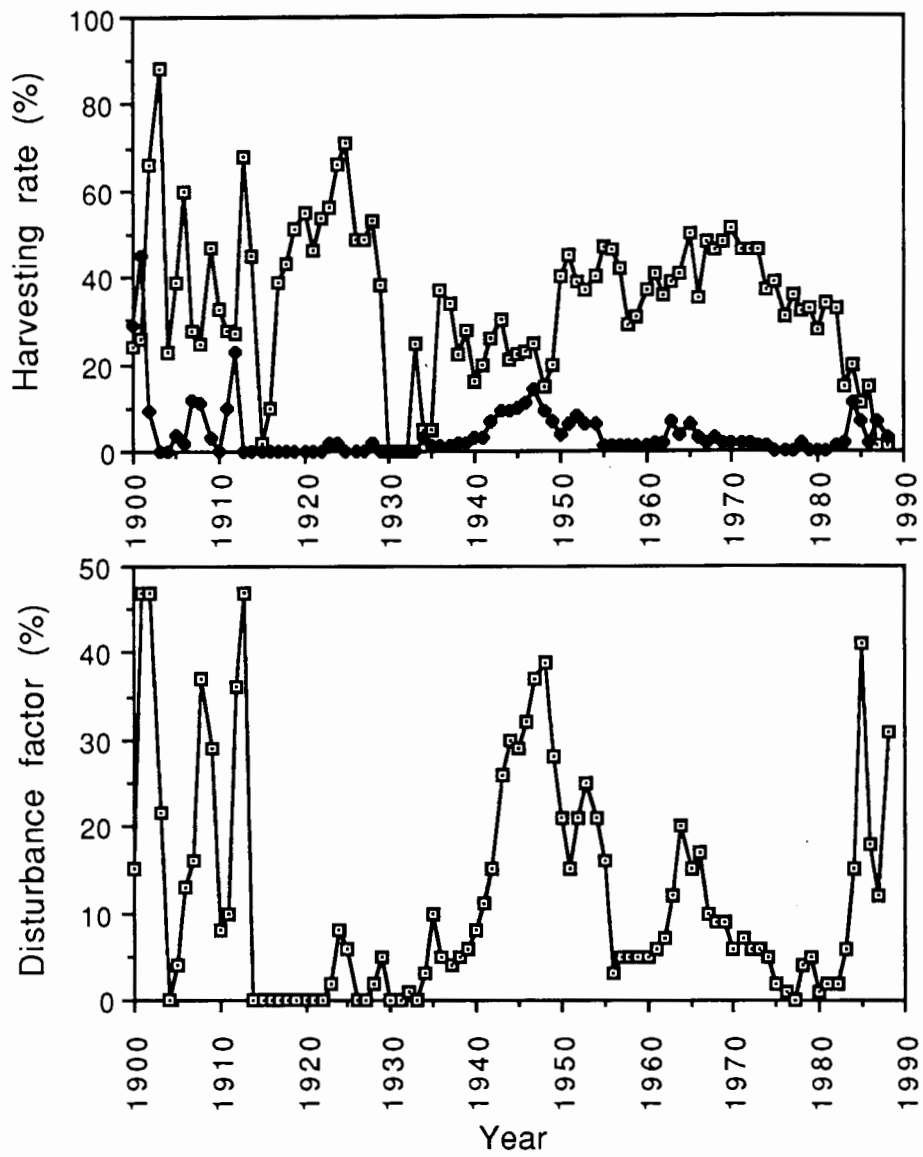
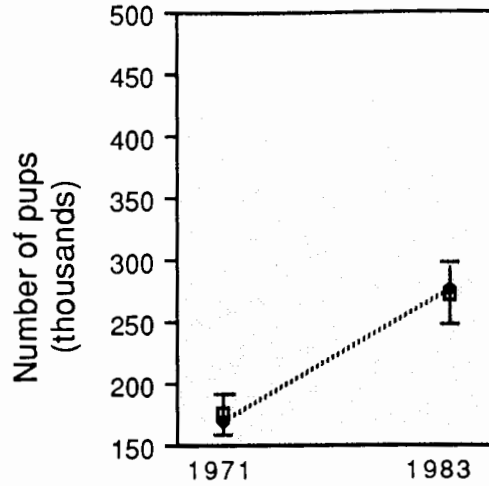
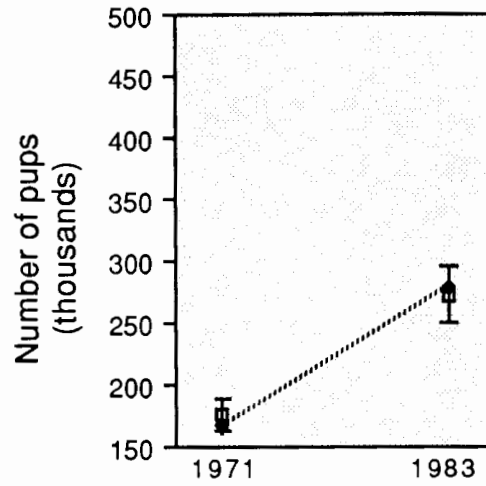


FIGURE 6.6 : The harvesting rate of pups (□) and bulls (●) since 1900 as determined by the Scaled Seal Model and the associated disturbance factor (percentage of potential number of pups due to be born that were lost as a result of disturbance during a bull harvest).

**Harvesting
WITH
Disturbance
effects**



**Harvesting
WITHOUT
Disturbance
effects**



**NO
Harvesting**

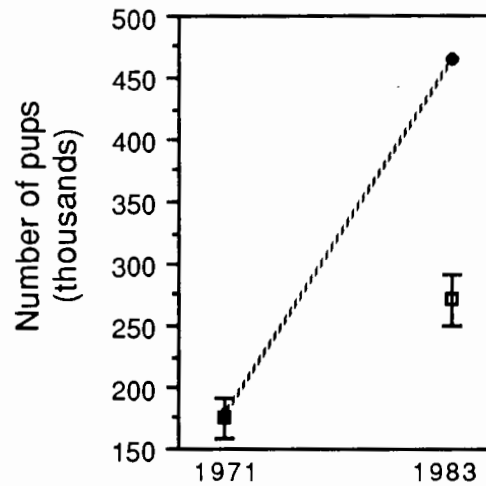


FIGURE 6.7 : The number of pups simulated by the Scaled Seal Model (♦) for the whole population, under different conditions of harvesting and its disturbance, compared to the mean number of pups (◻), ± 1 standard deviation, as estimated by David (1987b), which are given in Appendix 1. The shaded graphs show simulations that are considered to be representative of the estimated number of pups if the model estimates fall within one standard deviation of the mean.

Population estimation

The method for estimating the population size of the South African fur seal is a "rule of thumb" multiplication of the censused number of pups by 4 (estimated by Johnson, 1972 for the Northern fur seal). Harwood and Prime (1978) give a range of 3.5 to 4.5 as appropriate ratios. Butterworth *et al.* (1988) calculate that the ratio of total population to pups is 4.49. The use of a constant ratio requires caution because it relies on two assumptions. The first is that the ratio is density-independent, *i.e.* the relationship between population size and pups is linear. This also implies that the rate of increase of the population is fixed. However, Berkson and DeMaster (1985) show that the estimate of rates of population change from annual pup counts depend on which demographic parameters are density-dependent. Harwood and Prime (1978) also comment on the effect of variations in fecundity and mortality on the ratio. Secondly, the method is based on an assumption that sealing will have no influence on population structure. This latter assumption was also noted by Shaughnessy (1987) who comments that there are drawbacks in using a fixed ratio for the South African fur seal because of the history of harvesting and its disturbance at each colony.

The mean and one standard deviation of the annual ratios between pup numbers and each of the minimum, maximum and mean total population size are calculated to produce a mean and range of estimates for this ratio. This gives a range from 4.06 ± 1.02 (minimum population) to 5.03 ± 1.01 (maximum population) with a mean of 4.55 ± 1.01 (mean population size) for the population from 1900. The mean figure of 4.55 is therefore the model estimate of an average ratio and is not dissimilar from the Butterworth *et al.* (1987) figure of 4.49. The maximum model ratio of 5.03 is higher than the beginning-of-year ratio of 4.77 given by Butterworth *et al.* (1988). The annual range of ratios determined from the Scaled Seal Model since 1900 is presented in Fig. 6.8 with the range of values between those currently used (Johnson, 1972) and suggested (Butterworth *et al.*, 1988); this shows the variability in the ratio.

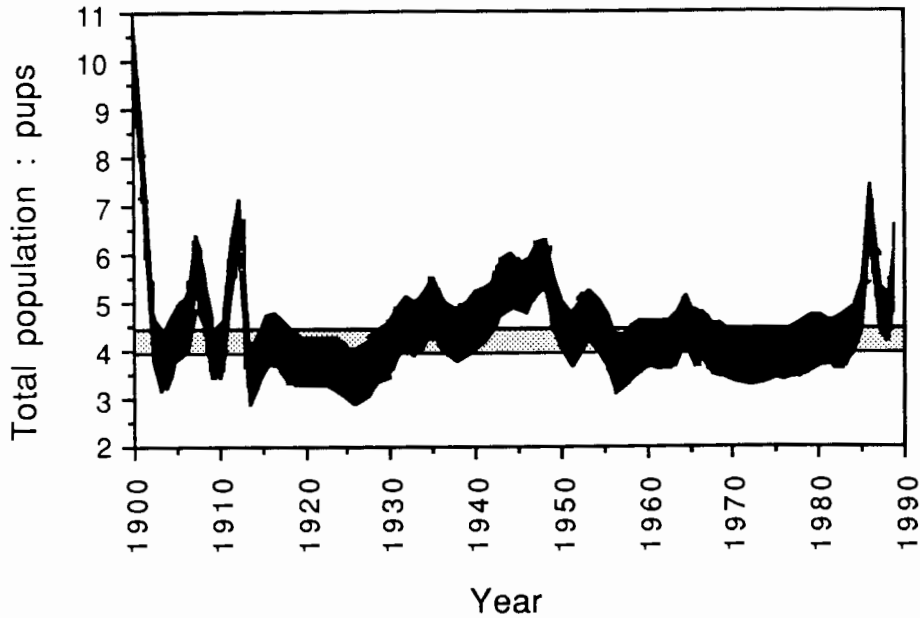


FIGURE 6.8 : The ratio between the total population and the number of pups as simulated by the Scaled Seal Model since 1900. The horizontal band represents the range of ratios that have been used (Johnson, 1972 and Butterworth *et al.*, 1988).

Fig. 6.9 shows the population size as simulated by the Scaled Seal Model compared to that estimated by multiplying the number of model pups by 4 (Johnson, 1972) and by 4.49 (Butterworth *et al.*, 1988) since 1973, when the Seabirds and Seals Protection Act was introduced. Between the years 1973 and 1982 when the management policy was essentially one of a maximum sustainable yield of pups, the mean model ratio is 3.6 with a standard deviation of 0.2. Since 1983, the ratios are somewhat higher and more variable. This is a result of the numerous changes in management policy and, consequently, harvest figures. In particular, the drop in pup production following the large harvest of bulls at Kleinsee in 1984 results in a higher ratio in 1985. In 1988, the ratio is simulated as being in the range 5.5 to 6.5.

In estimating density-dependent effects, often a change in the pup : population ratio is explored, but, as is seen here, this ratio is influenced by many other factors such as sealing, which is man-induced, not an intrinsic population response. Such an estimation procedure must therefore be carried out with caution to ensure that the mechanism affecting the ratio is specifically an inherent population response.

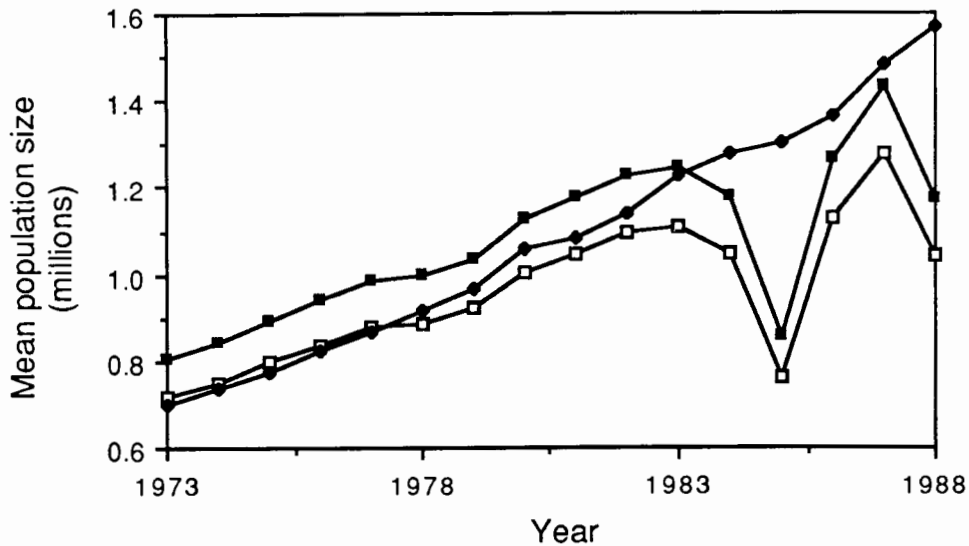


FIGURE 6.9 : Average annual population size as simulated by the Scaled Seal Model (●), compared to the population size determined by multiplying the model number of pups by 4 (Johnson, 1972) (□) and by 4.49 (Butterworth *et al.*, 1988) (■).

Future management scenarios

Fig. 6.10 shows the model forecast of the seal population and the number of animals killed until the year 2000 under different management regimes. Only a choice of bull and/or pup culling is chosen because the killing of cows is a poor choice because of gross fluctuations in the population structure (Chapter 5). Culling rates of pups and bulls that cause a change in the population trends are simulated based on the growth rate information presented in Fig. 5.5. If either pups or bulls are culled alone, the number that would need to be culled to cause a decreasing or approximately static population size is much higher than have been killed historically. This is not surprising since the policy of taking a maximum sustainable yield of pups at 33%, as was practiced prior to 1983, resulted in a continuing increase in the population. If pups and bulls are both culled each year at an annual rate of 20%, the model population declines, whereas if only 10% are culled the population continues its upward trend. The number of pups that would be killed is similar to the number taken historically but more bulls than have previously been taken would need to be killed. The number of animals that would need to be killed to have a decreasing/increasing population can be estimated from these graphs.

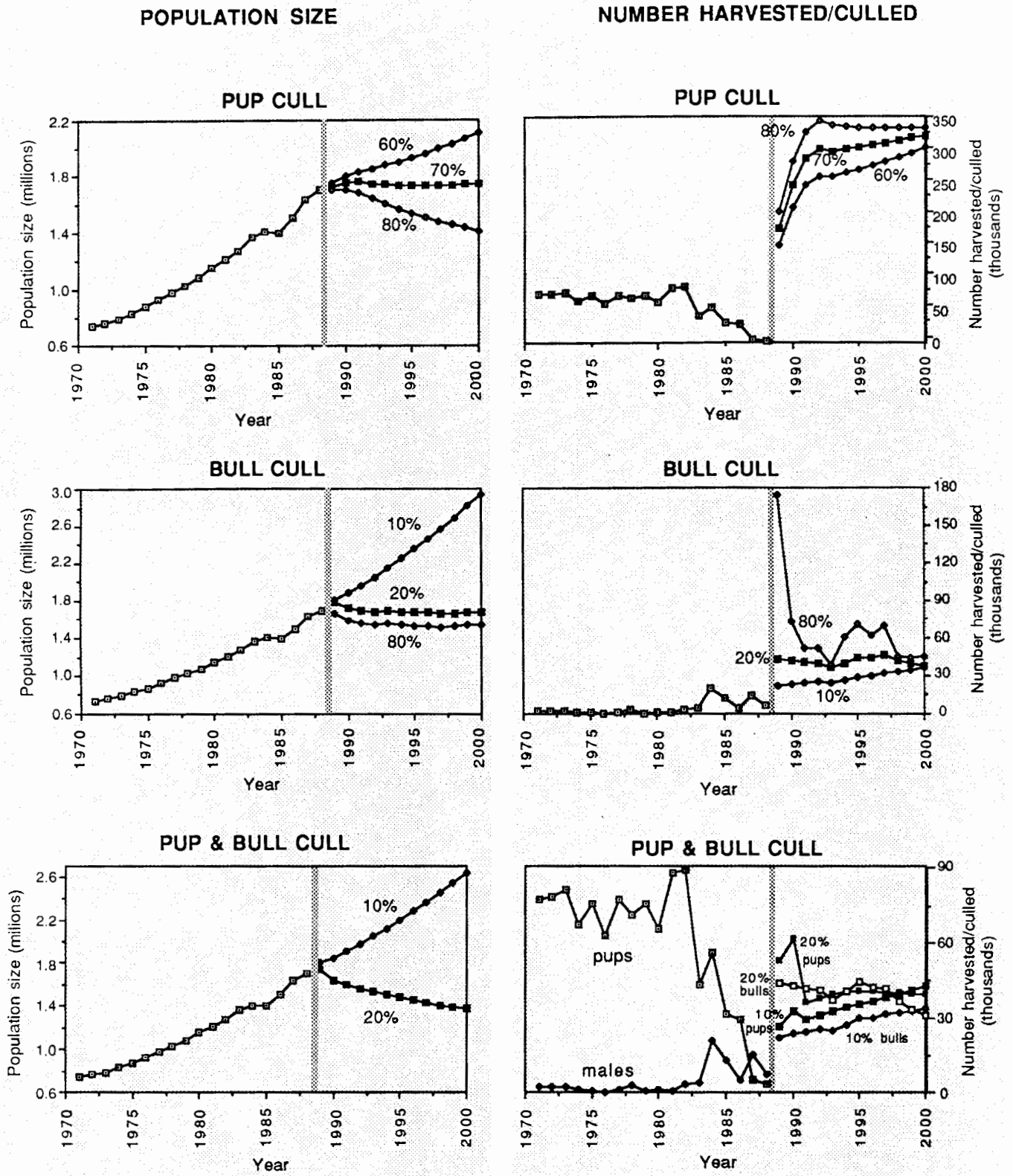


FIGURE 6.10 : The population size and number of seals culled, as simulated by the Scaled Seal Model under different management regimes from 1989 as compared to the historical harvest figures for 1971 to 1988. A vertical bar divides the historical from the forecast trends. Culling rates that cause a change in the population trends are shown.

CONCLUSIONS

The Scaled Seal Model and its parameters are used to simulate the whole South African fur seal population with valid results and this is a test of the plausibility of the model, in that the model can still be included in the set of speculative models that can realistically simulate the population. Colony-specific effects result in the model not being capable of simulating all subsets of the population reasonably with parameters that are averaged for the whole population. The harvesting rate of pups has dropped dramatically in the recent years, whereas that of bulls has increased over the past few decades. Disturbance effects were large in the 1940's, 1950's and in the present, corresponding to higher bull harvesting rates during these periods. The harvests that have taken place historically have influenced the trend in population size whereas the effects of culling disturbance have made little difference because the harvest of bulls historically has been small. In the last few years, pup numbers have undergone some fluctuation following the changes in management policy. These fluctuations are dampened in the total population trend which shows exponential growth. The annual growth rate of numbers of pups varies considerably and since 1983 has shown a negative annual growth rate of 1.2% compared to that of the total model population which has increased at an annual rate of 5.1%. Since the current method for estimating population size is to multiply the number of pups by a population : pup ratio, the annual population estimate can be very variable. The mean ratio between the number of pups and the total population since 1900 is simulated as 4.55, varying according to the harvesting rates. This is close to the figure of 4.49 given by Butterworth *et al.* (1987). The model estimates the population at approximately one-and-a-half million seals in 1988. Since 1983, the difference between the population size estimated by multiplying the number of pups by a population : pup ratio and the model estimate of total population size, is marked, showing the drawback of using the population : pup ratio to estimate population size. An increasing population changes to a decreasing population when the culling rate of pups is between 60% and 80% and between 10% and 20% for a combination of pups and bulls. When bulls only are taken, the population always continues to increase. To achieve a very low or a negative growth rate in the population, a greater number of pups or bulls would need to be culled than have on average been killed historically.

CHAPTER 7

ESTIMATION OF FISH CONSUMPTION BY THE SOUTH AFRICAN FUR SEAL UNDER DIFFERENT MANAGEMENT REGIMES

ABSTRACT

Both the "Seal Model" (Chapter 4) and the "Scaled Seal Model" (Chapter 6) are used to gain insight into changes in fish consumption by the South African fur seal population. The per capita consumption is similar under any of the management regimes; therefore it is not justified to cull a particular age or sex class solely to achieve reduced consumption. As a consequence of the total size of population resulting from different culling regimes, consumption is least for a particular culling rate when pups and bulls are culled, and greatest when pups only are culled. The small amount consumed under a pup and bull culling regime is mainly a consequence of the reduced population size resulting from a decrease in the number of births and in pup survival, caused by bull culling disturbance. An average figure of 8% body mass consumed per day produces similar results to using age-specific rates ranging between 5 and 20% in the models, and this is probably a good estimate for the whole population. The amount of fish of all species consumed in 1988 is estimated to be over 2 million tons, almost double that of a decade previously.

INTRODUCTION

A complaint of the some fishermen is that the South African fur seals consume a large amount of fish that could otherwise be harvested. The aim in this chapter is to use the "Seal Model" (Chapter 4) and the "Scaled Seal Model" (Chapter 6) as tools to estimate the relative and absolute amounts of fish consumed by the seal population, respectively, both historically and under various hypothetical management regimes. The consumption estimates that are calculated using the age- and sex-specific data in the model are compared to previous estimates of consumption which use average parameter values for the whole population.

METHODS

The output from the procedures relating to consumption in both the unscaled Seal Model (Chapter 4), and the Scaled Seal Model (Chapter 6) using the data from Table 4.1 is examined to simulate the amount of fish consumed under different conditions. Only the maximum amount consumed annually is calculated using the Seal Model because the relative output between different management regimes is of interest. The Scaled Seal Model outputs the minimum and maximum consumption figures to provide estimates of the amount of fish consumed annually.

The Scaled Seal Model is used to simulate the amount of fish consumed annually by the population since 1900. On the South African west coast (which has approximately 33% of the seal population (David, 1987a)), hake and anchovy are significant dietary species (approximately 23% each (David, 1987a)) and are the most important demersal and pelagic harvests in the South African fishery, respectively. The proportion of all fish consumed by seals on the west coast, and the consumption of hake and anchovy in this area are estimated using the above proportions.

David (1987a) and Butterworth *et al.* (1988) use different parameter values, which are not age- or sex-specific, in order to calculate consumption by the population. In the models used here, input

consists of parameters that are differentiated by sex and are separated by age up to 7 years old. In these models, the larger seals are all lumped into age class 7, which comprises 45% of the population (see Fig. 4.6). These seals are all assumed to have the same mass as a 7-year-old. At present there are not sufficient data for improvement of either age-specific body mass or consumption rate parameters so the lumping of ages over 7 years does not limit the use of available data. The parameter values used in the model and those suggested by David (1987a) and by Butterworth *et al.* (1988) are compared. All three sets of data are then used as input into the Seal Model and the output compared. For 1983, a comparison is made of the estimates calculated from the data of David (1987a) and Butterworth *et al.* (1988) and the consumption figures output by the Scaled Seal Model.

RESULTS AND DISCUSSION

Consumption by the population

The estimated total annual consumption of fish by the population since the year 1900 is shown in Fig. 7.1. The amount consumed increases steadily, and in 1988 is estimated to be between 2 089 000 and 2 311 000 tons, or a mean of 2 200 000 tons. Consumption by the model seal population is estimated to have almost doubled in the past decade. The amount of fish consumed during 1988 on the west coast is estimated at approximately 726 000 tons. Of this, approximately 167 000 tons each of hake and anchovy are estimated to be consumed. In 1988, the total natural mortality of hake in this area is estimated to be 176 000 tons (Sea Fisheries Research Institute, unpublished data) so the seal predation figure constitutes 95% of this total. This proportion is large and the causes for this are discussed in detail in Chapter 8. The total natural mortality of anchovy in 1988 is 2 968 000 tons (Butterworth, pers. comm., using an estimation technique that is an extension of that used in Bergh & Butterworth *et al.*, 1987) so the seal predation estimate is 6% of the total mortality. The 1988 catches in this area (ICSEAF Division 1.6) were 537 000 tons of anchovy and 94 000 tons of hake (Sea Fisheries Research Institute, unpublished data). If

we assume that the percentage composition of the diet has not changed, then the seals consumption of anchovy is about a third of the catch. If the same assumption is made, consumption of hake is approximately one-and-a-half times the catch. In the case of hake, seals consume fish discarded from the trawlers, a quantity which is included in the total catch, although these undersized hake are thrown overboard (David, 1987a). This amount of discarded fish which is included in both the catch and seal consumption figures, has not been quantified. This is discussed more fully in Chapter 8 in calculating the amount of discarded hake in the seal diet.

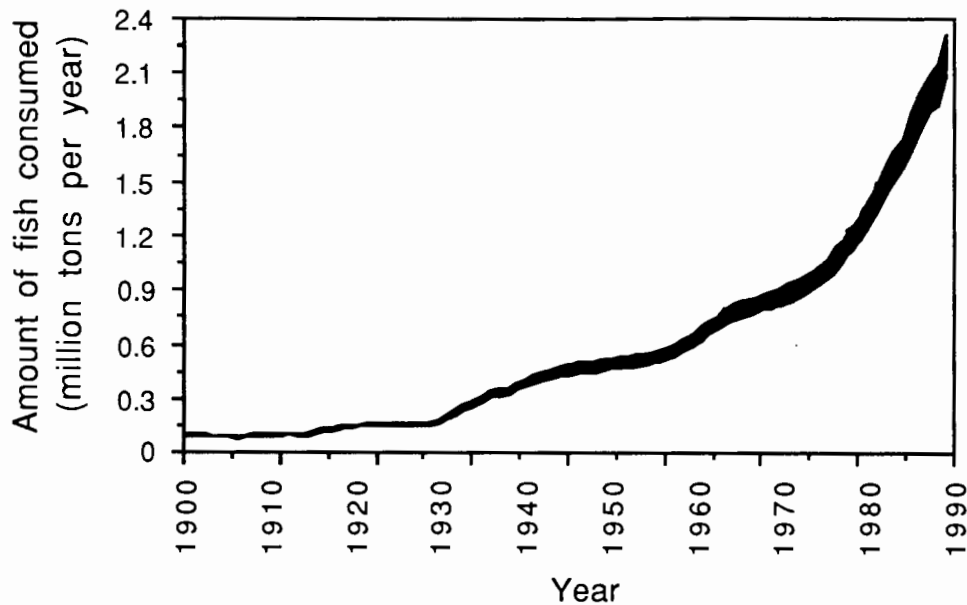


FIGURE 7.1 : The annual range in the amount of fish consumed annually from 1900, calculated from the annual population minima and maxima by the Scaled Seal Model.

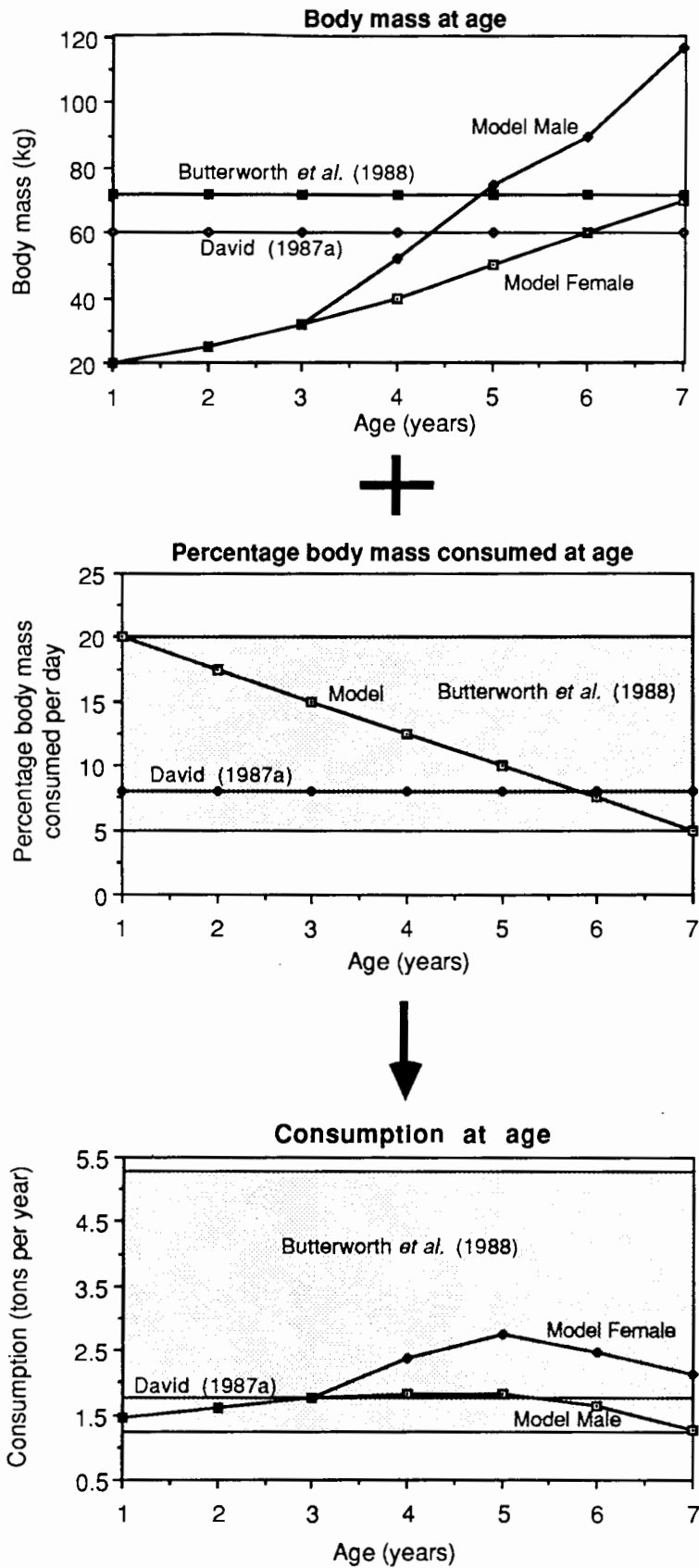


FIGURE 7.2 : Comparison of figures for average body mass, the percentage of body mass consumed per day and the various resulting combinations of these two parameters in terms of consumption rate. The data are based on that of David (1987a), Butterworth *et al.* (1988) (stippled range) and the Seal Model.

Comparison of consumption estimates

Calculation of the amount of fish consumed is dependent on three age and sex specific features of seal demography : the frequency distribution of the population, body mass and consumption rates. Assuming that the age and sex frequency distributions are realistic, the effect of altering the latter two is investigated. An age-consumption trend is determined by the combination of these two factors. The values for each of these trends used in the models and those given by David (1987a) and the range suggested by Butterworth *et al.* (1988) are compared in Fig. 7.2. The resultant consumption trends at age show that the consumption rates of David (1987a) are similar to those of the models, although his rates do not vary with age or sex. Both of these estimates fall in the lower part of the range given by Butterworth *et al.* (1988).

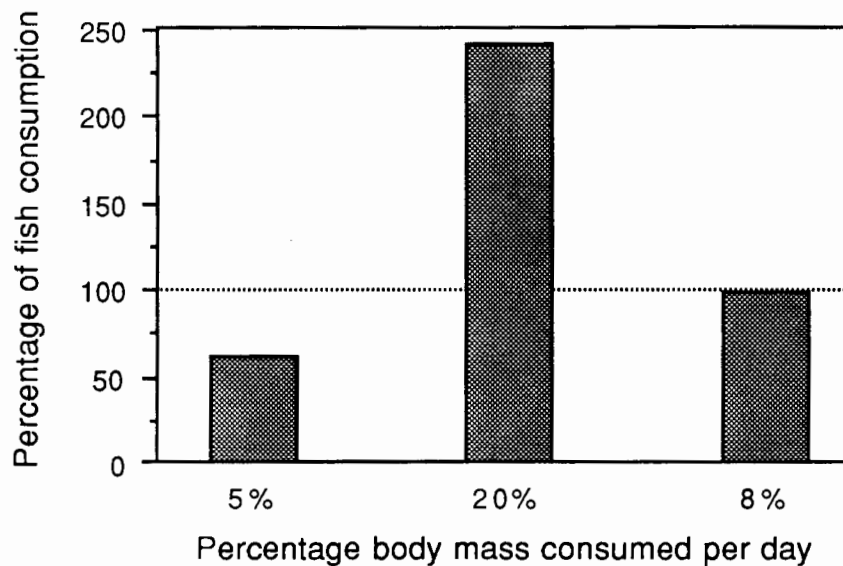


FIGURE 7.3 : Comparison of the annual amount of fish consumed as simulated by the Seal Model after 20 years when the percentage of body mass consumed per day is at 5% and 20% (from the range given by Butterworth *et al.*, 1988) and at 8% (David, 1987a). The results are presented as a percentage of the model output using the parameter values in Table 4.1 (100% reference line).

The effect of using the daily percentage body mass consumption of 8% (David, 1987a) and a low figure of 5% and the high figure of 20% (Butterworth *et al.*, 1988) over all ages is tested using the Seal Model (Fig. 7.3) for a simulation period of 20 years. The low and high rates produce amounts of fish consumed at approximately 60% to 240% respectively, of the model estimates using the parameter values in Table 4.1. It is interesting to note that by using a figure of 8% body mass daily consumption, the quantity consumed is equivalent (99%) to using the linearly decreasing range of 20% to 5% between ages 1 and 7, respectively (Table 4.1) in the model. Therefore the figure of 8% (David, 1987a) appears to be a good average population estimate, assuming the age and sex structure remains constant.

The most recent census of the entire South African fur seal population was done in 1983. For comparison, the amount of fish consumed by the seal population during 1983 is calculated using figures from David (1987a), Butterworth *et al.* (1988) and from simulation by the Scaled Seal Model (Table 7.1). The parameter values required are : estimates of feeding population size, body mass and consumption rate. The maximum feeding population during one year is taken as the total number of seals at the beginning of a year minus the pups, which are still suckling. David (1987a) estimates a maximum feeding population of 825 000 in 1983. The maximum feeding population is calculated to be 1 022 000 by multiplying the beginning-of-year ratio of 4.77 (Butterworth *et al.*, 1988) by the estimate of 271 000 pups in 1983 (David, 1987b). The Scaled Seal Model gives a maximum feeding population of 1 090 000 for this year.

The body mass and consumption rate figures differ between the three sources being compared. The consumption estimates produced from these three sets of parameters show some overlap. The model produces a range in the amount of fish consumed in 1983 between 1 580 000 and 1 740 000 tons. The estimate produced from the David (1987a) parameters is slightly lower than the model range. The range produced from the Butterworth *et al.* (1988) parameter values spans the other estimates, both of which are in the lower end of the range.

TABLE 7.1 : Information needed to calculate the amount of food consumed by seals in 1983 as estimated by different authors and simulated by the Scaled Seal Model. See text for explanation.

MAXIMUM FEEDING POPULATION SIZE	BODY MASS (kg)	CONSUMPTION RATE (%/day)	SOURCE	AMOUNT CONSUMED (thousand tons/year)
825 000	60	8	David (1987a)	1 445
1 022 000	72	5 & 20	Butterworth <i>et al.</i> (1988)	1 342 to 5 372
1 090 000	20 to 117	A range between 5 and 20	Model	1 580 to 1 740

Relative consumption under alternative management regimes

A comparison of the relative consumption of fish by seals under different management schemes as simulated by the Seal Model in the short- and long-term is presented in Fig. 7.4. In Chapter 5, the effects of bull culling disturbance were found to have a large effect on the total population size resulting from the culling regimes in which bulls were killed. This effect of disturbance will have similar consequences on the amount of fish consumed. If no disturbance were included in the model, consumption would be marginally reduced from that under a regime of no culling and the consumption when pups and bulls were culled would be similar to that of a pups-only cull.

In the short-term the culling of pups has the least effect on fish consumption, whereas the greatest reduction in fish consumption is achieved by a pup and bull cull. In the long-term, pup culling shows the least reduction in fish consumption at nearly all culling rates. At culling rates up to 20%, the effect of any of the other culling regimes is similar. Above this a bull cull shows no further reduction in fish consumption. The least amount of fish is consumed by seals when either cows or pups and bulls are being culled at rates above 20%. As was described in Chapter 4, the Seal Model does not include a density-dependent regulation mechanism. Therefore, after 20 years, if an intrinsic population control mechanism has come into play, the number of seals may be overestimated and consumption may likewise be slightly biased in this direction.

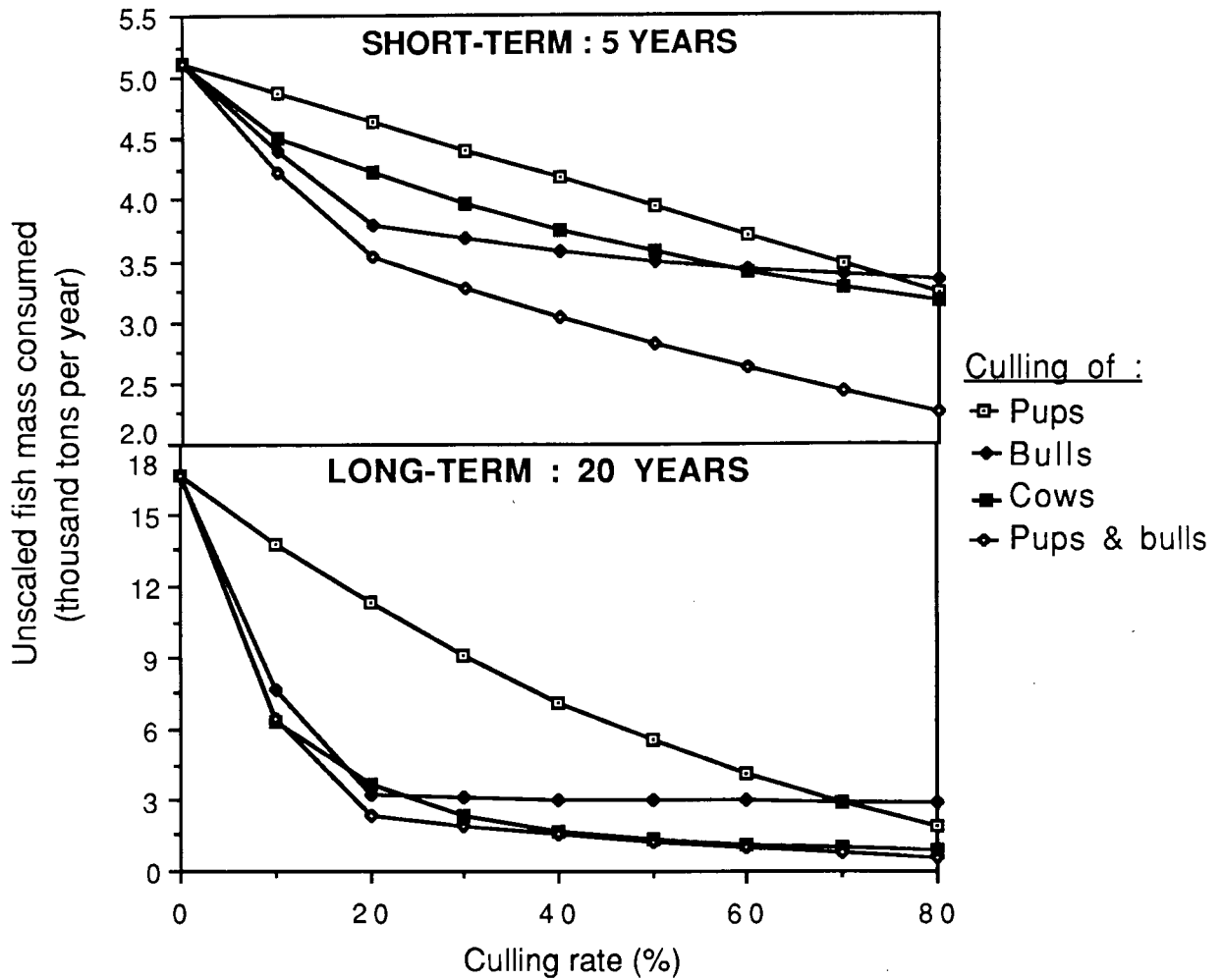


FIGURE 7.4 : The relative mass of fish consumed annually under different management regimes as simulated by the Seal Model, using a starting figure of a half a million pups.

Under different management regimes, the trends in the amount of fish consumed resemble the trends in population size fairly closely (compare Figs 5.2 and 7.4), other than at the higher culling rates in the short-term. Fig. 7.5 compares the amount of fish consumed at equivalent population sizes under different management regimes. In the short-term, the per capita consumption differs between the four management regimes whereas in the long-term, the scales on the axes are much larger so the differences are less noticeable. In both the short- and long-term, the amount consumed is greatest when cows are being culled. This is a result of this culling regime causing a highly skewed sex ratio in favour of males (see Fig. 5.4), and a male consuming a greater amount of fish than a female of equivalent age (see Table 4.1).

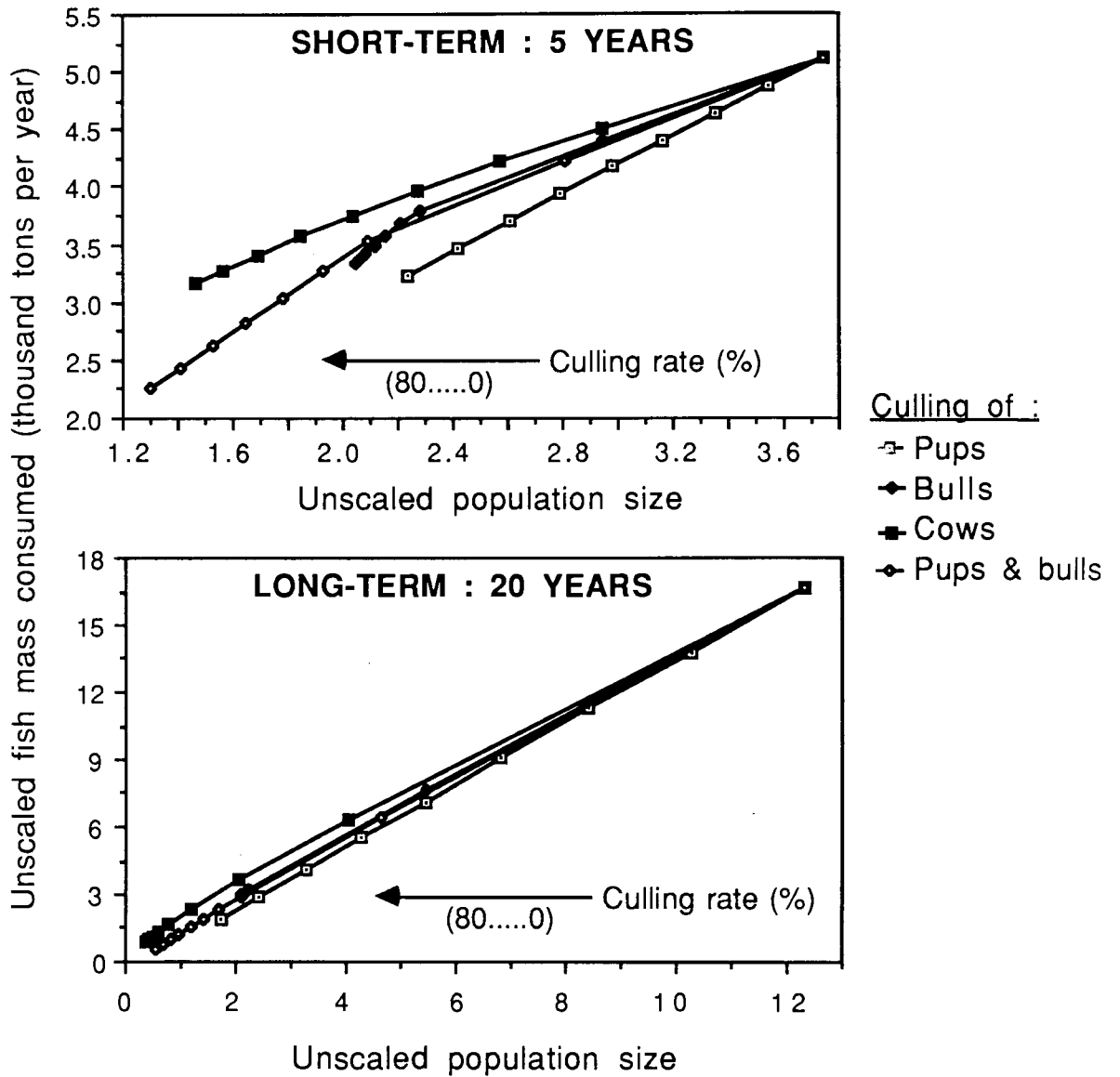


FIGURE 7.5 : Comparison of the amount of fish consumed at equivalent population sizes under different management regimes as simulated by the Seal Model, using a starting figure of half a million pups.

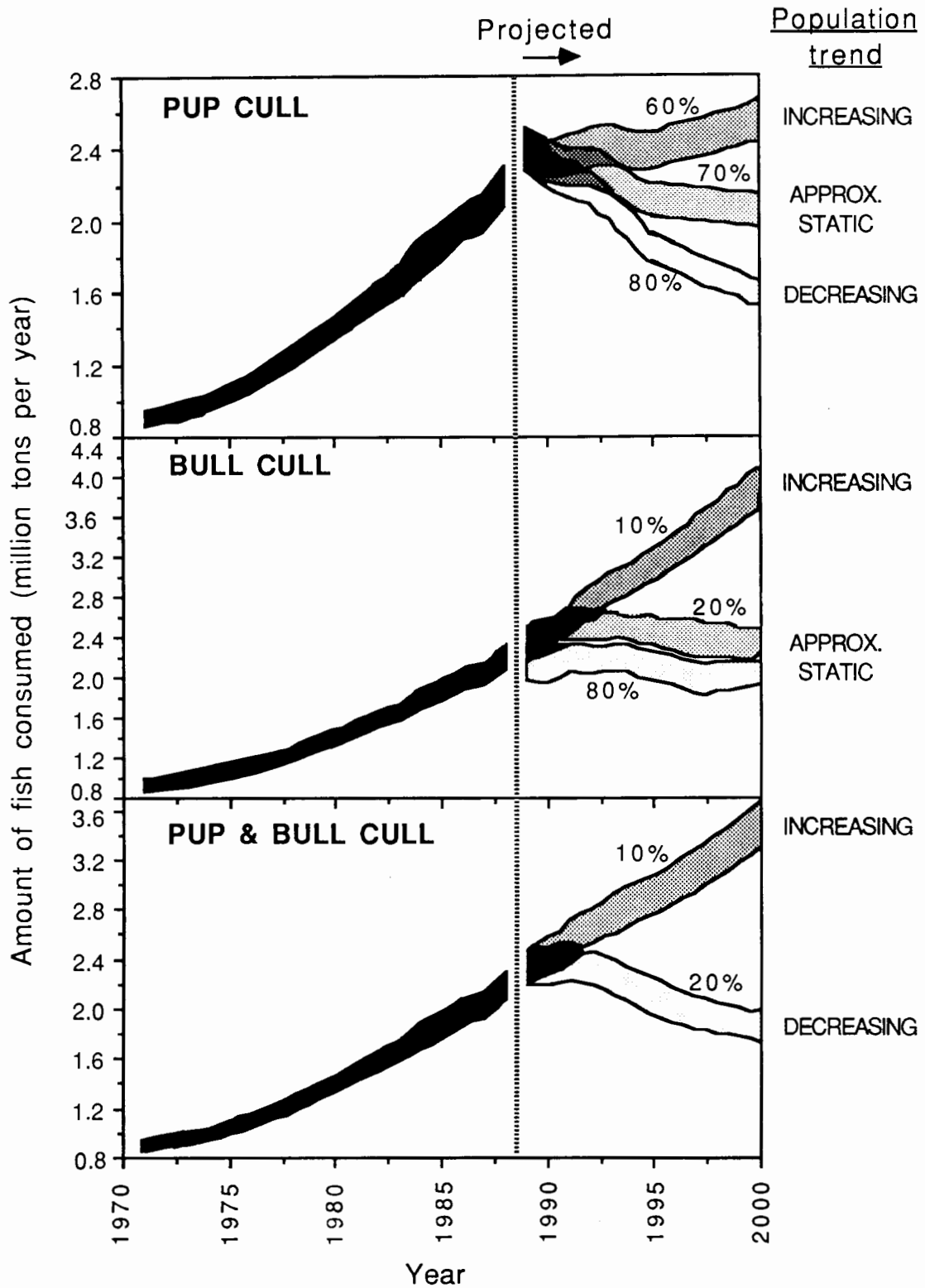


FIGURE 7.6 : The amount of fish consumed under the three management schemes presented in Fig. 6.10, as simulated by the Scaled Seal Model (using a starting figure of half a million pups), projected from 1989. The culling rates required to achieve the population trends are shown.

Forecast consumption under selected management objectives

Selected management strategies which result in different seal population trends up to the year 2000 are suggested in Chapter 6. The amount of fish estimated to be consumed by these projected population sizes is simulated by the Scaled Seal Model and can be obtained from the graphs in Fig. 7.6 depending on which management policy is selected. A bull cull results in the largest amount of fish being consumed, if the policy is to allow the population to increase. Similar amounts would be consumed under either the pup or bull culling regimes if the population were expected to remain approximately the same as the 1988 level. If culling is to cause the population to decrease, the reduction in fish consumption would be greatest under the pup culling regime. In each of these cases different numbers of seals would be killed, depending on which regime is chosen and the rates of increase or decrease in the population differ. The amount of fish consumed in each case depends on the population size resulting from the culling regime.

CONCLUSIONS

The Seal Model and the Scaled Seal Model provide estimates of fish consumption by seals based on simulations using age- and sex-specific data whereas previous consumption estimates have been based on average parameters for the whole population. Although different ages and sexes consume different amounts of fish, the per capita consumption by the model seal population is similar after 20 years under any of the management regimes. Thus it is not justified to cull a particular age or sex class in order to achieve a reduced consumption per seal. The amount of fish consumed under various management regimes shows that when pups are being culled, consumption is the greatest and is the least when pups and bulls are being culled. This is because of the total size of the population that results from these culling regimes. In the case of a pup-and-bull cull, the population is low mainly as a result of reduced pup production (fewer births and increased pup mortality) caused by the disturbance of a bull cull. If the population is allowed to

increase above the 1988 level, a bull cull results in the greatest amount being consumed. Equivalent amounts are consumed regardless of the management regime, if the population is to remain approximately the same as the current population level. The reduction in consumption would be the greatest under a pup culling regime if the policy is to force the population to decrease.

If the consumption rate of 8% of body mass per day for all seals (David, 1987a) is used in the model in place of the age- and sex-specific estimates (5 to 20%) for the South African fur seal (Table 4.1), the amount of fish consumed by the population is very similar. This figure of 8% is probably a good approximation for the whole population because there does not seem to be much variation in per capita consumption when culling of different ages and sexes of the population takes place.

The amount of fish consumed by the seal population in 1988 was over 2 million tons, almost double that of a decade previously. The fish in the diet comprise numerous species and those that are consumed in large quantities are of most interest since they may compete significantly with the fisheries. The effect of seal predation on the hake yield to the fishery is explored in detail in Chapter 8.

CHAPTER 8

THE EFFECT OF PREDATION BY THE SOUTH AFRICAN FUR SEAL ON SUSTAINABLE FISH YIELD

ABSTRACT

The effect of predation by the South African fur seal on the sustainable yield of the Cape hake to the commercial fishery on the South African west coast is examined using a simple yield-per-recruit model, the "Hake Model". A small proportion of hake in the seal diet is hake that has been discarded by the fishery. Seals prey on hake smaller than hake caught by the fishery. This results in a disproportionately large increase in the sustainable yield of hake when seal predation is reduced. The sustainable yield of hake also increases given a decrease in fishing mortality and vice versa. The model is limited by the assumptions that the residual natural mortality rate is constant with age, and that this mortality is static, regardless of the magnitude of other mortality rates. The species interactions in multi-species models, such as those designed by Butterworth *et al.* (1988), account for some of the changes to residual natural mortality that form the latter assumption. Depending on the types of interactions involved, different effects on sustainable yield are produced. The conclusion is therefore that the outcome of decreased predation from a reduced seal population may either result in an increased or a decreased sustainable yield to the fishery, but there is insufficient evidence to judge which effect is more likely.

INTRODUCTION

The effect of different seal predation levels on the commercial yield of a fish species can be explored by simulation. Northridge (1986) investigates methods for determining the impact that changes in a seal population may have on fishery yields and discusses the complexities involved in assessing the impact of seals on fish stocks. He examines some previous methods of assessment which have varied from the simplistic idea that all fish not eaten by predators will go to the fishery, to models in which a change in yield is dependent on the population dynamics of the fish and on the fishing mortality. He summarises the information available on the distribution, abundance, diets and feeding rates of nine seal species and their major dietary fish species to use as data for his models. However, he concludes that the data are insufficient for him to assess the impact of seals on commercial fish species in Canadian waters. The main reasons are that the data on seal feeding are limited and the dynamics of fish populations are not adequately understood. In particular two vital parameters had not been quantified for the species he studied : seal-induced mortality rate and the mean length of fish preyed upon by the seals.

David (1987a) documents the diet of the South African fur seal and assesses its competition with the fisheries in southern Africa. The dietary species (David, 1987a) and the predator-prey interactions between them (extracted from tables in Bergh *et al.* (1985)) are shown in Fig. 8.1. This highlights the extent of the diet both in terms of the numerous dietary species and the multitude of different types of interactions (predation, competition and cannibalism) between the different species. David (1987a) divides the seal population into three dietary areas : Namibia, and the South African west and south coasts. The complex set of dietary species shown in Fig. 8.1 can be reduced to a representative sample for each of these areas. From his data for each of these areas, the species that form more than 20% of the diet in each dietary area are presented diagrammatically in Fig. 8.2.

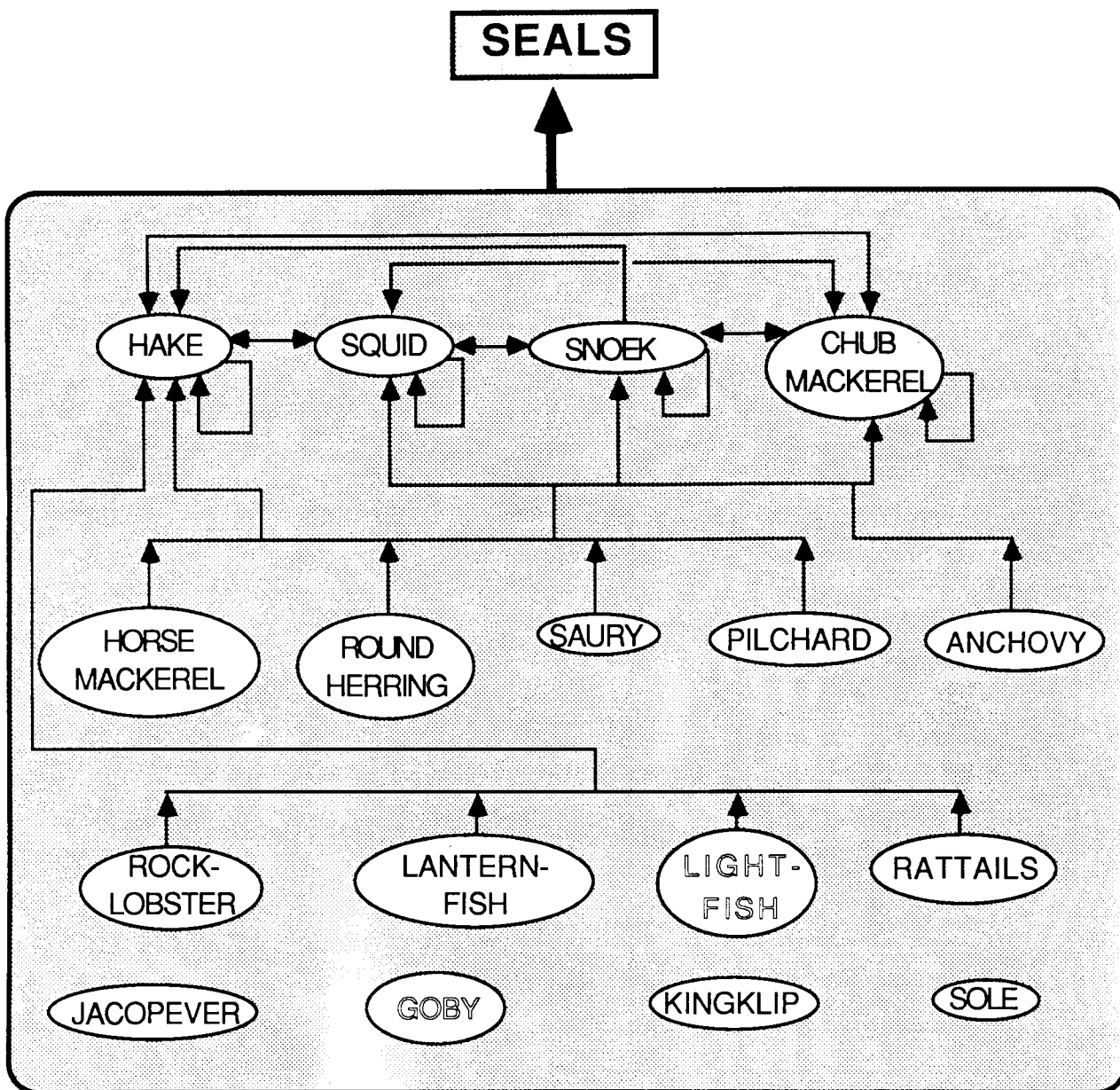


FIGURE 8.1 : The components of the diet of the South African fur seal and some important predator-prey interactions between them (indicated by arrows, showing the flow from prey to predator). The dietary species are given by David (1987a) and the interactions are from Bergh *et al.* (1985). The fish in outlined text are the only non-commercial species.

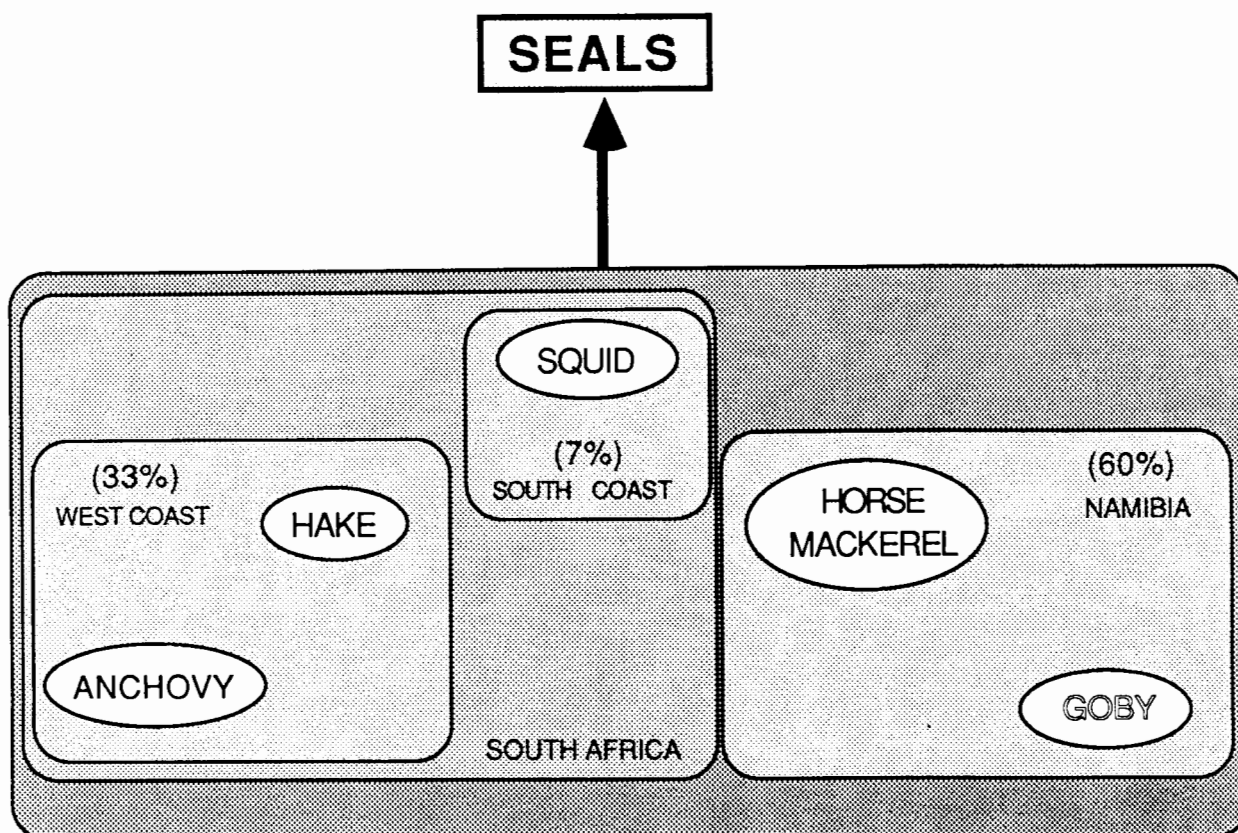


FIGURE 8.2 : The most important components of the seal diet; those that form at least 20% of the diet in each subarea (from Table 8.1). The percentages of the total seal population that are found in each subarea are shown in parentheses (David, 1987a). The goby is the only non-commercial species.

The Scaled Seal Model (Chapter 7) estimates a total fish consumption of 1 784 000 tons in 1984. If this consumption figure is split into each of the areas according to the percentage of seals that live in each of the areas (Namibia, 60%; S.A. west coast, 33%; S.A. south coast, 7% (David, 1987a)), the amount consumed in tons is estimated to be 1 070 000 (Namibia), 589 000 (South African west coast) and 125 000 (South African south coast). Using these figures and the percentage of the major species in the diet, seal consumption of these species is calculated. The quantities of the important dietary species eaten by seals, both from the estimates in David (1987a) and from the model, and the amount taken by the fishery in each area in 1984, are given in Table 8.1.

TABLE 8.1 : The amount of different species that form at least 20% of the seal diet in each of the subareas (also given by their ICSEAF Division numbers) in 1984 as calculated by David (1987a) and as estimated by the Scaled Seal Model (in bold), and the commercial catches of these species in 1984 (from David, 1987a). The percentage of each species in the diet in each area is given in parentheses.

SPECIES	NAMIBIA		SOUTH AFRICA			
	(1.3, 1.4 & 1.5)		SOUTH COAST (2.1 & 2.2)		WEST COAST (1.6)	
	Seals	Fishery	Seals	Fishery	Seals	Fishery
Horse mackerel	203 000	547 081				
Goby	246 100 (23)					
Squid	455 500 556 400 (52)		31 200 37 500 (30)	891		
Anchovy					107 000 135 500 (23)	272 367
Hake					105 000 135 500 (23)	82 763

In Namibia, seals may have consumed an amount of horse mackerel that is approximately 40% of the harvest in 1984. The goby constitutes approximately half of the seal diet in this area but is not a commercially-harvested species. Consumption of squid was much greater than the squid harvest in 1984. But the squid fishery was not well-established then and is now growing, the 1988 catch of squid in this area being 5 389 tons (Sea Fisheries Research Institute, unpublished data), which is six times that in 1984. Hake and anchovy are the most important species in the demersal and pelagic fisheries respectively, and they are significant prey items for seals on the South African west coast. The quantity of anchovy preyed upon by the seals is estimated to be approximately 40% to 50% of that caught by the fishery on the west coast in 1984. Seals are estimated to have

consumed more hake than was caught by the fishery on the west coast - perhaps one-and-a-half times as much in 1984 (David, 1987a and the Scaled Seal Model). However, seals do take hake that are discarded from the trawlers as undersized, and are therefore not competing with the fishery for this amount. Consequently, seals and the fishery on the South African west coast are only ostensibly important competitors, particularly for hake. Because of this, the South African west coast hake is chosen here as an example of a seal dietary species in the Benguela Ecosystem for exploring the effects of seal predation. Together, the hake catch for this area (ICSEAF Division 1.6) and consumption losses from the hake stock make up between 38% and 43% (depending on whether the estimate of consumption from David (1987a) or the Scaled Seal Model, respectively, is accepted) of the total 1984 hake biomass of 501 000 tons (Punt, pers. comm.).

A simulation model for the hake population is designed for two reasons, which are similar to those given by Northridge (1986). The first is to determine insufficiencies in the data and knowledge of the population dynamics and, the second is to simulate the change in sustainable yield to the fishery with a change in seal predation.

THE HAKE MODEL

Attributes

The Hake Model is formulated according to the following set of attributes. Appendix 11 gives the documentation and listing of the computer program used to run this model.

Purpose : The aim of this model is to explore the effect of different predation levels on the sustainable yield of hake to the fishery.

Brief description : The simulation model is a discrete single-species deterministic yield-per-recruit model with an age-structure to allow for predation and harvesting of different age classes to take place.

State variables : Age classes of hake (1, 2 ... 8, 9+ years) in which the last age class contains an accumulation of that age and older.

Units : Numbers of hake are used for all calculations but output is presented in the form of numbers and mass.

Time step : 1 year.

Time horizon : One cohort of hake is followed through 9 years (its approximate lifespan), resulting in the output, which is only presented after 9 years, being equivalent to a steady state analysis.

Calendar of events : Recruitment to the population occurs at the beginning of a model year, after which all forms of mortality take place continuously.

Assumptions and constraints

There are two species of hake, the deep-water *Merluccius paradoxus*, and the shallow-water *Merluccius capensis*, but they are lumped together and have a combined catch quota. The two species of hake are combined so the assumption is made that they have the same biological characteristics and parameter values. The assumptions which are implicit in the model, as in the Northridge (1986) model, include : immutable diet; density-independent seal feeding rates and density-independent fish growth rates. Both recruitment and residual natural mortality (*i.e.* that caused other than by seal predation) are assumed to be constant. Seal predation, which is explored in these simulations, will affect the size of the hake spawning biomass and therefore recruitment. But the assumption of constant recruitment is not as limiting as that of residual natural mortality since it is not as directly linked to the changes in seal predation. The assumption of static residual natural mortality is a constraint of the model because both this mortality and seal predation are components of total natural mortality and are likely to vary as functions of each other.

There is evidence for a large amount of cannibalism (Payne *et al.*, 1987) in hake. The effect of cannibalism is increased natural mortality rates for the younger age classes, but there are insufficient quantitative data to model this. Cannibalism is therefore ignored in the model and is assumed to be included in the natural mortality of the population. The consequence of using one figure for natural mortality of all age classes is discussed later.

Using a mean total length of 21.3 cm for hake in the seal diet (David, 1987a) in the following von Bertalanffy growth equation (Leslie, 1986) for hake on the South African west coast (where $L(t)$ is the length after t years), the mean age of hake in the diet is calculated at 1.7 years :

$$L(t) = 124.7 (1 - e^{-0.115(t - 0.0708)})$$

Seals are assumed to take hake from age classes 1 and 2 only, which effectively allows a prey size range of up to a maximum of 35.7 cm (as they near 3 years of age). Hake smaller than approximately 25 cm are generally discarded from the trawlers (David, 1987a), and hake from approximately age 2 and older (> 24.8 cm) are exploited and retained by the fishery. An assumption in the model is that all hake discarded by the fishery are consumed by the seals. Direct competition between the fishery and seals therefore occurs in age class 2 only, in which their preferred size ranges overlap.

Equations

The model equations are presented in the form given in Pitcher and Hart (1982) but include, in addition to a instantaneous natural mortality rate (M) and instantaneous fishing mortality (F) for each age class (i), a parameter for the instantaneous mortality rate due to seal predation (S). R represents the constant number of recruits each year. These equations are used to calculate yield to both the fishery (Y) and to the seals (P), in terms of numbers (subscript n) and, by multiplying this by the mean mass of each age class (W), the yields are also presented in terms of mass (subscript m).

Number Units :

$$Y_n = R \sum_{i=2}^9 \left(\left(\frac{F_i}{(F_i + M_i + S_i)} (1 - e^{-(F_i + M_i + S_i)}) \right) \left(e^{-\sum_{j=1}^{i-1} (F_j + M_j + S_j)} \right) \right)$$

$$P_n = R \sum_{i=1}^2 \left(\left(\frac{S_i}{(F_i + M_i + S_i)} (1 - e^{-(F_i + M_i + S_i)}) \right) \left(e^{-\sum_{j=1}^{i-1} (F_j + M_j + S_j)} \right) \right)$$

Mass Units :

$$Y_m = R \sum_{i=2}^9 \left(\left(\frac{F_i}{(F_i + M_i + S_i)} (1 - e^{-(F_i + M_i + S_i)}) \right) \left(e^{-\sum_{j=1}^{i-1} (F_j + M_j + S_j)} W_i \right) \right)$$

$$P_m = R \sum_{i=1}^2 \left(\left(\frac{S_i}{(F_i + M_i + S_i)} (1 - e^{-(F_i + M_i + S_i)}) \right) \left(e^{-\sum_{j=1}^{i-1} (F_j + M_j + S_j)} W_i \right) \right)$$

Input

David (1987a) compared consumption by seals to the hake harvest in 1984, so data for the parameters are taken from that year. The parameters are the instantaneous residual natural mortality rate for the whole population and the other age-dependent parameters : instantaneous fishing mortality rate, instantaneous seal predation rate and body mass. Since hake less than approximately 2 years of age are discarded, the fishing mortality of age 1 is reduced to zero for this age class. This results in the discarded fish not being added to the total yield. The discarded fish are likely to be moribund and therefore must be removed from the hake population, and this is accounted for by the assumption that seals consume all discarded hake. The values for the Hake Model parameters are given in Table 8.2.

Seals take hake that are discarded from the trawlers (Shaughnessy & Chapman, 1984; David, 1987a). The catch of hake less than 2 years of age is 9% by mass (Leslie, 1986) of the total catch of 79 000 tons resulting in 7 000 tons of discarded fish on the South African west coast. If it is assumed that seals take all of the discarded hake, the percentage of the discarded fish in the seal diet is small, between 5 and 7%, depending on whether the calculations use the consumption

estimates of the Scaled Seal Model or from David (1987a). The remaining amount consumed (between 98 000 and 146 000 tons) comes from the live hake population. The total biomass of hake dying naturally can be calculated as 130 000 tons using an annual natural mortality rate of 0.3 and the 1984 population biomass of 501 000 tons (Punt, pers. comm.). Approximately one quarter of the total biomass of hake are of age 1 and 2 years (based on data from Leslie, 1986), so 32 500 tons of hake of these small ages die naturally. Therefore the amount of hake estimated to be taken from the live hake population is greater than the amount of hake estimated to die naturally, a quantity which should include seal predation. This discrepancy may arise partly because a single value is used for natural mortality as opposed to age-dependent figures (for which there are no data), which are likely to show increased natural mortality of the younger ages. In addition, although a figure of 0.3 is used conventionally for the Cape hake, a larger mortality figure seems more likely (Andrew, 1986). However, the discrepancy in the data could be the result of error from a number of other sources (in the biomass, consumption estimates, or the ages assumed to be eaten and discarded), In the model, hypothetical seal predation rates are therefore used as input.

Table 8.2 : Data values for parameters of the Hake Model for the South African west coast (ICSEAF Division 1.6) in 1984 (Leslie, 1986).

AGE (Years)	NATURAL MORTALITY (year ⁻¹)	FISHING MORTALITY (year ⁻¹)	MEAN MASS (g)
1	0.3	0.00	46
2	0.3	0.50	181
3	0.3	0.51	419
4	0.3	0.49	752
5	0.3	0.63	1164
6	0.3	0.70	1636
7	0.3	0.73	2149
8	0.3	0.68	2685
9	0.3	0.68	3231

The model hake population is not scaled to the 1984 population size because the results only require investigation with respect to the comparative changes in yield under different levels of seal predation. To set up an initial population in the model, a constant number of recruits, chosen as 1000 individuals, is input. The number in this initial cohort surviving each age produces the number in each age class, so one simulation is equivalent to following a hake cohort for nine years.

Output

The hake yield and the amount taken as seal prey are output in terms of numbers and mass.

RESULTS AND DISCUSSION

Hake in the seal diet

Northridge's (1986) conclusions are that there are insufficiencies regarding data and understanding, and these restrict an assessment of the impact of seals on fish stocks in Canadian waters. His data are inadequate; in particular the age of fish taken by the seals is not available. This information is available for the South African west coast hake population. Northridge (1986) found that he could not estimate seal-induced mortality whereas the problem in this study is that the amount of hake estimated to be consumed by seals substantially exceeds the total estimated natural mortality, although seal predation is a form of natural mortality.

Northridge (1986) comments that it is interesting to know if seals take moribund fish preferentially. Seals do consume "stickers", small hake caught in the mesh, and they take hake that are discarded from the trawlers (Shaughnessy & Chapman, 1984; David, 1987a). In fact, Ryan & Moloney (1988) showed that the distribution of foraging South African fur seals is significantly influenced by commercial trawling activity. Quantification of the discard in the diet shows that this source of hake, which is moribund, is a small percentage of the total diet. It is calculated that there is, at most, only direct competition for the 2-year-old hake in terms of sizes preferred by the seals

and the fishery. The seals utilise the resource first because they exploit the younger size classes reducing them before the fishery can harvest them.

Sensitivity analysis

The output from the sensitivity analysis, carried out to check the performance of the model by increasing/decreasing each of the parameter values separately while excluding seal predation, are presented in Fig. 8.3. The change to hake population size and hake yield is presented in terms of both numbers and mass. Changing recruitment shows correctly that there is a 20% increase/decrease in population size and sustainable yield in terms of numbers and mass with the 20% change in number of recruits. Changing either natural mortality or fishing mortality has the same effect on population size, which is to be expected because both parameters operate in the same way. In both cases, there is a difference between the results in terms of numbers and mass, the effect on mass being a greater difference from the standard hake population size than in terms of numbers. When mortality is increased, more hake die and the population size is smaller, and vice versa. In terms of mass, the effect is greater because the amount of older, heavier hake is influenced by the mortality of the younger age classes, making the total biomass much smaller or greater when mortality is increased or decreased, respectively. An increase in natural mortality shows a decrease in sustainable yield and vice versa.

When fishing mortality is changed, an initially counter-intuitive and important trend in yield arises. The number of hake in the yield increases when fishing mortality is increased and vice versa, as expected. However, in mass terms, the yield decreases as fishing mortality is increased and increases as fishing mortality is decreased. The reason for this is that if fishing mortality is increased, more smaller hake are taken so fewer survive to older age classes where they weigh more, and the increased fishing mortality of these age classes is not sufficient to make up for the reduced mass of hake available to be caught.

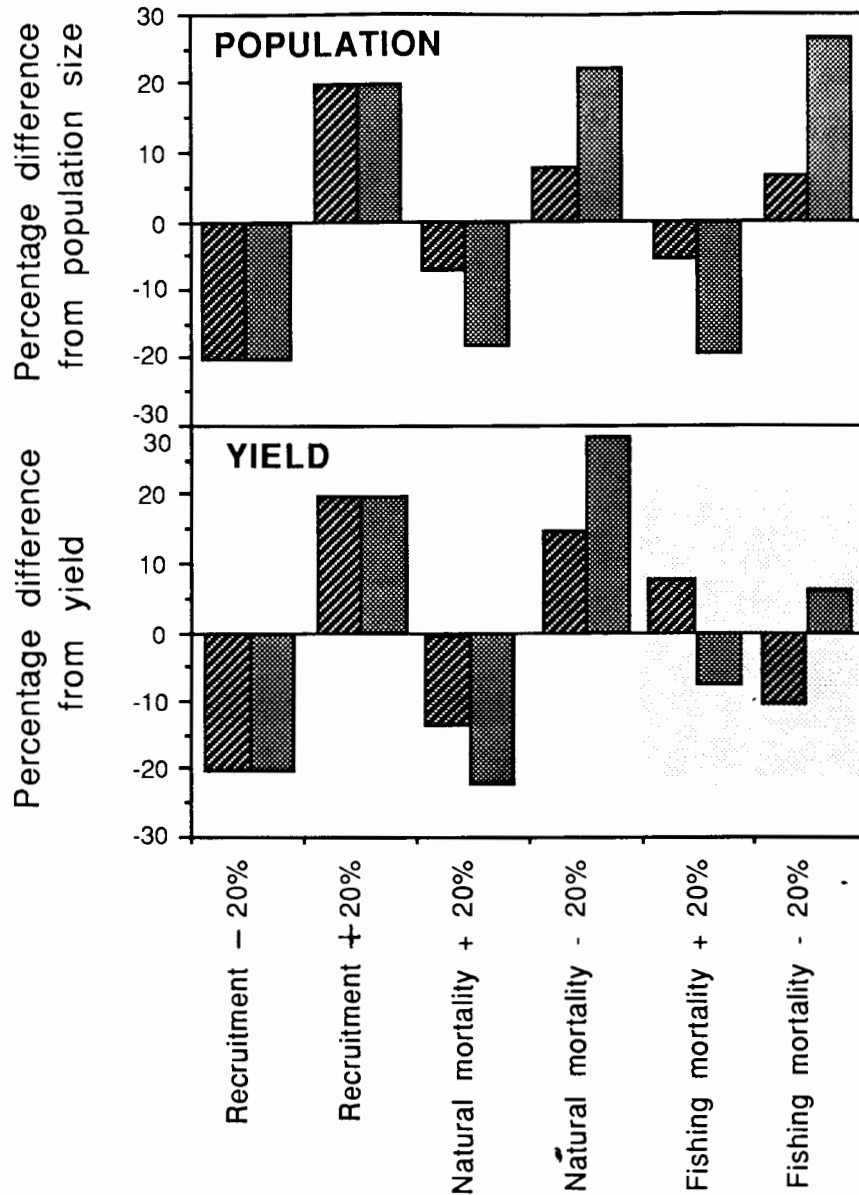


FIGURE 8.3 : Results of the sensitivity analysis on the Hake Model showing changes to the hake population and the sustainable hake yield to the fishery under different parameter values, presented in terms of numbers (▨) and mass (■).

Effect of seal predation on sustainable hake yield

The results of a set of simulations, performed to explore changes to sustainable fishery yield under different predation rates, are presented under three different residual natural mortality rates for the first two age classes. The output from three sets of fishing mortality rates are also shown, these being the estimated 1984 hake age-dependent fishing mortality rates (Leslie, 1986), and each of

these instantaneous rates increased or decreased by 50%. The sustainable yield of hake under different seal predation rates of the first two age classes only (age classes 3 and older have zero seal predation) is explored under all of these combinations of input.

Both the fishing mortality and natural mortality parameters apply directly to the number, rather than the mass, of hake in the population. However, yields and amounts consumed by the seals are more easily understood in terms of mass, so that the numbers of hake are converted to mass in the model. To aid explanation of the yield-predation output in terms of mass, the relationship is viewed in terms of both numbers and mass (Fig. 8.4). The graphs show the sustainable yield of hake in numbers or mass (Y-axis) against the number or mass of prey eaten by the seals (X-axis). The yield-predation trend is similar regardless of which of the three residual natural mortality rates (0.1, 0.2 and 0.3) is input, although the size of the yield differs. Under different fishing mortality rates, the magnitude of the sustainable yield and amount of prey differ, but the trends are equivalent. The yields under the same predation rates are greatest when the fishing mortality is decreased and smallest when fishing mortality is increased. This result is also shown in the sensitivity analysis and is explained in that section.

Number units : Under each of the three residual natural mortality rates, as the predation rate decreases, the number of hake in the sustainable yield to the fishery increases whereas the number preyed upon decreases. But the increase in number of hake in the sustainable yield is less than the number of hake that escape predation by seals. It is clear then from these simple simulations that the relationship between predation and yield in terms of numbers is not proportional. This is because the number of hake escaping predation are then subject to both residual natural mortality and fishing mortality, resulting in only a fraction of the escapees being added to the yield.

Mass units : When the yield-predation relationship is viewed in terms of mass, the result is quite different. Unlike on the graphs presented in number units, the axes on the mass graphs are on different scales, the range of the X-axis being far smaller than the range on the Y-axis. As the predation rate decreases, the increase in yield is far greater than the decrease in hake eaten by seals.

The reason for this is that although seals are not in direct competition to the fishery, reduced predation on the younger age by seals leads to more fish entering the older ages of larger, heavier hake which are available to the fishery. The important influences that result in the yield-predation trends are the difference in ages and masses of hake subject to predation and to capture by the fishery, and the different rates at which seals and the fishery take hake. Although this is quantitatively a striking result, the relative size of the increase in yield will decrease if residual natural mortality of the younger ages were larger. This increase in sustainable yield may not apply to all fished species because it depends on the relative ages taken by the seals and the fishery, the rates of residual natural mortality and the mass increment with age.

Three lines each representing the results under different residual natural mortality rates (M) are shown in Fig 8.4. The relationship between yield and prey probably lies somewhere between the upper and lower lines, depending on the predation rate. Residual natural mortality may range from a rate of 0.3 at low seal predation rates, to 0.1 at high seal predation rates. If an assumption is made that at a seal predation rate (S) of 0.6, $M=0.1$ while at $S=0$, $M=0.3$, a comparison between the points on these two lines can be made for each set of fishing mortalities. If S is reduced from 0.6 to zero, the increase in sustainable yield is twice that of the mass of hake that escaped predation, using the 1984 rates of fishing. Using increased fishing mortality rates, the increase is just over two times and under decreased fishing, the increase in sustainable yield is over one-and-a-half times the amount that escaped predation. Thus if the seal population is reduced, thereby decreasing the predation rate on younger hake, a disproportionately higher mass can be expected in the yield, provided that seals are not replaced by other predators. This would be very beneficial to the hake fishery. An interesting result is that the model sensitivity analysis shows that, if all else remains equal, a 20% decrease in fishing mortality also results in an increased yield in terms of mass. Therefore either of these factors could come into play and have an effect on sustainable fishery yields.

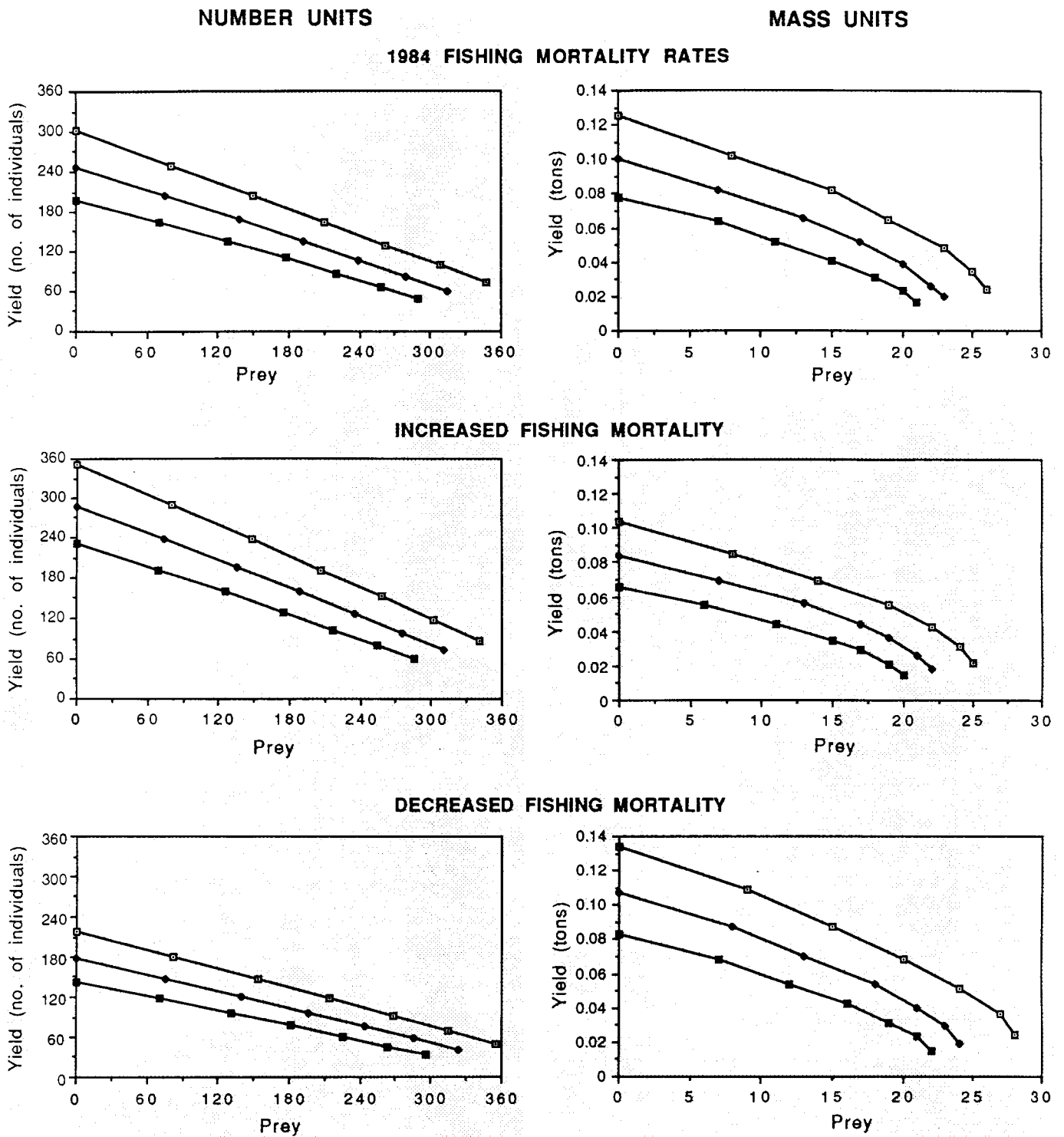


FIGURE 8.4 : The change in sustainable yield as a function of the number and mass of hake taken as seal prey in the first two age classes under three sets of fishing mortality rates (see text). In each case, simulations were carried using residual natural mortality rates of 0.1 (□) and 0.2 (◆) and the estimated value of 0.3 (■) (Leslie, 1986). Each data point represents a predation rate increasing from 0 to 60% in 10% intervals from left to right on each graph. The scale of the output is a result of an arbitrary 1 000 recruits being input into the model.

The results for the hake population are those that are obtained when a single-species approach to the problem is adopted. The conclusion of Northridge (1986) is that there is insufficient knowledge of the dynamics of fish mortality and this holds for the model of the South African hake population as well. The limitations of the model are that there are no age-dependent estimates of M for hake, and that there is inadequate knowledge of the change in residual natural mortality resulting from a change in seal predation on fish stocks. The amount of fish that would be susceptible to natural mortality if the seal predation rate were decreased is not known. There are always many intrinsic changes and compensatory effects in a population in response to changes in the system. The lack of this information does place some bounds on the utility of the model. The interactions between seals and fish in the Benguela Ecosystem are complex because seals consume species from different trophic levels such as predators (*e.g.* squid) and their prey (*e.g.* anchovy). Butterworth *et al.* (1988) explore the effect that a reduction in South African fur seal population may have on sustainable yield of commercial fish species with the use of single- and multi-species analytical models by investigating the above scenario. Multi-species models account for some of the changes that may result in the residual natural mortality of each species. They look at the systems represented in Fig. 8.5, as part of the Benguela Ecosystem and investigate some speculative models analytically. In each case they investigate the results with respect to the change in potential sustainable yield of anchovy. They show that reducing seal numbers in Model A produces a higher yield whereas in Model B, it causes a decrease in the yield. In Model B, this is a result of fewer seals eating less squid, resulting in a larger squid population eating more anchovy. For coexistence of all species to be maintained in Model C, seals are required to be relatively inefficient at catching anchovy. This essentially reduces Model C to an equivalent of Model B, in which seals do not prey on anchovy. In this system, decreasing seal numbers reduces sustainable yield because of the increase in the squid population. Their conclusion from this analytical investigation of the two-species and three-species systems is that it is not possible to predict whether a reduction in the seal population will have a positive or negative effect on the sustainable yield of anchovy, unless the appropriate model structure can be specified.

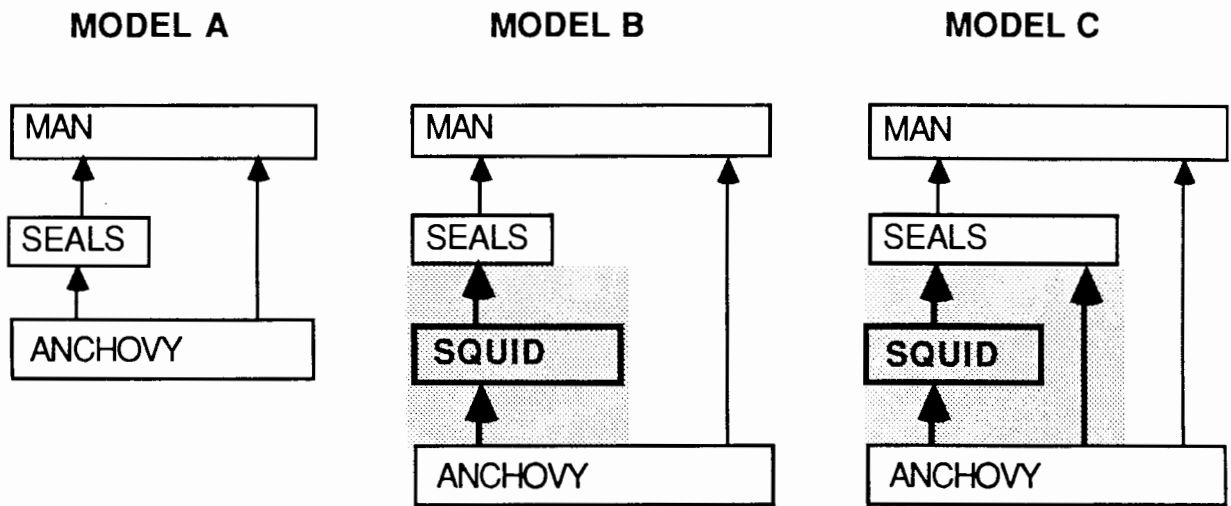


FIGURE 8.5 : Diagrams representing the species and interactions explored by Butterworth *et al.* (1988) using analytical models. The shaded areas indicate the additions made to Model A to achieve Models B and C.

The Butterworth *et al.* (1988) models are formulated to evaluate the effect on the sustainable yield of one species, anchovy under reduced seal predation levels. The squid population is not harvested in these models, although in reality, there may be a trade-off between maximising either the squid or the anchovy yields while sacrificing the other. This is the type of question that Beddington and May (1980) posed : whether the "harvesting emphasis be toward larger fishes for human food or toward smaller fishes as fish meal". This adds further complication to examining the effects of seal predation on fish yield, since there is more than one species whose sustainable yield could be maximised.

CONCLUSIONS

The single-species Hake Model and the multi-species models of Butterworth *et al.* (1988) are some of the models in a set of indeterminate size that can be used to explore the effects that predation will have on sustainable fish yield. In the Hake Model, an assumption is that residual natural mortality remains constant whereas in the Butterworth *et al.* (1988) set of models, the interactions between species account for some of the possible changes to residual natural mortality. The single species Hake Model and the two-species Seal-Anchovy model (Model A, Butterworth *et al.*, 1988) explore that same type of interaction - that of the effect of a change in seal predation on the sustainable yield of a fish species. The result is the same in both cases : the yield increases. In the three-species Seal-Squid-Anchovy system (Models B and C, Butterworth *et al.*, 1988) the additional link in the chain of feeding results in the opposite effect on the yield of anchovy, causing it to decrease. The elimination of this static residual natural mortality in these multi-species models therefore results in a different effect on yield. A further limitation of the Hake Model is that there is no variability in the residual natural mortality rate with age and this has important consequences on the results. In conclusion, the statement of Butterworth *et al.* (1988) still holds that "there is no basis to determine whether reducing the seal population would have a positive or negative effect on the sustainable yield of the population of commercial fish species....". The view of those fishermen who believe that reduced predation will increase their yields therefore cannot be accepted; a reduction in fishing mortality may also increase their yields and a change in seal predation levels may have the opposite effect, depending on the interactions in the real system, which are inadequately understood at present to resolve the issue.

CHAPTER 9

SYNTHESIS AND GENERAL CONCLUSIONS

METHODOLOGY

There are three main objectives to this thesis : to evaluate operational interactions between the South African fur seal and fisheries in the Benguela Ecosystem; to assess culling as a means of seal population control; and to assess seal culling as a means of reducing fish consumption and increasing fishery yields. In this thesis, the first objective is examined qualitatively. The second two objectives are explored by building parsimonious, single-species, speculative models interactively in consultation with seal biologists and fisheries managers. In this manner, it is possible to derive a whole-system perspective of the "seal problem", and to draw on the combined expertise of various parties to address the important interactions. The simulation models are used as an environment in which to examine various scenarios by introducing different management options and assessing the effects.

Essentially two models are developed, one of the seal population and one of a fish population, representing seal prey. Although the seal population has previously been modelled, none of the existing models (Shaughnessy & Best, 1980; Butterworth *et al.*, 1987) is appropriate for a full evaluation of the "seal problem", because these models simulate only the female seals. In the seal model described in this study, important consideration is given to bull sealing, and the disturbance effects associated with the shooting of bulls, making the model particularly relevant to assessing the "seal problem" in its entirety. Three versions of the seal model are developed; each of these is tested for plausibility of model structure and data and for credibility in terms of the set of possible models that could be designed to address this problem. Each of the models produces different forms of output. The Seal Age Model is designed to simulate the probability of a model seal reaching particular ages. The Seal Model provides general comparative results of population demography under different culling regimes and is not scaled to realistic population size. In contrast, the Scaled Seal Model includes historical culling data as input, and has been scaled to historical population sizes to produce numerically realistic output. The fish model is designed to simulate the Cape hake population and is a simple deterministic yield-per-recruit model.

The adoption of a system-type approach to assessment of the "seal problem" in this thesis provides an overall evaluation of the problem. In addition, the process of modelling and collection of information provides an opportunity, which may not have arisen otherwise, to fulfill the following additional functions :

- the models developed are useful for enhancing our understanding of the dynamics of the seal population and its management.
- the results of this study indicate areas in which future research should be directed.

INTERACTIONS BETWEEN SEALS AND FISHING OPERATIONS

The interaction between seals and fishing operations is evaluated qualitatively by collecting information from personnel associated with each of the commercial fisheries, and assesses whether seals disturb fishing operations, consume catches or damage gear. Analysis of the results showed that each of the fisheries is subject to interference by the seals in at least one way, but in most cases, the effect is not severe. The purse-seine fishermen are subject to the most detrimental effects from the seal interaction in each of the three ways. The worst period for interference with the purse-seine fishery is in the middle of the year, especially during April and May. Substantial disturbance of fishing operations occurs only in the purse-seine and tunny-poling industries. Substantial consumption of catches occurs in the purse-seine, long-line, hand-line and drift-net fisheries. Damage to gear does not seem to be a major problem other than in the drift-net industry. Because no satisfactory methods of deterring seals have been found to date, the seals are dealt with by the fishermen, mainly by shooting, when and where they occur. The interaction between seals and fishing operations is localised and seasonal and is unlikely to be solved through reduction in the whole seal population, unless the reduction is done on a massive scale.

CULLING AS A MEANS OF POPULATION CONTROL

The output from the seal models provides insight into the effects of different culling strategies. The most effective means of reducing the seal population is shown to be culling a combination of pups and bulls. At culling rates of 20% and more, negative growth of the model population is achieved. However, the main cause of the population reduction is as a result of disturbance during bull culling operations, causing reduced pup production (from reduced pregnancies and increased pup mortality), and not from the removal of the bulls and pups. Pup culling is the least effective means of reducing the seal population because it is only at very high pup culling rates (> 70%) that a zero or negative growth rate is achieved. When bulls only are taken, the population continues to increase irrespective of the culling rate. To achieve a very small or a negative growth rate in the population, a greater number of pups or bulls would need to be culled than the number that on average have been killed historically. When the culling of cows is considered, the models show that, other than at low culling rates, the sex ratio of the seal population is drastically altered. This change in the sex ratio may have undesirable consequences (such as a breakdown of the social structure and resulting in reduced pup production), and these are not accounted for in the models.

IMPACT OF SEAL PREDATION ON FISH

Although different age and sex classes of seals consume different amounts of fish, the per capita consumption by seals of both sexes and of all ages in the model is shown to be similar in the long-term under any of the management regimes. This result has important implications for management because it is therefore not justified to cull a particular age or sex class in order to achieve a lower per capita consumption. The different amounts of fish consumed are a consequence of the seal population size which is determined by culling. Consequently, for any particular culling rate, consumption is smallest when pups and bulls are being culled and is the greatest when only pups are being culled.

The effect of seal predation on fish yield is explored by using hake as an example of a commercial species. Seals take hake of age 1 and 2, whereas the fishery catches hake of 2 years and older. Seals therefore reduce the hake population prior to the fishery harvest and only compete directly for hake of age 2. In the model, the result of seal culling is an increase in the yield of hake that is disproportionately large compared to the amount of hake that escape seal predation. This increase in hake yield resulting from reduced seal predation may not apply to all harvested fish species because it depends on the residual natural mortality and growth rates of the fish, and the relative ages of fish taken by the seals and the fishery. In addition, the model shows that a 20% reduction in fishing mortality causes an increased hake yield, a counter-intuitive result that is explained by the age-specific masses of hake and the differing fishing mortality rates of different age classes.

Major limiting features of the single-species Hake Model are that residual mortality does not vary with age, and that it is assumed to be static, regardless of the magnitude of other forms of mortality. In multi-species models, the interactions between species account for variable residual natural mortality. Butterworth *et al.* (1988) designed a set of multi-species models to explore the relationship between seal population size and anchovy yield. They found that in a three-species chain system, such as a seal-squid-anchovy group, the intermediate predator (squid) in the food chain, increases in response to seal culling, resulting in a decrease in the yield of anchovy, which is the opposite to the desired effect. Thus the elimination of static residual natural mortality in the multi-species models changes the impact on fish yield. The yield of a fish species may increase or decrease if the seal population is reduced, depending on the importance of this species and its predators in the seal diet.

IMPROVING OUR UNDERSTANDING OF THE SEAL POPULATION

Population growth

In the past few years, the number of seal pups in the Benguela Ecosystem has undergone some fluctuations, following the changes in management policy. These fluctuations are smoothed in the

total population trend, which shows exponential growth. Between 1971, the first year of population censusing, and 1983, the annual growth rate of the pups in the model is estimated to be 4.1%. From 1983 onwards, the number of pups in the model decreased at an annual rate of 1.2%, whereas the total seal population shows a positive annual growth rate of 5.1%. The model results indicate that the total population of seals in 1988 was approximately one-and-a-half million seals.

Estimating total population size from pup numbers

At present, the total population size of the South African fur seal is calculated by multiplying the number of pups, which are counted during surveys, by a factor of 4. However, the model results show that there is large variability in this ratio under different management regimes. The ratio is shown to be always above 4, except when culling is directed at pups. The mean ratio between the number of pups and the total population since 1900 is estimated to be 4.55, but this ratio varies according to the harvesting rates. Furthermore, the annual growth rate of the pups varies considerably compared with that of the total population. Total population sizes that have been estimated by using a constant population : pup ratio should be viewed with caution because the total population may be different from that estimated by the constant ratio.

Age estimates

In the models, the longevity of South African fur seal males is estimated to be 43 years and of females, 47 years. The probability that either sex exceeds 20 years is estimated as 14%, and the probability of either sex reaching over 30 years is simulated as 6%.

Consumption

Consumption rates in the model are age- and sex-specific and range between 5 and 20% of seal body mass per day. The model results support the use of a general consumption rate of 8% of seal body mass per day (David, 1987a), which appears to be a good approximation, especially as there does not seem to be much variation in per capita consumption under different culling regimes. The amount of fish consumed by the seal population is estimated to have almost doubled in the last decade, and is estimated by the model to be over 2 million tons in 1988.

Harvesting

Seal harvesting is not a highly profitable industry. In South Africa over the past few years, the maximum annual wholesale value of seal products has not exceeded R150 000, which is a fraction of a percent of the annual wholesale value of hake in the South African demersal catches (which is the largest fishery). The market price for major seal products (pelts and genitals) has declined substantially in recent years. The oil by-product fetches the same price as fish oil, and the meat is difficult to market, and at present costs more to transport than to sell.

Both bulls and pups have been harvested during this century. The harvesting rate of pups has dropped dramatically in the past few years, whereas that of bulls has increased over the past few decades. The World Conservation Strategy (Anon, 1980) states that a renewable resource may be exploited, provided it is done on a rational basis with careful management of the harvest. The effects of different management strategies for the harvesting of different ages and sexes of seals are investigated in this thesis, and various options are studied. For any particular harvesting rate, the number of seals harvested is greatest when pups are killed, as opposed to any other age or sex classes of the population. When pups and bulls are harvested together, the harvest is not as great because pup production is reduced by disturbance during the bull harvest. The harvest of cows is small at any harvesting rate. However, there is little financial incentive to harvest cows because no specific markets exist, and on the two occasions when cows were taken historically, they were used only for meat and oil.

SUGGESTIONS FOR FUTURE RESEARCH

The collection of data for any population study is an ongoing process in which parameter values are constantly being refined. This study highlights some areas in which research might be concentrated to improve the data set for evaluating management of the seal population.

Seal deterrents

Interference by seals at fishing operations has been identified as an annoying problem for the fishery and may negatively affect fishery catches. Methods have been tried to deter seals from attendance at fishing operations, but these have all been unsuccessful. This is still an area that requires investigation.

Disturbance effects of seal culling

The magnitude of disturbance effects of culling on subsequent pup production was obtained for these models from discussion based on our present knowledge, because no quantitative information is available at present. The incorporation of disturbance effects in the models has a substantial effect on the model results, particularly with reference to bull culling. This aspect should be studied in some detail, using a monitoring programme. Disturbance factors can be assessed by estimating the changes in pup production that occur with variable culling rates and methods over a period of time.

Density-dependent influences

No density-dependent functional relationship has been established for the South African fur seal population and consequently, there is no basis for including density-dependent control in the model population. Two methods of assessing a density-dependent influence are attempted in this study; examination of the ratio between pups and bulls, and investigation of the relationship between pups and total number of seals. However, the data are found to be insufficient to define a density-dependent relationship statistically, and the seal population is not believed to be limited by space or food at present. The seal population is therefore assumed still to be in an exponential phase of growth. As a consequence, when the model is used to explore outcomes beyond the present population size range, this is examined in the light of there being no density-dependent population regulation.

Information on the ratio of total population size to pups can be collected from a variety of areas and assessed over a period of time. However, to demonstrate a density-dependent influence, the ratio must change as seal density increases. Therefore, data should only be collected from unsealed populations, because sealing is shown by the models to influence this ratio considerably. Alternatively, pup mortality can be measured at different seal population densities, to provide a direct measurement of one possible influence of density on population growth. Some areas on the coast have seal populations which are not increasing and are not at maximum capacity. These populations might be food limited and this aspect should be explored.

Mortality rates of fish species

A major limitation of the hake population model is that there is inadequate knowledge of the change in residual natural mortality resulting from a change in seal predation. An unknown number of fish might be susceptible to increased natural mortality from other sources, if the seal predation rate were decreased. Greater understanding of the relationship between predation and residual natural mortality is needed.

Although seal predation is a form of natural mortality, the amount of hake estimated to be consumed by seals exceeds the estimated natural mortality. This discrepancy between the hake and seal data sets should be investigated to provide better estimates of seal-induced mortality. This problem is likely to be resolved if hake of younger ages were subject to a larger mortality rate than that currently used. The collection of information to estimate age-specific mortality rates for the hake population is an area that requires investigation to improve understanding of hake population dynamics.

GENERAL CONCLUSIONS

This study differs from other analyses of seal-fisheries interactions in that it adopts an holistic approach. The evaluation of the "seal problem" combines detailed analyses of the operational and biological interactions between the South African fur seal and fisheries in the Benguela Ecosystem. Previous modelling studies of biological seal-fisheries interactions have either adopted the multi-species approach or have explored the effects using single-species fish models. The models that are presented in this thesis examine the problem from a fisheries perspective, but consider the interactions by focussing on the seal population. The "seal problem" is a controversial issue, and during the process of evaluating the problem, a large body of related information has been collected to place the problem in context and resolve misconceptions. Some important conclusions are reached as a result of the investigations carried out in this thesis.

Operational interactions between seals and the fisheries form a real and frustrating problem for the fishermen, and practical steps (such as the use of deterrents) should be considered to attempt to reduce the problem. In contrast, the biological interaction of competition between fishermen and seals for a common food resource is a less tangible problem, and the complexity of the interactions involved preclude simple intuitive measures to solve the problem. The whole-system modelling approach that is adopted in this thesis allows various interactions to be studied in context and the potential effects of different management strategies to be assessed.

Bergh *et al.* (1985) calculate that the most important predators on small shoaling fish (such as the important pelagic commercial species, the anchovy) are, in descending order of importance, predatory fish, squid, seals, seabirds and whales and dolphins. Therefore, in perspective, seals cannot be regarded as the main culprits in reducing fish stocks. David (1987a, pg 711) suggests that "... because of their conspicuous, 'high profile' behaviour patterns, it is probable that the role of seals as top predators has been overemphasised compared to other more arcane predators.". There are no complaints from fishermen that some predatory fish may be competing for a harvested resource, perhaps because the fishing industry benefits from the yield of fish

which may be predators or prey. If the fishing industry benefitted more from the yield of seals, the situation might be different because there would be a trade-off between maximising the benefit from fish and seal harvests.

Although the fishing industry claims that it is supporting an artificially high seal population through scavenging from the fishing boats, David (1987a) uses estimates of the number of seals seen attending boats and consumption rates to show that this is not the case. In addition, the amount of hake discarded from the trawlers is calculated in this study as being only a small percentage of the total consumption of hake by seals. Various fish species might well interfere with fishing operations but they are not visible and thus are less likely to be blamed. It appears as if the antagonism towards seals has stemmed from the annoyance of fishermen who are subjected to interference by seals during fishing operations and that this biases their reaction towards seals on other grounds as well. Therefore, although the two interactions are separate issues, it would appear that the magnitude of the biological interaction is exacerbated by the conflict between seals and fishermen during fishing operations, and this is the root of the problem. If a successful method could be found to deter seals from attending fishing operations, the main cause for complaint is likely to be eliminated.

As with other studies of seal-fishery interactions, the output of the models are not prescriptive for the biological interactions. The set of speculative models presented in this thesis provides a number of options for management of the South African fur seal, draws attention to regimes about which one should be cautious (*e.g.* the effects of cow culling), and indicates how secondary effects of culling operate (*e.g.* disturbance effects of culling). The models provide a number of guidelines which can assist the decision-making process regarding the management of the seal population :

If the aim of culling seals is to reduce fish consumption, no particular culling regime will result in a lower per capita consumption. Therefore, regardless of the strategy for reducing

the seal population, the equivalent amounts of fish will be consumed, irrespective of the age and sex structure of the seal population.

Reduced seal predation may increase hake yield, but may have less beneficial effects on other commercial species. The results of this particular aspect of the "seal problem" are inconclusive, demonstrating that at present there is no rational scientific basis for reducing the seal population as a means of increasing all catches for the commercial fisheries.

For long-lived species, such as the seal, long-term management objectives should be formulated if a management strategy is to be carried out successfully. The management of the South African fur seal has been subjected to various influences in the form of biological, economic and socio-political criteria. Consequently, management objectives for the seals have varied considerably in the past decade and no long-term goals have been set. For future management policies, whether the objective is to harvest seals for economic benefit or to cull to control seal population size, the objective should be long-term and based on sound scientific understanding.

The seal population is in a healthy state so it is feasible to kill seals if some rational gain is to be made. Harvesting is not viable, either economically, because the products are not easily marketable, or socio-politically, because of opposition by anti-sealing conservationists who have previously been able to exert a strong influence. Culling is acceptable to conservationists if there is a good scientific basis for it and the subsequent use of the products is found to be acceptable.

There are economic, socio-political and biological considerations that have to be accounted for when choosing a specific seal culling strategy. A pup cull is the least effective; it causes little reduction in the population and the marketing of pelts is politically and economically unpopular. A cow cull has a large effect on the population, but has possible undesirable side-effects (such as a breakdown of the social structure), and there is little financial gain to

be made from cow carcasses. The most beneficial cull in economic terms is the killing of bulls, but although this culling regime causes a reasonable reduction in the population, this results mainly from the disturbance effects of culling, which reduces pup production. The acceptability of this to the general public is questionable.

This study has presented a number of possible scenarios for management. It has explored the implications and effects of different management policies, and evaluated these in terms of different management objectives. With regard to the "seal problem", a management decision can no longer be justified in terms of a lack of knowledge or lack of direction; it is more a question of compromising between different political, economic and biological criteria.

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APPENDICES

APPENDIX 1

ESTIMATED PUP NUMBERS

Estimates of the number of pups and the annual growth rate of individual colonies are taken from David (1987b) and the estimates for groups of colonies are calculated from the data in David (1987b). The difference in numbers of pups between 1971 and 1983 are also given. The letters in parentheses, 'FB', 'MB' and 'AB' indicate False Bay, Mossel Bay and Algoa Bay, respectively.

COLONY	NUMBER OF PUPS		ANNUAL GROWTH (%)	PUPS ₁₉₈₃ - PUPS ₁₉₇₁
	1971	1983		
Cape Cross	15 797	22 596	3.12	6799
Hollam's Bird Isl	5 390	2 039	-7.73	-3351
Marshall Reef	1 045	120	-16.55	-925
Staple Rock	3 614	1495	-6.99	-2119
Boat Bay Rock	1 636	762	-6.01	-874
Dumfudgeon	2 343	540	-11.36	-1803
Long Island	13 478	16 286	1.70	2808
Wolf Bay	16 849	29 481	5.01	12632
Atlas Bay	28 497	66 604	7.36	38107
Albatross Rock	3 599	6 002	4.51	2403
Black Rock	163	326	7.02	163
Van Reenen Bay	2 915	5 554	5.74	2639
Sinclair Island	14 956	10 975	-2.35	-3981
Lion's Head	3 875	2 216	-4.60	-1749
Kleinsee	28 666	79 424	8.89	50758
Elephant Rock	1 354	2 269	4.35	915
Jacob's Reef	4 721	3 610	-2.07	-1111
Robbesteen	1 968	1 027	-5.02	-941
Seal Island (FB)	13 136	10 400	-1.90	-2736
Geyser Rock	3 530	8 216	7.42	4686
Quoin Rock	3 164	653	-12.33	-2511
Seal Island (MB)	3 297	528	-14.17	-2769
Black Rocks (AB)	1 037	328	-8.98	-709
MAINLAND	96 599	205 785	6.50	109 186
ISLAND	78 431	65 575	-1.47	-12 856
NAMIBIA	114 157	164 905	3.11	50 748
SA WEST COAST	36 709	86 330	7.43	49 621
SA EAST COAST	24 164	20 125	-1.51	-4 039
ALL COLONIES	175 030	271 360	3.73	96330

APPENDIX 2

WICKENS, P.A. & SHELTON, P.A. 1988. Report on the 1987 Benguela Ecology Programme series of workshops on seal-fishery interactions. *Benguela Ecology Programme Report 14* : 31 pp.

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BACKGROUND TO THE "SEAL PROBLEM"

The interaction between the Cape fur seal (*Arctocephalus pusillus pusillus*) population and the fishery in the Benguela Ecosystem is considered to be important because the seal population is increasing while some of the commercial and recreational fisheries are showing signs of being heavily exploited, and in some cases are overexploited (certain hake stocks) or collapsed (pilchard stocks off Namibia and South Africa). Diet analyses show that seals eat many of the species that are caught by the various fisheries.

Seals have been harvested in the Benguela Ecosystem since the 17th Century and by the time formal control was established in 1893 a number of colonies had disappeared and the population had been reduced to low levels. Since then the population has entered a recovery phase. In 1983 the international pelt market collapsed as a consequence of conservation pressure and there is now only a small harvest for the local pelt market. Most profit is made from the oriental market for bull genitals with meat and oil a by-product of both the bull and pup harvests. With the recovery of the population, pressure by conservationists has been replaced by pressure from the fishing community to cull seals or to apply some other form of control to maintain or reduce the population size. The rationale of the fishermen is that a reduction in the seal population will allow more fish to be harvested by the fishing industry without increasing the impact on the fish stocks. Although this is an over-simplified perception of how the ecosystem functions, it is in the same class as the commonly adopted single-species model prediction that decreased exploitation will allow an overexploited fish stock to recover towards the biomass that would have existed in the un-exploited state. In addition to the problem of the amount of commercial fish consumed by the seal population, fishermen also argue that seals interfere with fishing operations and damage fishing gear.

Prior to the collapse of the pelt industry, the policy was to maximise the sustainable yield from the seal population. Because there is now no large-scale utilization of seals which could allow the continuation of a policy of sustainable yield management, it is possible that a new policy of culling or some other form of control will be enacted to maintain or reduce the seal population size (see Anon 1986). The new Sea Fisheries Act (Anon 1988) provides for the "conservation of the marine ecology and the orderly exploitation, utilization and protection of certain marine resources" and it is in this context that any future decisions

related to the seal population will be viewed. The general policy under this new act is "(a) the protection of marine ecology; and (b) the promotion, protection and sustained utilization of the sea, its living resources and derivatives thereof, to the greatest benefit of the present and future inhabitants of the Republic, regard being had to economic, social and cultural values".

In most instances fisheries management objectives have formed the focus for single-species models in which production varies only as a function of stock size, and any harvest only affects the stock being harvested and no other components of the system. In some cases a random "noise" term is added to simulate variability not explicitly dealt with in the model. In reality, ecosystem variables such as predator and prey population sizes, fishing profit, fishing fleet size, workforce in the fishing industry etc. interact with each other, and a control applied to one variable is likely to influence other variables in the system in some way. As a consequence, objectives for individual variables in the system should not be viewed separately by managers because they may be antagonistic. Instead some kind of compromise between the desired states for the different variables should be pursued. Ways of efficiently reaching such compromises based on-existing understanding of how the variables interact are currently being explored in the context of the pelagic system (e.g. Stewart and Brent 1988). However, in most instances to date the multi-objective nature of management problems in the Benguela have been largely ignored (or not formally dealt with) in favour of a single-species approach. This approach is not possible with the seal-fishery interaction problem because it is, by definition, a multi-species problem. Some form of multi-species modelling is therefore required to evaluate alternative management options for seals.

APPLICATION OF A SCHEMA APPROACH TO THE "SEAL PROBLEM"

Starfield *et al.* (in press) argue that a "toolbox" of parsimonious, decision driven models should be developed to aid decision making for problems involving complex ecosystems. This is because there is seldom enough data of the right kind and of good enough quality to parameterise large models that contain all the variables of interest to managers, and in any event the output from such models are often difficult to interpret. Management objectives and control measures vary from year to year, depending

TABLE 1 : Schema used for structuring the seal-fishery decision environment (from Starfield *et al.* in prep).

SCOPE → OBJECTIVE ↓	Single species	Isotrophic multi-species	Predators and prey	Industry and fish
Ecological	1	2	3	4
Economic and social	5	6	7	8
Management, monitoring and research	9	10	11	12

on the immediate pressures on the decision makers and recent events both in the natural system and the fishery. Without clear management policy, research aimed at assisting in decision making for seal and fish populations must explore many alternative objectives as well as strategies for moving towards these objectives. This can be achieved with the aid of a suite of models each of which is designed to investigate a particular aspect.

The toolbox approach is facilitated by using a schema such as in Table 1 to structure the decision environment. The rows in this schema correspond to the decision objectives (purely ecological objectives, objectives related to economic and social values e.g. profit and employment, objectives dealing with management, monitoring or research e.g. when to cull, which sex or age groups to cull, when to census, what is most important to measure). The columns correspond to model scope (which components of the system are dealt with and which are left out).

The schema approach was used to good advantage during the series of seal-fishery interaction workshops held in 1987 to specify a number of different models of the problem. Not all of the models which could be specified were developed, and some of those that were built were severely data limited and therefore of little predictive use. Such models were termed "speculative" (Starfield and Bleloch 1986) and were considered to be useful for determining sensitivity to structure and parameters so as to determine priorities for future fieldwork, as well as for exploring the potential range of behaviour from models with plausible structure and parameters, and thus minimising future surprises from the real system. Some models of the dynamics of the seal population were already in existence before the start of the workshops (e.g. Shaughnessy and Best 1980, Butterworth *et al.* 1987), but their objectives are not specifically decision related.

The remainder of this document reports on the seal-fishery interaction workshops held during 1987, and then describes the models that were developed during this period. The cell into which each model fits in Table 1 is given. The results from the models are evaluated with respect to their usefulness for management and future lines of research are identified.

THE SEAL-FISHERY INTERACTION WORKSHOPS AND MODELS

The first workshop was held on 2 March 1987 and was attended by modellers and a seal biologist to review the relevant available information. Over the next five months a number of preliminary models were developed with two groups of modellers working independently of each other. These preliminary models were presented and discussed at a meeting on 5 August attended by modellers shortly after the arrival of Prof AM Starfield. Prof Starfield played a leading rôle in this and all subsequent workshops. The need for revision of the existing preliminary models and for the development of new models was established at this meeting and some new modellers were brought in to assist. These new and refined models were critically examined by seal biologists, modellers, resource managers and members of the fishing industry at a workshop on 13 August and subsequently further revision was undertaken.

Finally, on the 24 August, the progress of these workshops was communicated to a large open meeting of Benguela Ecology Programme participants and other interested people. Even at this stage some models were only in the early stages of construction and although this meeting marked the termination of the series of workshops and the departure of Prof Starfield, some further development of the models was carried out up until the end of 1987 and is also reported here. An in-depth PhD study of the seal-fishery interaction problem was initiated in January 1988 by Ms PA Wickens and this will expand on some of the aspects considered in the seal-fishery interaction workshops held in 1987. Some of the models discussed below are fairly elementary, but had a dual function of raising the level of insight of participants in the workshop, as well as being directed towards resolving the seal-fishery interaction problem.

Workshop 1

Date : 2 March 1987

Objectives : To scope the seal-fishery interaction problem and review the relevant available information

Participants : Prof JG Field, Dr RJM Crawford, Dr PA Shelton, Dr JHM David & Ms PA Wickens

Conclusions : A discussion was held to identify the positions in the schema for the models and the general model attributes.

Schema position -

From a consideration of the various cells of the schema (Table 1), the need for several kinds of models was anticipated. A major contention of the fishing industry is that seals consume valuable fish that could otherwise be harvested to increase profits. Focussing on cell 7 of the schema facilitated thinking about models that included seals and commercially exploited fish species, to examine such questions as the effect of reduced seal predation on fish production. If the assumption is made that seals are going to be culled (ignoring for the moment the rationale behind such a measure), then consideration of cell 9 leads to models that examine the effect of different culling strategies (e.g. culling cows or culling pups, culling at different times of the year, etc.). Also, within cell 9 it was anticipated that a single-species model could be run with different values for biological parameters such as fecundity, age at maturity, harem size etc. to examine the sensitivity of the model to uncertainty about these parameters, and so identify priorities for future field research. Expanding on this to include seals and fish, models fitting into cell 11 of the schema would answer questions related to the degree of culling that would be necessary before a change in fish yield could be expected to be measurable.

General Attributes -

- Purpose :** To determine the effect of age and sex selective culling on seal and fish populations
- Description :** Simple speculative models
- Variables :** A maximum of 4 state variables (2 predators and 2 prey - however since seal predators include fish, birds and mammals this was excluded as being impractical) and 3 forcing functions (stochastic environment, seal culling and fish harvesting)

- Constraints :
- insufficient knowledge on the age-structure of the population
 - minimum breeding age of males (approx. 12 years)
 - reproductive life-span
 - longevity (30 years in zoos but the dental ageing technique can only be used for up to 13 years)
 - carrying capacity
 - density-dependent factors (space not important because seals can tolerate crowding therefore food is probably the limiting factor)
 - culling disturbance effects

Data : Most of the data is obtained from tag-recapture experiments, aerial censusing, observations, culls and seals shot at sea and includes population size, age-dependent birth rate, age- and sex-dependent natural mortality rates, harem size and prey consumption rates

TABLE 2 : Data for preliminary models

PARAMETER	VALUE	SOURCE
<u>SEALS</u>		
<i>Pregnancy rate</i>		
4 year-old	0.5	David (pers. comm.)
5 year-old	0.75	" " "
6+ year-old	1.0	" " "
All age classes combined	0.78	David (1987a)
<i>Harem size</i>	21	David (pers. comm.)
<i>Percentage seals born female</i>	0.45	Butterworth <i>et al</i> (1987)
<i>Natural mortality</i>		
0 year-old	0.08	David (pers. comm.)
1 to 3 year-old	0.14	Butterworth <i>et al</i> (1987)
4+ year-old	0.08	" " " "
<i>Body weight</i>		
1 year-old	20 kg	David, pers. comm.
2 year-old	25 kg	" " "
3 year-old	32 kg	" " "
4 year-old (F/M)	40/52 kg	" " "
5 year-old (F/M)	50/75 kg	" " "
6 year-old (F/M)	60/90 kg	" " "
Average weight	60 kg	David (1987b)
<i>Consumption (% of body weight)</i>	8 % . day ⁻¹	David (1987b)
<u>FISH : Hake</u>		
<i>Natural mortality</i>	0.3	(Leslie, 1986)
<i>Fishing mortality (1984)</i>		
Division 1.6 :		
1 year-old	0.11	(Leslie, 1986)
2 year-old	0.50	"
3 year-old	0.51	"
4 year-old	0.49	"
5 year-old	0.63	"
6 year-old	0.70	"
7 year-old	0.73	"
8 year-old	0.68	"
9 year-old	0.68	"
All age classes combined	0.31	Estimated from David (1987b)
<i>Body weight</i>		
Division 1.6 :		
1 year-old	46 g	(Leslie, 1986)
2 year-old	181 g	"
3 year-old	419 g	"
4 year-old	752 g	"
5 year-old	1 164 g	"
6 year-old	1 636 g	"
7 year-old	2 149 g	"
8 year-old	2 685 g	"
9 year-old	3 234 g	"

First Modelling Exercise

Model 1

Cell : 7 & 11

Author : PA Wickens

Brief description : Deterministic, discrete, multi-species (seal - fish) simulation models

Hardware/Software : Macintosh, STELLA

Purpose : To examine the effects of different seal culling strategies (culling pups, cows and bulls) on the dynamics of seal and fish populations

State Variables : Seals (age classes - 0..3 years, cows 4+, bulls 4+), fish prey populations (one lumped population *or* two main Namibian prey species - horse mackerel and goby *or* three main South African prey - anchovy, squid and hake)

Units : Numbers of seals and biomass of fish

Parameters : Seals - age-dependent natural mortality rate; pregnancy rate; annual consumption rate. Fish - natural mortality rate; production rate; carrying capacity. Parameter values are given in Table 2.

Driving forces : Seal cull and fish harvest

Time step : 1 year

Time horizon : 50 years

Assumptions and constraints : Disturbance caused by culling has no effect on other sectors of the population; constant environment, linear density dependence in fish population growth determined by carrying capacity; seal population growth determined by the standing stock of fish; only seals 4 years and older reproduce.

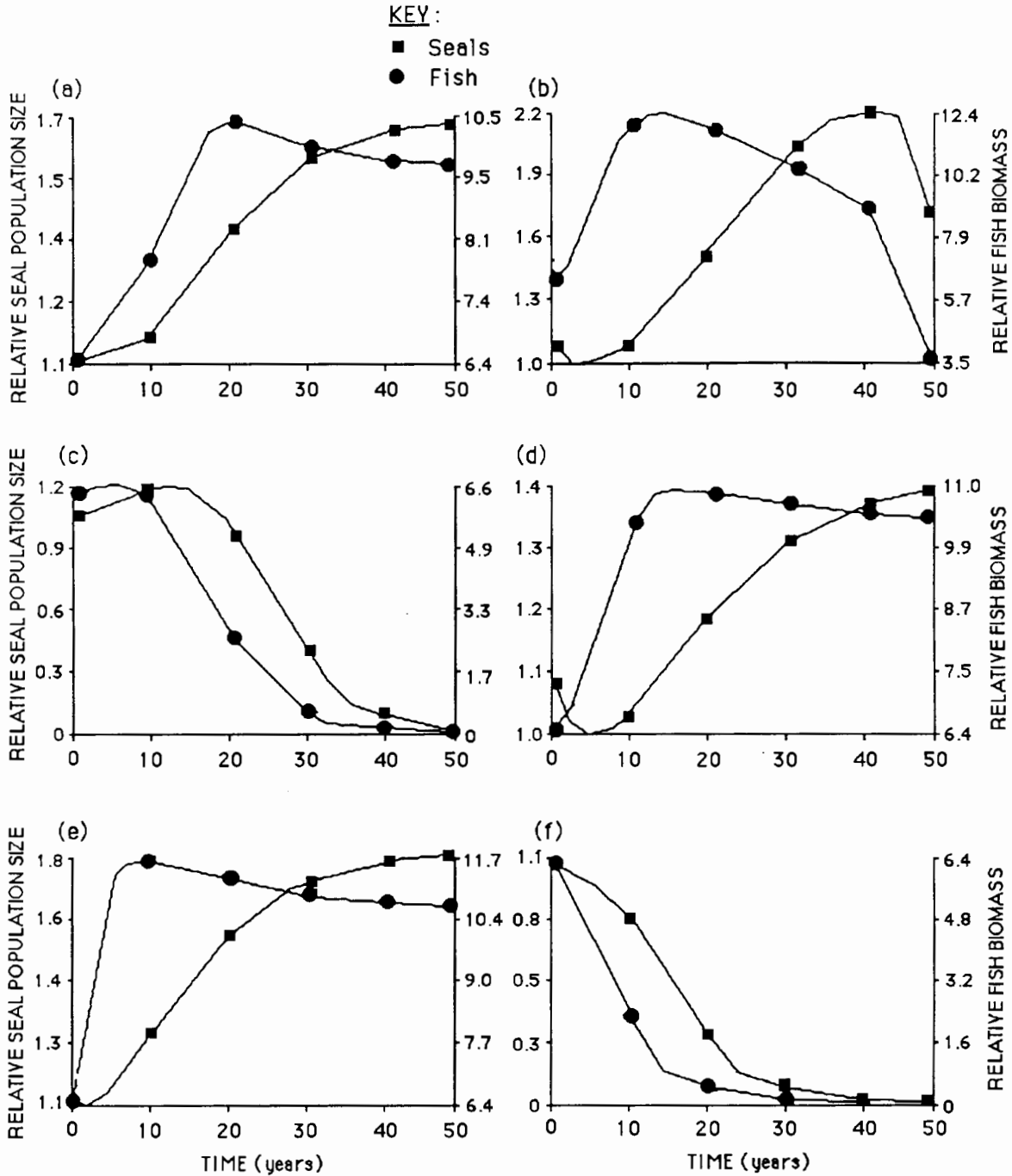
Equations :

$$S_0 = SC_{4+} P M_0$$

$$S_i = S_{i-1} (1 - M_{i-1} - C_{i-1}) \quad (i = 1 \text{ to } 3)$$

$$E = \sum_{i=1..4+} S_i R W_i$$

FIGURE 1 : Selected results from Model 1 with (a) a constant *proportion* of fish being harvested and seals culled and (b) a constant *amount* being fished and culled. Using the constant proportion model pup culling was decreased (c) and increased (d) by 5 % and fishing was likewise decreased (e) and increased (f).



$$F = F (1 + FP - FM - F/CC - H) - E$$

$$S_{4+} = S_3 (1 - M_3 - E/F - C_{4+}) + S_{4+} (1 - M_{4+} - C_{4+})$$

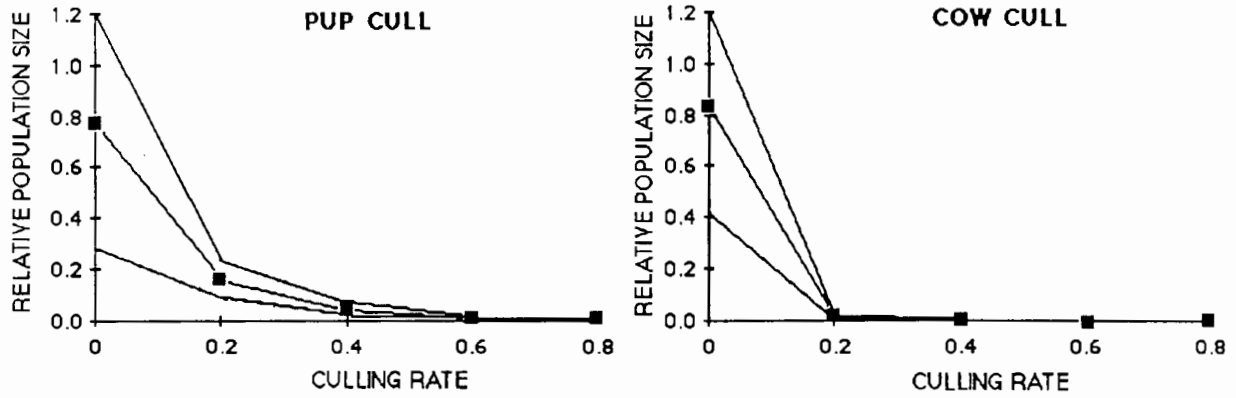
Where :

- S_i = number of seals in i^{th} age class
- SC_{4+} = number of cows aged 4+ years
- P = seal pregnancy rate
- M_i = annual seal natural mortality rate in the i^{th} age class
- C_i = annual seal culling rate in the i^{th} age class
- R = annual consumption per individual seal
- E = annual seal consumption of fish
- F = fish biomass
- FP = annual fish production rate
- FM = annual fish natural mortality rate
- CC = fish carrying capacity
- H = annual fish harvest rate
- W_i = mass of seal in the i^{th} age class

Output : Relative change in seal population size and fish biomass, when a constant proportion of seals are culled or fish are harvested - Fig. 1 (a), when a constant number of seals are culled or constant mass of fish are removed - Fig. 1 (b), decreasing the pup cull rate by 5% - Fig. 1 (c), increasing the pup cull rate by 5% - Fig. 1 (d), decreasing the fish harvest rate by 5% - Fig. 1 (e), increasing the fish harvest rate by 5% - Fig. 1 (f).

Conclusions : The models in which there were more than 2 prey populations were very unstable even under different conditions such as preferential or opportunistic feeding and when culling and fish harvesting as either constant amounts or constant proportions. Only the results of the lumped prey model (ie : two-species model) are shown. When a constant proportion of seals are culled or fish are harvested the populations reach equilibria; when a constant number of seals are culled or constant mass of fish are removed, the populations may collapse. Decreasing the cull rate of seal pups by 5% caused the seal population to initially increase from equilibrium, lagging a small increase in fish population size, before both seals and fish declined. Increasing the cull rate of seal pups by 5% caused the fish population to increase quite rapidly but after a lag this was also followed by an increase in the seal population size. Decreasing the fish harvest rate by 5% caused both seals and fish population sizes to increase. Increasing the fish harvest rate by 5% caused both the seal and fish population sizes to decrease.

FIGURE 2 : Results from Model 2 demonstrating that for the same culling rate the population declines more rapidly when cows are culled (a) than when pups are culled (b). Uncertainty in pregnancy rate and annual female survival is reflected by 1 standard deviation on the graphs.



Model 2

Cell : 9

Authors : PA Shelton & RJM Crawford

Brief description : Stochastic (Monte Carlo), discrete, single-species (seal) simulation model

Hardware/Software : Macintosh, MacPascal

Purpose : To examine the effect of culling cows and pups given uncertainty in female natural mortality rate and pregnancy rate

State Variables : Female seal population

Units : Numbers of seals

Parameters : Female natural mortality rate (uniform distribution, 0.04 - 0.4); pregnancy rate of 4 year old and older females (uniform distribution, 0.08 - 0.1). Parameter values are given in Table 2.

Driving forces : Seal cull

Time step : 1 year

Time horizon : 20 simulations over 50 years

Assumptions and constraints : Only seals 4 years and older reproduce; uniform distributions in pregnancy and natural mortality rates with given ranges

Equations :

$$S_{t+1} = S_t (1 - M_t) (1 - C_c) + S_{t-3} P (1 - C_p)$$

Where :

S_t = number of female seals in year t

M_t = annual natural mortality rate in year t

C_p, C_c = annual culling rate of cows and pups

P = pregnancy rate of females 4+ (= pups born in year $t+1$)

Output : Relative change in population size, \pm one standard deviation limits, for culling pups - Fig. 2(a), and culling cows - Fig. 2(b).

Conclusions : For the same culling rate the population declines more rapidly when cows are culled than when pups are culled because both the cow and her future pups are both lost from the population whereas pups have to survive to age 4 before producing pups of their own; at the annual culling rate of 0.2 the 95% confidence limits on population size overlap for pup and cow harvests whereas at higher levels of culling they do not, given the uncertainty with respect to natural mortality and pregnancy rate.

Model 3

Cell : 7

Authors : PA Shelton & RJM Crawford

Brief description : Deterministic, discrete, single-species (seal) simulation model

Hardware/Software : Macintosh, MacPascal

Purpose : To examine the effects of different seal culling strategies (culling pups, cows and bulls) on the dynamics of seal population and fish consumption

State Variables : Seals (age classes - 0..3 years, cows 4..6+ years, bulls 4..6+ years)

Units : Number of seals and biomass of fish

Parameters : Age-dependent natural mortality rates, consumption rate and pregnancy rates, harem size, proportion of pups that are female. Parameter values are given in Table 2.

Driving forces : Seal cull

Time step : 1 year

Time horizon : 20 years

Assumptions and constraints : Only seals 4 years and older breed; if cows are culled then the pup will die; only those cows that produce a pup or those bulls that have a harem can be culled; linear density dependent pup natural mortality rate dependent on size of adult population; males consume 1.8 times more fish than females; bulls hold a harem from their 6th year provided there are sufficient females.

Equations :

$$SP_{0,t} = \sum_{i=4..6} (P_i SC_{i,t})$$

$$SP_{1,t+1} = (SP_{0,t} - (SP_{0,t} C_c) - ((SP_{0,t} - SP_{0,t} C_c) C_p)) (1 - M_{p,t})$$

$$SP_{2,t+1} = SP_{1,t} (1 - M_a)$$

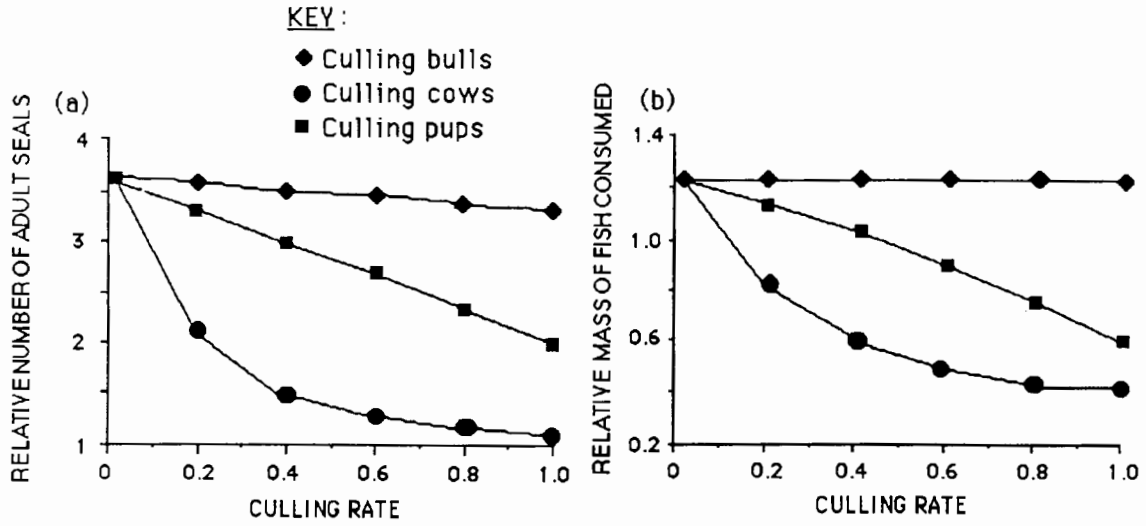
$$SP_{3,t+1} = SP_{2,t} (1 - M_a)$$

$$SC_{4,t+1} = SP_{3,t} (1 - M_a) D$$

$$SC_{5,t+1} = (SC_{4,t} - (SC_{4,t} P_4 C_c)) (1 - M_a)$$

$$SC_{6,t+1} = (SC_{5,t} - (SC_{5,t} P_5 C_c)) (1 - M_a)$$

FIGURE 3 : Results from Model 3 showing the seal population and quantity of fish consumed in the 20th year after the application of various annual culling rates to bulls, cows and pups.



$$\begin{aligned}
SC_{6,t+1} &= (SC_{6,t} - (SC_{6,t} P_6 C_c)) (1 - M_a) \\
SB_{4,t+1} &= SP_{3,t} (1 - M_a) (D - 1) \\
SB_{5,t+1} &= SB_{4,t} (1 - M_a) \\
SB_{6,t+1} &= SB_{5,t} (1 - M_a) \\
SB_{6,t+1} &= SB_{6,t} - (C_b \sum_{i=4..6} ((P_i SC_{i,t})/H)) (1 - M_a) \\
M_{p,t} &= 1 - (a - b \sum_{i=4..6} (SC_{i,t} + SB_{i,t})) \\
E_t &= \sum_{i=0..3} (R_p SP_{i,t}) + \sum_{i=4..6} ((R_c SC_{i,t}) + (R_b SB_{i,t}))
\end{aligned}$$

Where :

- $SP_{i,t}$, $SC_{i,t}$, $SB_{i,t}$ = number of pups, cows and bulls in the i^{th} age class in year t
- P_i = pregnancy rate of females in the i^{th} age class
- M_a = annual natural mortality rate of seals aged 1+ years
- $M_{p,t}$ = density-dependent annual pup natural mortality rate in first year of life for year t
- a, b = parameters for linear density dependence
- D = proportion of pups that are female
- H = harem size
- C_p, C_c, C_b = annual cull rate of pups, cows and bulls
- R_p, R_c, R_b = weight of fish eaten annually per pup, cow and bull
- E_t = seal consumption of fish in year t

Output : Adult population size after 20 years - Fig. 3 (a) and the tons of fish consumed in the 20th year - Fig. 3 (b) at various culling rates

Conclusions : Although bulls are assumed to eat 1.8 times more fish than cows, culling bulls is ineffective because only those that hold a harem are available. Culling cows is most effective in terms of both reducing the population and in reducing the amount of fish consumed.

Workshop 2

Date : 5 August 1987

Objectives : To examine critically the models developed so far and to discuss further modelling direction

Participants : Prof AM Starfield, Prof JG Field, Dr RJM Crawford, Dr PA Shelton, Ms PA Wickens & Mr HA Junod.

Conclusions : The results from Models 1 - 3 were presented and discussed. Model 1 gave typical Lotka-Volterra predator-prey type results. The dynamics are largely determined by the density dependent growth rate of the fish population and the dependence of the seal population on the amount of prey available. The outcome is sensitive to the parameters and is strongly influenced by culling seals or harvesting fish. Models 2 and 3 gave insight into the effect of culling different components of the seal population. Model 2 is possibly the simplest representation of the seal population. There is no density dependence or age structure and only the female component of the population is modelled. Because pregnancy and natural mortality rates can vary, these were selected randomly from a uniform distribution spanning minimum and maximum values. In the absence of density dependence the population can either be constant (when births exactly match deaths), grow exponentially or decline exponentially. The uncertainty in the parameter values can result in individual runs of the Monte Carlo simulation being quite variable over the 20 year time horizon, but on average the seal population declines exponentially at all culling rates. What is of interest is the much larger affect culling cows has on the population compared with culling pups, the reason being that by removing a female her unborn pup is also lost. Model 3 emphasizes this point with a much more complex model which includes age structure and density dependence. The results from this model shows that the amount of fish consumed annually by seals also decreases most for culling cows, even though bulls eat nearly twice as much fish per individual than cows in the model.

Prof Starfield commented on the modelling approach adopted to date and suggested that further modelling proceed at three levels:

- (i) a seal model from which the amount of fish consumed at different seal population sizes resulting from culling could be determined,
- (ii) a fish model in which the effect of different levels of fish consumption could be examined, and

- (iii) a seal-fish model in which both the seal and fish populations were included and their interaction modelled.

He suggested that some important questions to attempt to answer with these models were :

- (i) what effect do different culling strategies (culling pups, cows or bulls) have on the seal population (population size, age structure, sex structure) and fish consumption?
- (ii) what would the effect of culling 100% of the population on one island rather than 10% of the total population distributed between all colonies ?
- (iii) how do different seal density-dependent functions affect the model and how important is it to understand these better ? (look in the literature for different functions for example, Eberhardt, 1981)
- (iv) what is the time delay before any culling effect would be noticeable (probably a 4+ year effect if pups are culled or a 10+ year effect if adults are culled),
- (v) what are the short (5 years) and long (20 years) term effects of culling?
- (vi) is culling cost effective ?

Second Modelling Exercise

Model 4

Cell : 1 & 9

Author : PA Wickens

Brief description : Deterministic, discrete, single-species (seal) simulation model

Hardware/Software : Macintosh, MacPascal

Purpose : To examine the effect of different culling strategies (culling pups, cows or bulls) on the number of seal culled, the seal population (population of feeding seals, age and sex structure), and fish consumption

State Variables : Seals (age classes - 0..3 years, cows 4..6+ years, bulls 4..6+ years)

Units: Number of seals

Parameters : Age-dependent natural mortality rate, pregnancy rate and body weight, harem size, consumption rate, carrying capacity. Parameter values are given in Table 2.

Driving forces : Seal cull

Time step : 1 year

Time horizon : 5 & 20 years

Assumptions and constraints: the density dependent function was assumed to be one in which pup natural mortality increased linearly with an increasing adult population; two assumptions about culling were made :

- only breeding cows are culled and one pup dies with each cow
- only territorial bulls are culled.

Equations :

$$F_p = \sum_{i=3..6} (P_i SC_i)$$

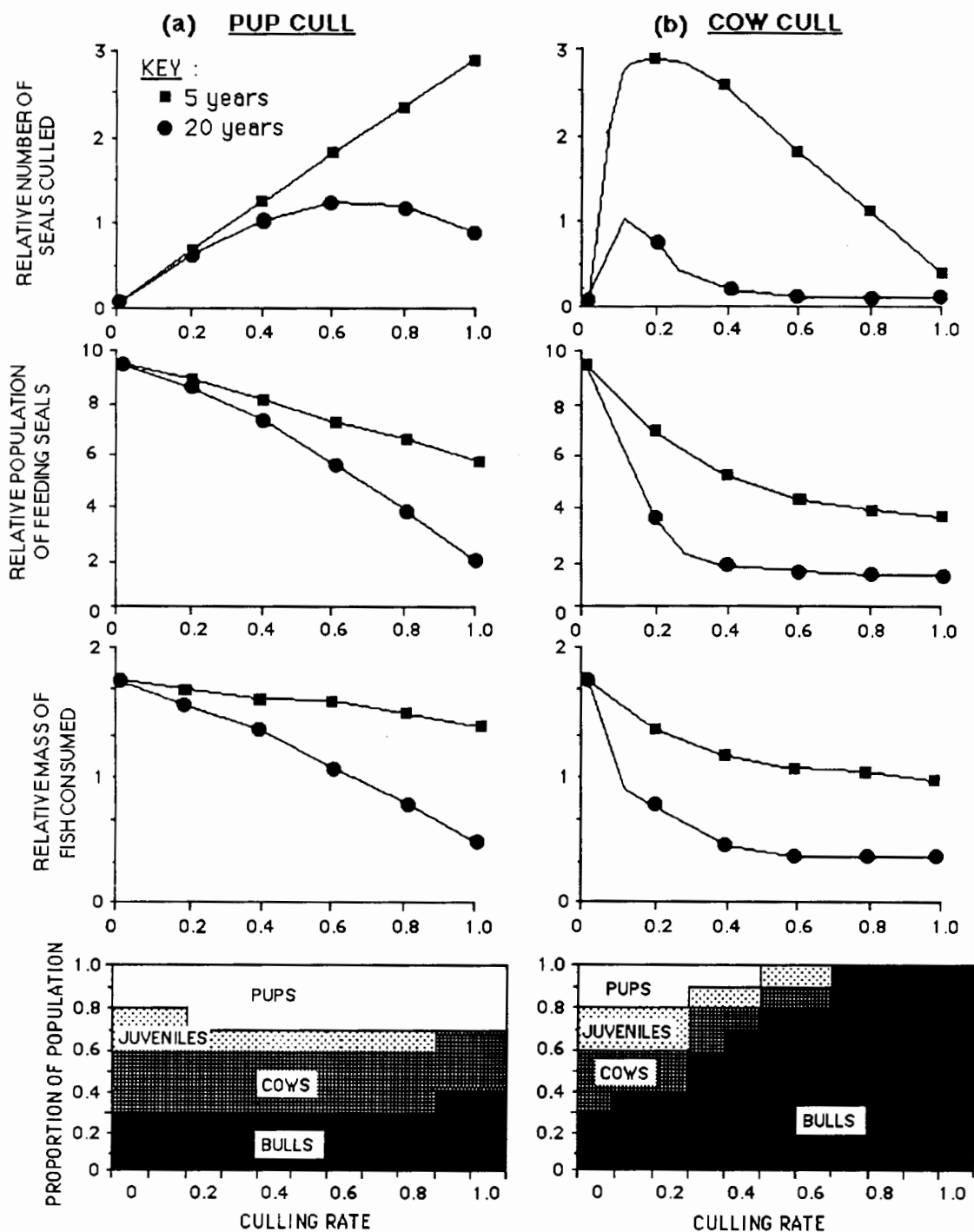
$$S_a = \sum_{i=3..6} SC_i + SB_i$$

$$S_0 = F_p$$

$$S_1 = S_0 ((1 - M_0) (1 - S_a/CC) - C_c - C_p (S_0 - C_c))$$

$$S_{2..5} = S_{1..4} (1 - M_{1..4})$$

FIGURE 4 : Results from Model 4 giving an indication of the number of seals culled (a and b), the feeding population (c and d), the amount of fish consumed (e and f) and the sex/age ratio of the population (g and h) when pups and cows are being culled.



$$SB_{6+} = SB_5 (1 - M_{m5} - C_b F_p/H)$$

$$SC_{6+} = SC_5 (1 - MC_6 - C_c F_p)$$

$$E_t = \sum_{i=1..6} (S_i W_i R)$$

Where :

S_i = number of seals in i^{th} age class undifferentiated by sex

SC_i, SB_i = number of cows and bulls in the i^{th} age class

CC = carrying capacity of seals

S_a = number of adult seals

P_i = pregnancy rate of a cow in the i^{th} age class

M_i, M_{ci}, M_{bi} = natural mortality rate of juveniles, cows and bulls in the i^{th} age class

C_b, C_c, C_p = culling rate of bulls, cows and pups

F_p = number of cows producing pups

H = harem size

R = percentage body weight consumed by seals

E_t = total amount of fish consumed by seals

W_i = mass of seal in i^{th} class

Output : The relative number of seals culled, the relative population size of the feeding population of seals, the relative amount of fish eaten and the age/sex composition of the population for a periods of 5 and 20 years for pup culling - Fig. 4(a) and cow culling - Fig. 4(b).

Conclusions : Culling cows has the greatest effect on the feeding population of seals and therefore the amount of fish consumed, with the least number of individuals culled. However the sex ratio of the population becomes skewed towards an increasing proportion of bulls at high culling rates. When pups are culled the sex ratio remains approximately the same. A bull cull had a minimal effect and the results are not shown.

Model 5

Cell : 5 & 8

Authors : PA Shelton & RJM Crawford

Brief description : Deterministic, discrete single-species (hake) simulation model

Hardware/Software : Macintosh, MacPascal

Purpose : To calculate the effect on the cumulative yield to the fishery from one cohort of fish over its entire lifespan with age dependent fishing mortality, using as input the amount of fish eaten by seals under different culling strategies (output from Model 4).

State Variables : Hake (1 cohort)

Units : Number and biomass of hake and yield in mass

Parameters : Age-dependent body weight and fishing mortality, natural mortality. Parameter values are given in Table 2.

Driving forces : Seal consumption of hake after 20 years at at different culling rates as estimated by Model 4

Time step : 1 year

Time horizon : 25 years

Assumptions and constraints : Seals only consume 2 year-old hake

Equations:

$$H_{i+1} = (H_i e^{-(M/2 + F_i/2)} - C/W_i) e^{-(M/2 + F_i/2)}$$
$$Y = \sum_i [(F_i / (F_i + M) H_i e^{-(M/2 + F_i/2)} W_i) + (F_i / (F_i + M) (H_i e^{-(M/2 + F_i/2)} - C/W_i) e^{-(M/2 + F_i/2)} W_i)]$$

Where:

H_i = number of hake in the i^{th} year class

M = instantaneous natural mortality rate

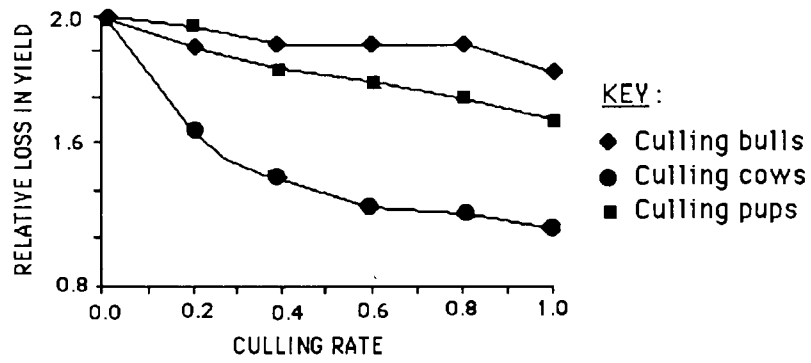
F_i = instantaneous fishing mortality rate on the i^{th} year class

Y = yield

W_i = weight of hake in the i^{th} age class

C = tons of hake consumed by seals (output from Model 4)

FIGURE 5 : Results from Model 5 showing the relative loss in hake yield from a cohort of hake after the application of different culling strategies to the seal population after a period of 20 years.



Output : The relative loss in hake yield from a cohort of hake after the application of different culling strategies to the seal population for a period of 20 years - Fig. 5.

Conclusions : The loss in hake yield from the commercial fishery to the seals is reduced most effectively by culling cows and least effectively by culling bulls. At cow culling rates higher than 0.2 there is only a further marginal increase in fish yield.

Workshop 3

Date : 13 August 1987

Objectives : To review modelling progress and obtain critical comment from the seal biologists and resource managers

Participants : Prof AM Starfield, Prof JG Field, Dr RJM Crawford, Dr PA Shelton, Ms PA Wickens & Mr HA Junod (modellers); Dr JHM David, Dr P Best & Mr H Oosthuizen (seal biologists); Mr G de Villiers (manager), Mr A Punt (mathematician) & Ms K Knox & Mr C Attwood (Zoology students)

Conclusions : Prof Field, as chairman of the meeting, outlined the objectives and approach to the project. Ms Wickens and Dr Shelton presented some of the objectives, assumptions and predictions of the models that had been developed so far, and this formed the basis for discussion. Several suggestions were made by the seal biologists regarding improving assumptions or parameter estimates :

- (i) When a cow is culled, one additional life will be lost (the foetus) and possibly two, if the pup is still dependent on the cow.
- (ii) The possibility of harvesting non-territorial bulls, because they are available on the periphery of breeding colonies and on non-breeding colonies, was given consideration. It was noted that if territorial bulls are culled they will be replaced by "spare" bulls, but the harem size, and therefore pup production, will probably be reduced. This is based on the observation by Dr David that after a large bull cull at Kleinsee (1984) the number of pups born was severely reduced.
- (iii) It was decided to accept a sex ratio of 1:1 in further modelling.
- (iv) Although males are sexually mature at 3 to 4 years, they cannot mate until they are able to hold territories which occurs 13 to 14 years of age. It was decided to treat seals along the whole coast as one population because there is considerable movement between colonies.
- (v) The following estimates for fecundity (annual pregnancy rate per female) were agreed to by the seal biologists: 0 to 3 year olds = 0%, 4 year olds = 10%, 5 and 6 year olds = 68%, 7+ year olds = 81%. The rate for 7+ year olds may decline with age.
- (vi) The participants made some calculations of annual natural mortality rates of females from data on branded animals

TABLE 3 : Calendar of events taking place in a seal colony

MONTH	INDIVIDUALS ON COLONY	BEST TIME FOR PARTICULAR CULL
November	Bulls arrive first to set up territories for breeding. Females arrive to pup. Breeding starts towards end of the month.	Bulls
December	Breeding period tailing off towards end of month.	
January	Bulls leave colony	
January - June	Cows feeding pups until they are about 7 months old. Cows on the colony for about 50 % of the time.	
July	Until now cows are feeding pups.	Pups
August	Some pups are weaned and can survive alone.	Pups, Cows
September	Still some pups and cows on colony	Cows
October	Pups all weaned (10 - 11 months old). Least number of individuals on colony	

presented by Dr David. Estimates varied from 0.15 to 0.05. The value of 0.08 used in the model was considered adequate. It was pointed out by the seal biologists that the natural mortality for pups would vary with area. For example, pups on an island could be washed away in storms whereas on the mainland colonies predators (brown hyena and jackal) are an additional mortality factor. A model including seal predators was considered feasible.

- (vii) The seal biologists considered it necessary to take into account the uncertainty in estimating diet. Seals discard the head when eating large hake so no otoliths are found. Diet is also only sampled in the inshore region.
- (viii) A calendar of events at a colony over a year period was drawn up by the Workshop and is presented in Table 3. The workshop considered that the best time for a bull harvest is when the bulls arrive to set up territories, before the cows arrive. A cow harvest would be best in August/September once the pups are weaned (although it would be less effective in terms of reducing seal population size than a cull earlier in the year when pups are still dependent on cows for food). A traditional pup harvest for pelts is in July/August when the pups are 7/8 months old and disturbance is minimal.
- (ix) The need for input from managers with regard to the management objective for seals was stressed in the workshop. In this respect the use of seal products should be taken into account, as this can influence the type of cull. The market for pelts is small but there is some market for bull genitalia, and carcasses have been used for meal and crab bait at Cape Cross.
- (x) It was re-emphasized that one must look at long and short-term trends because some years can elapse before the effect of a cull is noticeable.

TABLE 4 : Updated table of data for the seal-fish models

PARAMETER	VALUE	SOURCE
<u>SEALS</u>		
<i>Pregnancy rate</i>		
4 year-old	0.1	David (pers. comm.)
5 year-old	0.68	" " "
6+ year-old	0.81	" " "
All age classes combined	0.78	David (1987a)
<i>Harem size</i>	21	David (pers. comm.)
<i>Percentage seals born female</i>	0.45	Butterworth <i>et al</i> (1987)
<i>Natural mortality</i>		
0 year-old	0.08	David (pers. comm.)
1 to 3 year-old	0.14	Butterworth <i>et al</i> (1987)
4+ year-old	0.08	" " "
	0.05 - 0.15	David (unpubl. data)
<i>Body weight</i>		
1 year-old	20 kg	David, pers. comm.
2 year-old	25 kg	" " "
3 year-old	32 kg	" " "
4 year-old (F/M)	40/52 kg	" " "
5 year-old (F/M)	50/75 kg	" " "
6 year-old (F/M)	60/90 kg	" " "
Average weight	60 kg	David (1987b)
<i>Consumption (% of body weight)</i>	8 % . day ⁻¹	David (1987b)
<u>FISH : Hake</u>		
<i>Number of recruits per spawning biomass</i>	1310	Estimated from Leslie, (1986)
<i>Natural mortality</i>	0.3	(Leslie, 1986)
<i>Fishing mortality (1984)</i>		
Division 1.6 :		
1 year-old	0.11	(Leslie, 1986)
2 year-old	0.50	"
3 year-old	0.51	"
4 year-old	0.49	"
5 year-old	0.63	"
6 year-old	0.70	"
7 year-old	0.73	"
8 year-old	0.68	"
9 year-old	0.68	"
All age classes combined	0.31	Estimated from David (1987b)
<i>Body weight</i>		
Division 1.6 :		
1 year-old	46 g	(Leslie, 1986)
2 year-old	181 g	"
3 year-old	419 g	"
4 year-old	752 g	"
5 year-old	1 164 g	"
6 year-old	1 636 g	"
7 year-old	2 149 g	"
8 year-old	2 685 g	"
9 year-old	3 234 g	"

Third Modelling Exercise

Model 4 (revised)

Cell : 7 & 11

Author : PA Wickens

Brief description : Deterministic, discrete, single-species (seal) simulation model

Hardware/Software : Macintosh, MacPascal

Purpose : To examine the effect of different culling strategies (culling pups, cows or bulls) on the number of seals culled, the seal population (population of feeding seals, age and sex structure), and fish consumption

State Variables : Seals (age classes - 0..3 years, cows 4..6+, bulls 4..6+ years)

Units : Number of seals

Parameters : Age-dependent natural mortality rate, pregnancy rate and body weight, harem size, consumption rate, carrying capacity. Parameter values are given in Table 4.

Driving forces : Seal cull

Time step : 1 year

Time horizon : 5 & 20 years

Assumptions and constraints : the density dependent function was assumed to be one in which pup natural mortality increased linearly with an increasing adult population; two assumptions about culling were made :

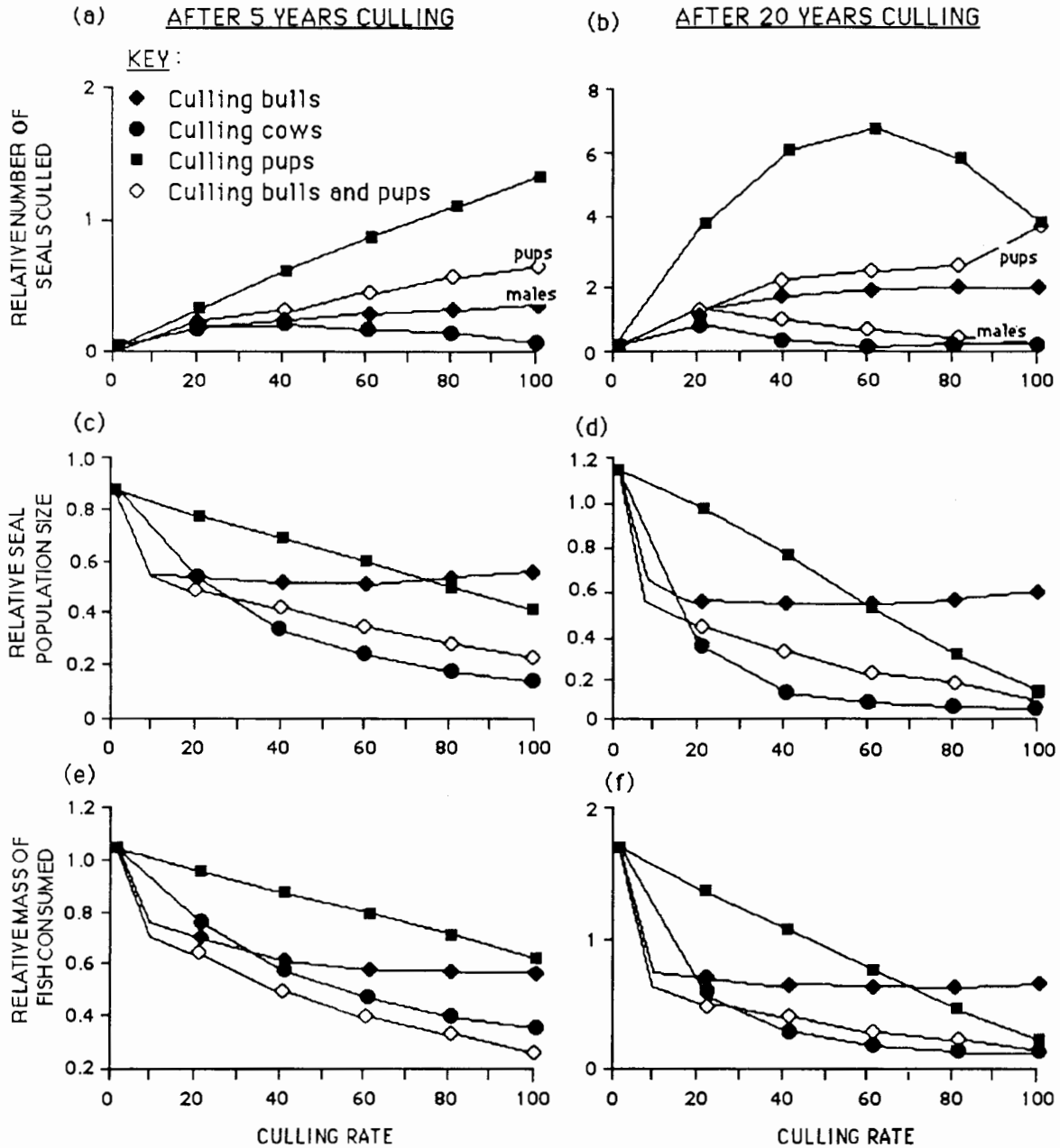
- only breeding cows are culled and one pup dies with each cow
- only territorial bulls are culled, territorial bulls are culled first and the disturbance causes the pup production of these harems to be reduced by half.

Equations :

In addition to the equations presented in Model 4, the following was added for the case when territorial bulls are culled -

$$S_0 = F_p (1 - 0.5 C_m H/F_p)$$

FIGURE 6 : Some results from the revised Model 4 giving an indication of the number of seals culled (a and b), the population size (c and d) and amount of fish consumed (e and f) under different culling strategies in short-term (5 years) and long-term (20 years).



Where :

S_0 = number of pups born

C_b = culling rate of bulls

F_p = number of cows producing pups

H = harem size

Output : The model with the new parameter values was run for 5 years to allow adjustment to parameters then culling was introduced. Fig. 6 shows the results after 5 years (a, c and e) and after 20 years (b, d, and f).

Conclusions : Culling pups has the least effect on seal population size and amount of fish consumed, but with the greatest number of animals killed. Culling bulls reduces the population by approximately half at all culling rates and likewise with fish consumption. Culling cows has a large effect particularly in the long-term and the least number of animals are killed. Culling a combination of pups and bulls also has the largest effect on the amount of fish consumed, reducing it substantially. This is particularly noticeable in the short-term. In the long-term a cow cull causes a greater reduction in the amount of fish consumed than a pup and bull cull.

Model 6

Cell : 3 & 7

Author : HA Junod

Brief description : Deterministic, discrete, multi-species (seal-hake) simulation model

Hardware/Software : IBM-compatible PC, Fortran

Purpose : To examine the interaction between seals, the hake fishery and their common resource, hake, under different culling strategies for seals.

State Variables : Seals (age classes - 0..6 years) and hake (age classes 0..10 years)

Units : Numbers of seals and biomass of hake

Parameters : Seals - age-dependent natural mortality rate, pregnancy rate and body weight, squanchovy biomass, consumption rate. Hake - age-dependent natural mortality rate and body weight. Parameter values are given in Table 4.

Driving forces : Seal cull

Time step : 1 month

Time Horizon : 50 years

Assumptions and constraints : A constant biomass of "squanchovy" ("squanchovies" = combined biomass of squid and anchovy) was incorporated as an alternative food source for seals. Density-dependence was incorporated as linearly decreasing pup production with increasing spawning stock. Pup mortality was related to the condition of the mother in the last six months, a function of the ratio of food required to food available averaged over this period. "Squanchovy" biomass was taken to be equal to a proportion of the initial biomass of hake.

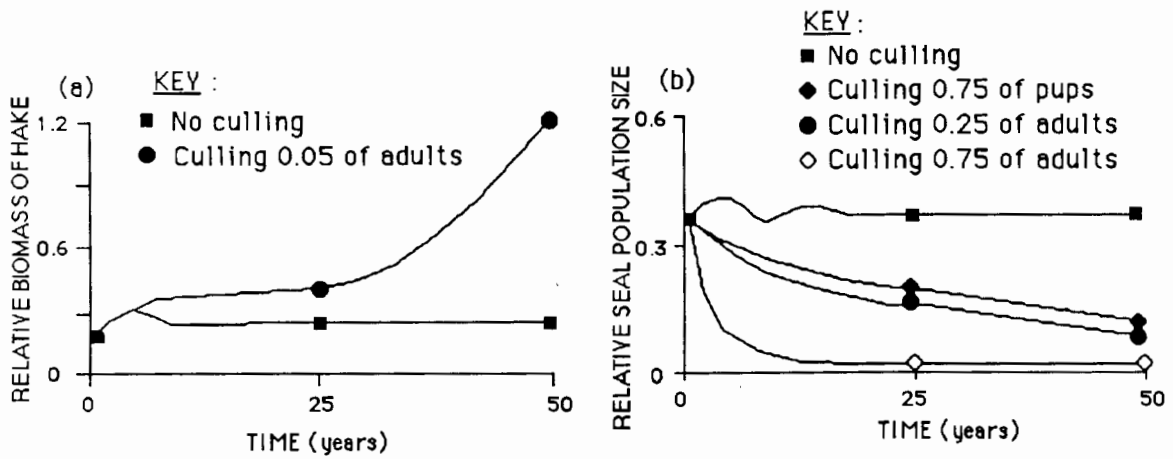
Equations :

For month k within year t (t subscripts omitted) :

$$FR_k = BW \sum_{i=1..6} (WS_i S_{i,k})$$

$$FAV_k = A + (H_{3,k} Wh_3)$$

FIGURE 7 : Some results from Model 6 showing changes under different culling strategies in the hake population (a) and seal population (b) in separate simulations.



$$\text{If } FAV_k/FR_k < X \text{ then } R_k = FAV_k/(X FR_k) \text{ else } R_k = 1$$

$$E_k = FR_k R_k H_{3,k} Wh_3/FAV_k$$

$$S_{i,k+1} = S_{i,k}(1 - Ms_i)$$

$$H_{i,k+1} = H_{i,k} (1 - Mh_i) - E/Wh_i - F/Wh_i H_{i,k}/\sum_{i=3..10} H_{i,k}$$

For year $t+1$ (year begins 1 December) :

$$D_{t+1} = \sum_{k=7..12} (1 - R_{k,t})$$

If $D_t > Y$ then for year $t+1$

$$Ms_0 = MMs_0^{0.083} \text{ else } Ms_0 = (0.1 + ((MMs_0 - 0.1)/Y) D_t)^{0.083}$$

$$S_{0,1,t+1} = \sum_{i=3..5} (P_i S_{i,12,t}) / 2$$

$$H_{0,1,t+1} = \sum_{i=3..9} H_{i,12,t} * RH$$

Where :

FR_k = food required by seals in month k

BW = percentage body weight of food consumed per month

Ws_i = weight of a seal in the i^{th} age class

$S_{i,k,t}$ = number of seals in the i^{th} age class in month k , year t

FAV_k = food available to seals in the k^{th} month

A = biomass of "squanchovy"

$H_{i,k,t}$ = number of hake in the i^{th} age class in month k , year t

Wh_i = weight of a hake in the i^{th} age class

X = critical value of FAV/FR below which R_k decreases linearly

R_k = degree to which seal population food requirement is satisfied, related to the FAV/FR

E_k = amount of food consumed by seals in month k

Ms_i = monthly natural mortality rate of seals in the i^{th} age class

$H_{i,k,t}$ = number of hake in the i^{th} age class in month k , year t

Mh_i = monthly natural mortality rate of hake in the i^{th} age class

D_t = cumulative food deficit

Y = critical value of the accumulated food deficit below which pup mortality decreases linearly

Ms_0 = monthly pup mortality

MMs_0 = maximum annual pup mortality

RH = annual hake recruitment per unit spawner biomass

Output : The relative change in population size of hake - Fig. 7 (a) and seals - Fig. 7 (b) over time for different culling strategies.

Conclusions : Pup culling was found to most ineffective with respect to reducing the seal population and reducing the effect on hake. Model output was found to be very sensitive to assumptions about values for X and Y (the critical values used in the density-

dependent functions). The hake population in the model had a tendency to decline to extinction under hake fishing. This behaviour was largely determined by a constant biomass of "squanchovy" maintaining a relatively high population of seals compared to the size of the hake population, leading to compensatory mortality on hake.

Model 7

Cell : 8 & 12

Authors : CG Attwood & K Knox

Brief description : An expert system using answers to questions to trigger rules which lead to one or more decisions relating to seals, the seal-fishery interaction or culling of seals.

Hardware/software : IBM-compatible PC, Starfield, Adams & Louw expert system shell

Purpose : To rationalise present thought on management strategies for, and the ethics involved in the exploitation of the South African fur seal. As many criteria as possible have been incorporated and all decisions are based on purely logical deductions. Many issues are purely subjective and are left to the user to decide upon.

System components : The system has 23 decisions, each reached by one or more of 55 rules, triggered by the answers to 29 questions.

Conclusions : The expert system forced users to think of many factors involved in deciding on management controls for the seal population (provided a rational check list for decision making). Managers should use the expert system to suggest a solution and then examine the logic pathway used in reaching the solution in some detail. One of the authors of the system felt it had little real scientific value. One author concluded that the interactions between man and seals need to be better quantified.

Presentation of results

Date : 24 August 1987

Objectives : To report on progress made during the workshops and modelling exercises

Presenters : JHM David, PA Shelton, PA Wickens, HA Junod

Audience : Benguela Ecology Programme participants

Summary : Dr David presented the background to the "seal problem" (see section on BACKGROUND TO THE "SEAL PROBLEM" in this report). Dr Shelton then described the series of workshops and modelling exercises that had taken place over the preceding weeks and months. Ms Wickens presented the revised seal model and results and Mr Junod put forward his preliminary model of the seal-hake interaction. Mr Attwood gave an example from an expert system designed by Ms Knox and himself. Prof Starfield then gave his comments on the project and the method of tackling the problem. In particular he made the point that on a controversial matter such as the culling of seals, the distinction must be made between scientific procedure and the morals, ethics and opinions of scientists involved in resource management problems. The expert system developed by Attwood and Knox was useful in this respect. Prof Starfield pointed out that while most of the models that had been developed were highly sensitive to the assumptions contained in them, the model building process itself allowed the identification of areas in which more information needs to be gained about the population dynamics of the species and the interaction between species.

Several comments and questions were received from the floor :

- (i) The natural mortality rate of females appear to be incorrect because even if 100 % of the pups were culled the residual population continues to produce more pups for at least 20 years (Model 4 (Revised)).
- (ii) Fish consumption is probably not 8 % of the body weight of seals for all size classes of seals. It is more likely that the percentage is greater for juveniles and smaller for adults.
- (iii) Are seals taking hake discarded by the fishery ?
- (iv) Who pays for the seal cull - the fishery or the state ? In either case the trade-off between culling and improvement of the fish yield should be considered by managers.

OVERALL CONCLUSIONS FROM THE EXERCISE AND SUGGESTIONS FOR FUTURE MODELLING WORK RELATED TO THE "SEAL PROBLEM"

Participants in the exercise generally found the workshop approach to be stimulatory and Workshop 3, in which a manager, biologists, and modellers used the existing models as a basis for discussion and interaction, was particularly successful. Such informed group interaction appears to be all too infrequent in addressing resource management problems. To improve on the approach in the future, it may be desirable to build fewer, more focussed models which are fully discussed by workshop participants during their development phase and which are extensively "played" with on the computer by the majority of participants and further debated before the existing models are revised or new models are developed. Careful records should be kept at this stage of model shortcomings, non-intuitive output, interesting results etc.

In most cases the models that were constructed were considered to be speculative, in that there was insufficient data or understanding to allow a rigorous approach to specifying model structure and fitting parameters. Although this necessarily precludes using these models as quantitative predictive tools in seal management, at least some of the results were robust to assumptions about structure or data and resurfaced in several of the models, and these may have some value in qualitatively guiding managers in their approach to the "seal problem". The two most important of these were :

- (i) culling cows with dependent pups is the most effective way of reducing the seal population and at the same time is most effective in reducing the consumption of fish by seals,
- (ii) culling pups or bulls is not an effective method of increasing fish yield. Culling cows may improve fish yield but a large number of animals would need to be killed (at least 40 % of all cows). This second point is dealt with in some detail in the treatment of the seal problem off Canada by Northridge (1986).

Another useful outcome of building these speculative models is that they caused biologists and modellers to make a very careful search of all available data to determine functional relationships, and in so doing, brought into focus areas where data are either poor or non-existent. Where model predictions are sensitive to the relationships dependent on this data the collection of new or

improved data could be emphasised. Some of the most important areas of data shortage are listed below:

- (i) consumption rates in percentage body weight consumed per day for different-sized animals
- (ii) longevity and adult mortality
- (iii) harem size
- (iv) the nature of any density dependent functional responses by seals
- (v) disturbance effects of culling seals
- (vi) the functional response of other sources of fish mortality to reduced seal predation. For an interesting consideration of this point see Butterworth *et al.* (1988).

Finally, the conclusions by Northridge (1986) "Our overall lack of both data and the theoretical tools to understand the complexities of seal-fishery interactions means that the models in the present study can be little more than illustrative of possible effects.", and by Butterworth *et al.* (1988) "It is argued that there is currently no scientific basis upon which to predict whether such reduction (of the seal population) would have a positive or negative impact on sustainable yields of commercial fish species, nor is such a prediction likely to be possible in the immediate future." are not substantially different from those reached in the present study. However we are very aware that resource managers cannot always wait until they have certain predictions of outcomes before acting. Decisions often have to be made even when the outcome is uncertain, and where the understanding gained through modelling the available data can reduce the odds on a future outcome from 50:50 to 49:51, it will not be ignored.

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APPENDIX 3

SEALING FIGURES SINCE 1900

A summary of the number of seals killed annually since 1900 is tabulated for the different colonies, those taken from unspecified areas, and the totals. The data are consolidated from the following sources - 1900 to 1972 : Best (Appendix 1, 1973); 1973 to 1983 : David (1987b); post-1983 : Annual Reports of the Sea Fisheries Research Institute. The figures for each colony are given in the form : pups + bulls + cows when figures for all of these are present. When one harvest figure is given for a group of colonies, this total is shown under each of the colonies in parenthesis with a numeric code. The numeric codes (in square brackets) for the table are :

- 1 - Black Rocks (Algoa Bay) and Seal Island (Mossel Bay) catches combined
- 2 - Robbesteen and Jacob's Reef catches combined
- 3 - Sinclair Island and Long Island catches combined, and some years including Hollam's Bird Island
- 4 - Approximate or unknown amounts of sealing
- 5 - Some sealing but was also included under the Long Island catch
- 6 - Private sealing - no catch figures
- 7 - Jacob's Reef and Seal Island (False Bay) catches combined
- 8 - Taken at Atlas Bay on behalf of Namibia
- 9 - Including 75 seals from Black Rock (Namibia)
- 10 - Number of skins declared by processor
- 11 - Illegal harvest
- 12 - In addition there are unknown reports of an unknown amount of poaching
- 13 - Quoin Rock and Geyser Rock catches combined

SEALING FIGURES FOR COLONIES ON THE SOUTH AFRICAN COASTLINE

YEAR	BLACK ROCKS (AB)	SEAL ISLAND (MB)	QUOIN ROCK	GEYSER ROCK	SEAL ISLAND (FB)	ROBBE- STEEN	JACOB'S REEF	ELE- PHANT ROCK	KLEINSEE
1900	0	0	0	0	0	0	0	0	0
1901	0	0	0	0	0	0	0	0	0
1902	0	0	0	0	0	1379	0	0	0
1903	0	0	0	0	0	0	0	0	0
1904	0	0	0	0	0	0	0	0	0
1905	0	0	0	0	0	479	84	760	0
1906	0	0	0	1824	0	0	0	940	0
1907	(350) [1]	(350) [1]	0	0	0	(1623) [2]	(1623) [2]	900	0
1908	853	59	0	0	0	0	1067	469	0
1909	0	65	0	0	0	0	1094	1110	0
1910	0	51	0	0	0	0	827	918	0
1911	0	0	0	0	0	0	933	1139	0
1912	0	81	38	0	0	0	1033	834	0
1913	0	0	0	2626	0	0	953	580	0
1914	0	0	0	0	0	0	319	0	0
1915	0	0	0	0	0	0	0	0	0
1916	0	0	0	878	0	0	525	878	0
1917	0	255	0	1904	0	0	311	663	0
1918	0	0	0	902	0	675	560	902	0
1919	0	0	784	1690	195	867	846	906	0
1920	0	0	1057	3450	17	877	649	233	0
1921	0	0	0	828	0	0	0	828	0
1922	0	0	714	3336	0	0	0	824	0
1923	0	0	599	3126	0	0	0	868	0
1924	0	0	683	3303	0	0	0	851	0
1925	0	0	486	3169	0	0	0	884	0
1926	0	0	0	1881	0	0	0	0	0
1927	0	0	595	1905	0	0	297	595	0
1928	0	0	266	1972	0	0	0	1287	0
1929	0	0	0	2077	0	0	0	790	0
1930	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0
1932	0	0	0	0	0	0	0	0	0
1933	0	0	0	0	0	0	0	0	0
1934	0	0	0	2320 [4]	0	0	0	0	0
1935	0	0	0	2180 [4]	0	0	0	0	0
1936	0	0	54	2689	0	950	0	250 [4]	0
1937	0	0	0	2358	0	1766	0	201 [4]	0
1938	0	0	0	1793	0	109	0	210 [4]	0
1939	0	0	0	1608	0	0	0	302	0
1940	0	0	0	2285	0	0	0	310 [4]	0
1941	0	0	0	1944	0	0	0	0	0
1942	0	0	523	3150	0	0	0	812	0
1943	0	0	101	4052	0	0	0	0	0
1944	0	1	0	3496	0	458	0	0	0
1945	0	0	3	3608	0	543	0	0	0
1946	0	2	0	3513	0	284	0	457	0
1947	0	2	33	3529	0	2	535	0	0
1948	0	0	56	1972	0	202	0	0	0
1949	0	0	0	2276	0	0	0	179	0
1950	0	0	103	4372	0	0	0	1869	0

(Continued on page 231)

YEAR	BLACK ROCKS (AB)	SEAL ISLAND (MB)	QUOIN ROCK	GEYSER ROCK	SEAL ISLAND (FB)	ROBBE- STEEN	JACOB'S REEF	ELE- PHANT ROCK	KLEINSEE
1951	0	[6]	100	5650	(1100) [7]	0	(1100) [7]	1391	0
1952	0	[6]	0	3533	258	0	249	1241	0
1953	0	[6]	15	2229	0	0	0	1366	0
1954	0	[6]	0	2064	1326	0	0	873	0
1955	0	2050	3	1522	3363	0	0	916	0
1956	0	0	0	1101	4036	0	0	0	0
1957	0	0	0	2331	2798	0	0	1208	0
1958	0	0	0	2392	3211	0	0	0	0
1959	0	0	0	2329	2344	0	0	0	0
1960	0	0	0	3247	3641	0	0	0	0
1961	0	0	0	3518	3601	0	0	0	0
1962	0	0	0	2977	3029	0	0	0	0
1963	0	0	0	2725	4024	0	0	0	0
1964	0	0	0	2879	2987	0	0	0	0
1965	0	0	0	2817	3786	135	0	1558	0
1966	0	0	0	1026	2630	209	0	2758	0
1967	0	0	518	1844	4798	235	0	1380	4416
1968	0	0	246	2368	3308	255	0	1333	7041
1969	0	0	855	1654	3747	64	0	2191	9419
1970	0	0	914	2345	2024	102	0	783	11110
1971	0	2006	1223	1671	3495	107	0	663	13186
1972	0	1876[10]	1408	2077	3608	259	0	941	13756
1973	0	2150+80	1421	2310	2839	458	0	449	15582
1974	0	2054+16	1207	1493	1635	292	0	1550	17000
1975	0	1638	970	138	139	350	0	872+365	13615
1976	0	0	806	0	0	365	0	1097	5318
1977	0	91 [11]	323	482	0	171	0	0	14000
1978	0	0	0	256 [12]	1843+181	175	0	0	14045
1979	0	0	0	0	2656+387	0	0	0	15000
1980	0	0	0	741	2925+547	0	0	0	15000
1981	0	0	0	0	1069+640	0	0	0	20043
1982	0	0	0	452	0+1100	0	0	0	22500+2000
1983	0	0	0	0	0	0	0	0	0
1984	0	0	0+(114)[13]	0+(114)[13]	0+2030	0	0	0	15000+10035
1985	0	0	0	0	0	0	0	0	0+6223+6890
1986	0	0	0	0	0	0	0	0	10196
1987	0	0	0	0	0	0	0	0	0+12039
1988	0	0	0	0	0	0	0	0	0+3519

SEALING FIGURES FOR COLONIES ON THE NAMIBIAN COASTLINE

YEAR	SINCLAIR ISLAND	ALBATROSS ROCK	LONG ISLAND	WOLF/ ATLAS BAY	LUDERITZ ISLANDS	HOLLAM'S BIRD ISLAND	CAPE CROSS	CAPE FRIO	UN-SPECIFIED
1900	0	0	0	0	0	0	0	0	3246+1002
1901	0	0	0	0	0	0	0	0	2607+2491
1902	0	0	0	0	0	0	0	0	2443+559
1903	0	0	0	0	0	0	0	0	6124
1904	0	0	0	0	0	0	0	0	3039
1905	0	0	0	0	0	0	0	0	5300+631
1906	0	0	0	0	0	400	0	0	6140+308
1907	0	0	0	0	0	0	0	0	1032+1948
1908	0	0	0	0	0	0	0	0	1007+1649
1909	0	0	0	0	0	0	0	0	2782+423
1910	0	0	0	0	0	0	0	0	2304
1911	0	0	0	0	0	0	0	0	2696+1237
1912	0	0	0	0	0	0	0	0	2687+2650
1913	0	0	3784	0	0	0	0	0	397+544
1914	0	0	4174	0	0	0	0	0	0
1915	0	0	0	0	0	0	0	0	421
1916	0	0	0	0	0	0	0	0	0
1917	0	0	5111	0	0	0	0	0	0
1918	0	0	6241	0	0	0	0	0	0
1919	0	0	6476	0	0	0	0	0	266
1920	0	0	7479	0	0	0	0	0	96
1921	0	0	9343	0	0	0	0	0	1192
1922	0	0	8234	0	0	0	0	0	1764
1923	0	0	8152	0	0	0	0	0	3280
1924	0	0	7197	0	0	0	2533	0	4323+600
1925	0	0	8681	0	0	0	2094	0	4249
1926	0	0	8124	0	0	0	1529	0	2667
1927	0	0	8144	0	0	0	4014 [4]	0	0
1928	(12643) [3]	0	(12643) [3]	0	0	0	0	0	850+500
1929	2602	0	5022	0	0	1606	0	0	0
1930	0	0	0	0	0	0	0	0	0
1931	0	0	0	0	0	0	0	0	0+90
1932	0	0	0	0	0	0	0	0	0+50
1933	2717	0	6804	0	0	0	0	0	0
1934	0	0	0	0	0	0	0	0	0+875
1935	0	0	0	0	0	0	0	0	0+430
1936	(12095) [3]	0	(12095) [3]	0	0	0	0	0	0+339
1937	3393	0	8904	200	0	0	0	0	0+450
1938	1819	0	8107	0	0	34	0	0	0+695
1939	400 [4]	0	[4]	0	0	0	4000 [4]	0	9669+879
1940	3000	0	0	0	0	0	4000 [4]	0	0+1471
1941	(6228) [3]	0	(6228) [3]	[5]	0	0	3800 [4]	0	61+1656
1942	(7664) [3]	0	(7664) [3]	[5]	0	0	3900 [4]	0	0+4002
1943	(9834) [3]	0	(9834) [3]	[5]	0	0	4000 [4]	0	0+4758
1944	(7720) [3]	0	(7720) [3]	[5]	0	0	[4]	0	0+4305
1945	(3412) [3]	0	(3412) [3]	[5]	0	0	5000	0	0+4850
1946	(4608) [3]	0	(4608) [3]	[5]	0	0	5000	0	0+5486
1947	(6063) [3]	0	(6063) [3]	[5]	0	0	4870	0	0+7014
1948	0	0	1566	[5]	0	0	4941	0	0+4720
1949	(3918) [3]	0	(3918) [3]	[5]	0	0	5149	0	0+3911
1950	(4642) [3]	0	(4642) [3]	11101	0	0	5202	0	0+2269

(Continued on pg 233)

YEAR	SINCLAIR ISLAND	ALBATROSS ROCK	LONG ISLAND	WOLF/ ATLAS BAY	LUDERITZ ISLANDS	HOLLAM'S BIRD ISLAND	CAPE CROSS	CAPE FRIO	UN- SPECIFIED
1951	1683	834	2728	15257	0	270	5394	0	0+3250
1952	1642	1078	2070	16707	28	0	5871	0	0+4827
1953	2736	353	1373	15195	135 [9]	174	6100	0	0+3806
1954	2514	941	1908	14952	0	0	6459	0	340+3833
1955	2728	768	1622	19597	0	0	6690	0	0+578
1956	3959	1446	2387	20758	0	0	8054	0	0+1050
1957	2244	1023	2588	24438	0	0	8424	0	0+1094
1958	2524	1424	2220	15327	0	0	4821	0	0+1081
1959	2027	1195	2523	17966	0	0	6215	0	0+1213
1960	3452	914	3169	22150	0	0	5360	0	0+1304
1961	4787	1097	1723	25272	0	0	8054	0	0+1551
1962	5008	1436	2042	21396	0	0	8286	0	0+2020
1963	4694	392	3019	27986	0	0	7800	0	0+5503
1964	5781	1021	483	31261	0	0	6948	0	0+3552
1965	2959	748	1347	38937	0	0	7770	0	0+5106
1966	688	0	0	29698	0	0	8424	0	0+3232
1967	451	755	1478	41056	0	0	7126	0	0+2420
1968	2819	827	1734	41833	0	0	7043	0	0+3198
1969	3054	812	2672	43115	0	0	6902	0	0+2083
1970	1923	597	2045	50657	0	0	8707	0	0+2456
1971	2006	325	2320	40055	0	0	9750	0	0+2204
1972	2233	126	2048	42227	0	0	7470	0	0+2240
1973	454	224	1543	45891+1002	0	0	7353+1164	0	0
1974	0	0	3740	31506+62	0	0	6399+1089	0	0
1975	4222	1668	5282	35616	744	0	9543+421	148	0
1976	4294	1125	3831	30968	1689	1879	11095	0	0
1977	5117+423	1567+204	4189+472	35823	0	0	14631	0	0
1978	4062+636	1510+206	1883+460	36964	230+206	0	9439+1294	0	0
1979	4288	1503	3861	38628	0	0	9147	0	0
1980	0	0	0	39912	0	0	6596+800	0	0
1981	4020	1693	5012	42136	0	0	12992	0	0
1982	3544	1504	5564	42775	0	0	12075	0	0
1983	0	0	0	40580+2693	0	0	2139+1327	0	0
1984	0	0	0	34126+7006	0	0	6207+1108	0	0
1985	0+470	0	0+303	25037+4952	0	0	6118+710	0	0
1986	0	0	0+321	14151+3574	0	0	4495+830	0	0
1987	0	0	0	4937+688	0	0	0+2012	0	0
1988	0	0	0	0	0	0	3322+2632+3625	0	0

SEALING FIGURES FOR ALL COLONIES

YEAR	PUPS	BULLS	COWS	TOTAL
1900	3246	1002	0	4248
1901	2607	2491	0	5098
1902	3822	559	0	4381
1903	6124	0	0	6124
1904	3039	0	0	3039
1905	6623	631	0	7254
1906	9304	308	0	9612
1907	3905	1948	0	5853
1908	3455	1649	0	5104
1909	5051	423	0	5474
1910	4100	0	0	4100
1911	4798	1237	0	6035
1912	4673	2650	0	7323
1913	8340	544	0	8884
1914	4493	0	0	4493
1915	421	0	0	421
1916	2281	0	0	2281
1917	8244	0	0	8244
1918	9280	0	0	9280
1919	12030	0	0	12030
1920	13858	0	0	13858
1921	12191	0	0	12191
1922	14872	0	0	14872
1923	16025	0	0	16025
1924	18890	600	0	19490
1925	19563	0	0	19563
1926	14201	0	0	14201
1927	15550	0	0	15550
1928	17018	500	0	17518
1929	12097	0	0	12097
1930	0	0	0	0
1931	0	90	0	90
1932	0	50	0	50
1933	9521	0	0	9521
1934	2320	875	0	3195
1935	2180	430	0	2610
1936	16038	339	0	16377
1937	16822	450	0	17272
1938	12072	695	0	12767
1939	15979	879	0	16858
1940	9595	1471	0	11066
1941	12033	1656	0	13689
1942	16049	4002	0	20051
1943	17987	4758	0	22745
1944	1675	4305	0	15980
1945	2566	4850	0	17416
1946	3864	5486	0	19350
1947	5034	7014	0	22048
1948	8737	4720	0	13457
1949	11522	3911	0	15433
1950	27289	2269	0	29558

(Continued on page 235)

YEAR	PUPS	BULLS	COWS	TOTAL
1951	34407	3250	0	37657
1952	32677	4827	0	37504
1953	29676	3806	0	33482
1954	31377	3833	0	35210
1955	39259	578	0	39837
1956	41741	1050	0	42791
1957	45054	1094	0	46148
1958	31919	1081	0	33000
1959	34599	1213	0	35812
1960	41933	1304	0	43237
1961	48052	1551	0	49603
1962	44174	2020	0	46194
1963	50640	5503	0	56143
1964	51360	3552	0	54912
1965	60057	5106	0	65163
1966	45433	3232	0	48665
1967	64057	2420	0	66477
1968	68807	3198	0	72005
1969	74485	2083	0	76568
1970	81207	2456	0	83663
1971	76807	2204	0	79011
1972	78029	2240	0	80269
1973	80674	2246	0	82920
1974	66876	1167	0	68043
1975	74945	786	0	75731
1976	62467	0	0	62467
1977	76394	1099	0	77493
1978	70407	2983	0	73390
1979	75083	387	0	75470
1980	65174	1347	0	66521
1981	86965	640	0	87605
1982	88414	3100	0	91514
1983	42719	4020	0	46739
1984	55333	20293	0	75626
1985	31155	12658	6890	50703
1986	28842	4725	0	33567
1987	4937	14739	0	19676
1988	3322	7144	2632	13098
1900-1988	2 510 841	197 727	9 522	2 718 090

APPENDIX 4

COMMENTS FROM PURSE-SEINE SKIPPERS' RECORDS REGARDING SEALS

Summary of any comments (translated from Afrikaans) made by skippers on their catch records for 1988. Some of the surnames refer to different skippers but the initials are unknown. For November there are records but none with comments. There are no records for December.

Key to factories :

DG = Da Gama
GM = Gansbaai Marine
L = Laaiplaats
LBC = Lambert's Bay Canning
SBC = Saldanha Bay Canning

SHBF = St Helena Bay Fishing
SO = Suid Oranje
SP = Sandy Point
SSFE = Southern Sea Fishing Enterprises
WP = West Point

DATE	BOAT	SKIPPER	COMMENT
January			
17	Runtu (GM)	Wessels	Seals are serious
18	Kalahari (L)	Blaauw	Many seals
24	Rietvlei (SO)	Jacobs	Few seals
26	Christiaan de Wet (SP)	Fouche	Many seals
27	Rietvlei (SO)	Jacobs	Few seals
27	Silver Snapper (WP)	Basson	Many seals
31	Bosbok (GM)	Groenewald	Many seals
31	Christiaan de Wet (SP)	Fouche	Many seals
February			
1	Bosbok (GM)	Groenewald	Many seals
1	Rietvlei (SO)	Tredoux	Few seals
2	Bella daluna (SO)	Segal	Many seals
2	Christiaan de Wet (SP)	Fouche	Many seals
2	Rietvlei (SO)	Tredoux	Many seals
2	Rooijantjiesfontein (SO)	Dipaola	Many seals
3	Bosbok (GM)	Groenewald	Many seals
3	Loeriesfontein (SO)	Coetzee	Many seals
4	Bosbok (GM)	Groenewald	Many seals
5	Bosbok (GM)	Groenewald	Many seals
5	Oosterdam (SSFE)	Miggels	Many seals
8	Oosterdam (SSFE)	Miggels	Many seals
10	Bosbok (GM)	Groenewald	Many seals
10	Oosterdam (SSFE)	Miggels	Many seals
10	Runtu (GM)	Wessels	Seals are becoming even more
11	Bosbok (GM)	Groenewald	Many seals
11	Runtu (GM)	Wessels	Many seals. The pest continues.
12	Bosbok (GM)	Groenewald	Many seals
14	Atlantic Skipper (DG)	Wichman	Many seals
14	Bosbok (GM)	Groenewald	Many seals
15	Rietvlei (SO)	Tredoux	Few seals

DATE	BOAT	SKIPPER	COMMENT
February (continued)			
16	Bosbok (GM)	Groenewald	Many seals
16	Runtu (GM)	Wessels	The seals are increasing
17	Bosbok (GM)	Groenewald	Many seals
17	Duinekus (SO)	Dipaola	Many seals
17	Rooijantjiesfontein (SO)	Dipaola	Many seals
18	Bosbok (GM)	Groenewald	Many seals
18	Oosterdam (SSFE)	Miggels	Many seals
19	Bosbok (GM)	Groenewald	Many seals
20	Bosbok (GM)	Groenewald	Many seals
20	Oom Piet (GM)	Fourie	Many seals
21	Bosbok (GM)	Groenewald	Many seals
22	Bosbok (GM)	Groenewald	Many seals
22	Rietvlei (SO)	Tredoux	Many seals
23	Bosbok (GM)	Groenewald	Many seals
23	Silver Snapper (WP)	Basson	Many seals
24	Bosbok (GM)	Groenewald	Many seals
24	Caprivi (GM)	Geldenhuis	Seals
25	Bosbok (GM)	Groenewald	Many seals
26	Bosbok (GM)	Groenewald	Many seals
27	Bosbok (GM)	Groenewald	Many seals
28	Bosbok (GM)	Groenewald	Many seals
March			
1	Bosbok (GM)	Groenewald	Many seals
1	Kolgans (GM)	Otto	Too many seals
2	Atlantic Skipper (DG)	Wichman	Seals chase the fish out
2	Bosbok (GM)	Groenewald	Many seals
3	Bosbok (GM)	Groenewald	Many seals
3	Duinekus (SO)	Dipaola	Many seals
3	Elomi (SHBF)	Tredoux	Many seals
3	Rietvlei (SO)	Tredoux	Few seals
4	Bosbok (GM)	Groenewald	Many seals
4	Oceana Emerald (DG)	van Zyl	Many seals
4	Oceana Krans (DG)	Smith	Many seals
6	Drakenskop (L)	Walters	Seals very annoying
7	Baracuda (WP)	Theart	Many seals
7	Bosbok (GM)	Groenewald	Many seals
7	Drakenskop (L)	Walters	Seals very annoying
8	Bosbok (GM)	Groenewald	Many seals
8	Drakenskop (L)	Walters	Seals very annoying
8	Elomi (SHBF)	Tredoux	Many seals
8	Kalahari (L)	Blaauw	Many seals
8	Oom Joos (LBC)	Schreuder	Hauls 2 & 4 : Seals in the net
8	Rooijantjiesfontein (SO)	Dipaola	Many seals
9	Allan Lees (LBC)	Raymond	Many seals chased fish from the net
9	Atlantic Endeavour (WP)	Lambe	Seals is eating half of the fish at every cast, if you can make a cast
9	Kolgans (GM)	Otto	Too many seals
9	Oceana Point (LBC)	Hunter	150 seals in net
9	Oom Joos (LBC)	Schreuder	Cannot count the seals but estimate \pm 200 in the net. Could be more
9	Paul (LBC)	Schreuder	6 thousand seals, chase fish from net
10	Kolgans (GM)	Otto	Too many seals
11	Kolgans (GM)	Otto	Too many seals
13	Atlantic Skipper (DG)	Wichman	Many seals
13	Oceana Emerald (DG)	van Zyl	Many seals

DATE	BOAT	SKIPPER	COMMENT
March (continued)			
14	Atlantic Skipper (DG)	Wichman	Fewer seals
15	Oceana Amethyst (DG)	Ely	Too many seals
16	Oceana Emerald (DG)	van Zyl	Many seals
17	Christiaan de Wet (SP)	Fouche	Many seals
17	Oceana Emerald (DG)	van Zyl	Many seals
21	Atlantic Skipper (DG)	Wichman	Many seals
21	Christiaan de Wet (SP)	Fouche	Many seals
21	Oceana Emerald (DG)	van Zyl	Many seals
24	Runtu (GM)	Wessels	Pilchard are opening up the sea. They are becoming a plague like the seals
25	Kalahari (L)	Blaauw	Many seals
25	Oceana Emerald (DG)	van Zyl	Many seals
27	Kalahari (L)	Blaauw	Many seals
27	Oceana Emerald (DG)	van Zyl	Many seals
27	Seegans (GM)	Lourens	Many seals
28	Allan Lees (LBC)	Raymond	Seals chased fish out. Many seals were present at every haul
28	Atlantic Skipper (DG)	Wichman	Many seals chase fish out of net
28	Oceana Emerald (DG)	van Zyl	Many seals
28	Oceana Ruby (DG)	Prygonski	Too many seals, scattered fish too much
28	Seegans (GM)	Lourens	Many seals
29	Atlantic Skipper (DG)	Wichman	Many seals
29	Bosbok (GM)	Groenewald	Many seals
29	Klaas (LBC)	Boonzaaier	Thousands of seals look like SWAPO forces
29	Kolgans (GM)	Otto	Too many seals
29	Oceana Emerald (DG)	van Zyl	Many seals
29	Oceana Krans (DG)	Smith	Many (1000's) of seals. The pest hinders you when catching fish. Bulls, cows and young ones
29	Oceana Topaz (DG)	van Boom	Many seals
29	Oom Joos (LBC)	Schreuder	Seals chase fish out. Many seals in net. Cannot count them. All young seals
30	Atlantic Skipper (DG)	Wichman	Many seals
30	Bosbok (GM)	Groenewald	Many seals
30	Christiaan de Wet (SP)	Fouche	Many many seals
30	Kolgans (GM)	Otto	Too many seals
30	Oceana Emerald (DG)	van Zyl	Many seals
April			
1	Bosbok (GM)	Groenewald	Many seals. 2nd throw : 6 seals. 3rd : 3
5	Bosbok (GM)	Groenewald	Many seals
6	Bosbok (GM)	Groenewald	Many seals
6	Kolgans (GM)	Otto	Too many seals
7	Bosbok (GM)	Groenewald	Many seals
8	Bosbok (GM)	Groenewald	Many seals
8	Kolgans (GM)	Otto	Too many seals
9	Bosbok (GM)	Groenewald	Many seals
11	Bosbok (GM)	Groenewald	Many seals
12	Atlantic Enterprise (SBC)	Veer	1st throw : 10 seals
12	Bosbok (GM)	Groenewald	Many seals
12	Eigeveld (WP)	Mostert	Very few seals
12	Hoeveld (SO)	Smith	Seals 9
12	Oceana Kloof (DG)	Kotze	There were 40 seals present at the two hauls
12	Oceana Viking (SHBF)	Brand	± 1000 seals
12	Silver Dolphin (WP)	Mouton	The fish "drop out" because of the seals
13	Bella Prima (SO)	Theart	50 to 60 in net and 20 - 25 outside
13	Christiaan de Wet (SP)	Fouche	Millions of seals in and around the net

DATE	BOAT	SKIPPER	COMMENT
April (continued)			
13	Doloreze (SP)	Tolken	Seals ± 2 with every throw
13	Eigeveld (WP)	Mostert	A few seals
13	Hoefeld (SO)	Smith	Seals 12 and 10
13	Kalahari (L)	Blaauw	Seals 15 - 18
13	Libra (SO)	Houghton	Seals observed 160
13	Loeriesfontein (SO)	Coetzee	Seals observed 140
13	Oceana Apollo (SP)	van Dyk	Seals observed : 1st - 10 to 15 in and around net. 2nd - 5 to 6 in and around net
13	Oceana Kloof (DG)	Kotze	There were 15 seals present at the two hauls
13	Silver Hunter (SBC)	Smit	61 seals counted
14	Atlantic Skipper (DG)	Wichman	Many seals
14	Bosbok (GM)	Groenewald	Many seals
14	Christiaan de Wet (SP)	Fouche	Millions of seals
14	Doloreze (SP)	Tolken	± 5 seals with every haul
14	Duinekus (SO)	Dipaola	250 seals in the net
14	Kalahari (L)	Blaauw	Seals 12 - 15
14	Kavalier (SBC)	Theart	Seals many (200)
14	Loeriesfontein (SO)	Coetzee	Seals observed 37
14	Oceana Apollo (SP)	van Dyk	Seals observed : 15 to 20 per throw around and in net
14	Oceana Kloof (DG)	Kotze	There were 50 seals present at the three hauls
14	Oceana Krans (DG)	Smith	Seals chase fish out of the net. A pest
14	Oceana Topaz (DG)	van Boom	Many seals
15	Atlantic Skipper (DG)	Wichman	Seals cause fish to "drop out". Many seals
15	Bosbok (GM)	Groenewald	Seals observed : Hauls 1 & 2 : 200 seals. Last throw : 350 seals
15	Christiaan de Wet (SP)	Fouche	Seals and even more seals
15	Oceana Emerald (DG)	van Zyl	Many seals
15	Oceana Viking (SHBF)	Brand	5000 seals
15	Oom Piet (GM)	Fourie	Seals to much of a nuisance
15	Runtu (GM)	Wessels	So many seals. Cannot count that far. Seals are now a plague
17	Arno Louise (GM)	Lourens	3 seals drowned (Range per throw : 20 - 200)
17	Bosbok (GM)	Groenewald	150 seals per throw observed
17	Caprivi (GM)	Germushuys	Approximately 200 seals often chase the fish out
17	Eigeveld (WP)	Mostert	Very few seals
17	Kavalier (SBC)	Theart	Seals (50)
17	Kavalier (SBC)	Theart	Seals (50)
17	Libra (SO)	Houghton	Seals observed 40
17	Merlene (GM)	Groenewald	Seals, 200 with every haul
17	Oceana Kloof (DG)	Kotze	There were 60 seals present at the two hauls
17	Oom Piet (GM)	Fourie	Many seals. Approximately 800
17	Runtu (GM)	Wessels	Many many seals
17	Silver Hunter (SBC)	Smit	15 seals counted
17	Silver Snapper (WP)	Basson	Many seals
18	Arno Louise (GM)	Lourens	No dead seals. (Range per throw : 10 - 40)
18	Bosbok (GM)	Groenewald	150 seals per throw observed
18	Caprivi (GM)	Germushuys	At least 300 seals chase the seals out a lot
18	Christiaan de Wet (SP)	Fouche	Many seals
18	Eigeveld (WP)	Mostert	Very few seals
18	Elomi (SHBF)	Tredoux	There were 4 seals
18	Jacobrose (SBC)	Strydom	Many seals
18	Oom Piet (GM)	Fourie	Many seals. Approximately 200
18	Runtu (GM)	Wessels	Seals are now so serious, cannot catch fish
19	Caprivi (GM)	Germushuys	10 seals
19	Kalahari (L)	Blaauw	Seals 10 - 12
20	Caprivi (GM)	Germushuys	300 seals or more

DATE	BOAT	SKIPPER	COMMENT
February (continued)			
26	Kolgans (GM)	Otto	Too many seals
26	Oceana Kloof (DG)	Kotze	There were 30 seals present at the two hauls
26	Runtu (GM)	Wessels	It is 14 days since we were last in the sea and the seals have not become any fewer
28	Caprivi (GM)	Germushuys	Many seals. 200 or more
May			
1	Arno Louise (GM)	Lourens	No seals caught. Observed 20 to 80
1	Bosbok (GM)	Groenewald	Seals observed. 200
1	Caprivi (GM)	Germushuys	20 seals
1	Christiaan de Wet (SP)	Fouche	Thousands of seals.
1	Duinekus (SO)	Dipaola	150 seals in net
1	Jacobrose (SBC)	Strydom	Many seals
1	Oceana Emerald (DG)	van Zyl	Many seals
1	Runtu (GM)	Wessels	Skipper is getting a headache because of thousands of seals. He hopes the a plan can finally be made
1	Silver Hunter (SBC)	Smit	200 seals counted
2	Bosbok (GM)	Groenewald	Seals observed. 150
2	Caprivi (GM)	Germushuys	2 seals
2	Highland Queen (SO)	Bal	Many young seals
2	Kavalier (SBC)	Theart	Seals 200+
2	Oceana Emerald (DG)	van Zyl	Many seals
2	Oceana Kloof (DG)	Kotze	There were 30 seals present
2	Oceana Krans (DG)	Smith	Too much seals around and in net
2	Oceana Topaz (DG)	van Boom	Many seals
2	Oom Joos (LBC)	Schreuder	Seals chase fish from net. Many seals with every throw
2	Rietvlei (SO)	Tredoux	Few seals
2	Runtu (GM)	Wessels	A person should not preserve a thing like a seal. It is a plague
2	Silver Hunter (SBC)	Smit	Many many seals. Uncountable
3	Caprivi (GM)	Germushuys	50 seals
3	Jacobrose (SBC)	Strydom	Many seals
3	Oceana Concorde (SHBF)	Huysamen	Many seals present
3	Oceana Pluto (SHBF)	Viola	1000 seals
3	Oom Piet (GM)	Fourie	Many seals. Estimation 200
3	Runtu (GM)	Wessels	10 tons of fish in net but 70 tons of seals
3	Silver Snapper (WP)	Basson	Many seals (500)
4	Arno Louise (GM)	Lourens	No seals caught. Observed 10 to 20.
4	Duinekus (SO)	Dipaola	Many seals (150) in net
4	Runtu (GM)	Wessels	Seals wait at Cape Point for Gansbaai but now our clubbing at the Island has worked
5	Bosbok (GM)	Groenewald	Seals observed. First 2 throws, 150 per throw. Last throw, 200
5	Caprivi (GM)	Germushuys	50 seals
5	Highland Queen (SO)	Bal	Many seals
5	Oceana Emerald (DG)	van Zyl	Many seals
5	Runtu (GM)	Wessels	Seals thousands. If they eradicate all the seals and write a book, when the descendants read the book in 300 years, they will say that their forefathers did a good thing
5	Silver Hunter (SBC)	Smit	Many seals. Too many to count
6	Arno Louise (GM)	Lourens	Seals concentrate a lot on pilchard. Count = 120
6	Bosbok (GM)	Groenewald	Seals observed. 200 per throw. 1 dead in fish pump.
6	Kavalier (SBC)	Theart	Seals 500
6	Runtu (GM)	Wessels	Many seals, still a plague

DATE	BOAT	SKIPPER	COMMENT
May (continued)			
6	Seegans (GM)	Lourens	200 seals observed. \pm 250 per throw
6	Silver Hunter (SBC)	Smit	140 seals counted
7	Bosbok (GM)	Groenewald	Seals are increasing and increasing
7	Bosbok (GM)	Groenewald	Seals observed. 200 per throw.
8	Arno Louise (GM)	Lourens	No dead seals. 10.
8	Bosbok (GM)	Groenewald	Seals are very serious. Damage the net
8	Bosbok (GM)	Groenewald	Seals observed. 250 per throw
8	Caprivi (GM)	Germushuys	No seals
8	Eigeveld (WP)	Mostert	Very few seals
8	Kavalier (SBC)	Theart	Seals (100)
8	Rietvlei (SO)	Tredoux	Few seals
8	Silver Hunter (SBC)	Smit	500 seals counted
8	Silver Snapper (WP)	Basson	Many seals
9	Arno Louise (GM)	Lourens	Relatively few seals seen. 50
9	Bosbok (GM)	Groenewald	Many many seals. HELP !
9	Bosbok (GM)	Groenewald	Seals observed. 150 per throw
9	Duinekus (SO)	Dipaola	Many seals
9	Oceana Kloof (DG)	Kotze	There were 50 seals present
9	Oom Piet (GM)	Fourie	Many seals
9	Petrie Hein (SHBF)	Pyper	\pm 1000 seals present
9	Silver Snapper (WP)	Basson	Many seals
10	Bosbok (GM)	Groenewald	Seals are still a plague
10	Bosbok (GM)	Groenewald	Seals observed. 150 per throw
10	Kavalier (SBC)	Theart	Seals \pm 200
10	Oom Piet (GM)	Fourie	Many seals A few hundred
10	Silver Hunter (SBC)	Smit	Many seals. 100 seals counted
11	Atlantic Skipper (DG)	Wichman	Many seals
11	Bosbok (GM)	Groenewald	It is impossible to catch fish with so many seals. A distress signal follows, HELP !! The seals are devouring us
11	Bosbok (GM)	Groenewald	Seals observed. 100 per throw
11	Caprivi (GM)	Germushuys	50 seals
11	Doloreze (SP)	Tolken	\pm 10 seals with every throw
11	Kavalier (SBC)	Theart	Seals \pm 200
11	Oom Piet (GM)	Fourie	Many seals. A few hundred
11	Silver Hunter (SBC)	Smit	30 seals counted
11	Silver Snapper (WP)	Basson	Many seals
12	Atlantic Skipper (DG)	Wichman	Many seals
12	Bosbok (GM)	Groenewald	Still many seals
12	Oom Piet (GM)	Fourie	Many seals
12	Silver Hunter (SBC)	Smit	80 seals counted
13	Bosbok (GM)	Groenewald	Many many seals
13	Bosbok (GM)	Groenewald	Seals observed. 350 per throw
13	Oom Piet (GM)	Fourie	Many seals
13	Seegans (GM)	Lourens	Many many seals force fish to sound
14	Bosbok (GM)	Groenewald	Seals observed. 200 per throw
16	Duinekus (SO)	Dipaola	150 seals
16	Jacobrose (SBC)	Strydom	Many seals
17	Vegkop (L)	Theart	Many thousands of seals
18	Duinekus (SO)	Dipaola	150 seals
18	Silver Hunter (SBC)	Smit	200 seals counted
19	Arno Louise (GM)	Lourens	3 seals wound in net. 50 - 200
20	Bosbok (GM)	Groenewald	Seals observed. 200 per throw
20	Oom Piet (GM)	Fourie	Many seals
23	Jacobrose (SBC)	Strydom	Many seals
24	Bosbok (GM)	Groenewald	Were 13 days last at sea. Seals have doubled

DATE	BOAT	SKIPPER	COMMENT
May (continued)			
24	Oom Piet (GM)	Fourie	Many seals
24	Rietvlei (SO)	Tredoux	Many seals
24	Silver Hunter (SBC)	Smit	250 seals counted
24	Silver Snapper (WP)	Basson	Many seals
25	Elomi (SHBF)	Tredoux	200 seals
25	Oceana Kloof (DG)	Kotze	There were 60 seals present at the two hauls
26	Jacobrose (SBC)	Strydom	Incredible number of seals
27	Kavalier (SBC)	Theart	Seals 200
27	Silver Hunter (SBC)	Smit	300 seals estimated
29	Atlantic Skipper (DG)	Wichman	Seals very troublesome
29	Christiaan de Wet (SP)	Fouche	Many many seals
29	Kavalier (SBC)	Theart	Seals (100+)
29	Oceana Emerald (DG)	van Zyl	Many seals
29	Rietvlei (SO)	Tredoux	Few seals
29	Silver Hunter (SBC)	Smit	400 seals counted
30	Bella daluna (SO)	Segal	200 to 250 seals
30	Christiaan de Wet (SP)	Fouche	Many many seals
30	Elomi (SHBF)	Tredoux	Many seals
30	Jacobrose (SBC)	Strydom	Relatively large number of seals
30	Kavalier (SBC)	Theart	Seals ± 2000
30	Oceana Kloof (DG)	Kotze	There were 50 seals present
30	Oom Piet (GM)	Fourie	Many seals
30	Rooijantjiesfontein (SO)	Dipaola	Many seals
30	Silver Dolphin (WP)	Mouton	Many seals
30	Silver Hunter (SBC)	Smit	300 seals counted
30	Silver Snapper (WP)	Basson	Hundreds of seals
31	Doloreze (SP)	Tolken	± 30 seals in net
31	Elomi (SHBF)	Tredoux	200 seals
31	Oceana Apollo (SP)	van Dyk	Many seals
June			
1	Highland Queen (SO)	Bal	Many seals
7	Elomi (SHBF)	Tredoux	There were 4 seals
8	Elomi (SHBF)	Tredoux	40 seals
8	Hoefeld (SO)	Smith	Generally from 200 seals per throw
8	Jacobrose (SBC)	Strydom	Fair number of seals
8	Oceana Kloof (DG)	Kotze	There were hundreds of seals present
8	Silver Hunter (SBC)	Smit	100 seals counted
9	Duinekus (SO)	Dipaola	500 seals
9	Elomi (SHBF)	Tredoux	20 seals
9	Hoefeld (SO)	Smith	Many seals
9	Jacobrose (SBC)	Strydom	Many seals
9	Oceana Ruby (DG)	Prygonski	Plenty seals
10	Bella daluna (SO)	Segal	150 seals
10	Bosbok (GM)	Groenewald	Seals observed. 150 per throw
10	Drakenskop (L)	Walters	Seals chase fish out
10	Elomi (SHBF)	Tredoux	200 seals
10	Elomi (SHBF)	Tredoux	1000 seals
10	Oceana Concorde (SHBF)	Huysamen	Fish were difficult to catch because of the many seals
10	Oceana Concorde (SHBF)	Huysamen	Schools are scarce and difficult to catch because of the seals
10	Oceana Kloof (DG)	Kotze	There were hundreds of seals present
10	Oom Piet (GM)	Fourie	Many seals
10	Rietvlei (SO)	Tredoux	Many seals
10	Stormkop (L)	Brand	Many seals
13	Kolgans (GM)	Otto	There are too many seals

DATE	BOAT	SKIPPER	COMMENT
June (continued)			
13	Oom Joos (LBC)	Schreuder	No seals in net
13	Oom Piet (GM)	Fourie	Many seals
15	Elomi (SHBF)	Tredoux	100 seals
15	Kavalier (SBC)	Theart	Seals 80
15	Oceana Ruby (DG)	Prygonski	Fish scarce, too many seals
15	Oosterdam (SSFE)	Burger	Many seals
15	Silver Hunter (SBC)	Smit	200 seals counted
16	Elomi (SHBF)	Tredoux	50 seals
16	Noordzee (SSFE)	Donaggi	Many seals
16	Oom Piet (GM)	Fourie	Many seals
16	Oosterdam (SSFE)	Burger	Many seals
16	Rietvlei (SO)	Tredoux	Few seals
17	Petrie Hein (SHBF)	Pyper	Many seals
17	Rietvlei (SO)	Tredoux	2 seals
19	Libra (SO)	Houghton	120 seals
19	Oosterdam (SSFE)	Burger	Many seals
19	Silver Hunter (SBC)	Smit	200 seals counted
20	Oceana Mercury (SHBF)	Buckle	Many seals
21	Duinekus (SO)	Dipaola	500 seals
21	Oosterdam (SSFE)	Burger	Many seals
22	Christiaan de Wet (SP)	Fouche	Many seals and the fish remain deep and open
22	Jacobrose (SBC)	Strydom	Many seals
22	Oosterdam (SSFE)	Burger	Many seals
22	Rietvlei (SO)	Tredoux	Few seals
23	Elomi (SHBF)	Tredoux	100 seals
23	Oceana Emerald (DG)	van Zyl	Many seals
23	Oceana Ruby (DG)	Prygonski	Plenty seals
23	Oom Joos (LBC)	Botha	Many seals
23	Oosterdam (SSFE)	Burger	Many seals
23	Rietvlei (SO)	Tredoux	Many seals
23	Silver Hunter (SBC)	Smit	100 seals counted
24	Baracuda (WP)	Theart	Many seals
24	Duinekus (SO)	Dipaola	500 seals
24	Elomi (SHBF)	Tredoux	100 seals
24	Oceana Viking (SHBF)	Brand	Many seals
24	Oosterdam (SSFE)	Burger	Many seals
24	Silver Snapper (WP)	Basson	Many seals
26	Oosterdam (SSFE)	Burger	Many seals
27	Elomi (SHBF)	Tredoux	200 seals
27	Oosterdam (SSFE)	Burger	Many seals
27	Rietvlei (SO)	Tredoux	Few seals
28	Bosbok (GM)	Groenewald	Seals observed. Haul 1 - 100 seals. Thereafter 250 seals per throw
28	Duinekus (SO)	Dipaola	Many seals in the net
28	Elomi (SHBF)	Tredoux	100 seals
28	Kolgans (GM)	Otto	Many seals and they are a nuisance
28	Oom Joos (LBC)	Schreuder	Seals are a nuisance
28	Oom Piet (GM)	Fourie	Many seals
28	Oosterdam (SSFE)	Burger	Many seals
29	Bosbok (GM)	Groenewald	Seals observed. 250 to 400 per throw
29	Highland Queen (SO)	Bal	Many young seals
29	Kolgans (GM)	Otto	Many seals and they are a nuisance
29	Oceana Ruby (DG)	Prygonski	Plenty seals
29	Oom Piet (GM)	Fourie	Many seals
29	Oosterdam (SSFE)	Burger	Many seals
29	Paul (LBC)	Schreuder	Hauls 1 & 3 : Too many seals

DATE	BOAT	SKIPPER	COMMENT
June (continued)			
29	Rietvlei (SO)	Tredoux	Few seals
30	Elomi (SHBF)	Tredoux	200 seals
30	Highland Queen (SO)	Bal	Many seals
30	Jacobrose (SBC)	Strydom	Many seals
30	Oosterdam (SSFE)	Burger	Many seals
30	Rietvlei (SO)	Tredoux	Seals
30	Silver Hunter (SBC)	Smit	2000 seals counted
30	Silver Snapper (WP)	Basson	Many seals
31	Bella daluna (SO)	Segal	30 seals
31	Kavalier (SBC)	Theart	Seals 1000 ±
31	Oceana Ruby (DG)	Prygonski	Too many seals
31	Silver Hunter (SBC)	Smit	Many many seals
July			
1	Oosterdam (SSFE)	Burger	Many seals
3	Libra (SO)	Houghton	Many seals ±60
3	Oceana Kloof (DG)	Kotze	30 seals in with fish
3	Oosterdam (SSFE)	Burger	Many seals
3	Silver Hunter (SBC)	Smit	Many many seals. Uncountable
4	Vegkop (L)	Theart	Seals chase everything out
10	Drakenskop (L)	Walters	Seals very annoying
10	Jacobrose (SBC)	Strydom	Many seals
10	Oceana Orion (SHBF)	Kotze	20 seals
10	Oom Piet (GM)	Fourie	Many seals
10	Oosterdam (SSFE)	Burger	Many seals
11	Bella daluna (SO)	Segal	Many seals
11	Drakenskop (L)	Walters	Seals very annoying
11	Duinekus (SO)	Dipaola	Fish drop out. Too many seals in net
11	Elomi (SHBF)	Tredoux	Seals in net
11	Highland Queen (SO)	Bal	Many seals
11	Marcon (L)	Boonzaaier	Seals chase fish out of net
11	Oceana Orion (SHBF)	Kotze	30 seals
11	Petrie Hein (SHBF)	Pyper	Too many seals
11	Silver Hunter (SBC)	Smit	300 seals counted
12	Baracuda (WP)	Theart	Many seals
12	Bella daluna (SO)	Segal	Incredibly many seals
12	Drakenskop (L)	Walters	Seals very annoying
12	Eigeveld (WP)	Mostert	Many seals. Too many
12	Elomi (SHBF)	Tredoux	1000 seals
12	Highland Queen (SO)	Bal	Many seals
12	Jacobrose (SBC)	Strydom	Many seals
12	Jacobrose (SBC)	Strydom	Many seals between Saldanha and Vondeling
12	Kokoaveld (SO)	Brand	Many seals
12	Oceana Wind (LBC)	Muller	Many seals
12	Oosterdam (SSFE)	Burger	Many seals
12	Rietvlei (SO)	Tredoux	Few seals ± 500
12	Silver Hunter (SBC)	Smit	500 seals and more estimated
12	Silver Snapper (WP)	Basson	Many seals
13	Drakenskop (L)	Walters	Seals very annoying
13	Elomi (SHBF)	Tredoux	±600 seals
13	Kalahari (L)	Blaauw	Many seals
13	Oosterdam (SSFE)	Burger	Many seals
13	Silver Snapper (WP)	Basson	Many seals
14	Baracuda (WP)	Theart	Many seals
14	Bella daluna (SO)	Segal	Many seals
14	Drakenskop (L)	Walters	Seals very annoying

DATE	BOAT	SKIPPER	COMMENT
July (continued)			
14	Elomi (SHBF)	Tredoux	600 seals
14	Oceana Orion (SHBF)	Kotze	40 seals
14	Oosterdam (SSFE)	Burger	Many seals
14	Rietvlei (SO)	Tredoux	100+ seals
14	Silver Hunter (SBC)	Smit	500 seals estimated
15	Highland Queen (SO)	Bal	Many seals
18	Baracuda (WP)	Theart	Many seals
18	Bella daluna (SO)	Segal	Many seals
18	Doloreze (SP)	Tolken	Fish "drop out" because of seals. Many seals
18	Drakenskop (L)	Walters	Seals very annoying
18	Elomi (SHBF)	Tredoux	500 seals
18	Highland Queen (SO)	Bal	Many seals
18	Kokoaveld (SO)	Brand	Many many seals
18	Oceana Orion (SHBF)	Kotze	25 seals
18	Oosterdam (SSFE)	Burger	Many seals
18	Petrie Hein (SHBF)	Pyper	Too many seals
18	Silver Snapper (WP)	Basson	Many seals
18	Tabita (WP)	Mouton	Many seals
22	Highland Queen (SO)	Bal	Many seals
22	Rietvlei (SO)	Tredoux	10 000+ seals
24	Baracuda (WP)	Theart	Many seals
24	Bella daluna (SO)	Segal	Many seals
24	Kransberg (L)	Thiart	Seals
24	Oceana Orion (SHBF)	Kotze	1500 seals
24	Runtu (GM)	Wessels	Many seals - chase fish out of net
24	Silver Hunter (SBC)	Smit	700 seals and more
24	Silver Snapper (WP)	Basson	Many seals
25	Kalahari (L)	Blaauw	Many seals
25	Oosterdam (SSFE)	Burger	Many many seals
25	Rietvlei (SO)	Tredoux	+500 seals
26	Elomi (SHBF)	Tredoux	100 seals
26	Highland Queen (SO)	Bal	Many seals
26	Oceana Orion (SHBF)	Kotze	100 seals
26	Rietvlei (SO)	Tredoux	1000+ seals
26	Silver Hunter (SBC)	Smit	Many seals. Approximately 500 and more
27	Baracuda (WP)	Theart	Many seals
27	Bella daluna (SO)	Segal	Seals mess a lot in fish. Catches bad
28	Mizpah (SSFE)	Tolken	Thousands of seals
28	Oceana Orion (SHBF)	Kotze	1000 seals
28	Oosterdam (SSFE)	Burger	Many seals
28	Silver Hunter (SBC)	Smit	500 seals counted
31	Oosterdam (SSFE)	Burger	Many seals
August			
1	Bella daluna (SO)	Segal	Seals chase all fish out. 200 to 1000 seals
1	Doloreze (SP)	Tolken	Many seals
1	Drakenskop (L)	Walters	Seals chase the fish out. Seals very annoying
1	Elomi (SHBF)	Tredoux	600 seals
1	Oceana Emerald (DG)	van Zyl	Many seals
1	Oom Piet (GM)	Fourie	Many many seals
1	Oosterdam (SSFE)	Burger	Many seals
1	Rietvlei (SO)	Tredoux	200+ seals
1	Tabita (WP)	Mouton	Many seals
2	Atlantic Skipper (DG)	Wichman	Many seals chase schools of fish apart
2	Baracuda (WP)	Theart	Many seals
2	Bella daluna (SO)	Segal	Many seals

DATE	BOAT	SKIPPER	COMMENT
August (continued)			
2	Doloreze (SP)	Tolken	Many seals
2	Elomi (SHBF)	Tredoux	200 seals
2	Jacobrose (SBC)	Strydom	Many seals
2	Oceana Concorde (SHBF)	Huysamen	Many seals present
2	Oceana Emerald (DG)	van Zyl	Many seals
2	Oom Piet (GM)	Fourie	Many many seals
2	Oosterdam (SSFE)	Burger	Many seals
2	Silver Hunter (SBC)	Smit	600 seals and more counted
2	Silver Katonkel (WP)	van Dyk	Many seals in fish shoals
3	Atlantic Skipper (DG)	Wichman	Many seals
3	Drakenskop (L)	Walters	Seals very annoying
3	Jacobrose (SBC)	Strydom	Many seals
3	Jacobrose (SBC)	Strydom	Many seals
3	Oceana Orion ((SHBF)	Kotze	30 seals
3	Oom Piet (GM)	Fourie	Many many seals
3	Oosterdam (SSFE)	Burger	Many seals
3	Pokkie M. (WP)	Mouton	Many seals
3	Silver Hunter (SBC)	Smit	Many seals. Uncountable
4	Jacobrose (SBC)	Strydom	Many seals
4	Oom Piet (GM)	Fourie	Many many seals
4	Oosterdam (SSFE)	Burger	Many seals
5	Drakenskop (L)	Walters	Seals very annoying
5	Oosterdam (SSFE)	Burger	Many seals
8	Drakenskop (L)	Walters	Seals very annoying. Seals chase fish out
9	Elomi (SHBF)	Tredoux	100 seals
9	Oosterdam (SSFE)	Burger	Many seals
9	Tabita (WP)	Mouton	Many seals
10	Atlantic Skipper (DG)	Wichman	Many seals
10	Drakenskop (L)	Walters	Seals chase fish out
10	Oceana Emerald (DG)	van Zyl	Many seals
10	Oom Joos (LBC)	Botha	Many seals
10	Oosterdam (SSFE)	Burger	Many seals
10	Rietvlei (SO)	Tredoux	100+ seals
11	Atlantic Skipper (DG)	Wichman	Many seals
11	Elomi (SHBF)	Tredoux	200 seals
11	Oceana Emerald (DG)	van Zyl	Many seals
11	Oosterdam (SSFE)	Burger	Many seals
11	Rietvlei (SO)	Tredoux	100+ seals
12	Oceana Sapphire (DG)	Prygonski	Fish good but seals - its unbelievable, too many of them
14	Jacobrose (SBC)	Strydom	Many seals
14	Oosterdam (SSFE)	Burger	Many seals
14	Paul (LBC)	Schreuder	Too many seals (2000)
15	Atlantic Skipper (DG)	Wichman	Many seals
15	Bella daluna (SO)	Segal	Many seals
15	Drakenskop (L)	Walters	Seals very annoying
15	Oceana Emerald (DG)	van Zyl	Many seals
15	Oceana Sapphire (DG)	Prygonski	Fish stays open, too many seals
15	Oosterdam (SSFE)	Burger	Many seals
15	Rietvlei (SO)	Tredoux	Many seals
16	Elomi (SHBF)	Tredoux	200 seals
16	Oceana Emerald (DG)	van Zyl	Many seals
16	Oceana Sapphire (DG)	Prygonski	Fish stays open, all night seals all open
16	Oom Piet (GM)	Fourie	Many many seals
16	Oosterdam (SSFE)	Burger	Many seals
16	Rietvlei (SO)	Tredoux	50+ seals

DATE	BOAT	SKIPPER	COMMENT
August (continued)			
17	Oosterdam (SSFE)	Burger	Many seals
18	Elomi (SHBF)	Tredoux	±100 seals
18	Oosterdam (SSFE)	Burger	Many seals
18	Rietvlei (SO)	Tredoux	100+ seals
19	Atlantic Skipper (DG)	Wichman	Many seals !
19	Oceana Emerald (DG)	van Zyl	Many seals
21	Bella daluna (SO)	Segal	Many seals
22	Atlantic Skipper (DG)	Wichman	Many seals !
22	Elomi (SHBF)	Tredoux	200 seals
22	Kolgans (GM)	Otto	Many seals and they are a great nuisance
22	Oceana Krans (DG)	Smith	Lots of seals
22	Oom Joos (LBC)	Schreuder	Seals chase all the fish out. Many seals in net
23	Oceana Emerald (DG)	van Zyl	Many seals
23	Oceana Point (LBC)	Hunter	± 500 seals chase all the fish from net
24	Arno Louise (GM)	Lourens	Seals chased fish out
24	Elomi (SHBF)	Tredoux	50 seals
24	Klaas (LBC)	Boonzaaier	Many seals chase fish out of the net
24	Oceana Apollo (SP)	Visser	Many seals
24	Oceana Emerald (DG)	van Zyl	Many seals
24	Oom Joos (LBC)	Schreuder	Seals chase all the fish out. Many seals. A plan must be made about the seals
24	Oosterdam (SSFE)	Burger	Many seals
25	Atlantic Skipper (DG)	Wichman	Thousands of seals
25	Kalahari (L)	Blaauw	Many seals
25	Oceana Emerald (DG)	van Zyl	Many seals
28	Elomi (SHBF)	Tredoux	100 seals
28	Oceana Emerald (DG)	van Zyl	Many seals
29	Oceana Emerald (DG)	van Zyl	Many seals
30	Elomi (SHBF)	Tredoux	50 seals
31	Bella daluna (SO)	Segal	Seals chase may fish out
September			
4	Allan Lees (LBC)	Schreuder	Many seals
4	Baracuda (WP)	Theart	Many seals
4	Bella daluna (SO)	Segal	Many seals
4	Elomi (SHBF)	Tredoux	10 seals
4	Kolgans (GM)	Otto	Seals are a great nuisance
4	Oceana Point (LBC)	Hunter	± 200 seals in net with every throw
4	Oom Joos (LBC)	Schreuder	Hauls 1, 2, 3 & 6 : many seals in net. All young seals
5	Oceana Point (LBC)	Hunter	± 200 seals in net with every throw
6	Allan Lees (LBC)	Schreuder	Incredible number of seals
6	Elomi (SHBF)	Tredoux	100 seals
6	Elomi (SHBF)	Tredoux	1000 seals
6	Kalahari (L)	Blaauw	Many seals
6	Oom Piet (GM)	Lourens	Many many seal with each throw
6	Oosterdam (SSFE)	Burger	Many seals
6	Seegans (GM)	DuToit	Seals chase fish out of net
7	Bella daluna (SO)	Segal	Many seals chase fish out
8	Kolgans (GM)	Otto	Many seals and they are a great nuisance
8	Seegans (GM)	DuToit	Many seals
19	Drakenskop (L)	Walters	Seals very annoying

DATE	BOAT	SKIPPER	COMMENT
October			
4	Oceana Mercury (SHBF)	Buckle	Seals difficult
6	Baracuda (WP)	Theart	Many seals
11	Bella daluna (SO)	Segal	Many seals
12	Elomi (SHBF)	Tredoux	100 seals
12	Jacobrose (SBC)	Strydom	Many seals
19	Jacobrose (SBC)	Strydom	Many seals
23	Jacobrose (SBC)	Strydom	Many seals
30	Bella daluna (SO)	Segal	Many many seals
30	Oceana Point (LBC)	Hunter	Seals are devouring the boat
31	Bella daluna (SO)	Segal	Many seals
31	Jacobrose (SBC)	Strydom	Many seals

APPENDIX 5

ESTIMATION OF NUMBER OF PUPS PER SEAL AT DIFFERENT DENSITIES

The number of pups and total seals have been counted for the recolonised, Mercury Island and Sinclair Island and the newly colonised, Paternoster Rocks. The area of each colony is calculated for estimation of the density of the colonies in different years.

AREA ESTIMATES

Sinclair Island

This island is estimated as having an area of 8 acres (Rand, 1963) which is converted to metric units, giving an area of approximately 32 370 m².

Mercury Island

Rand (1963) estimates the area of Mercury to be 7.3 acres, not accounting for the relief of the island. This island is precipitous, having a maximum height of 125' above sea level (Rand, 1963). Using the map and scale from Plate VI (Rand, 1963), the flat view of Mercury Island is approximated by a rectangle (1800' x 250'). Since the island has a ridge running lengthwise along it, the relief area is represented by two rectangles lying with their lengths at 90° to one another, so that the end-on view of the island forms a triangle. This results in a relief area of approximately 60 390 m² (or 14.9 acres).

Paternoster Rocks

Paternoster Rocks consists of two large rocks and a few smaller ones. The area of the largest rock was calculated by estimating the length and breadth of the rock in terms of "seal lengths" (the length of an average cow seal on the photograph). Approximating the rock as a rectangle, the length and breadth in "seal lengths" was converted to dimensions of 113 x 100 m using a length of 1.5m (David, pers. comm.) for an average cow seal. This produced an area of 11 300 m². In terms of the photographs, the area of the remaining rocks was estimated to amount to an area almost equivalent to the large rock, so the total area of Paternoster Rocks is assumed to be approximately 20 000 m².

YEAR	PUPS	TOTAL	SOURCE	PUPS/TOTAL	TOTAL/1000m2
Sinclair Island					
1971	348	1 196	Shaughnessy (1980b)	0.29	37
1976	766	1 211	" "	0.63	37
1977	1 954	2 715	" "	0.72	84
Mercury Island					
1983	73	6 542	Crawford <i>et al.</i> (1989)	0.01	108
1984	1 128	6 947	"	0.16	115
1985	3 626	9 878	"	0.37	164
1986	3 828	16 320	"	0.23	270
1987	5 215	11 947	Sea Fisheries Research Institute (unpublished data)	0.44	198
1988	3 114	12 668	"	0.25	210
Paternoster Rocks					
1985	127	11 765	Oosthuizen & David (1988)	0.011	588
1986	74	14 984	" "	0.005	749
1987	903	17 061	" "	0.052	853
1988	1 098	19 056	Sea Fisheries Research Institute (unpublished data)	0.058	953

APPENDIX 6

DOCUMENTATION AND PROGRAM CODE FOR SEAL MODEL

PROGRAM SPECIFICATION

This program runs the Seal Model - a simulation model of the South African fur seal population, designed to explore management strategies and population dynamics.

SPECIFICATIONS FOR USE

Hardware and Software

MacPascal on an Apple Macintosh.

Input specifications

All parameters/variables excluding those related to culling rates form part of the program code. Additional input is requested by the following questions from the user before the model starts running. The questions and answers are written to the MacPascal Text window so that they can be printed together with the output on completion of a run.

Do you want to simulate all culling rates ?

If "yes" then

Enter the culling rates :

Pups =

Bulls =

Cows =

else

Do you want a pup cull ?

Do you want a bull cull ?

Do you want a cow cull ?

Do you want to print the output of only two years ?

If "yes" then

Which two years do you want printed ?

First =
Second =

Output format

The output is printed to the MacPascal Text window. During each year of simulation, the output is printed (unless the choice is made to print only two of the years).

If all culling rates are requested then for each year the following is written :

Pup cull : Bull cull : Cow cull :

The remaining output is printed under the following headings :

<i>Year</i>	<i>Number culled</i>			<i>Pups</i>	<i>Population</i>	<i>Fish eaten</i>
	<i>Pups</i>	<i>Bulls</i>	<i>Cows</i>			
<i>.....</i>	<i>.....</i>	<i>.....</i>	<i>.....</i>	<i>.....</i>	<i>.....</i>	<i>.....</i>

Pop : pup ratio (max/min) =

If there is a pup cull then

Percentage of males : in population =in pup harvest =

else

Percentage of males : in population =

Loss in pup production due to disturbance (%) =

Disturbance factors - cows :

- bulls : this year next year

The results are then imported to the Macintosh application, "Cricketgraph" to produce graphical output.

Guide to error messages

If an erroneous input value is inserted and the breeding population is reduced to a negative value, the following error message is output and the run can be stopped manually :

No breeders

Run time

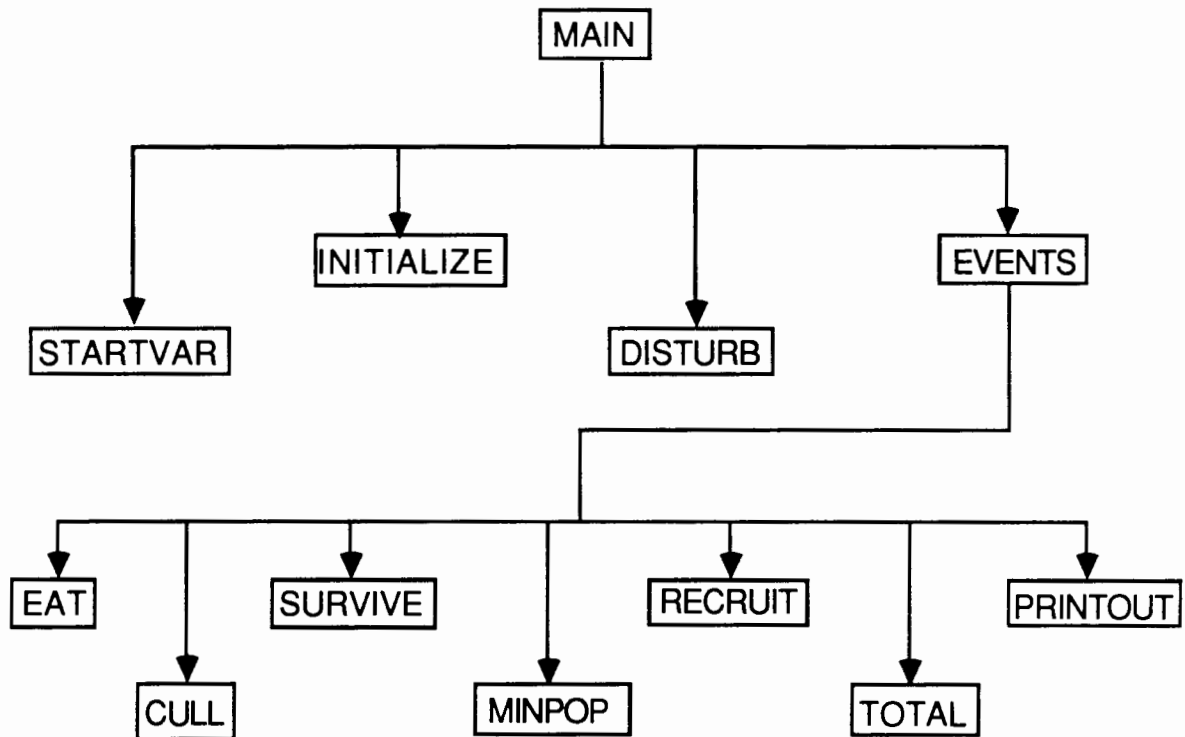
A 20-year simulation takes 20 seconds to run.

PROGRAM DESIGN

Overall description

The program of 323 lines is self-contained in that it handles all input and output without the using external files. The program first accepts all interactive input. During each year of the simulation, the output is printed, unless the choice is made to print only during two of the years.

Inter-relationship between procedures



Function of each procedure

Main : This procedure calls the procedures to set up all variables for the simulation (Startvar and Initialise) and calls the procedures to do the simulations (Events and Disturb).

Startvar : The initial population is set up by using the input number of pups as a starting point and calculating the surviving number in each age class. The total population and the number of female breeders is calculated.

Initialise : Parameters are assigned values; input culling rates and the years to be printed are requested and the input read in. Headings are printed.

Disturb : The loss in pup production due to disturbance of a bull or cow cull is calculated.

Events : This procedure is called annually and it calls the procedures (Eat, Cull, Survive, Recruit, Total) to calculate the annual changes to the seal population and its consumption and to printout out the output (Printout).

Eat : This calculates annual fish consumption by the seal population in thousands of tons.

Cull : The number of seals of different ages and sexes that are culled is calculated and these are removed from the model population.

Survive : The number of seals surviving from one age class to the next is calculated.

Minpop : The post-mortality population for the year is calculated.

Recruit : The number of pups born at the end of the year, accounting for the loss in pup production due to culling disturbance is calculated.

Total : The total number of seals, the percentage of males and the ratio of the population to pups is calculated.

Printout : The output is printed.

Code validation

Results were cross-checked by hand for errors.

PROGRAM CODE

```
program SealModel;
```

```
  const  
    simtime = 20;  
    numvar = 12;  
    territsurv = 0.71;  
    surv4plus = 0.92;  
    surv1to3 = 0.86;  
    surv0 = 0.80;  
    fec3 = 0.1;  
    fec45 = 0.68;  
    fec67 = 0.81;  
    fguts1 = 1460;  
    fguts2 = 1597;  
    fguts3 = 1752;  
    fguts4 = 1825;  
    fguts5 = 1825;  
    fguts6 = 1643;  
    fguts7 = 1278;  
    mguts1 = 1460;  
    mguts2 = 1597;
```

```

mguts3 = 1752;
mguts4 = 2373;
mguts5 = 2738;
mguts6 = 2464;
mguts7 = 2135;
aggregation = 21;
mpupprop = 0.55;
mharvprop = 0.65;
disturbcow = 0.15;
disturbthis = 0.15;
disturbnext = 0.5;

type
ages = array[0..7] of real;

var
mal, fem : ages;
t, a, printyr1, printyr2 : integer;
answer, print2, message, iter, typepup, typemal, typefem : string;
adults, fish, fishtot, breeders, pups, pop, ppratio, minratio : real;
malecull, femcull, mpupcull, fpupcull, pupcull, cullpup, cullmale, cullfem : real;
femtot, maltot, juvtot, poptot, mal7surv, minpop : real;
malrat, femratio, harvrat, pupratio : real;
cowdisturb, bulldisturb1, bulldisturb2, disturbloss, disturbsurv : real;

procedure Initialise;
var
i : integer;
begin
showtext;
write('Do you want to simulate all culling rates ? ');
readln(iter);
if iter <> 'y' then
begin
writeln('Enter the culling rates : ');
write('Pups = ');
readln(cullpup);
write('Bulls = ');
readln(cullmale);
write('Cows = ');
readln(cullfem);
writeln;
end
else
begin
cullpup := 0;
cullmale := 0;
cullfem := 0;
typepup := 'X';
typemal := 'X';
typefem := 'X';
writeln;
write('Do you want a pup cull ? ');
readln(typepup);
write('Do you want a bull cull ? ');
readln(typemal);
write('Do you want a cow cull ? ');
readln(typefem);
end;
writeln;
write('Do you want to print the output of only two years ? ');
readln(print2);
if (print2 = 'y') then
begin
writeln(' Which two years do you want printed?');
write('First = ');
readln(printyr1);
write('Second = ');
readln(printyr2);

```

```

end;
writeln;
if iter <> 'y' then
begin
  writeln('Culling Rates : Pups    Bulls    Cows');
  writeln('          ', cullpup : 5 : 2, ' ', cullmale : 5 : 2, ' ', cullfem : 5 : 2);
end;
writeln;
writeln('Time    Number culled    Pups    Population    Fish Eaten');
writeln('    Pups    Bulls    Cows');
writeln;
end;

procedure Startvar;
var
  i : integer;
begin
  fem[0] := 500000 * (1 - mpupprop);
  fem[1] := fem[0] * surv0;
  fem[2] := fem[1] * surv1to3;
  fem[3] := fem[2] * surv1to3;
  fem[4] := fem[3] * surv1to3;
  fem[5] := fem[4] * surv4plus;
  fem[6] := fem[5] * surv4plus;
  fem[7] := fem[6] * surv4plus;
  mal[0] := 500000 * mpupprop;
  mal[1] := mal[0] * surv0;
  mal[2] := mal[1] * surv1to3;
  mal[3] := mal[2] * surv1to3;
  mal[4] := mal[3] * surv1to3;
  mal[5] := mal[4] * surv4plus;
  mal[6] := mal[5] * surv4plus;
  mal[7] := mal[6] * surv4plus;
  pop := 0;
  for i := 0 to 7 do
    pop := pop + fem[i] + mal[i];
  breeders := fec3 * fem[3] + fec45 * (fem[4] + fem[5]) + fec67 * (fem[6] + fem[7]);
end;

procedure Disturbance;
begin
  if cullfem > 0 then
    cowdisturb := disturbcow
  else
    cowdisturb := 0;
  if (cullmale > 0) then
    begin
      if (cullmale < disturbthis) then
        bulldisturb1 := cullmale
      else
        bulldisturb1 := disturbthis;
      if (cullmale < 0.2) then
        bulldisturb2 := disturbnext / 0.2 * cullmale
      else
        bulldisturb2 := disturbnext;
    end
  else
    begin
      bulldisturb1 := 0;
      bulldisturb2 := 0;
    end;
end;

procedure Eat;
begin
  fish := fem[1] * fguts1 + fem[2] * fguts2 + fem[3] * fguts3 + fem[4] * fguts4;
  fish := fish + fem[5] * fguts5 + fem[6] * fguts6 + fem[7] * fguts7;
  fish := fish + mal[1] * mguts1 + mal[2] * mguts2 + mal[3] * mguts3 + mal[4] * mguts4;
  fish := fish + mal[5] * mguts5 + mal[6] * mguts6 + mal[7] * mguts7;

```

```

fish := fish / 1000000;
end;

procedure Cull;
begin
breeders := fec3 * fem[3] + fec45 * (fem[4] + fem[5]) + fec67 * (fem[6] + fem[7]);
femcull := cullfem * breeders;
breeders := breeders - femcull;
fpupcull := cullpup * (1 - mharvprop) * (fem[0] + mal[0]);
mpupcull := cullpup * mharvprop * (fem[0] + mal[0]);
if fpupcull > fem[0] then
begin
mpupcull := mpupcull + (fpupcull - fem[0]);
fpupcull := fem[0];
end;
if mpupcull > mal[0] then
begin
fpupcull := fpupcull + (mpupcull - mal[0]);
mpupcull := mal[0];
end;
pupcull := fpupcull + mpupcull;
if pupcull > 0 then
harvrat := mpupcull / pupcull * 100;
malecull := cullmale * mal[7];
fem[0] := fem[0] - fpupcull;
mal[0] := mal[0] - mpupcull;
fem[3] := fem[3] * (1.0 - fec3 * cullfem);
fem[4] := fem[4] * (1.0 - fec45 * cullfem);
fem[5] := fem[5] * (1.0 - fec45 * cullfem);
fem[6] := fem[6] * (1.0 - fec67 * cullfem);
fem[7] := fem[7] * (1.0 - fec67 * cullfem);
mal[7] := mal[7] - malecull;
end;

procedure Survive;
begin
if (breeders / aggregation) < mal[7] then
mal7surv := ((mal[7] - (breeders / aggregation)) * surv4plus + (breeders / aggregation * territsurv)) / mal[7]
else
mal7surv := territsurv;
mal[7] := mal[7] * mal7surv + mal[6] * surv4plus;
mal[6] := mal[5] * surv4plus;
mal[5] := mal[4] * surv4plus;
mal[4] := mal[3] * surv1to3;
mal[3] := mal[2] * surv1to3;
mal[2] := mal[1] * surv1to3;
mal[1] := mal[0] * surv0;
fem[7] := (fem[6] + fem[7]) * surv4plus;
fem[6] := fem[5] * surv4plus;
fem[5] := fem[4] * surv4plus;
fem[4] := fem[3] * surv1to3;
fem[3] := fem[2] * surv1to3;
fem[2] := fem[1] * surv1to3;
fem[1] := fem[0] * surv0;
end;

procedure Minpopulation;
var
i : integer;
begin
minpop := 0;
for i := 1 to 7 do
minpop := minpop + mal[i] + fem[i];
if (mal[0] + fem[0]) > 0 then
minratio := minpop / (mal[0] + fem[0])
else
minratio := 0;
end;
end;

```

```

procedure Recruit;
begin
breeders := fec3 * fem[3] + fec45 * (fem[4] + fem[5]) + fec67 * (fem[6] + fem[7]);
mal[0] := breeders * mpupprop;
fem[0] := breeders * (1 - mpupprop);
disturbsurv := breeders * (1 - bulldisturb1) * (1 - bulldisturb2) * (1 - cowdisturb);
disturbloss := breeders - disturbsurv;
mal[0] := mal[0] - disturbloss * mpupprop;
fem[0] := fem[0] - disturbloss * (1 - mpupprop);
if (breeders > 0) then
  disturbloss := disturbloss / breeders * 100
else
  begin
  writeln('No breeders');
  disturbloss := 0;
  end;
end;

procedure Total;
begin
maltot := mal[0] + mal[1] + mal[2] + mal[3] + mal[4] + mal[5] + mal[6] + mal[7];
femtot := fem[0] + fem[1] + fem[2] + fem[3] + fem[4] + fem[5] + fem[6] + fem[7];
poptot := femtot + maltot;
pups := fem[0] + mal[0];
malrat := maltot / poptot * 100;
ppratio := poptot / pups;
end;

procedure Printout;
begin
write(t : 2, ' ', pupcull : 6 : 1, ' ', malecull : 6 : 1, ' ', femcull : 6 : 1);
writeln(' ', Pups : 6 : 1, ' ', Poptot : 7 : 1, ' ', Fish : 7 : 1);
if minratio > 0 then
  writeln('Pop : pup ratio (max/min) = ', ppratio : 3 : 2, '/', minratio : 3 : 2)
else
  writeln('Pop : pup ratio (max/min) = ', ppratio : 3 : 2);
if pupcull > 0 then
  writeln('Percentage males : in population = ', malrat : 3 : 2, ' in pup harvest = ', harvrat : 2 : 1)
else
  writeln('Percentage males : in population = ', malrat : 3 : 2);
if disturbloss > 0 then
  writeln('Loss in pup production due to disturbance (%) = ', disturbloss : 3 : 2);
writeln;
end;

procedure Events;
begin
Eat;
Cull;
Survive;
Minpopulation;
Recruit;
Total;
if (print2 = 'y') then
  begin
  if ((t = printyr1) or (t = printyr2)) then
    Printout
  end
else
  Printout;
end;

begin
Startvar;
Initialise;
if iter = 'y' then
  for a := 1 to 8 do
    begin
    Startvar;

```

```

if typepup = 'y' then
  cullpup := a * 0.1;
if typemal = 'y' then
  cullmale := a * 0.1;
if typefem = 'y' then
  cullfem := a * 0.1;
writeln('Pup Cull : ', cullpup : 3 : 2, ' Bull cull : ', cullmale : 3 : 2, ' Cow cull : ', cullfem : 3 : 2);
writeln;
Disturbance;
writeln('Disturbance factors - cows : ', cowdisturb : 3 : 2);
writeln('          - bulls : this year : ', bulldisturb1 : 3 : 2, ' next year : ', bulldisturb2 : 3 : 2);
writeln;
for t := 1 to simtime do
  Events;
  writeln;
end
else
begin
  Disturbance;
  writeln('Disturbance factors - cows : ', cowdisturb : 3 : 2);
  writeln('          - bulls : this year : ', bulldisturb1 : 3 : 2, ' next year : ', bulldisturb2 : 3 : 2);
  writeln;
  for t := 1 to simtime do
    Events;
  end;
end.

```

APPENDIX 7

DOCUMENTATION AND PROGRAM CODE FOR SEAL AGE MODEL

PROGRAM SPECIFICATION

This program is designed to run the Seal Age Model - a simulation model of the South African fur seal population for estimating probabilities of reaching particular ages.

SPECIFICATIONS FOR USE

Hardware and Software

MacPascal on an Apple Macintosh.

Input specifications

All parameters/variables form part of the program code. No additional input is required.

Output format

The output is printed to the MacPascal Text window under the following headings :

Percentage of individuals over each age

<i>Age</i>	<i>Males</i>	<i>Females</i>
.....

The results are then imported to the Macintosh application, "Cricketgraph" to produce graphical output.

Run time

For a longevity of 47 years, the model takes 25 seconds to run.

PROGRAM DESIGN

Overall description

The program of 68 lines is self-contained in that it handles all model input and tabular output without the using external files. There is no division into different procedures.

Code validation

Results were cross-checked by hand for errors.

PROGRAM CODE

```
program SealAgeModel;

const
  simtime = 100;
  territsurv = 0.71;
  surv4plus = 0.92;
  surv1to3 = 0.86;
  surv0 = 0.80;
  fec3 = 0.10;
  fec45 = 0.68;
  fec67 = 0.81;
  mpupprop = 0.55;
  numages = 100;
  aggregation = 21;

type
  ages = array[0..numages] of real;

var
  i : integer;
  mal, fem, pop : ages;
  ratio, poptot, popover30, malover30, femover30, maltot, femtot : real;
  breeders, territmalsurv, malover7, mal7surv, all : real;

begin
  showtext;
  fem[0] := 100;
  mal[0] := 100;
  poptot := 0;
  fem[1] := fem[0] * surv0;
  mal[1] := mal[0] * surv0;
  for i := 2 to 4 do
    begin
      fem[i] := fem[i - 1] * surv1to3;
      mal[i] := mal[i - 1] * surv1to3;
    end;
  for i := 5 to 6 do
    begin
      fem[i] := fem[i - 1] * surv4plus;
      mal[i] := mal[i - 1] * surv4plus;
    end;
  malover7 := 0;
  breeders := fec3 * fem[3] + fec45 * (fem[4] + fem[5]);
  for i := 7 to numages do
    begin
      fem[i] := fem[i - 1] * surv4plus;
      mal[i] := mal[i - 1] * surv4plus;
      malover7 := malover7 + mal[i];
    end;
  end;
```

```

    breeders := breeders + fec67 * fem[i];
end;
if (breeders / aggregation) < malover7 then
    mal7surv := ((malover7 - (breeders / aggregation)) * surv4plus + breeders / aggregation * territsurv) / malover7
else
    mal7surv := territsurv;
for i := 7 to numages do
    mal[i] := mal[i - 1] * mal7surv;
writeln(' Percentage of individuals over each age ');
writeln;
writeln('   Age       Males   Females ');
writeln;
for i := 0 to numages do
    begin
        if (mal[i] > 1.5) and (fem[i] > 1.5) then
            writeln(i, '           ', mal[i] : 6 : 1, '           ', fem[i] : 6 : 1);
        if (mal[i] < 1.5) and (fem[i] > 1.5) then
            writeln(i, '           ', fem[i] : 6 : 1);
        end;
    end.

```

APPENDIX 8

AGES OF SOUTH AFRICAN FUR SEALS HELD IN CAPTIVITY

Below is a list of all South African fur seals held in captivity in South Africa and their approximate ages. If the date of birth is unknown, the date that the seal was acquired is given and marked with an asterisk. Likewise, if a seal was transferred from one locality to another, this date is marked with an asterisk.

DATE OF BIRTH/ACQUISITION	DATE DIED/TRANSFERRED	MINIMUM AGE (on 11-89)	LOCALITY
MALES			
11-63	2-81	17	Port Elizabeth Oceanarium
11-74		15	Oceanographic Research Institute, Durban
11-76		13	Hartbeespoort Dam Snake and Animal Park
11-76		12	Port Elizabeth Oceanarium
11-77		12	Johannesburg Zoo
11-81		8	Oceanographic Research Institute, Durban
11-83		6	Port Elizabeth Oceanarium
11-73	1-79	6	Port Elizabeth Oceanarium
11-84		5	Pretoria Zoo
11-86		3	Oceanographic Research Institute, Durban
10-76*	5-78*	>2	Port Elizabeth Oceanarium to Italy
11-87		2	Hartbeespoort Dam Aquarium
11-88		1	Hartbeespoort Dam Aquarium
01-88		1	Port Elizabeth Oceanarium
FEMALES			
11-67	11-85*	18	Hartbeespoort Dam Aquarium
11-73		16	Port Elizabeth Oceanarium
11-73/74		>15	Oceanographic Research Institute, Durban
11-74		15	Oceanographic Research Institute, Durban
11-74		15	Oceanographic Research Institute, Durban
11-75		14	Port Elizabeth Oceanarium
11-65/66	5-78*	>11	Port Elizabeth Oceanarium to Italy
5-79		10	Oceanographic Research Institute, Durban
11-79		10	Port Elizabeth Oceanarium
11-80		9	Hartbeespoort Dam Snake and Animal Park
11-82		7	East London Aquarium
11-82		7	East London Aquarium
11-82		7	East London Aquarium
11-82		7	East London Aquarium
11-82		7	Johannesburg Zoo
12-76*	1-83	>6	Port Elizabeth Oceanarium
4-85*		>5	Johannesburg Zoo
4-85*		>5	Johannesburg Zoo
11-85		4	Pretoria Zoo
11-86		3	Pretoria Zoo
11-87		2	Port Elizabeth Oceanarium
11-87		2	Port Elizabeth Oceanarium
11-87		2	Hartbeespoort Dam Aquarium
12-87		2	Port Elizabeth Oceanarium
11-88		1	Port Elizabeth Oceanarium
12-88		1	Johannesburg Zoo

APPENDIX 9

DOCUMENTATION AND PROGRAM CODE FOR SCALED SEAL MODEL

PROGRAM SPECIFICATION

This program runs the Scaled Seal Model - a simulation model of the South African fur seal population designed to model historical seal population dynamics and explore future management strategies.

SPECIFICATIONS FOR USE

Hardware and Software

MacPascal on an Apple Macintosh.

Interactive input

All parameters/variables excluding those related to culling rates form part of the program code. Additional input is requested by the following questions from the user before the model starts running. The questions and answers are written to the MacPascal Text window so that they can be printed together with the output on completion of a run.

Which colony do you want to simulate ?

<i>All (a)</i>	<i>Mainland (m)</i>	<i>Islands (i)</i>
<i>Namibia (n)</i>	<i>SA west coast (w)</i>	<i>SA east coast (e)</i>
<i>Kleinsee (k)</i>	<i>Wolf/Atlas Bay (b)</i>	<i>Cape Cross (c)</i>

Enter the first and last year of simulation ?

First =

Last =

Do you want a printout of years 1971 and 1983 and post-1988 only ?

Enter the culling rates for 1989 onwards :

Pups =

Bulls=
Cows =

Enter the initial population -

Output format

The output is printed to the MacPascal Text window. During each year of the simulation, the output is printed (unless the choice is made to print only during two of the years).

Total culling figures are for years 19... to 19...

Initial population =

<i>Year</i>	<i>Number culled</i>			<i>Pups</i>	<i>Population</i>	<i>Fish eaten</i>
	<i>Pups</i>	<i>Bulls</i>	<i>Cows</i>			
.....

Percentage of males : in population =

Culling rates - pup : bull : cow :

Ratio of population to pups (max/min population) =

Disturbance : cow

bull : this year :

next year :

Loss in pup production due to disturbance (%) =

The results are then imported to the Macintosh application, "Cricketgraph" to produce graphical output.

Guide to error messages

If any age class of the population is too small for the number of seals culled to be removed from it then the following error message is output and the run can be stopped manually :

**** ERROR - starting population too small year ****

If an erroneous input value is inserted and the breeding population is reduced to a negative value, the following error message is output and the run can be stopped manually :

No breeders

Run time

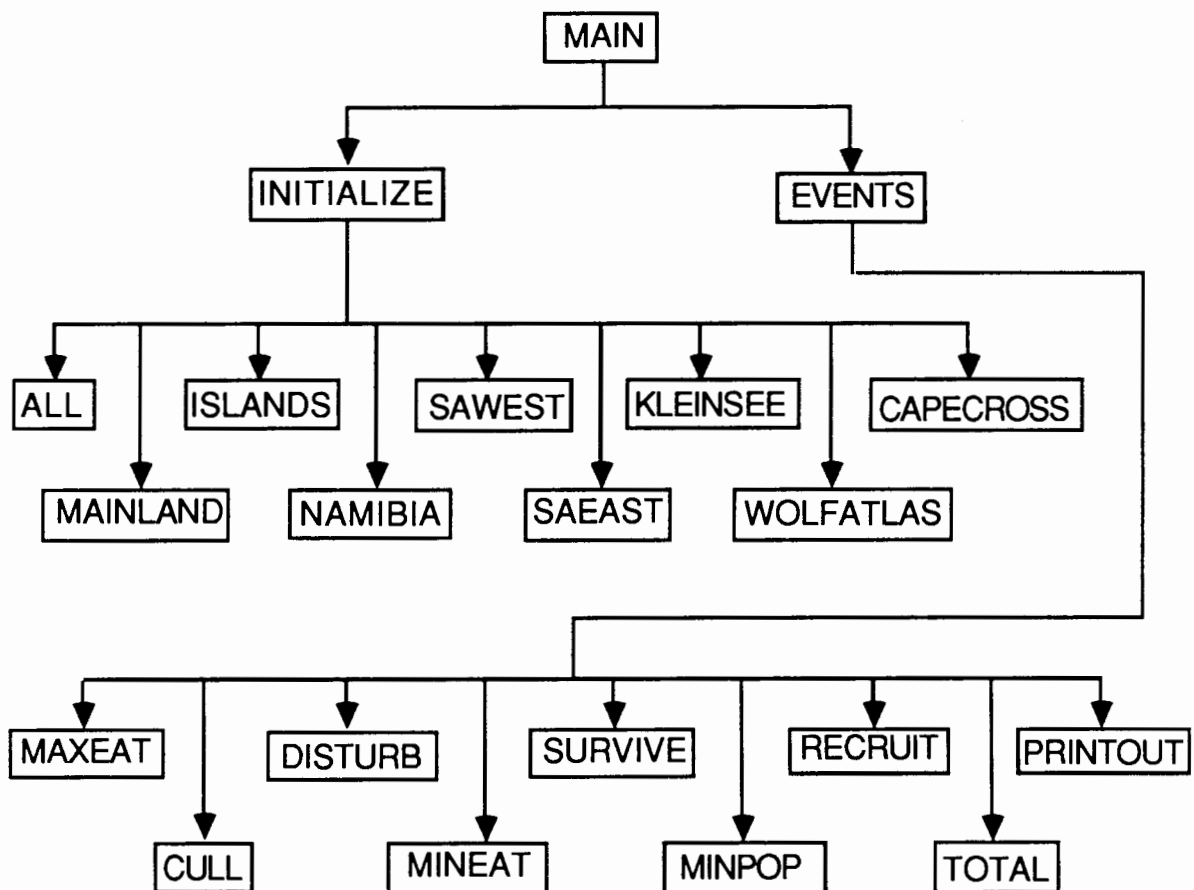
To simulate the years, 1900 to 1988 takes approximately 7 minutes, including printing the output to the MacPascal Text window.

PROGRAM DESIGN

Overall description

The program of 834 lines is self-contained in that it handles all data input (both from values assigned to arrays and interactively input data) and output without the using external files. In practice, the program was split in two, one containing the data for Namibia, SA west coast, SA east coast, mainland and islands and the other having the data for all colonies, Kleinsee, Cape Cross and Wolf and Atlas Bays. If all these data are entered in one program, it becomes too long for execution.

Inter-relationship between procedures



Function of each procedure

Main : This procedure calls the procedures to set all variables for the simulation (Startvar and Initialize) and calls the procedures to do the simulations (Events and Disturb).

Initialize : Parameters are assigned values; the relevant procedure (All, Mainland, Islands, Namibia, SAwest, SAeast, Kleinsee, WolfAtlas or CapeCross) is called depending on which colony or group of colonies the user wishes to simulate; input culling rates for future years and the years to be printed are requested and the input read in. Headings are printed.

All, Mainland, Islands, Namibia, SAwest, SAeast, Kleinsee, WolfAtlas, CapeCross : These procedures set up arrays which contain the number of seals culled from each of these colonies or groups of colonies.

Events : This procedure is called annually, and it calls the procedures (Eat, Cull, Survive, Recruit, Total) to calculate the annual changes to the seal population and its consumption and print out the output (Printout).

Disturb : The loss in pup production due to disturbance of a bull or cow cull is calculated.

Cull : The number of seals of different ages and sexes that are culled is calculated and these are removed from the population.

Eat : This calculates annual fish consumption by the seal population in thousands of tons.

Survive : The number of seals surviving from one age class to the next is calculated.

Minpop : The post-mortality population for the year is calculated.

Recruit : The number of pups born at the end of the year, accounting for the loss in pup production due to culling disturbance is calculated.

Total : The total number of seals, the percentage of males and the ratio of the population to pups is calculated.

Printout : The output is printed.

Code validation

Results were cross-checked by hand for errors.

PROGRAM CODE

Program ScaledSealModel;

```
const
numvar = 12;
territsurv = 0.71;
surv4plus = 0.92;
surv1to3 = 0.86;
surv0 = 0.80;
fec3 = 0.1;
fec45 = 0.68;
fec67 = 0.81;
fguts1 = 1460;
fguts2 = 1597;
fguts3 = 1752;
fguts4 = 1825;
fguts5 = 1825;
fguts6 = 1643;
fguts7 = 1278;
mguts1 = 1460;
mguts2 = 1597;
mguts3 = 1752;
mguts4 = 2373;
mguts5 = 2738;
mguts6 = 2464;
mguts7 = 2135;
aggregation = 21;
mpupprop = 0.55;
mharvprop = 0.65;
disturbcow = 0.15;
disturbthis = 0.15;
disturbnext = 0.5;

type
ages = array[0..7] of real;
cullarray = array[0..100] of real;

var
mal, fem : ages;
answer, colony, printyears : string;
cullpup, cullmale, cullfem, bulldisturb : cullarray;
t, a, printyr1, printyr2, firstcull, lastcull, startyear, lastyear : integer;
adults, fish, fishtot, breeders, pups, minpop, minfish, maxfish : real;
malecull, femcull, mpupcull, fpupcull, pupcull : real;
femtot, maltot, juvtot, feeders, poptot, pop, minratio : real;
malrat, femratio, harvrat, pupratio, disturbnext, mal7surv : real;
cowdisturb, disturbloss, disturbsurv : real;

procedure All;
begin
firstcull := 0;
lastcull := 88;
writeln('Total culling figures are for years 1900 to 1988');
cullpup[0] := 3246;
cullpup[1] := 2607;
cullpup[2] := 3822;
cullpup[3] := 6124;
cullpup[4] := 3039;
cullpup[5] := 6623;
cullpup[6] := 9304;
cullpup[7] := 3905;
cullpup[8] := 3455;
cullpup[9] := 5051;
cullpup[10] := 4100;
cullpup[11] := 4798;
cullpup[12] := 4673;
cullpup[13] := 8340;
```

cullpup[14] := 4493;
cullpup[15] := 421;
cullpup[16] := 2281;
cullpup[17] := 8244;
cullpup[18] := 9280;
cullpup[19] := 12030;
cullpup[20] := 13858;
cullpup[21] := 12191;
cullpup[22] := 14872;
cullpup[23] := 16025;
cullpup[24] := 18890;
cullpup[25] := 19563;
cullpup[26] := 14201;
cullpup[27] := 15550;
cullpup[28] := 17018;
cullpup[29] := 12097;
cullpup[33] := 9521;
cullpup[34] := 2320;
cullpup[35] := 2180;
cullpup[36] := 16038;
cullpup[37] := 16822;
cullpup[38] := 12072;
cullpup[39] := 15979;
cullpup[40] := 9595;
cullpup[41] := 12033;
cullpup[42] := 16049;
cullpup[43] := 17987;
cullpup[44] := 11675;
cullpup[45] := 12566;
cullpup[46] := 13864;
cullpup[47] := 15034;
cullpup[48] := 8737;
cullpup[49] := 11522;
cullpup[50] := 27289;
cullpup[51] := 34407;
cullpup[52] := 32677;
cullpup[53] := 29676;
cullpup[54] := 31377;
cullpup[55] := 39259;
cullpup[56] := 41741;
cullpup[57] := 45054;
cullpup[58] := 31919;
cullpup[59] := 34599;
cullpup[60] := 41933;
cullpup[61] := 48052;
cullpup[62] := 44174;
cullpup[63] := 50640;
cullpup[64] := 51360;
cullpup[65] := 60057;
cullpup[66] := 45433;
cullpup[67] := 64057;
cullpup[68] := 68807;
cullpup[69] := 74485;
cullpup[70] := 81207;
cullpup[71] := 76807;
cullpup[72] := 78029;
cullpup[73] := 80674;
cullpup[74] := 66876;
cullpup[75] := 74945;
cullpup[76] := 62467;
cullpup[77] := 76394;
cullpup[78] := 70407;
cullpup[79] := 75083;
cullpup[80] := 65174;
cullpup[81] := 86965;
cullpup[82] := 88414;
cullpup[83] := 42719;
cullpup[84] := 55333;
cullpup[85] := 31155;

cullpup[86] := 28842;
cullpup[87] := 4937;
cullpup[88] := 3322;
cullmale[0] := 1002;
cullmale[1] := 2491;
cullmale[2] := 559;
cullmale[5] := 631;
cullmale[6] := 308;
cullmale[7] := 1948;
cullmale[8] := 1649;
cullmale[9] := 423;
cullmale[11] := 1237;
cullmale[12] := 2650;
cullmale[23] := 544;
cullmale[24] := 600;
cullmale[28] := 500;
cullmale[31] := 90;
cullmale[32] := 50;
cullmale[34] := 875;
cullmale[35] := 430;
cullmale[36] := 339;
cullmale[37] := 450;
cullmale[38] := 695;
cullmale[39] := 879;
cullmale[40] := 1471;
cullmale[41] := 1656;
cullmale[42] := 4002;
cullmale[43] := 4758;
cullmale[44] := 4305;
cullmale[45] := 4850;
cullmale[46] := 5486;
cullmale[47] := 7014;
cullmale[48] := 4720;
cullmale[49] := 3911;
cullmale[50] := 2269;
cullmale[51] := 3250;
cullmale[52] := 4827;
cullmale[53] := 3806;
cullmale[54] := 3833;
cullmale[55] := 578;
cullmale[56] := 1050;
cullmale[57] := 1094;
cullmale[58] := 1081;
cullmale[59] := 1213;
cullmale[60] := 1304;
cullmale[61] := 1551;
cullmale[62] := 2020;
cullmale[63] := 5503;
cullmale[64] := 3552;
cullmale[65] := 5106;
cullmale[66] := 3232;
cullmale[67] := 2420;
cullmale[68] := 3198;
cullmale[69] := 2083;
cullmale[70] := 2456;
cullmale[71] := 2204;
cullmale[72] := 2240;
cullmale[73] := 2246;
cullmale[74] := 1167;
cullmale[75] := 786;
cullmale[77] := 1099;
cullmale[78] := 2983;
cullmale[79] := 387;
cullmale[80] := 1347;
cullmale[81] := 640;
cullmale[82] := 3100;
cullmale[83] := 4020;
cullmale[84] := 20293;
cullmale[85] := 12658;

```

cullmale[86] := 4725;
cullmale[87] := 14739;
cullmale[88] := 7144;
cullfem[85] := 6890;
cullfem[88] := 2632;
end;

procedure Mainland;
begin
  firstcull := 65;
  lastcull := 88;
  writeln('Total culling figures are for years 1965 to 1988');
  cullpup[65] := 46707;
  cullpup[66] := 38122;
  cullpup[67] := 52598;
  cullpup[68] := 55917;
  cullpup[69] := 59436;
  cullpup[70] := 70474;
  cullpup[71] := 62991;
  cullpup[72] := 63453;
  cullpup[73] := 68826;
  cullpup[74] := 54905;
  cullpup[75] := 58774;
  cullpup[76] := 47381;
  cullpup[77] := 64454;
  cullpup[78] := 60448;
  cullpup[79] := 62775;
  cullpup[80] := 61508;
  cullpup[81] := 75171;
  cullpup[82] := 77350;
  cullpup[83] := 42719;
  cullpup[84] := 55333;
  cullpup[85] := 31155;
  cullpup[86] := 28842;
  cullpup[87] := 4937;
  cullpup[88] := 3322;
  cullmale[73] := 2166;
  cullmale[74] := 1151;
  cullmale[75] := 421;
  cullmale[78] := 1294;
  cullmale[80] := 800;
  cullmale[82] := 2000;
  cullmale[83] := 4020;
  cullmale[84] := 18149;
  cullmale[85] := 11885;
  cullmale[86] := 4404;
  cullmale[87] := 14739;
  cullmale[88] := 7144;
  cullfem[85] := 6890;
  cullfem[88] := 2632;
end;

procedure Islands;
begin
  firstcull := 65;
  lastcull := 88;
  writeln('Total culling figures are for years 1965 to 1988');
  cullpup[65] := 13350;
  cullpup[66] := 7311;
  cullpup[67] := 11459;
  cullpup[68] := 12890;
  cullpup[69] := 15049;
  cullpup[70] := 10733;
  cullpup[71] := 13816;
  cullpup[72] := 14576;
  cullpup[73] := 11848;
  cullpup[74] := 11971;
  cullpup[75] := 16171;
  cullpup[76] := 15086;

```

```

cullpup[77] := 11940;
cullpup[78] := 9959;
cullpup[79] := 12308;
cullpup[80] := 3665;
cullpup[81] := 11794;
cullpup[82] := 11064;
cullmale[73] := 80;
cullmale[74] := 16;
cullmale[75] := 365;
cullmale[77] := 1099;
cullmale[78] := 1689;
cullmale[79] := 387;
cullmale[80] := 547;
cullmale[81] := 640;
cullmale[82] := 1100;
cullmale[84] := 2144;
cullmale[85] := 773;
cullmale[86] := 321;
end;

```

```

procedure Namibia;
begin
  firstcull := 65;
  lastcull := 88;
  writeln('Total culling figures are for years 1965 to 1988');
  cullpup[65] := 51761;
  cullpup[66] := 38810;
  cullpup[67] := 50866;
  cullpup[68] := 54256;
  cullpup[69] := 56555;
  cullpup[70] := 63929;
  cullpup[71] := 54465;
  cullpup[72] := 54104;
  cullpup[73] := 55465;
  cullpup[74] := 41645;
  cullpup[75] := 57223;
  cullpup[76] := 54881;
  cullpup[77] := 61327;
  cullpup[78] := 54088;
  cullpup[79] := 57427;
  cullpup[80] := 46508;
  cullpup[81] := 65853;
  cullpup[82] := 65462;
  cullpup[83] := 42719;
  cullpup[84] := 40333;
  cullpup[85] := 31155;
  cullpup[86] := 18646;
  cullpup[87] := 4937;
  cullpup[88] := 3322;
  cullmale[73] := 2166;
  cullmale[74] := 1151;
  cullmale[75] := 421;
  cullmale[77] := 1099;
  cullmale[78] := 2802;
  cullmale[80] := 800;
  cullmale[83] := 4020;
  cullmale[84] := 8114;
  cullmale[85] := 6435;
  cullmale[86] := 4725;
  cullmale[87] := 2700;
  cullmale[88] := 3625;
  cullfem[88] := 2632;
end;

```

```

procedure SAwest;
begin
  firstcull := 65;
  lastcull := 88;
  writeln('Total culling figures are for years 1965 to 1988');

```

```

cullpup[65] := 1693;
cullpup[66] := 2967;
cullpup[67] := 6031;
cullpup[68] := 8629;
cullpup[69] := 11674;
cullpup[70] := 11995;
cullpup[71] := 13956;
cullpup[72] := 14956;
cullpup[73] := 16489;
cullpup[74] := 18842;
cullpup[75] := 14837;
cullpup[76] := 6780;
cullpup[77] := 14171;
cullpup[78] := 14220;
cullpup[79] := 15000;
cullpup[80] := 30000;
cullpup[81] := 20043;
cullpup[82] := 22500;
cullpup[84] := 15000;
cullpup[86] := 10196;
cullmale[75] := 365;
cullmale[82] := 2000;
cullmale[84] := 10035;
cullmale[85] := 6223;
cullmale[87] := 12039;
cullmale[88] := 3519;
cullfem[85] := 6890;
end;

```

```

procedure SAeast;
begin
  firstcull := 65;
  lastcull := 88;
  writeln('Total culling figures are for years 1965 to 1988');
  cullpup[65] := 6603;
  cullpup[66] := 3656;
  cullpup[67] := 7160;
  cullpup[68] := 5922;
  cullpup[69] := 6256;
  cullpup[70] := 5283;
  cullpup[71] := 8395;
  cullpup[72] := 8969;
  cullpup[73] := 8720;
  cullpup[74] := 6389;
  cullpup[75] := 2885;
  cullpup[76] := 805;
  cullpup[77] := 896;
  cullpup[78] := 2099;
  cullpup[79] := 2656;
  cullpup[80] := 3666;
  cullpup[81] := 1069;
  cullpup[82] := 452;
  cullmale[73] := 80;
  cullmale[74] := 16;
  cullmale[78] := 181;
  cullmale[79] := 387;
  cullmale[80] := 547;
  cullmale[81] := 640;
  cullmale[82] := 1100;
  cullmale[84] := 2144;
end;

```

```

procedure Kleinsee;
begin
  firstcull := 65;
  lastcull := 88;
  writeln('Kleinsee culling figures are for years 1965 to 1988');
  cullpup[67] := 4416;
  cullpup[68] := 7041;

```

```

cullpup[69] := 9419;
cullpup[70] := 11110;
cullpup[71] := 13186;
cullpup[72] := 13756;
cullpup[73] := 15582;
cullpup[74] := 17000;
cullpup[75] := 13615;
cullpup[76] := 5318;
cullpup[77] := 14000;
cullpup[78] := 14045;
cullpup[79] := 15000;
cullpup[80] := 15000;
cullpup[81] := 20043;
cullpup[82] := 22500;
cullpup[84] := 15000;
cullpup[86] := 10196;
cullmale[82] := 2000;
cullmale[84] := 10035;
cullmale[85] := 6223;
cullmale[87] := 12039;
cullmale[88] := 3519;
cullfem[85] := 6890;
end;

```

```

procedure WolfAtlas;
begin
  firstcull := 65;
  lastcull := 88;
  writeln('Wolf/Atlas Bay culling figures are for years 1965 to 1988');
  cullpup[65] := 38937;
  cullpup[66] := 29698;
  cullpup[67] := 41056;
  cullpup[68] := 41833;
  cullpup[69] := 43115;
  cullpup[70] := 50657;
  cullpup[71] := 40055;
  cullpup[72] := 42227;
  cullpup[73] := 45891;
  cullpup[74] := 31506;
  cullpup[75] := 35616;
  cullpup[76] := 30968;
  cullpup[77] := 35823;
  cullpup[78] := 36964;
  cullpup[79] := 38628;
  cullpup[80] := 39912;
  cullpup[81] := 42136;
  cullpup[82] := 42775;
  cullpup[83] := 40580;
  cullpup[84] := 34126;
  cullpup[85] := 25037;
  cullpup[86] := 14151;
  cullpup[87] := 4937;
  cullmale[73] := 1002;
  cullmale[74] := 62;
  cullmale[83] := 2693;
  cullmale[84] := 7006;
  cullmale[85] := 4952;
  cullmale[86] := 3574;
  cullmale[87] := 688;
end;

```

```

procedure CapeCross;
begin
  firstcull := 65;
  lastcull := 88;
  writeln('Cape Cross culling figures are for years 1965 to 1988');
  cullpup[65] := 7770;
  cullpup[66] := 8424;
  cullpup[67] := 7126;

```

```

cullpup[68] := 7043;
cullpup[69] := 6902;
cullpup[70] := 8707;
cullpup[71] := 9750;
cullpup[72] := 7470;
cullpup[73] := 7353;
cullpup[74] := 6399;
cullpup[75] := 9543;
cullpup[76] := 11095;
cullpup[77] := 14631;
cullpup[78] := 9439;
cullpup[79] := 9147;
cullpup[80] := 6596;
cullpup[81] := 12992;
cullpup[82] := 12075;
cullpup[83] := 2139;
cullpup[84] := 6207;
cullpup[85] := 6118;
cullpup[86] := 4495;
cullpup[88] := 3322;
cullmale[73] := 1164;
cullmale[74] := 1089;
cullmale[75] := 421;
cullmale[78] := 1294;
cullmale[80] := 800;
cullmale[83] := 1327;
cullmale[84] := 1108;
cullmale[85] := 710;
cullmale[86] := 830;
cullmale[87] := 2012;
cullmale[88] := 3625;
cullfem[88] := 2632;
end;

procedure Initialize;
var
  i : integer;
begin
  showtext;
  writeln('Which colony do you want to simulate?');
  writeln(' All (a) Mainland (m) Islands (i)');
  writeln(' Namibia (n) SA west coast (w) SA east coast (e)');
  writeln(' Kleinsee (k) Wolf/Atlas Bay (b) Cape Cross (c)');
  readln(colony);
  writeln;
  if colony = 'a' then
    All;
  if colony = 'm' then
    Mainland;
  if colony = 'i' then
    Islands;
  if colony = 'n' then
    Namibia;
  if colony = 'w' then
    SAwest;
  if colony = 'e' then
    SAeast;
  if colony = 'k' then
    Kleinsee;
  if colony = 'b' then
    WolfAtlas;
  if colony = 'c' then
    CapeCross;

  writeln;
  writeln('Enter the first and last year of simulation');
  write(' First = ');
  readln(startyear);
  write(' Last = ');

```

```

readln(lastyear);

for i := 0 to firstcull - 1 do
begin
  cullpup[i] := 0;
  cullmale[i] := 0;
  cullfem[i] := 0;
  bulldisturb[i] := 0;
end;
for i := lastcull + 1 to lastyear do
begin
  cullpup[i] := 0;
  cullmale[i] := 0;
  cullfem[i] := 0;
  bulldisturb[i] := 0;
end;
writeln;
if lastyear > 88 then
begin
  writeln('Do you want a printout of years 1971 and 1983 and post-1988 only?');
  readln(printyears);
  if lastcull < lastyear then
  begin
    writeln;
    writeln('Enter the culling rates for 1989 onwards: ');
    write(' Pups = ');
    readln(cullpup[lastcull + 1]);
    write(' Bulls = ');
    readln(cullmale[lastcull + 1]);
    write(' Cows = ');
    readln(cullfem[lastcull + 1]);
    for i := lastcull + 2 to lastyear do
    begin
      cullpup[i] := cullpup[lastcull + 1];
      cullmale[i] := cullmale[lastcull + 1];
      cullfem[i] := cullfem[lastcull + 1];
    end;
  end;
end
else
begin
  writeln('Do you want a printout of years 1971 and 1983 only?');
  readln(printyears);
end;

writeln;
write('Enter the initial pup population - ');
readln(pups);
fem[0] := pups * (1 - mpupprop);
fem[1] := fem[0] * surv0;
fem[2] := fem[1] * surv1to3;
fem[3] := fem[2] * surv1to3;
fem[4] := fem[3] * surv1to3;
fem[5] := fem[4] * surv4plus;
fem[6] := fem[5] * surv4plus;
fem[7] := fem[6] * surv4plus;
mal[0] := pups * mpupprop;
mal[1] := mal[0] * surv0;
mal[2] := mal[1] * surv1to3;
mal[3] := mal[2] * surv1to3;
mal[4] := mal[3] * surv1to3;
mal[5] := mal[4] * surv4plus;
mal[6] := mal[5] * surv4plus;
mal[7] := mal[6] * surv4plus;
pop := 0;
for i := 0 to 7 do
  pop := pop + fem[i] + mal[i];
writeln;
writeln('Initial population = ', pop : 5 : 1);

```

```

breeders := fec3 * fem[3] + fec45 * (fem[4] + fem[5]) + fec67 * (fem[6] + fem[7]);
writeln;
writeln('Time      Number culled      Pups      Population      Fish Eaten ');
writeln('      Pups Bulls Cows              Max/Min      Max/Min');
writeln;
end;

procedure MaximumEat;
begin
maxfish := fem[1] * fguts1 + fem[2] * fguts2 + fem[3] * fguts3 + fem[4] * fguts4;
maxfish := maxfish + fem[5] * fguts5 + fem[6] * fguts6 + fem[7] * fguts7;
maxfish := maxfish + mal[1] * mguts1 + mal[2] * mguts2 + mal[3] * mguts3 + mal[4] * mguts4;
maxfish := maxfish + mal[5] * mguts5 + mal[6] * mguts6 + mal[7] * mguts7;
maxfish := maxfish / 1000000;
end;

procedure Disturbance;
begin
if cullfem[t] > 0 then
  cowdisturb := disturbcow
else
  cowdisturb := 0;
if cullmale[t] > 0 then
  begin
  if (cullmale[t] > disturbthis) then
    begin
    if bulldisturb[t] = 0 then
      bulldisturb[t] := disturbthis
    else
      bulldisturb[t] := 1 - ((1 - bulldisturb[t]) * (1 - disturbthis));
    end
  else
    begin
    if bulldisturb[t] = 0 then
      bulldisturb[t] := cullmale[t]
    else
      bulldisturb[t] := 1 - ((1 - bulldisturb[t]) * (1 - cullmale[t]));
    end;
  if (t <> lastyear) then
    begin
    if cullmale[t] > 0.2 then
      bulldisturb[t + 1] := disturbnext
    else
      bulldisturb[t + 1] := disturbnext / 0.2 * cullmale[t];
    end;
  end;
end;

procedure Cull;
begin
breeders := fec3 * fem[3] + fec45 * (fem[4] + fem[5]) + fec67 * (fem[6] + fem[7]);
pups := mal[0] + fem[0];
if t <= lastcull then
  begin
  femcull := cullfem[t];
  pupcull := cullpup[t];
  malecull := cullmale[t];
  cullfem[t] := femcull / breeders;
  cullpup[t] := pupcull / pups;
  cullmale[t] := malecull / mal[7];
  if (femcull > breeders) or (pupcull > pups) or (malecull > mal[7]) then
    writeln('** ERROR - starting population too small year ', t : 2 : 1, '**');
  end
else
  begin
  femcull := cullfem[t] * breeders;
  breeders := breeders - femcull;
  pupcull := pups * cullpup[t];
  malecull := cullmale[t] * mal[7];

```

```

end;
fpupcull := pupcull * (1 - mharvprop);
mpupcull := pupcull * mharvprop;
if fpupcull > fem[0] then
begin
mpupcull := mpupcull + (fpupcull - fem[0]);
fpupcull := fem[0];
end;
if mpupcull > mal[0] then
begin
fpupcull := fpupcull + (mpupcull - mal[0]);
mpupcull := mal[0];
end;
pupcull := fpupcull + mpupcull;
if pupcull > 0 then
harvrat := mpupcull / pupcull * 100;
fem[0] := fem[0] - fpupcull;
mal[0] := mal[0] - mpupcull;
fem[3] := fem[3] * (1.0 - fec3 * cullfem[t]);
fem[4] := fem[4] * (1.0 - fec45 * cullfem[t]);
fem[5] := fem[5] * (1.0 - fec45 * cullfem[t]);
fem[6] := fem[6] * (1.0 - fec67 * cullfem[t]);
fem[7] := fem[7] * (1.0 - fec67 * cullfem[t]);
mal[7] := mal[7] - malecull;
end;

procedure MinimumEat;
var
i : integer;
begin
minfish := fem[1] * surv1to3 * fguts1 + mal[1] * surv1to3 * mguts1;
minfish := minfish + fem[2] * surv1to3 * fguts2 + mal[2] * surv1to3 * mguts2;
minfish := minfish + fem[3] * surv1to3 * fguts3 + mal[3] * surv1to3 * mguts3;
minfish := minfish + fem[4] * surv4plus * fguts4 + mal[4] * surv4plus * mguts4;
minfish := minfish + fem[5] * surv4plus * fguts5 + mal[5] * surv4plus * mguts5;
minfish := minfish + fem[6] * surv4plus * fguts6 + mal[6] * surv4plus * mguts6;
minfish := minfish + fem[7] * surv4plus * fguts7 + mal[7] * surv4plus * mguts7;
minfish := minfish / 1000000;
end;

procedure Survive;
begin
if (breeders / aggregation) < mal[7] then
mal7surv := ((mal[7] - (breeders / aggregation)) * surv4plus + (breeders / aggregation * territsurv)) / mal[7]
else
mal7surv := territsurv;
mal[7] := (mal[7] * mal7surv + mal[6] * surv4plus);
mal[6] := mal[5] * surv4plus;
mal[5] := mal[4] * surv4plus;
mal[4] := mal[3] * surv1to3;
mal[3] := mal[2] * surv1to3;
mal[2] := mal[1] * surv1to3;
mal[1] := mal[0] * surv0;
fem[7] := (fem[6] + fem[7]) * surv4plus7;
fem[6] := fem[5] * surv4plus;
fem[5] := fem[4] * surv4plus;
fem[4] := fem[3] * surv1to3;
fem[3] := fem[2] * surv1to3;
fem[2] := fem[1] * surv1to3;
fem[1] := fem[0] * surv0;
end;

procedure Minpopulation;
var
i : integer;
begin
minpop := 0;
for i := 1 to 7 do
minpop := minpop + mal[i] + fem[i];

```

```

minratio := minpop / (mal[0] + fem[0])
end;

procedure Recruit;
begin
breeders := fec3 * fem[3] + fec45 * (fem[4] + fem[5]) + fec67 * (fem[6] + fem[7]);
mal[0] := breeders * mpupprop;
fem[0] := breeders * (1 - mpupprop);
disturbsurv := breeders * (1 - bulldisturb[t]) * (1 - cowdisturb);
disturbloss := breeders - disturbsurv;
mal[0] := mal[0] - disturbloss * mpupprop;
fem[0] := fem[0] - disturbloss * (1 - mpupprop);
if (breeders > 0) then
  disturbloss := disturbloss / breeders * 100
else
  begin
  writeln('No breeders');
  disturbloss := 0;
  end;
end;

procedure Total;
begin
maltot := mal[0] + mal[1] + mal[2] + mal[3] + mal[4] + mal[5] + mal[6] + mal[7];
femt0t := fem[0] + fem[1] + fem[2] + fem[3] + fem[4] + fem[5] + fem[6] + fem[7];
poptot := femt0t + maltot;
pups := fem[0] + mal[0];
feeders := poptot - fem[0] - mal[0];
malrat := maltot / poptot * 100;
pupratio := poptot / pups;
end;

procedure Printout;
begin
write(t : 2, ' ', pupcull : 6 : 1, ' ', malecull : 6 : 1, ' ', femcull : 6 : 1);
write(' ', Pups : 6 : 1, ' ', Poptot : 7 : 1, '/', Minpop : 7 : 1);
writeln(' ', maxfish : 5 : 1, '/', minfish : 5 : 1);
writeln('Percentage males in population = ', malrat : 3 : 1);
write('Culling rates - pup : ', cullpup[t] * 100 : 3 : 1, ' bull : ');
writeln(cullmale[t] * 100 : 3 : 1, ' cow : ', cullfem[t] * 100 : 3 : 1);
writeln('Ratio of population to pups (max/min population) = ', pupratio : 4 : 1, '/', minratio : 4 : 1);
if disturbloss > 0 then
  begin
  write('Disturbance : cow = ', cowdisturb * 100 : 2 : 1);
  write(' bull : this yr = ', bulldisturb[t] * 100 : 2 : 1);
  if t <> lastyear then
    write(' next yr = ', bulldisturb[t + 1] * 100 : 2 : 1);
  writeln;
  writeln('Loss in pup production due to disturbance (%) = ', disturbloss : 2 : 1);
  end;
writeln;
end;

procedure Events;
begin
MaximumEat;
Cull;
Disturbance;
MinimumEat;
Survive;
Minpopulation;
Recruit;
Total;
if printyears = 'y' then
  begin
  if (t = 71) or (t = 83) or (t > 88) then
    Printout;
  end
else

```

```
    Printout;
end;

begin
  Initialize;
  for t := startyear to lastyear do
    Events;
  writeln;
end.
```

APPENDIX 10

OUTPUT FROM THE SCALED SEAL MODEL

Where two figures, separated by a dash, are given for each category, these represent values corresponding to minimum and maximum population sizes for the year.

YEAR	PUPS	POPULATION	POPULATION : PUP RATIO	SEX RATIO	HARVESTING RATES(%)		DISTURBANCE FACTOR (%)	FISH CONSUMPTION (thousand tons)
					PUPS	BULLS		
1900	9937	58403 - 68341	5.9 - 6.9	54	24	29	15	92 - 103
1901	5769	56696 - 62466	9.8 - 10.8	52	26	45	47	93 - 107
1902	6903	52716 - 59620	7.6 - 8.6	51	66	9	47	94 - 104
1903	12776	48877 - 61654	3.8 - 4.8	51	88	0	22	90 - 99
1904	16664	52556 - 69220	5.2 - 4.2	51	23	0	0	84 - 92
1905	15343	55170 - 70513	3.6 - 4.6	50	39	4	4	85 - 95
1906	13594	54661 - 68255	4.0 - 5.0	49	60	2	13	86 - 95
1907	13604	55801 - 69406	4.1 - 5.1	48	28	12	16	81 - 93
1908	10691	57311 - 68002	5.4 - 6.4	47	25	11	37	83 - 94
1909	12310	56191 - 68501	4.6 - 5.6	46	47	3	29	89 - 98
1910	16833	57818 - 74651	3.4 - 4.4	47	33	0	8	89 - 98
1911	16928	61104 - 78033	3.6 - 4.6	47	28	10	10	89 - 100
1912	12138	62815 - 74953	5.2 - 6.2	45	27	23	36	90 - 105
1913	9813	60049 - 69862	6.1 - 7.1	45	68	0	47	97 - 106
1914	20621	59122 - 79743	2.9 - 3.9	46	45	0	0	94 - 103
1915	21415	70091 - 91507	3.3 - 4.3	47	2	0	0	94 - 103
1916	21119	78608 - 99727	3.7 - 4.7	48	10	0	0	109 - 120
1917	21351	81490 - 102841	3.8 - 4.8	49	39	0	0	120 - 132
1918	23450	83796 - 107246	3.6 - 4.6	49	43	0	0	125 - 137
1919	25160	85415 - 110575	3.4 - 4.4	48	51	0	0	132 - 144
1920	26370	86824 - 113194	3.3 - 4.3	48	55	0	0	139 - 152
1921	27376	90415 - 117792	3.3 - 4.3	48	46	0	0	142 - 155
1922	28162	92231 - 120394	3.3 - 4.3	48	54	0	0	145 - 158
1923	28226	93180 - 121407	3.3 - 4.3	47	56	2	2	145 - 160
1924	27479	91771 - 119251	3.3 - 4.3	46	66	2	8	146 - 161
1925	28932	90013 - 118946	3.1 - 4.1	45	71	0	6	146 - 159
1926	31729	93908 - 125637	3.0 - 4.0	45	49	0	0	144 - 157
1927	32052	98314 - 130367	3.1 - 4.1	45	49	0	0	148 - 162
1928	31601	100920 - 132521	3.2 - 4.2	45	53	2	2	152 - 167
1929	31701	107405 - 139106	3.4 - 4.4	46	38	0	5	155 - 170
1930	34599	122903 - 157503	3.6 - 4.6	47	0	0	0	165 - 181
1931	35692	138800 - 174493	3.9 - 4.9	49	0	0	0	187 - 206
1932	37368	154185 - 191554	4.1 - 5.1	50	0	0	1	212 - 233
1933	40909	162037 - 202946	4.0 - 5.0	50	25	0	0	237 - 260
1934	43060	177392 - 220453	4.1 - 5.1	50	5	3	3	254 - 280
1935	43322	193210 - 236533	4.5 - 5.5	51	5	1	10	282 - 311
1936	48289	196823 - 245113	4.1 - 5.1	51	37	1	5	309 - 340
1937	52665	204016 - 256681	3.9 - 4.9	50	34	1	4	318 - 349
1938	55663	217467 - 273131	3.9 - 4.9	51	22	2	5	329 - 362
1939	56891	228472 - 285363	4.0 - 5.0	50	28	2	6	350 - 385

(Continued on page 282)

YEAR	PUPS	POPULATION	POPULATION : PUP RATIO	SEX RATIO	HARVESTING RATES(%)		DISTURBANCE FACTOR (%)	FISH CONSUMPTION (thousand tons)
					PUPS	BULLS		
1940	58490	244164 - 302654	4.2 - 5.2	51	16	3	8	365 - 403
1941	59765	257365 - 317130	4.3 - 5.3	51	20	3	11	384 - 425
1942	59988	265162 - 325151	4.4 - 5.4	50	26	7	15	401 - 448
1943	55596	270364 - 325961	4.9 - 5.9	49	30	9	26	414 - 464
1944	55692	277140 - 332833	5.0 - 6.0	49	21	9	30	425 - 475
1945	58596	282105 - 340701	4.8 - 5.8	49	22	10	29	435 - 487
1946	58268	287374 - 345643	4.9 - 5.9	48	23	11	32	441 - 495
1947	56044	289510 - 345554	5.2 - 6.2	47	25	14	37	443 - 500
1948	55594	296887 - 352482	5.3 - 6.3	47	15	9	39	449 - 502
1949	67562	301610 - 369173	4.5 - 5.5	47	20	7	28	461 - 513
1950	75584	304555 - 380140	4.0 - 5.0	47	40	4	21	472 - 521
1951	83527	307245 - 390772	3.7 - 4.7	47	45	6	15	476 - 527
1952	79476	315939 - 395415	4.0 - 5.0	47	39	8	21	478 - 533
1953	76830	323554 - 400384	4.2 - 5.2	46	37	6	25	490 - 545
1954	82790	327090 - 409880	4.0 - 5.0	46	40	6	21	500 - 555
1955	90826	331986 - 422813	3.7 - 4.7	46	47	1	16	511 - 560
1956	106756	340559 - 447315	3.2 - 4.2	46	46	1	3	520 - 571
1957	107169	358204 - 465373	3.3 - 4.3	46	42	1	5	535 - 587
1958	109212	384659 - 493871	3.5 - 4.5	47	29	1	5	559 - 615
1959	112256	407695 - 519951	3.6 - 4.6	47	31	1	5	594 - 654
1960	116891	425370 - 542262	3.6 - 4.6	47	37	1	5	629 - 692
1961	122640	440372 - 563012	3.6 - 4.6	47	41	2	6	661 - 728
1962	126975	461447 - 588423	3.6 - 4.6	48	36	2	7	692 - 762
1963	124404	475402 - 599807	3.8 - 4.8	47	39	7	12	722 - 802
1964	118255	487447 - 605702	4.1 - 5.1	47	41	4	20	747 - 825
1965	129985	485324 - 615309	3.7 - 4.7	46	50	6	15	761 - 844
1966	132857	506827 - 639684	3.8 - 4.8	47	35	3	17	765 - 843
1967	147020	513433 - 660453	3.5 - 4.5	47	48	2	10	796 - 877
1968	152404	527036 - 679440	3.5 - 4.5	46	46	3	9	807 - 889
1969	156955	539860 - 696816	3.4 - 4.4	46	48	2	9	824 - 906
1970	164734	549535 - 714270	3.3 - 4.3	46	51	2	6	843 - 927
1971	169309	568481 - 737790	3.4 - 4.4	46	46	2	7	861 - 946
1972	174971	587921 - 762892	3.4 - 4.4	46	46	2	6	888 - 977
1973	179598	608004 - 787602	3.9 - 4.4	46	46	1	6	916 - 1007
1974	187852	642019 - 829871	3.4 - 4.4	46	37	1	5	948 - 1040
1975	199126	672863 - 871989	3.4 - 4.4	47	39	0	2	999 - 1096
1976	209277	720890 - 930168	3.4 - 4.4	47	31	0	1	1051 - 1151
1977	219767	759831 - 979598	3.5 - 4.5	47	36	0	0	1122 - 1232
1978	221481	807193 - 1028675	3.6 - 4.6	48	32	2	4	1184 - 1304
1979	230243	849900 - 1080143	3.7 - 4.7	48	33	0	5	1266 - 1388
1980	251164	963262 - 1154426	3.8 - 4.6	48	28	0	1	1339 - 1470
1981	261927	951296 - 1213223	3.6 - 4.6	49	34	0	2	1427 - 1565
1982	273531	1000580 - 1274112	3.7 - 4.7	49	33	1	2	1503 - 1653
1983	276772	1090341 - 1367114	3.9 - 4.9	49	15	2	6	1580 - 1740
1984	261813	1147554 - 1409367	4.4 - 5.4	49	20	11	15	1680 - 1887
1985	190136	1208556 - 1398692	6.4 - 7.4	49	11	7	41	1773 - 1981
1986	282180	1222266 - 1504446	4.3 - 5.3	49	15	2	18	1896 - 2089
1987	318527	1321529 - 1640056	4.1 - 5.1	50	1	7	12	1931 - 2143
1988	260456	1442018 - 1702475	5.5 - 6.5	50	1	3	31	2089 - 2311

APPENDIX 11

DOCUMENTATION AND PROGRAM CODE FOR HAKE MODEL

PROGRAM SPECIFICATION

This program runs the Hake Model - a simulation model of the South African west coast population designed to explore the effects of different seal predation levels. Although the equations of the Hake Model require instantaneous parameter values, for ease of programming, all values are input as an annual rates and the equations in the program are converted accordingly.

SPECIFICATIONS FOR USE

Hardware and Software

MacPascal on an Apple Macintosh.

Input specifications

Most parameters/variables form part of the program code. Additional input is requested by the following questions from the user before the model starts running. The questions and answers are written to the MacPascal Text window so that they can be printed together with the output on completion of a run.

Enter seal predation mortality of first two age classes :

Enter natural mortality -

First two age classes :

All older classes :

Do you want to enter fishing mortality values ?

If "yes" then

Enter age of first fishing :

Enter fishing mortality value :

Output format

The output is printed to the MacPascal window.

All output in tons/1000

<i>Age</i>	<i>Fishing mortality</i>	<i>Seal predation</i>	<i>Natural mortality</i>		
.....		
	<i>Population</i>	<i>Yield</i>	<i>Predation mortality</i>	<i>Other mortality</i>	<i>Total</i>
<i>Mass:</i>
<i>No. :</i>

<i>Age</i>	<i>Number</i>	<i>Mass</i>
....

The results are then imported to the Macintosh application, "Cricketgraph" to produce graphical output.

Run time

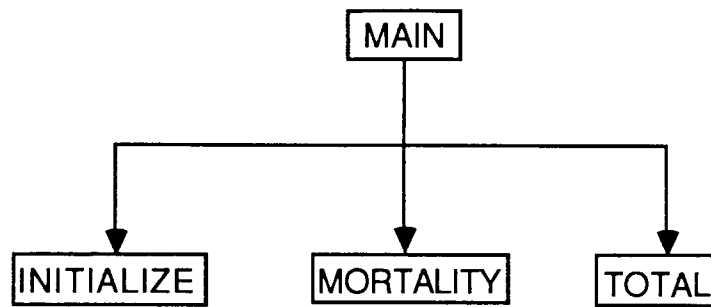
The model takes 20 seconds to run.

PROGRAM DESIGN

Overall description

The program of 174 lines is self-contained in that it handles all data input, tabular and graphical output without the using external files. The program first accepts all input necessary for a simulation. During each year of the simulation, the output is printed. The output is also written to arrays for graphical use at the end of all calculations.

Inter-relationship between procedures



Function of each procedure

Main : This procedure calls the procedure to set all the variables for the simulation (*Initialize*) and calls the procedures to do the simulations (*Mortality* and *Total*).

Initialize : Parameters are assigned values, input is requested and the answers read in, and the different mortality rates and headings are printed.

Mortality : The number surviving from one age class to the next is calculated.

Total : The number and mass of hake in the population is calculated.

Code validation

Results were cross-checked by hand for errors.

PROGRAM CODE

```
program Hake;

const
  simtime = 9;
  numages = 9;
  numruns = 10;
  rec = 1000;

type
  ages = array[1..numages] of real;
  meanarray = array[1..simtime] of real;

var
  hakeno, hakewt, fishmort, sealeat, agewt, natmort, surv : ages;
  answer : string;
  meanyieldwt, meanpopwt, meanrecruit, mean : meanarray;
  allages, fage, fa, i, t, a, counter : integer;
  popwt, hakebreed, yield, predation, othermort, pop, yieldwt, predwt, otherwt : real;
  totmort, indrat, predrat, othrat, totrat, S, M, F, totsurv : real;
  totmortwt, indratwt, predratwt, othratwt, totratwt : real;
```

```

procedure Initialize;
var
  a : integer;
begin
showtext;
fishmort[1] := 0;
fishmort[2] := 0.4;
fishmort[3] := 0.4;
fishmort[4] := 0.4;
fishmort[5] := 0.5;
fishmort[6] := 0.5;
fishmort[7] := 0.5;
fishmort[8] := 0.5;
fishmort[9] := 0.5;
agewt[1] := 0.046;
agewt[2] := 0.181;
agewt[3] := 0.419;
agewt[4] := 0.752;
agewt[5] := 1.164;
agewt[6] := 1.636;
agewt[7] := 2.149;
agewt[8] := 2.685;
agewt[9] := 3.231;
hakeno[1] := rec;
write('Enter seal predation mortality of first two age classes : ');
readln(S);
sealeat[1] := S;
sealeat[2] := S;
for a := 3 to numages do
  sealeat[a] := 0;
writeln;
writeln('Enter natural mortality -');
writeln;
write(' First two age classes : ');
readln(natmort[1]);
natmort[2] := natmort[1];
writeln;
write(' All older age classes : ');
readln(natmort[3]);
for a := 4 to numages do
  natmort[a] := natmort[3];
writeln;
write('Do you want to enter fishing mortality values ? ');
readln(answer);
writeln;
if answer = 'y' then
begin
  write('Enter age of first fishing : ');
  readln(fa);
  writeln;
  write('Enter fishing mortality value : ');
  readln(F);
  for a := 1 to fa - 1 do
    fishmort[a] := 0;
  for a := fa to numages do
    fishmort[a] := F;
  writeln;
end;
writeln('All output in tons / 1 000');
writeln;
writeln('Age Fishing mortality Seal Predation Natural mortality');
for a := 1 to numages do
  writeln(' ', a : 1, ' ', fishmort[a] : 2 : 2, ' ', sealeat[a] : 2 : 2, ' ', natmort[a] : 2 : 2);
writeln;
writeln(' Population Yield Predation Other Total ');
writeln(' mortality mortality');
writeln;
end;

```

```

procedure Mortality;
var
  a : integer;
begin
  yield := 0;
  predation := 0;
  othermort := 0;
  yieldwt := 0;
  predwt := 0;
  otherwt := 0;
  for a := 1 to numages - 1 do
    begin
      surv[a] := (1 - fishmort[a]) * (1 - sealeat[a]) * (1 - natmort[a]);
      totmort := fishmort[a] + sealeat[a] + natmort[a];
      if (tortmort > 0) then
        begin
          yield := yield + (fishmort[a] / totmort) * hakeno[a] * (1 - surv[a]);
          predation := predation + (sealeat[a] / totmort) * hakeno[a] * (1 - surv[a]);
          othermort := othermort + (natmort[a] / totmort) * hakeno[a] * (1 - surv[a]);
          yieldwt := yieldwt + (fishmort[a] / totmort) * hakeno[a] * (1 - surv[a]) * agewt[a];
          predwt := predwt + (sealeat[a] / totmort) * hakeno[a] * (1 - surv[a]) * agewt[a];
          otherwt := otherwt + (natmort[a] / totmort) * hakeno[a] * (1 - surv[a]) * agewt[a];
        end;
      end;
      totmort := yield + predation + othermort;
      totmortwt := yieldwt + predwt + otherwt;
      if (tortmort > 0) then
        begin
          indrat := yield / totmort;
          predrat := predation / totmort;
          othrat := othermort / totmort;
          indratwt := yieldwt / totmortwt;
          predratwt := predwt / totmortwt;
          othratwt := otherwt / totmortwt;
        end
      else
        begin
          indrat := 0;
          predrat := 0;
          othrat := 0;
          indratwt := 0;
          predratwt := 0;
          othratwt := 0;
        end;
      end;
    end;

procedure Total;
var
  a : integer;
begin
  for a := (numages - 1) downto 1 do
    hakeno[a + 1] := hakeno[a] * surv[a];
    pop := 0;
    popwt := 0;
    for a := 1 to numages do
      begin
        pop := pop + hakeno[a];
        popwt := popwt + hakeno[a] * agewt[a];
      end;
    end;

begin
  Initialize;
  Mortality;
  for a := 1 to (numages - 1) do
    hakeno[a + 1] := hakeno[a] * surv[a];
  hakeno[1] := rec;
  Mortality;

```

```

Total;
write('Mass : ', popwt : 5 : 1, ' ', yieldwt : 5 : 1, '(, indratwt : 2 : 2);
write(' ', predwt : 5 : 1, '(, predratwt : 2 : 2, ' ');
writeln(otherwt : 5 : 1, '(, othratwt : 2 : 2, ' ', totmortwt : 5 : 1);
write('No. : ', pop : 5 : 1, ' ', yield : 5 : 1, '(, indrat : 2 : 2);
write(' ', predation : 5 : 1, '(, predrat : 2 : 2, ' ');
writeln(othermort : 5 : 1, '(, othrat : 2 : 2, ' ', totmort : 5 : 1);
writeln;
writeln;
writeln('Age      Number      Mass');
writeln;
for a := 1 to numages do
  writeln(' ', a : 2, hakeno[a] : 11 : 1, hakeno[a] * agewt[a] : 10 : 1);
writeln;
writeln;
end.

```