A DEVELOPMENT AND MANAGEMENT FRAMEWORK FOR A NEW *OCTOPUS VULGARIS* FISHERY IN SOUTH AFRICA.

A thesis submitted in fulfilment of the requirements for the degree of

DOCTOR OF PHILOSOPHY
(Science)

of

RHODES UNIVERSITY

By

ANÉ OOSTHUIZEN

November 2003

ABSTRACT

A new policy incorporating an operational protocol was developed for the establishment of new fisheries in South Africa. The common octopus, *Octopus vulgaris* was used as a candidate species for the project. The operational protocol consisted of a three-phased development framework, namely information gathering (Phase 0), an experimental fishery (Phase 1) and the final implementation of a commercial fishery (Phase 2). The present study focussed on phase 0 of this theoretical framework and protocol and was implemented by using a proposed octopus pot fishery in South Africa as a case study. Phase 0 included a desktop study, information gathering in the field, an economic feasibility study and the formulation of a Fishery Management Plan and experimental design for the fishery. Information gaps identified during the desktop study were addressed during field investigations into the population structure and biology of *O. vulgaris* along the southeast coast. Immature females were found to use the intertidal area to feed and grow before migrating to the subtidal area to mature and spawn. Mean size differed substantially between intertidal and subtidal areas, with larger octopus found subtidally. Age and growth trials using tetracycline as a marker showed that *O. vulgaris* deposit daily growth lines in their beaks. A genetic study showed that there is most likely only one panmitic population along the coast. The economic feasibility study indicated that a longline pot fishery could be feasible provided a 30% catch in 6600 pots/month is attained. Only existing, debt-free vessels should be used in this fishery. The Fishery Management Plan proposed in this study includes management measures such as effort limitation of licences and gear, size restrictions, vessel monitoring systems, and observer programmes. Based on the population dynamics and biology of *O. vulgaris* it is suggested that a precautionary approach to developing fisheries for this species in both the inter- and subtidal areas along the South African coast.

CONTENTS

SECTION B – IMPLEMENTATION

PHASE 0: STEP 1 - CHAPTER 3: A REVIEW OF OCTOPUS BIOLOGY, FISHERIES AND MANAGEMENT

PHASE 0: STEP 2 - CHAPTERS 4, 5 & 6: INFORMATION GATHERING IN THE FIELD

CHAPTER 4: POPULATION BIOLOGY OF *OCTOPUS VULGARIS* ON THE TEMPERATE SOUTHEAST COAST OF SOUTH AFRICA.

PHASE 0: STEP 3 - CHAPTER 7: ECONOMIC FEASIBILITY OF AN EXPERIMENTAL OCTOPUS FISHERY IN SOUTH AFRICA

PHASE 0: STEP 4 - CHAPTER 8: PROPOSED FISHERY MANAGEMENT PLAN AND EXPERIMENTAL DESIGN FOR THE OCTOPUS POT FISHERY

“Education is a progressive discovery of our own ignorance."

- Will Durant -

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to the following for their contribution and support during this degree,

- Dr Malcolm Smale at the Port Elizabeth Museum (Bayworld) for his encouragement and discussion and many hours spent underwater searching for octopus.

- Professor Warwick Sauer of Rhodes University for his thought and input into this project, and his advice on how to become a manager!

- To the numerous divers that assisted with subtidal collections of octopus. Special thanks to Dr Nadine Strydom (SAIAB), Steven Warren (Bayworld) and Dr Shirley Parker-Nance (UPE) without whom this work would not have been possible.

- To all the staff at Bayworld for their friendly and enthusiastic support.

- National Research Foundation and Rhodes University for funding of this project.

- To Nadine for accompanying me on this journey through science, your love, support and enthusiasm have been invaluable.

- Aan my ouers, Marianne en Hannes, en my broers, Hanno en Dieter-Johann vir hulle liefde, ondersteuning en aanmoedeging deur dik en dun.

SECTION A - GOVERNANCE

CHAPTER 1

INTRODUCTION

FISHERIES MANAGEMENT TRENDS - A GLOBAL PERSPECTIVE

Overexploitation of traditional fisheries, overcapitalisation of fleets, increases in product demand and growing world populations all put increasing pressure on marine ecosystems (Caddy 1999). It is estimated that approximately 70% of the world's fisheries are exploited, depleted or recovering. This state of depletion is particularly evident in the developed and industrialised nations of the northern hemisphere, but is also found to a lesser extent in developing countries. Overexploitation levels of fisheries in the United States of America and the European Union alone have reached 45% and 59% respectively (Rosenberg et al. 1993). Some of the better-known fishery collapses have been the Peruvian anchovy and the Canadian cod stocks (Buckworth 1998). Both fisheries collapsed after overfishing caused by fleet overcapitalisation in the case of Peru, technological advances in the cod fishery, and the failure of management to acknowledge risks within the management measures employed (Muck 1989; Walters & Maguire 1996).

Caddy (1999) suggested that the depleted state of marine resources worldwide is not only attributable to the 'tragedy of the commons' in open-access fisheries, but to the shortcomings of general management paradigms. For example, limited licence schemes and target reference points have not prevented the overexploitation and collapse of fisheries. The failure of fisheries management to take technological advances into account has caused an increase in effort and a decrease in fish stocks even where limited licence schemes were in place (Caddy 1999). Moreover, the uncertainty or risk in management measures such as target reference points has largely been ignored in the past (Cochrane 2002a). The lack of failsafe mechanisms to reduce this risk has had disastrous consequences, with collapses of even those fisheries managed by 'safe' MSY (Maximum Sustainable Yield) target points (Caddy 1999). MSY is now considered as a limit reference point rather than a target point, with MSY only used as a target in the rebuilding of stocks.

Non-compliance by fishers and ineffective policing and enforcing of management measures has also resulted in overfishing, as well as misreporting and increased dumping of bycatch. Disregard of the law is common in some fisheries because fishers do not respect government-imposed regulations (Beddington et al. 1997). This is largely due to the top-down approach of fisheries management, in which government decisions are enforced upon fishers without adequate stakeholder input or consultation (Charles 1995; Caddy 1999). In addition, overfishing has caused changes within whole ecosystems, where long-lived species at the top of the food chain are being replaced by faster growing, lower-ranked species (Caddy 1999). This so-called ‘fishing down the food chain’ has economic implications, as the long-lived species are generally higher value commodities than those that replace them. It is therefore apparent that traditional management measures have not been effective in ensuring sustainable resources and ecosystems.

As the global human population continues to grow and fish production declines (Watson & Pauly 2001), demand for, and prices of, marine products are likely to increase. However, new fisheries are still being developed, and fisheries landings of underdeveloped and underutilised resources have increased considerably in the last twenty years compared to traditional finfish fisheries (Perry et al. 1999). Many of these underdeveloped resources are marine invertebrates, landings of which have increased by approximately 46% between the mid-1980s and mid-1990s, compared to only 19% and 3% growth for pelagic and demersal finfishes respectively (FAO 1997). Countries such as Canada and Australia are particularly focussed on the development of new invertebrate fisheries. Currently, 35 invertebrate species are exploited in Canada, and these contributed to a 130% increase in invertebrate landings in British Columbia over the mid-1980s-1990s period (Perry et al. 1999). Comparatively, Canadian groundfish landings only increased by 58%, while pelagic landings of species such as herring decreased by 20%. In Australia, 78% of new fisheries are based on invertebrates, comprising 14 previously unexploited species (Halmarick 1999).

Unfortunately, the development of most new fisheries has been far from sustainable, and has typically been fast and unrestrained with an inevitable collapse following soon after. These boom and bust fisheries developed faster than the species’ biology could be assessed and management measures implemented (Hilborn & Sibert 1988; Perry et al. 1999). However, it is particularly important to prevent new and developing fisheries from following the same route of overexploitation and commercial extinction that transpired in many traditional fisheries (Caddy 1999).

It is evident that a complete paradigm shift is needed in fisheries management, so that standard methods of stock assessment include more ecosystem and environmental considerations, and socio-economic factors are also taken into account (Caddy 1999). Revised management policies and sustainable utilization are necessary on a global scale (FAO 1995, 1996; Caddy 1999; Perry et al. 1999).

Recent international agreements and legislation have given new hope and guidance towards the sustainable use of marine resources. The United Nations Convention on the Law of the Sea (1982), the Code of Conduct for Responsible Fisheries (FAO 1995) and the Reykjavik Declaration (2001) are three of the most prominent intergovernmental agreements that could provide more protection for marine resources. Important principles fostered by the Code are conservation and rebuilding of marine resources, together with sustainable use to ensure a food source, a livelihood and a heritage for future generations. More specifically, these principles are to be achieved through responsible fisheries management based on best scientific knowledge, supportive legislation, inclusive management, effective monitoring and enforcement, and sustainable fishing effort (FAO 1995). A summary of pertinent objectives of the Code is given in Table 1. In addition, the precautionary approach to fisheries management proposed by the FAO (Food and Agriculture Organisation of the United Nations) in 1993 is fundamental to the conservation of marine and inland aquatic resources (FAO 1996). It advocates that conservative and precautionary steps be taken in the face of risk. Specifically, it states that where uncertainty is high and knowledge is poor, harvests should be reduced. Furthermore, it states that target and limit references points should be determined in advance, as indicators of undesirable fishing. With revised management paradigms advocated and endorsed on a global scale (Caddy 1999; Perry et al. 1999; FAO 1995, 1996; Anon 2002a), it is essential that these principles also be applied to new underdeveloped and non-conventional resources such as invertebrate fisheries, to ensure sustainable utilization and development (Caddy 1999).

Table 1. A summary of the Code of Conduct for Responsible Fisheries (FAO 1995) principles and objectives pertinent to fisheries management.

- Conservation of aquatic ecosystems. The right to fish carries with it the obligation to do so in a responsible manner so as to ensure effective conservation and management of the living aquatic resources.
- Fisheries management should promote the maintenance of the quality, diversity and availability of fishery resources for present and future generations.
- Measures for long-term conservation and sustainable use of fisheries resources should be adopted by States through an appropriate policy, legal and institutional framework.
- The precautionary approach should be applied to conservation, management and exploitation of living aquatic resources taking account of the best scientific evidence available.
- Relevant domestic parties should be identified and engaged in management to achieve responsible fisheries.
- Compliance should be ensured through effective mechanisms of fisheries monitoring, surveillance, control and enforcement.
- States and management organizations should adopt appropriate management measures, based on the best scientific evidence available.
- Excess fishing capacity should be prevented and/or eliminated to ensure sustainable levels of fishing effort.

The Code of Conduct also supports the inclusion of stakeholders (fishers, communities, etc.) in decision-making processes and the mobilization of consumer power in attaining the goal of future sustainability of marine resources. Including interested and affected parties in the management of a resource creates a custodianship and sense of responsibility towards the resource, so transferring more management responsibility onto user groups and involving them in the decision-making process helps increase support for management regulations (Pinkerton 1989). This concept of ‘co-management’ has gained acceptance as a management practice in both industrialized and developing nations (Hutton & Pitcher 1998).

The Reykjavik Declaration (2001) encompasses most of these principles and concepts but broadens it towards an ecosystem approach. It further requested the FAO to prepare operational guidelines to underpin these principles of an ecosystem approach to fisheries (EAF) (FAO 2003). More recently a plan of implementation of these principles in capture fisheries was adopted at the World Summit on Sustainable Development (WSSD, Johannesburg, South Africa, 2003).

The labelling of food products to indicate responsible or ‘green’ fisheries is a useful method of harnessing consumer power to discriminate against unsustainable fishing practises. The Marine Stewardship Council (MCS) was constituted in 1997 to certify fisheries and products complying with environmentally responsible principles. This certification was based on the principles of the FAO Code of Conduct for Responsible Fisheries. MCS is a global, non-profit organisation that is "*seeking to harness consumer purchasing power to generate change and promote environmentally responsible stewardship of the world's most important renewable food source*" (Anon 2002a). This is a relatively new concept, with only seven international fisheries certified to date and another eight in the process thereof. These include both small fisheries such as Thames herring and Burry Inlet cockles in the United Kingdom (Anon 2003a, b), as well as large industrial fisheries such as Alaska salmon and Western Australia rock lobster (Anon 2003c, d). Currently one of South Africa's most valuable fisheries, the hake trawl fishery, is undergoing assessment by MCS (Anon 2003e).

POLICY AND MANAGEMENT FRAMEWORKS FOR NEW FISHERIES

The most basic requirements for recognised fishery policies and their implementation measures are the adherence to internationally sanctioned legislation and agreements such as the Convention on the Law of the Sea 1982, Precautionary Principle, and Code of Conduct (Die 2002). Various countries and fisheries management bodies recognise these by incorporating the principles into their national legislation or fisheries policies. Furthermore, fisheries policy should, through goals and objectives, accurately convey its principles to the fishery (Cochrane 2002b), and provide guidelines for the Fisheries Management Plan (FMP) that is ultimately used to manage the fishery on a daily basis. Precautionary approaches to prevent unsustainable development (FAO 1995, 1996) imply that Fishery Management Plans should stipulate clear objectives, including plans for monitoring and assessing the effects of fishing. Guiding policy therefore needs to be in place before fisheries and FMPs are developed. In this way, the principles of internationally accepted fisheries policy filter down to actual implementation.

Information pertaining to the governance of new and experimental fisheries is scarce, with few countries specifically formulating policies and FMPs on new fisheries development. A new or developing fishery was defined by Halmarick (1999) as:

'*a fishery within which there is little or no exploitation, there is potential for development and which is currently subject to prohibition. There may also be little information regarding:*

- *the stock under consideration,*
- *the role of this stock in both local and larger marine ecosystems,*

- *the possible uses of the harvested materials,*
- *potential domestic and/or foreign markets,*
- *explicit management objectives, policies and/or operating regulations.*'

Unexploited marine resources, as well as those exploited at exploratory or developmental levels at the creation of 'new' fisheries, are included in this definition. However, the existence of such a resource will not guarantee commercial exploitation (Halmarick 1999).

The lack of FMPs for new fisheries is cause for concern, as it is of paramount importance to approach a new fishery within a structured framework that is in harmony with fisheries legislation (FAO 1995; Perry et al. 1999). Australia and Canada have, however, instituted policy on new fisheries. Both these countries are progressive in their management approach and have incorporated the Precautionary Principle and the Code of Conduct (Canada only) in their national fisheries legislation (Anon 1998a; Fish Resources Management Act, Western Australia 1994 in Halmarick 1999). These principles, including ecological and economic sustainability, have been included in the respective policies in Canada (Anon. 2001) and in management plans in Australia (Halmarick 1999) pertaining to new and developing fisheries. Factors identified as important in these documents were a scientific knowledge base to the fishery, strong conservation principles and economic viability of the fishery.

Moreover, management frameworks have been designed specifically for the development of new invertebrate fisheries (Perry et al. 1999). These management frameworks include several components important in the realisation of practical fishery management. Caddy (1999) suggests that there is an urgent need for controlled field experimentation in fisheries management theory, both on pilot and large scale, involving government, academic institutions and fishers in different management approaches. An experimental fishery phase was considered important in ensuring sustainable development of these new fisheries (Caddy 1999; Perry et al. 1999).

Lessons from experimental fisheries

Experimental fisheries for invertebrates have been conducted in many countries, including Alaska (Paust 1997), Canada (Gillespie et al. 1998) and the United States of America (Rasmussen 1997; Whitaker et al. 1991; Roper 1997). Varying degrees of success were achieved, but none developed into a new commercial fishery, even though the stock was in most cases large enough to sustain a fishery (Paust 1997; Roper 1997). None of the experimental fisheries was conducted under controlled conditions or according to formal protocols, and a rigid scientific basis - an essential aspect to experimental fisheries - was absent in most of them (Walters 1986; Roper 1997). Several other factors also impacted on the fisheries. Market demand, the driving factor behind the fisheries, was found to be both species- and area-dependent (Rasmussen 1997), highlighting the importance of selecting the right species for a new fishery, as well as establishing whether market demand exists before the fishery is developed. Furthermore, new invertebrate fisheries were perceived as supplemental to other existing fisheries, which could relieve pressure on overexploited species (Rasmussen 1997).

Particular difficulties associated with these fisheries were low catch rates (Paust 1997; Rasmussen 1997) and a high degree of experimentation required to determine optimal fishing techniques and fishing areas (Gillespie et al. 1998). In most cases reported, few results were obtained due to the fishermen’s inexperience and lack of commitment; consequently no further fishery development took place (Paust 1997; Roper 1997). Moreover, a business plan was shown to be essential for fishers to establish goals and objectives for the fishing venture (Paust 1997).

The South African situation is similar, with experimental fisheries conducted on hake, kingklip and rock lobster resources reaching variable levels of success and failure. Several other experimental fisheries are planned (limpets, octopus, gurnard and sole) or already in process (panga trap fishery). Common to all of these fisheries is the lack of a structured framework for their development and management.

A number of lessons can be learnt from South Africa’s kingklip-directed longline fishery, which started in 1983. Prior to the start of the longline fishery, kingklip (*Genypterus capensis*) was already being exploited through a trawl fishery. However the stock status was not assessed before embarking on the longline fishery (Punt & Japp 1994), and no scientific experiments were conducted to test the effects of gear, soak time, depth, hook size etc. on CPUE or biomass (Badenhorst 1988). Furthermore, permits were allocated on an ad hoc basis. In the first year, permits were granted to inexperienced fishers who had little fishing success. More experienced foreign skippers were contracted in the second year, which resulted in good catches, so six more licences were issued the following year. Effort increased by 300% in the third year, which caused overexploitation of the stock to below the 50% biomass level. The fishery was terminated in 1990 (Punt & Japp 1994), and remains one of the largest fishery management failures in South Africa. Specific reasons for failure include:

- No prior investigation into stock status
- No scientific basis to the experimental fishery
- No precaution employed and high exploitation rates were ignored
- No formal protocol employed in planning and executing the fishery.

The hake- (*Merluccius capensis, M. paradoxus*) directed longline fishery was approached more cautiously, given the kingklip fishery failure. This two-year experiment was well planned and executed (Japp 1995; Anon 1997). Preliminary results were mixed, because inexperienced fishers did not achieve expected success. However, the fishery proceeded to a medium-term experimental fishery from 1996, with allocations of up to 6000 tons made in consecutive years.

A crustacean-directed experimental fishery was initiated in 1994, to evaluate the potential for exploiting the Natal deep-water lobster (*Palinurus delagoae*) in a trap fishery. This was a scientifically sound experiment with predetermined objectives and standardized fishing methods (Anon 1995). The fishery was conducted over three years, but a significant decline in CPUE during 1997, together with other biological research, suggested that the resource was not large enough to sustain a fishery, so it was halted (Anon 1998b; Groeneveld 2000).

The lack of formal protocol, which led to the kingklip disaster, was enough to compel caution in the development of the hake and lobster fisheries. A similar procedure was followed in the development of both these fisheries where Marine and Coastal Management (Dept. Environmental Affairs and Tourism) designed, approved and implemented the experimental fisheries. Although this procedure provided some structure to the development of the above-mentioned fisheries, there was no continuity of this process to the development of subsequent experimental fisheries. Unfortunately, as with other fishery developments in South Africa, this also did not occur in the octopus fishery.

A pot fishery for octopus was proposed during the mid-1990s, applications were accepted, but no permits were issued. Applicants were invited to re-submit during 1998 (Saunders 1998). A preliminary investigation was subsequently launched into creating a small-scale octopus fishery in the Western Cape (Smith 1999), but the viability could not be established due to a moratorium placed on all rights allocations by the Department of Environmental Affairs and Tourism's Marine and Coastal Management Branch in 2001 (Mather et al. 2002). New permit applications for the octopus fishery were put out to tender during 2002 for a third time (Anon. 2002b). These applications were again rescinded once it was realised that no policy on experimental fisheries existed. The lack of guiding policy and formal protocol would decrease the chance of success of the above-mentioned new fisheries. It is thus imperative that a formal policy and operational procedure be put in place to set a standard in the development process of new fisheries in South Africa.

DEVELOPMENT OF A NEW POLICY AND OPERATIONAL PROTOCOL

The backdrop of changing fishery management in the world and South Africa, and the increased demand for new economic ventures based on marine resources, provides an ideal opportunity to develop and manage a fishery from inception according to a new management paradigm. Major issues that could contribute to the success and sustainability of a new commercial fishery were identified as follows:

- Adherence of national/fisheries policy to international legal standards (Die 2002)
- Clear guiding policy specific to the fishery needs (Cochrane 2002b)
- A formal protocol for the establishment of new fisheries (Perry et al. 1999)
- Well planned experimental fisheries (Caddy 1999; Perry et al. 1999).

This study aims to develop policy and operational protocol for establishing new fisheries in South Africa, using the octopus fishery as a case study. Guiding policy is particularly important in order to reconcile socio-economic considerations with sustainable resource use, especially in the South African context. In the face of global advocacy of sustainable and responsible fisheries it is the responsibility of the State and the fishery manager to ensure this (FAO 1995).

The development of an octopus fishery in South Africa provides an ideal opportunity to use information available on the development and management of new fisheries globally, and to convert this theoretical framework into a working model. The rest of the study focuses on the implementation of the before-mentioned policy and operational protocol in the octopus directed fishery.

THESIS OUTLINE:

- **Chapter 2:** *Establishing a framework policy and operational protocol for the development of new fisheries in South Africa*. The operational protocol consists of three phases, of which Phase 0 is completed, with the various benchmarks realized in subsequent chapters.
- **Chapter 3: Phase 0 - Step 1:** *A review of octopus biology, fisheries and management*. A review to identify gaps in available information.
- **Chapters 4, 5 & 6: Phase 0 - Step 2:** The collection of additional biological information in the field. These chapters were written as separate scientific papers each covering one biological aspect.
    - **Chapter 4: Step 2a:** *Population biology of O. vulgaris on the temperate southeast coast of South Africa.*
    - **Chapter 5: Step 2b:** *Age and growth assessment of O. vulgaris southeast coast of South Africa.*
    - **Chapter 6: Step 2c:** *Population genetics of O. vulgaris around the South African coast.*
- **Chapter 7: Phase 0 - Step 3:** *Economic feasibility of an experimental octopus fishery in South Africa.*
- **Chapter 8: Phase 0 - Step 4:** Proposed Fishery Management Plan and experimental design for the octopus fishery.
- **Chapter 9:** *Synthesis and recommendation.*

REFERENCES

ANON. 1995. *Research Highlights* 4. SFRI, Department of Environmental Affairs and Tourism, Cape Town, South Africa. 44 pp.

ANON. 1997. *Research Highlights* 6. SFRI, Department of Environmental Affairs and Tourism, Cape Town, South Africa. 45pp.

ANON. 1998a. Responsible fishing in Canada. Department of Fisheries and Oceans, Canada. Retrieved June 2003, from http://www.dfo-mpo.gc.ca/communic/fish_man/resp98/index_e.htm.

ANON. 1998b. *Research Highlights* 7. SFRI, Dept Environmental Affairs and Tourism, Cape Town, South Africa. 68pp.

ANON. 2001. New emerging fisheries policy. Department of Fisheries and Oceans, Canada. Retrieved June 2003, from http://www.dfo-mpo.gc.ca/communic/fish_man/nefp_e.htm.

ANON. 2002a. Marine Stewardship Council. About MSC. (2002) Retrieved June 2003, from http://www.msc.org/html/content_462.htm.

ANON. 2002b. *Government Gazette*. Republic of South Africa. Pretoria. Vol. 447, No. 23812. 16 pp.

ANON. 2003a. Marine Stewardship Council. Certified fisheries. Thames herring. (June 2003) Retrieved June 2003, from http://www.msc.org/html/content_489.htm.

ANON. 2003b. Marine Stewardship Council. Certified fisheries. Burry Inlet Cockles. (June 2003) Retrieved June 2003, from http://www.msc.org/html/content_486.htm.

ANON. 2003c. Marine Stewardship Council. Certified fisheries. Alaska Salmon. (June 2003) Retrieved June 2003, from http://www.msc.org/html/content_485.htm.

ANON. 2003d. Marine Stewardship Council. Certified fisheries. Western Australia rock lobster. (June 2003) Retrieved June 2003, from http://www.msc.org/html/content_490.htm.

ANON. 2003e. Marine Stewardship Council. Fisheries undergoing assessment. South African Hake. (March 2003) Retrieved June 2003, from http://www.msc.org/html/content_496.htm.

BADENHORST A. 1988. Aspects of the South African longline fishery for kingklip *Genypterus capensis* and the Cape hakes *Merluccius capensis* and *M. parradoxus*. *S. Afr. J. mar. Sci.* **6**: 33-42.

BEDDINGTON J.R., LORENZEN K. and PAYNE I. 1997. Limits to the exploitation of capture fisheries. In: *Developing and sustaining world fisheries* resources. *The state of science and management*. Proceedings of the 2nd world fisheries congress, Brisbane, July 1996. Hancock D.A., Smith D.C., Grant A. and Beumer J.P. (Eds). CSIRO Publishing, Collingwood, Australia. p 529-536.

BUCKWORTH R.C. 1998. World fisheries are in crisis? We must respond! In: *Reinventing fisheries management*. Chapter 1. Pitcher T.J., Hart J.B. and Pauly D. (Eds). Kluwer Academic Publishers, London. p 3-14.

CADDY J.F. 1999. Fisheries management in the twenty-first century: will new paradigms apply? *Rev. Fish Biol. Fish*. **9**: 1-43.

CHARLES A.T. 1995. The Atlantic Canadian groundfishery: roots of a collapse. *Dalhousie Law J*. **18**: 261-267.

COCHRANE K.L. 2002a. The use of scientific information in the design of management strategies. In A fishery manager's guidebook. Management measures and their application. Chapter 5. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 95-130.

COCHRANE K.L. 2002b. Fisheries management. In: A fishery manager's guidebook. Management measures and their application. Chapter 1. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 1-20.

DIE D. 2002. Design and implementation of management plans. In: A fishery manager's guidebook. Management measures and their application. Chapter 9. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 205-226.

FAO. 1995. Code of Conduct for Responsible Fisheries. FAO, Rome. 41 pp.

FAO. 1996. Precautionary approach to capture fisheries and species introduction. *FAO Technical guidelines for responsible fisheries* No. **2**. FAO, Rome. 54 pp.

FAO. 1997. Review of the state of world fishery resources: Marine fisheries. *FAO Fisheries Circular* **920**. FAO, Rome. 169 pp.

FAO. 2003. The ecosystem approach to fisheries. *FAO Technical guidelines for responsible fisheries* No. **4**. Suppl. 2. FAO, Rome. 112 pp.

GILLESPIE G.E., PARKER G. and MORRISON J. 1998. A review of octopus fisheries biology and British Columbia octopus fisheries. *Canadian Stock Assessment Secretariat Research Document* **98/87**. Department of Fisheries and Oceans, Canada. 66 pp.

GROENEVELD J.C. 2000. Stock assessment, ecology, and economics as criteria for choosing between trap and trawl fisheries for the spiny lobster *Palinurus delagoae. Fish. Res.* **48**: 141-155.

HALMARICK L. 1999. Developing new fisheries in Western Australia. A guide to applicants for developing fisheries. *Fisheries Management Paper* **130**. Fisheries Western Australia, Perth, Australia. 40 pp.

HILBORN R. and SIBERT J. 1988. Adaptive management of developing fisheries. *Mar. Pol*. **12**: 112-121.

HUTTON T. and PITCHER T.J. 1998. Current directions in fisheries management policy: A perspective on co-management and its application to South African fisheries. *S. Afr. J. mar. Sci*. **19**: 471–486.

JAPP D. 1995. The hake-directed longline pilot study conducted from 23 May to 31 May 1995. Report submitted to the Longline Management Committee, Sea Fisheries Research Institute. Cape Town.

MATHER D., BRITZ P.J., HECHT T. & SAUER W.H.H. 2002. An economic and sectoral study of the South African fishing industry, Vol 1: Economic and regulatory principles, Survey results, Transformation and socio-economic impact. Report prepared for Department of Environmental affairs and Tourism, Marine and Coastal Management. Rhodes University, Grahamstown, South Africa.

MUCK P. 1989. Major trends in the pelagic ecosystem off Peru and their implications for management. In: *The Peruvian upwelling system: dynamics and interactions*. ICLARM conference proceedings **18**. Pauly D., Muck P., Mendo J. and Tsukayama I. (Eds). International Center for Living Aquatic Resources Management (ICLARM), Manilla. p 386- 403.

PAUST B.C. 1997. Octopus marketing aspects with attention to the development of domestic (North American) food markets. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 135-139.

PERRY R., WALTERS C. and BOUTILLIER J. 1999. A framework for providing scientific advice for the management of new and developing invertebrate fisheries. *Rev. Fish Biol. Fish*. **9**: 125-150.

PINKERTON 1989. Introduction: attaining better fisheries management through co-management – prospects, problems and propositions. In*: Co-operative management of local fisheries. New directions for improved management and community* *development*. Pinkerton E.W. (Ed). University of British Columbia Press, Vancouver. p 3-33.

PUNT A.E. and JAPP D.W. 1994. Stock assessment of the kingklip *Genypterus capensis* off South Africa. *S. Afr. J. mar. Sci.* 1**4**: 133-150.

RASMUSSEN A. 1997. Octopus, a fishermen's perspective. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 151-155.

ROPER C.F.E. 1997. Experimental Octopus Fisheries: Two Cases Studies. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (eds). Smithsonian Institution, Washington. p 157-168.

ROSENBERG A.A., FOGARTY M.J., SISSENWINE M.P., BEDDINGTON J.R. and SHEPHERD J.G. 1993. Achieving sustainable use of renewable resources. *Science*. **262**: 828-829.

SAUNDERS S. 1998. Experiment to test viability of octopus fishery. *SA Shipping news & Fishing industry Review* (March/April): 27

SMITH C.D. 1999. Population biology and ecology of octopus in the southwestern Cape: A study towards the establishment of a small-scale octopus fishery. University of Cape Town. M.Sc. Thesis. 111 pp.

WALTERS C.J. 1986. *Adaptive management of renewable resources*. MacMillan Press, New York. 384 pp.

WALTERS C.J. and MAGUIRE J.-J. 1996. Lessons for stock assessment from the northern cod collapse. *Rev. Fish Biol. Fish.* **6**: 125-137.

WATSON R. and PAULY D. 2001. Systematic distortions in world fisheries catch trends. *Nature*. **414**: 534-536.

WHITAKER J.D., DELANCY L.B. and JENKINS J.E. 1991. Aspects of the biology and fishery potential for *Octopus vulgaris* off the coast of South Carolina. *Bull. Mar. Sci.* **49**(1/2): 482-493.

CHAPTER 2

ESTABLISHING A FRAMEWORK POLICY AND OPERATIONAL PROTOCOL FOR THE DEVELOPMENT OF NEW FISHERIES IN SOUTH AFRICA.

BACKGROUND POLICY ISSUES

The political climate in South Africa during the 1990s was conducive to change and paradigm shifts in all realms of life. Following the first democratic elections and the change in government in 1994, a model Constitution was introduced that necessitated the redrafting of most supporting legislation in order to promote social equity and redress consequences of past racial discrimination. Equal opportunity, justice, transformation and socio-economic development were the vision for a new South Africa. In terms of marine resource use and fisheries management this created the opportunity for change in policy and management frameworks. The pre-1994 Government had a top-down management approach and was specifically resource-oriented (Britz et al. 2001). However, the state of South African demersal and pelagic fisheries was good compared to the generally poor state of fisheries worldwide (Cochrane et al. 1997; Payne & Bannister 2003). This stability in South Africa's large fisheries resources could be ascribed to various factors. Firstly, the political and economic isolation of South Africa during the Apartheid era created limited access from other countries to resources for many years. Furthermore, management of resources was informed by sound scientific input (Kleinschmidt et al. 2003), and resource exploitation by a limited number of participants facilitated control (Cochrane et al. 1997). However, this small group of rights-holders was dominated by predominantly white-owned companies (Britz et al. 2001).

The post-1994 Government became instrumental in changing fisheries management from traditional 'resource'-oriented to 'people'-oriented management through the new Marine Fisheries Policy of South Africa (1997). The policy states that '..*all natural marine living resources of South Africa, as well as the environment in which they exist and in which mariculture activities may occur, are a national asset and the heritage of all its people, and should be managed and developed for the benefit of present and future generations in the country as a whole.*'

The Marine Living Resources Act promulgated in 1998 provided new goals on fisheries management, transformation, co-management and other issues to rectify these past imbalances in the fishing sector. Both the fisheries policy and Act rested firmly on the principles of:

- Ecologically sustainable development of marine resources
- The precautionary approach in management and development of marine resources, and
- Transformation in the fishing industry to address historical imbalances, amongst others.

Subsequently these goals were refined through consultation with all stakeholders, including the fishing industry, managers and scientists, into greater detail and definition (Anon. 2001a). Pertinent goals were:

- Sustainable utilization through:
  - Conservation of overexploited resources
  - Exploitation of new resources.
- Transformation through:
  - Equal access
  - Racially representative fishing industry.
- Optimisation of long-term socio–economic benefits through:
  - Economic growth
  - Human resource development
  - Capacity building in the fishery sector.

However, this process of transformation and creating socio-economic growth was far from smooth, and was severely constrained by lack of institutional capacity and poor planning (Mather et al. 2002). Transformation in the fishing sector was implemented through the redistribution of fishing quotas from historically white- to new black-owned companies, without a defined policy guiding the process (Kleinschmidt et al. 2003). This resulted in legal challenges to the Government and instability in many fisheries, including suspension of fishing in certain sectors (Mather et al. 2002; Kleinschmidt et al. 2003). A moratorium was placed on all new fishing rights and a process started to identify key issues relevant to socio-economic development and transformation in the fishing industry (Kleinschmidt et al. 2003). Included in this process was the establishment of small- and medium-sized fishing enterprises to encourage further development in coastal areas (Kleinschmidt et al. 2003). The aim of this was to create employment, develop human resources and enhance transformation in the fishing sector (Britz et al. 2001).

Development of new fisheries in South Africa – problems

The challenge lay in creating new economic opportunities within the fishing sector, while promoting equity, transformation and social development. However, the expansion of the fishing sector is limited by the natural productive capacity of the resources, most of which are either heavily utilized or overexploited in existing fisheries in South Africa. Although the large offshore resources in South Africa seem to be in a stable state (Cochrane et al. 1997), many species supporting inshore fisheries, such as the traditional linefishery, abalone and rock lobster fisheries, are depleted or on the brink of collapse (Britz et al. 2001). The expansion and creation of new economic opportunities and increased access to the marine resources is therefore largely limited to previously unexploited finfish and invertebrate species (Britz et al. 2001).

Although progress is being made in ensuring equity and transformation in South African fisheries, most historically disadvantaged individuals (HDIs) lack skills and knowledge to enter directly into a fishery, and require interim support while developing fishery ‘know-how’. This became evident after the first attempts at transformation (Kleinschmidt et al. 2003), when historically disadvantaged individuals and companies sold their fishing rights rather than participating in the fishing industry themselves. Instead of selling their so-called ‘paper quotas’, these rights-holders could have developed their knowledge through cooperation and partnerships with companies and individuals with experience in fisheries.

It is important that policy guidelines for the development of new fisheries do not confuse the fundamental prerequisites associated with an experimental fishery with that of a commercial venture. A commercial fishery implies economic returns and employment, while experimental fisheries assess the resource to determine the possibility of future commercial exploitation. It is imperative to involve individuals or entities with existing and available infrastructure, as well as experience and skills. Safeguarding the scientific integrity of the experimental fishery will ensure that any commercial rights granted will be to the benefit of all. Furthermore, great caution must be exercised in terms of introducing additional, new fishing capacity when undertaking experimental fishing. Experimental fishing should, as far as realistically feasible, aim to use fishing vessels already deployed in South African waters.

Conducting experimental fisheries according to these principles will ensure the sustainable development of South Africa's marine resources in line with Government's objectives of long-term social and economic development. Government should commit to capacity building (through knowledge and skills transfer, and human resource development) within the fishing sector to enhance transformation and ensure success of new entrants into new commercial fisheries. Government should also strive to attain inclusive management in all sectors of the fishing industry, since shared responsibilities between resource users and government will increase the likelihood of compliance and sustainable use of the resource.

Recently a protocol for the management and implementation of developing fisheries was formulated (Perry et al. 1999). This framework focussed on invertebrates, but is applicable to any new developing fishery and has been implemented in octopus, elasmobranch and crab fisheries in Canada (Morrison et al. 1999; Benson et al. 2001; Krause et al. 2001). This framework is particularly well structured, allowing for step-by-step planning and execution of a fishery. It consists of three phases. First, a pre-fishery research phase (phase 0) is initiated, where available information on the species and fishery is collected and potential management strategies are suggested. During the phase 1, information lacking from phase 0 is collected. New information is gathered though sampling and surveys of the population and habitat, and an experimental fishery is conducted. This information is then used in the regulation and implementation of the commercial fishery, which commences in the last phase (phase 2).

The present study uses the framework proposed by Perry et al. (1999) to build a suitable model for the development and management of new fisheries in South Africa. A policy is proposed containing an operational protocol consisting of a 3-phased development framework The operational protocol for South Africa also consists of three phases: i) information gathering including information collected in the field (phase 0 & 1 in Perry et al. 1999), ii) experimental phase where the experimental fishery is conducted and possible regulation is proposed and implemented and iii) the commencement of the commercial fishery. This protocol adheres to the concepts of the precautionary approach, sustainable resource use and responsible fisheries management suggested by FAO (1995) and Perry et al. (1999).

The following policy and protocol for the establishment of new fisheries in South Africa is based on and structured according to a combination of:

- International policy on developing fisheries
    - Western Australia, Halmarick (1999)
    - Canada, Anon. (2001b)
- Fisheries management literature on policy issues
    - Cochrane (2002a)
- Marine Living Resources Act (1998)
- Interim policy on developing fisheries by MCM (Anon. 2003)
- Management framework (Perry et al. 1999).

The policy is introduced by describing the reasoning behind and need for new fisheries in South Africa, the necessity for policy that is specific to new fisheries, and pertinent national legislation. The policy principles are explored through the mission statement, guiding principles, and goal and objectives. The operational protocol includes the development of the fishery according to a three-phased approach, and the process of implementation (applications, assessment, licensing etc.).

POLICY DOCUMENT:
ESTABLISHMENT OF NEW FISHERIES IN SOUTH AFRICA.

Submitted as a discussion document to the Deputy Director General,
Department of Environmental Affairs and Tourism,
Branch: Marine and Coastal Management.

By
A. Oosthuizen.
Department of Ichthyology and Fisheries Science,
Rhodes University,
Grahamstown.

OCTOBER 2003

INTRODUCTION

The Marine Living Resources Act of 1998 states that the marine environment and all living resources within it is a national heritage and should be developed sustainably for the benefit of all South Africans. Government priority lies in the development and diversification of existing fisheries and the establishment of new fisheries in order to fulfil the key objectives of:

- Job creation
- Human Resource Development
- Social Sector Service Delivery: expanding the commercially exploitable resource base, broadening access and prioritising the poor and disadvantaged
- Rural Development Programmes – focusing particularly on previously neglected areas such as the Eastern Cape
- Transformation.

More specifically, the Department of Environmental Affairs and Tourism will attain these through the Branch: Marine and Coastal Management (MCM), subsequently referred to as "the Department". The Department is committed to delivery on all of these objectives, and sees the establishment of several new fisheries as a high priority.

The establishment of new fisheries should be addressed in a structured manner, by:

- Bringing already on-going fishing activities which have emerged without coherent management, or in the absence of formal management altogether, under adequate control
- Effectively implementing the Department's policy for development of new fisheries when initiating a new fishery
- Applying the Precautionary Principle with respect to the utilization of resources (sustainability is paramount).

Definition of a new fishery

A new fishery is a regulated fishery that exploits a resource or part of a resource that has not previously been managed by the state as a commercial fishery. It also includes previously unexploited resources, underexploited resources that had hitherto been a bycatch of another fishery, or fully exploited or even overexploited resources that had hitherto not been subject to any management controls.

New fisheries may be explored where a resource shows potential for development. However, the existence of such a resource and the associated experimentation does not guarantee that commercial access would be granted.

MISSION STATEMENT

The development of marine living resources, through ecological sustainability, the precautionary principle and responsible fishing, towards economic and social gain for all South Africans.

GUIDING PRINCIPLES

The policy complies with the Code of Conduct for Responsible Fisheries (FAO 1995) and the Precautionary Principle (FAO 1996). Sustainable development of a new fishery should thus take place according to the principles of:

- Ecological sustainable use, through the maintenance of ecological processes, preservation of biodiversity and responsible fishing
- The Precautionary Principle: in the event of uncertainty or risk, management will be cautious and conservative
- Management based on best scientific evidence available
- Economic feasibility of fisheries.

POLICY GOAL

- Sustainable resource development through scientific integrity, sound management and responsible fishing.

POLICY OBJECTIVES

- To govern the development of new fisheries according to policy principles
- To institute a standardised operational protocol for the establishment of new fisheries
- To ensure that experimental fisheries are executed successfully, and attain objectives of
    - Assessment of resource availability
    - Optimisation of harvesting techniques
    - Establishment of biological characteristics of the resource
    - Assessment of economic viability of the fishery.
- To ensure that skill and knowledge transfer and human resource development ensue at the start of a new commercial fishery.

MANAGEMENT STRATEGY TO ACHIEVE OBJECTIVES

- The Department must provide infrastructure in terms of designated officials and/or resource managers and resources to execute the implementation of new fisheries.
- New fisheries should be developed according to the prescribed operational protocol.
- A Fisheries Management Plan (FMP) adhering to the guiding principles of the policy should be drafted for each new fishery.

OPERATIONAL PROTOCOL: A THREE-PHASED DEVELOPMENT FRAMEWORK FOR NEW FISHERIES

The operational protocol for the development of new fisheries in South Africa consists of three phases (Fig. 1), namely:

- **Phase 0: Information gathering**
  - Step 1: Desktop study
  - Step 2 (Optional): Information gathering in the field and/or exploratory fishery
  - Step 3: Economic feasibility study
  - Step 4: Experimental fishery design and Fishery Management Plan
- **Phase 1: Implementation of the experimental fishery**
  - Step 1: Fishery implementation
  - Step 2: Data collection, monitoring and control of the fishery
  - Step 3: Fishery-independent research
  - Step 4: Reassessment of the fishery
  - Step 5: Ministerial decision on the approval/prohibition of commercial exploitation of the resource
- **Phase 2: Commercial fishery**
  - Step 1: Revision of the Fishery Management Plan
  - Step 2: The allocation of rights according to general policy on commercial fisheries, giving due consideration to the need for transformation and capacity building
  - Step 3: Knowledge and skills transfer
  - Step 4 & 5: Monitoring of the fishery and fishery-independent research.

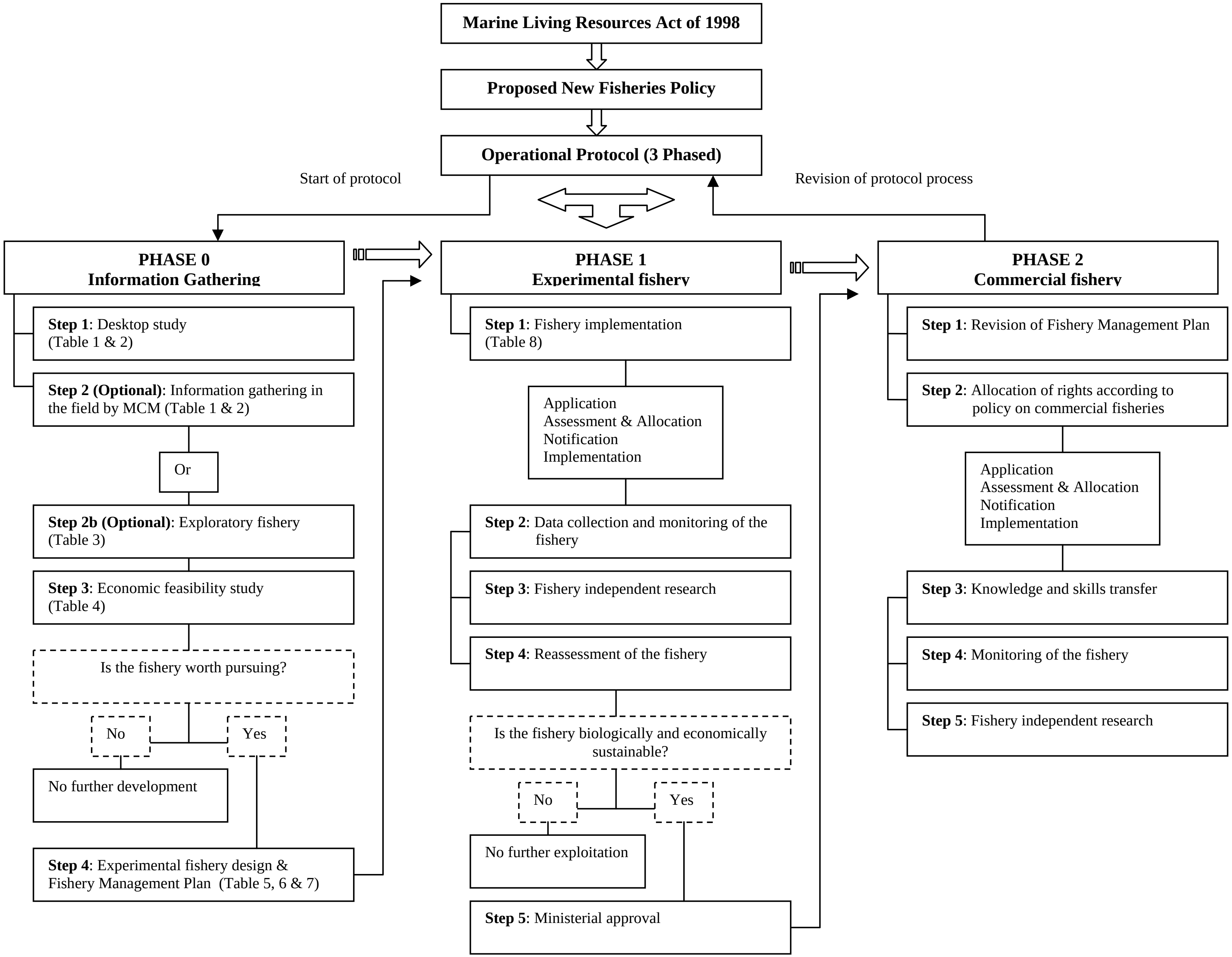

Figure 1. Three-phased operational protocol for the development of new fisheries in South Africa.

PHASE 0: INFORMATION GATHERING

This preliminary phase comprises a synthesis of all known information on the target species. Furthermore, critical information gaps are identified and new information generated on biology, fisheries, management and economics of the species and potential fishery. This phase consists of four distinct steps, namely a desktop study (literature review), information collection in the field (which can include an exploratory fishery), an economic feasibility study and, lastly, the design of the experimental fishery and the Fishery Management Plan.

Step 1: *Desktop study*

In Step 1, data will be accumulated on the basic biology of the species, existing fisheries, and management approaches previously used on similar species and fisheries. Crucial to this step is the identification of information gaps, so as to ensure a precautionary approach to management of the developing fishery. Understanding the basic biology of the species, information on potential fishing techniques, catch trends and market dynamics will all give insight into the potential success or failure of the fishery (Perry et al. 1999). This provides vital background information for effective implementation of management measures. Depending on the species and fishery type under consideration, areas of biological and fishery information that may need to be identified during this step for the implementation of appropriate management measures are listed in Table 1 and 2.

Table 1. Basic **biological information** required to understand the productive characteristics of a species, and to implement appropriate management measures. Reference is shown as superscript.

Control type	Management measure	Biological information required		Reference
		Mobile demersal/pelagic	**Sessile/sedentary benthic**	
Input control	Size limits	Size at maturity[1, 2] Size at age[1] Growth rates[1, 2, 3] Reproduction[2] Natural mortality[1] Yield per recruit[1] Survival after capture and release[1]	Size at maturity[1, 2] Size at age[1] Yield per recruit[1, 2, 3] Growth rates[1, 2, 3] and natural mortality[1] on a spatial scale Survival after capture and release[1]	[1]Perry et al. 1999 [2]Gillespie et al. 1999 [3]Caddy 1989
	Effort regulation	Unit stock[1] Growth rate[1, 3] Migrations[1, 3] Recruitment[1]	Spatial patterns Unit stock[1] Dispersal and migrations[1, 3]	
Output control	Quota/TAC	Unit stock[1] Migrations[1, 3] Abundance[1] Growth, recruitment, mortality[1, 3] Habitat distribution	Spatial patterns Unit stock[1] Abundance[1] on a spatial scale Habitat distribution Growth rates[1, 2, 3] and natural mortality[1] on a spatial scale Larval dispersal scales	

Table 2. Basic **fisheries** and **management information** required to implement appropriate management measures. Reference is shown as superscript.

Fisheries information required		Reference
Fishery description[2]	Scale of fishery (large, small) Type of fishery (demersal, coastal, high seas)	[1]Perry et al. 1999 [2]Halmarick 1999
Fishing techniques[1, 2]	Vessel and gear type Gear selectivity and efficiency Catch rates	
Management measures used	Input vs. output control Successes / failures of measures	
Environmental impacts[2]	Fishery disruption of habitat, ecosystem	

Step 2 (Optional): *Information gathering in the field and/or exploratory fishery*

Critical information gaps identified during Step 1 can be addressed by additional research. This can proceed either through fishery-independent research conducted by the Department, or through an exploratory fishery. The Department will decide on the method of information gathering. If information gathering in the field by the Department's staff is deemed too time- and effort-consuming, an exploratory fishery might be implemented to collect the required information. The nature of the fishery and information needs will further influence the method of information gathering.

<u>Exploratory fishery:</u> This refers to a situation in which an entrepreneur has approached the Department with an original idea to utilize an unexploited or underexploited resource. The desktop study (Phase 0: Step 1) must be completed and information requirements identified by the Department before an exploratory permit can be issued. An exploratory permit will be issued for a limited time period and/or catch volume to allow the entrepreneur to test the idea, as well as market acceptability of products. Pertinent biological, fisheries and economic data can be collected during this stage. The implementation process for an exploratory fishery is summarized in Table 3.

The Department is committed to a general policy of rewarding entrepreneurship, and some protection might be required for proponents of innovative ideas, techniques, gear use, etc. If an entity has proposed a promising venture/design that might have beneficial results in terms of Government's key focus areas, and providing there is no specific reason why the entity should not be allowed to fish, the entity should be granted a licence to embark on an exploratory fishery. The Department (a management committee chaired by the CD: Resource Management) will evaluate these cases. The allocation process will be a closed one, with a single permit allocated to the interested party. Requests for access to exploratory fishing proposals will be dealt with in accordance with the provisions of the Promotion of Access to Information Act 2 of 2000. Approval to conduct an exploratory fishery should not be interpreted as an automatic right of entry to experimental or full commercial phases of the fishery. However, if the Department implements an experimental fishery at a later stage, the entity's contribution should be taken into account in selection of participants for the experimental fishery. Similar considerations apply if a commercial fishery is the final outcome.

Table 3. Summary of the **implementation process** of an exploratory fishery.

Implementation Process	Responsibility	Method	Minimum Requirements
Application	Applicant	Application form Business plan	Fishing experience Vessel ownership Ability to produce gear Presentation of business plan Commitment to workshops, data collection Observer assistance
Assessment & Allocation	The Department: Working group	Evaluation	Process must be transparent, fair, legal
Notification	The Department: Resource / project manager	Written reply	Reasons for not being successful
Implementation	Applicant & The Department: Resource / project manager	Check-ups on progress	Adherence to business plan milestones

Step 3: *Economic feasibility study*

It is essential to establish which vessel type and fishing methods will be economically feasible. This study should include a description of the proposed fishing operation, a basic financial analysis, and market research to determine market areas, demand and prices.

Table 4. Basic **economic information** needed to assess the economic feasibility of a fishery. Reference is shown as superscript.

Economic information required	Reference
Market demand[1, 2]	[1]Perry et al. 1999
Potential economic value of sp. [1, 2]	[2]Halmarick 1999
Expected catch rates[1, 2]	[3]Cochrane 2002b
Cost of fishing[3]	
Vessel and gear type[1, 2]	

Step 4: *Experimental fishery design and Fishery Management Plan*

Experimental fishery design: The basic requirements of responsible fishing and a precautionary approach (FAO 1995; Roper 1997) are applicable to various aspects of an experimental fishery. For example, the extent or scale of the experimental fishery in terms of number of participants or tonnage allocated should be determined according to the precautionary principle, with limited available information warranting a more conservative approach. The duration of the experimental fishery should be medium term to create stability and confidence in the fishing sector. An four-year term would create a suitable environment for investment, and would also be sufficient to assess the characteristics of the fishery, according to the specific objectives of the policy. The choice of gear and technology must be approved by the Department, and would depend on catch rates, socio-economic and ecosystem considerations, the potential for inter- or cross-sectoral conflict, overall economic feasibility, and control. The blueprint for the experimental fishery design will be based on the outcome of the desktop study, information gathered in the field, and the recommendations from the economic feasibility study. All relevant information will be considered to ensure a well-balanced scientific experiment suited to local needs (Tables 5 & 6).

Table 5. The key **information required from** an experimental fishery. Reference is shown as superscript.

Information requirement	Necessity for information	Method of attaining information	Reference
Abundance/biomass	To determine if stock is large enough to support commercial exploitation	Analysing trends in CPUE	Roper 1997
Distribution	To identify areas of abundance	Equal fishing effort in all fishing areas	
Catch rate	To assess efficiency of gear, fishing techniques	Experimentation with fishing gear	
Species biology	To understand the productive characteristics	Biological analysis of catch	

Table 6. Basic **requirements for** the design of an experimental fishery. Reference is shown as superscript.

Experimental fishery requirements		Reference
Statistically valid experiments [3]	Small and large scale	[1]Perry et al. 1999
	Government and fisher involvement	[2]Halmarick 1999
	Fishery-dependent and -independent research	[3]Caddy 1999
Early controls on harvesting capacity [1,4]	Low vessel numbers[4]	[4]Roper 1997
	Specified time frame (3-4 yrs) [2, 4]	[5]FAO 1995
	Strict licence conditions[4]	
	Monitoring and compliance	
Fishery Management Plan[4, 5]		

Fishery Management Plan (FMP): The minimum information requirements for an FMP are listed in Table 7. An FMP must broadly adhere to international legislation and the objectives of national or fishery-specific policy (Die 2002). The operational objectives of the fishery must be stated clearly and should be (Cochrane 2002b):

- Measurable
- Realistic and achievable
- Accepted by interested parties
- Linked to a time frame.

The management measures must be described and critical components of the ecosystem specified, as well as threats to these components and proposed preventative measures. The FMP should also define performance indicators and reference points. The reference points measure the state of the resource, i.e. whether it is in a desirable state (target reference point) or in a state to be avoided (limit reference point) (Cochrane 2002b). Indicators and reference points must be set for all objectives of the FMP, including biological, ecological, economic and social objectives. Furthermore, consultation measures and review processes of the FMP should be specified (Die 2002).

Table 7. Minimum requirements of a Fishery Management Plan. Reference is shown as superscript.

Fishery Management Plan requirements		Reference
Adherence to national and international legislation[1]		[1]Die 2002
Fishery description[1]		
Management objectives[1]	Clear & achievable operational objectives	
Management strategy to achieve objectives[1]	Management measures Reference points Performance indicators	
Consultation process of FMP[1]	Public consultation*	
Review process of FMP[1]		

*This step will not be required during the experimental fishery.

Framework for a typical Fishery Management Plan:

- Description of the resource
- Goal
- Management objectives
- Description of the proposed fishery
  - Duration, fishing area, number of participating vessels/licences, vessel type, gear type, etc.
- Experimental design of the fishery
  - Objective of experiment, methods of data collection, statistical analysis
- Management strategy
  - Suggested management measures and alternatives
- Performance indicators to measure achievement of management objectives
- Administration process
  - Notification, monitoring and compliance, penalties, reviewing and amendment procedures.

PHASE 1: IMPLEMENTATION OF THE EXPERIMENTAL FISHERY

The implementation and execution of the experimental fishery occurs during this five-step second phase, and the process of developing a new fishery is initiated. This stage determines whether the species/stock exists in harvestable quantities and can be captured by a particular gear type, and also investigates habitat impacts and the economic feasibility of the fishery.

Step 1: *Fishery implementation*

Departmental infrastructure: The Department should put systems in place to address research and management issues related to the implementation of new fisheries. Procedures to deal with applications for exploratory and experimental fisheries will be as follows. A *project manager* will be appointed to coordinate the implementation of a new fishery. If the fishery falls within the remit of an existing scientific working group, scientific issues could be dealt with there. If not, an ad hoc working group or task team could be established. Recommendations emanating from the scientific working group or ad hoc working group should be submitted to the Director: Research and Development, Director: Compliance, Chief Director: Research, Antarctica and Islands and Chief Director: Resource Management for submission to the Minister or his delegate for approval.

Implementation Process (Table 8)

1) ***Application:*** Calls for applications to participate in experimental fisheries will be published in the Government Gazette and/or printed media by the Department. The notification should invite interested parties to submit a formal application and business plan (Appendix 1), and should include policy objectives, application criteria and the experimental design. The application criteria should be consistent with the policy for new fisheries. Application criteria: Applicants will need to meet minimum requirements (fishery-dependent), and illustrate their capacity to perform by means of evidence of previous involvement in the fishing industry, knowledge of fishing grounds, and ability to purchase or manufacture minimum gear. Applicants will have to provide proof of vessel ownership, and illustrate commitment by presenting a work plan for the first two years of fishing. Willingness to attend workshops, meticulously record data, assist observers and fishery officers, and commitment to experimental procedures must also be indicated.
2) ***Assessment and allocation:*** A designated Group within or appointed by the Department will assess all applications and business plans. Allocation procedures will be transparent,

fair, legally sound and equitable. Applications should be assessed using the following tools:

- A question and point system (Appendix 2, point system to be developed by the Department)
- The panel may request further information from the applicant to assist in its assessment and allocation
- Information contained in the application may be subject to validation.

3) ***Notification of status:*** The applicant is notified of the approval/refusal of an application.

4) ***Implementation/Participation:*** Successful applicants commence participation and bring the fishery to life. The permit-holder must start fishing within a prescribed time frame. If not, the permit-holder will be penalized through loss of permit and/or legal action. Fishery officers should liase with the permit-holders to ensure timely procedure of the fishery (3 - 6 month check-up).

Table 8. Summary of the **implementation process** of the experimental fishery.

Implementation Process	Responsibility	Method	Minimum Requirements	Guiding time frame
Notification	The Department: Resource / project manager	Publication in Government Gazette	Policy objectives Experimental design Minimum requirements for application	
Application	Applicant	Application form Business plan	Fishing experience Vessel ownership Ability to produce gear Presentation of business plan Commitment to workshops, data collection, experimental design Observer assistance	1 month
Assessment & Allocation	The Department: Working group	Question system Point system Validation of data	Process must be transparent, fair, legal	4 months
Notification	The Department: Resource / project manager	Written reply	Reasons for not being successful	2 weeks
Implementation	Applicant & The Department: Resource / project manager	Check-ups on progress	Adherence to business plan milestones	4 months
Timeframe from notification to:			Implementation: Actual fishing:	5.2 months, 9.2 months

Step 2: *Data collection, monitoring and control of the fishery*

Observers: Observers may be required to collect data and monitor fishing activities. The funding of observer programmes will be determined on a resource-specific basis. In general, funding of the observer programme should be on the User Pays principle. However, in the case of small-scale fisheries, the Department may carry the costs for all or part of the observer programme. This would be a Resource Management responsibility and should be budgeted for by the Chief Directorate: Resource Management. Information collected will include biological data and catch and effort data, as set out in the experimental design.

Data collection (Fishery-dependent): High quality and reliable catch and effort data, as well as samples for biological research, will need to be provided by participants. Specific information required may vary from resource to resource (refer to Tables 1-3 of Phase 0). Furthermore, permit-holders will be obliged to service the Department with biological, fisheries and economic data and information.

Data Analysis: The collation and analysis of information will be the responsibility of the Department.

Monitoring and control: Specific regulations set by the Department (by means of permit conditions, if necessary) with regard to species size limits, bycatch limits, designated areas, designated landing points or harbours, fishing seasons, closed areas, catch limits (by area if appropriate), and effort limitation must be observed. Compliance can be reported on by the on-board observers and Vessel Monitoring Systems (VMS), as well as by Extension Officers and/or Honorary Marine Conservation Officers (Ref MLRA section 9 (2)) if required by the Department. Designated landing points/harbours will be identified where fishery control officers and contracted marine monitors will observe adherence to permit conditions, as well as record catch data. Resource-specific rules regarding the handling of non-target species must also be established.

Step 3: *Fishery-independent research*

According to the Code of Conduct for Responsible Fisheries (FAO 1995), sound fishery research must be conducted in areas of biology, ecology, and socio-economics. Fishery-dependent and -independent research should be conducted pre-, during and post-experimental fishery to ensure that the fishery is well planned, executed and monitored. The research should be consistent with international trends in the development and management of new fisheries. Information gaps identified during Phase 0, Step 1 must be addressed. Research objectives will vary between resources.

Departmental research guidelines

- ***Prioritising research on potential experimental fisheries***: All new or underutilized resources need to be assessed and prioritised, in order to identify research focus areas (due to staff capacity shortages, researchers need to focus attention on key/identified resources).
- Researchers and managers involved in the development of new fisheries need to access, integrate and disseminate various information sources and types. These can be biological, social and economic, but legal and administrative issues should also be taken into account in advising on the way forward.

Step 4: *Reassessment of the fishery*

Review, assessment and modification: An annual review of performance achieved by the permit-holders against their business plan, with a full review of the developing fishery, its condition, and status occurring at the end of the developmental period, will be conducted. Both reviews are to be assessed by a designated Working Group or in sourced capacity using data and information supplied by the Department and participants. Permit-holders classified as under/non-performers will be requested to provide reasons in writing within a prescribed time frame as to why their permit should not be revoked. Failure to produce a valid reason will result in the permit being revoked. Criteria for performance measurement of permit-holders could include:

- General compliance to permit conditions
- Commitment to experimental procedure, timely return of data
- Performance in harvesting
- Business feasibility.

Reporting and recommendations: The dissemination of results and recommendations (feedback and progress reports) to participants will be the responsibility of the Department. Recommendations based on the results of the experiment will form the basis of a decision on whether to implement the next phase, i.e. a commercial fishery. If a commercial fishery is proposed, results of the experimental fishery should form the basis of a Fishery Management Plan for the specific fishery. Recommendations should include information on fishing areas, fishing methods, fishing seasons, fishing and fleet effort, size limits and bycatch levels and responsibilities, amongst others.

Note: *All data/information collected in the course of an experimental phase of a new fishery should be made publicly available.*

Step 5: *Ministerial decision on the approval / prohibition of commercial exploitation of the resource.*

PHASE 2: COMMERCIAL FISHERY

Once the Department has enough information about a specific resource to be able to determine a TAC, TAE or Precautionary Maximum Catch Limit (PMCL) and commercial exploitation has been approved by the Minister, rights are allocated for the requisite period and the commercial fishery commences.

Step 1: *Revision of the Fishery Management Plan*

Step 2: *The allocation of rights according to general policy on commercial fisheries, giving due consideration to the need for transformation and capacity building*

Application, assessment and allocation: The criteria for implementing a new, full-scale fishery would be in line with those for any existing commercial fishery. However, experienced applicants/experimental fishers should submit proposals indicating how they intend to transfer skills to non-experienced persons and/or applicants.

Step 3: *Knowledge and skills transfer*

Departmental responsibilities:

Identification of client group: The sector or client groups that the Department identifies to benefit from the new fishery should be defined. Whenever applicable and relevant, it should be stated that the client groups are small operators and that the main objective in establishing a new commercial fishery is job creation. Inter-sectoral conflict needs to be considered, e.g. the impact of the new fishery on existing sectors such as subsistence fishers or on other existing fisheries. The Department will, as far as possible, implement a system to ensure that the client groups optimise the potential profits derived from such ventures. Participants will be encouraged to be involved in all facets of the venture (including the marketing of the species) in order to enhance their profit margins.

Knowledge transfer: The role of the Department in collecting and disseminating market-related information would depend on the client group. In the case of potential small-scale commercial fisheries (targeting Historically Disadvantaged Individuals or new entrants), the Department would have to take on the responsibility for acquiring this information and presenting such information to the participants. In some cases, relevant information could be provided by the Department to guide potential investors.

Skills transfer: When applying for a commercial licence, the experimental fisher must outline a practical plan for skills transfer. However, the Department should develop a protocol for, and oversee the process of, skills transfer.

Step 4 & 5: *Monitoring of the fishery and fishery-independent research*

Once the fishery been established, all the management procedures with respect to the resource, the users, monitoring and control, and research will be applied, as for other commercial fisheries. However, special attention will be given to new fisheries to ensure that a precautionary approach is followed.

NOTE: *In any of the above three scenarios, the Department will reserve the right to decide whether to allow a fishery to progress to the next phase or to terminate a fishery at any stage, based on resource or any other considerations.*

CONCLUSION

This policy document was submitted to MCM and was favourably received. It will most likely be used as the formal policy on the development of new fisheries in South Africa. However this document needs to be assessed and reviewed to optimise cooperation by all stakeholders.

ACKNOWLEDGEMENTS

I would like to thank Dr C. J. Augustyn and Mr. S. Munkejord (Marine and Coastal Management) for comment on a draft of this work.

REFERENCES

ANON. 2001a. Draft discussion document for the fisheries management plan to improve the process of allocating fishing rights. Rights Allocation Unit, Department of Environmental Affairs and Tourism, Cape Town.

ANON. 2001b. New emerging fisheries policy. Department of Fisheries and Oceans, Canada. Retrieved June 2003, from http://www.dfo-mpo.gc.ca/communic/fish_man/nefp_e.htm.

ANON. 2003. Policy for the establishment of new fisheries, Draft version 6. Marine and Coastal Management. Cape Town.

BENSON A.J., MCFARLANE G.A. and KING J.R. 2001. A phase '0' review of Elasmobranch biology, fisheries, assessment and management. *Canadian Science Advisory Secretariat Research Document* **2001/129**. Department of Fisheries and Oceans, Canada.

BRITZ P.J., SAUER W.H.H., MATHER D., OELLERMAN L.K., COWLEY P.D., TER MORSHUIZEN L. and BACELA N. 2001. Baseline study of the utilization of living marine resources in the Eastern Cape. Dept. Ichthyology and Fisheries Science, Rhodes University, Grahamstown. 103 pp.

CADDY J.F. 1989. A perspective on the population dynamics and assessment of scallop fisheries, with special reference to the sea scallop, *Placopecten magellanicus* Gmelin. In: *Marine invertebrate fisheries: their assessment and management*. Caddy J.F. (Ed). John Wiley and Sons, New York. p 559-589.

CADDY J.F. 1999. Fisheries management in the twenty-first century: will new paradigms apply? *Rev. Fish Biol. Fish.* **9**: 1-43.

COCHRANE K.L. 2002a. Fisheries management. In: A fishery manager’s guidebook. Management measures and their application. Chapter 1. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 1-20.

COCHRANE K.L. 2002b. The use of scientific information in the design of management strategies. In: A fishery manager’s guidebook. Management measures and their application. Chapter 5. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 95-130.

COCHRANE K.L., BUTTERWORTH D.S. and PAYNE A.I.L. 1997. South Africa’s offshore living marine resources: The scientific basis for management of the fisheries. *Trans. Roy. Soc. S. Afr.* **52**(1): 149-176.

DIE D. 2002. Design and implementation of management plans. In: A fishery manager's guidebook. Management measures and their application. Chapter 9. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 205-226.

FAO 1995. Code of Conduct for Responsible Fisheries. FAO, Rome. 41 pp.

FAO 1996. Precautionary approach to capture fisheries and species introduction. *FAO Technical guidelines for responsible fisheries* No. **2**. FAO, Rome. 54 pp.

GILLESPIE G.E., PARKER G. and MORRISON J. 1998. A review of octopus fisheries biology and British Columbia octopus fisheries. *Canadian Stock Assessment Secretariat Research Document* **98/87**. Department of Fisheries and Oceans, Canada. 66 pp.

HALMARICK L. 1999. Developing new fisheries in Western Australia. A guide to applicants for developing fisheries. *Fisheries Management Paper* **130**. Fisheries Western Australia, Perth, Australia. 40 pp.

KLEINSCHMIDT H., SAUER W.H.H. and BRITZ P. 2003. Commercial fishing rights allocation in Post-Apartheid South Africa: Reconciling equity and stability. *Afr. J. mar. Sci.* **25**: 25-35.

KRAUSE G.G., WORKMAN G. and PHILLIPS A.C. 2001. A Phase '0' review of the biology and fisheries of the Tanner Crab (*Chionoecetes bairdi*). *Canadian Science Advisory Secretariat Research Document* **2001/160**. Department of Fisheries and Oceans, Canada.

MATHER D., BRITZ P.J., HECHT T. and SAUER W.H.H. 2002. An economic and sectoral study of the South African fishing industry, Vol 1: Economic and regulatory principles, Survey results, Transformation and socio-economic impact. Report prepared for Department of Environmental affairs and Tourism, Marine and Coastal Management. Rhodes University, Grahamstown, South Africa.

MORRISON J., PARKER G. and GILLESPIE G.E. 1999. A discussion paper on the future development of British Columbia octopus fisheries. Department Fisheries and Oceans Canada. 24 pp.

PAYNE A.I.L. and BANNISTER R.C.A. 2003. Science and fisheries management in southern Africa and Europe. *Afr. J. mar. Sci*. **25**: 1-23.

PERRY R., WALTERS C. and BOUTILLIER J. 1999. A framework for providing scientific advice for the management of new and developing invertebrate fisheries. *Rev. Fish Biol. Fish.* **9**: 125-150.

ROPER C.F.E. 1997. Experimental Octopus Fisheries: Two Cases Studies. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 157-168.

SECTION B – IMPLEMENTATION

CHAPTER 3

PHASE 0: STEP 1 – A REVIEW OF OCTOPUS BIOLOGY, FISHERIES AND MANAGEMENT.

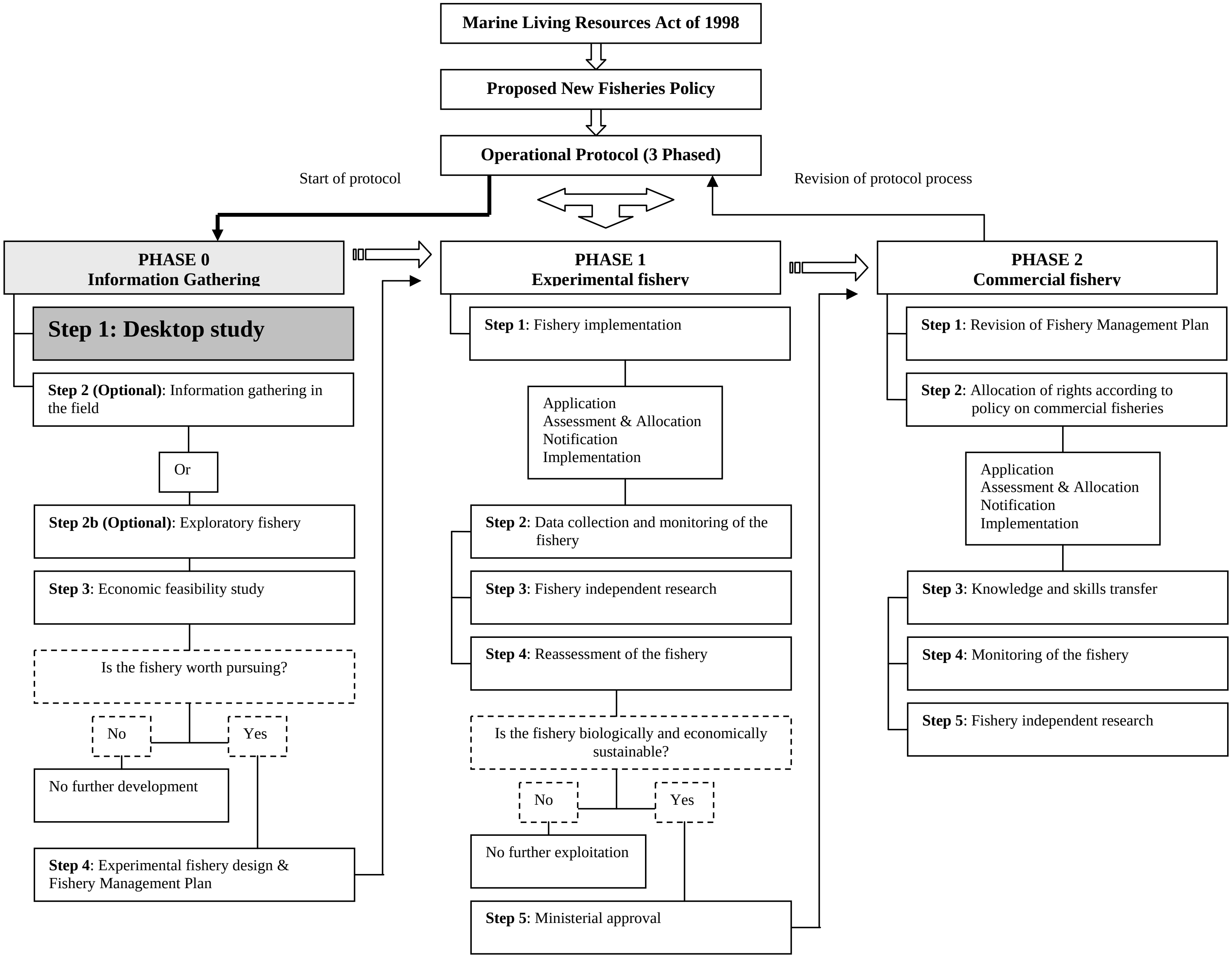

Figure A. Step 1: Desktop study of available information.

CHAPTER 3

PHASE 0: STEP 1 – A REVIEW OF OCTOPUS BIOLOGY, FISHERIES AND MANAGEMENT

OCTOPUS SPECIES IN SOUTH AFRICA AND THEIR POTENTIAL FOR COMMERCIAL EXPLOITATION

To date 195 cephalopod species have been recorded in southern African waters, of which 39 are from the Order Octopoda, and five of these are octopus species belonging to the family Octopodidae (Roeleveld 1998). These species differ considerably with respect to their distribution, current exploitation levels and potential for further commercial exploitation. At present no commercial fishery exists for octopus, but four species (*Octopus magnificus, O. vulgaris, O. cyanea* and *Veladona togata capensis*) are being exploited at low levels. A number of other cephalopod species could also be of commercial interest, with the squid (*Loligo vulgaris reynaudii*) currently the only directly exploited cephalopod resource in South Africa (Roeleveld 1998).

Octopus vulgaris

In southern Africa, *Octopus vulgaris* occurs from Lüderitz (26^{o}38'S, 15^{o}06'E) on the coast of Namibia to Durban (29^{o}53'S, 30^{o}53'E) on the east coast of South Africa (Smale et al. 1993). The taxonomy of this species is currently under review and might consist of a species complex (Mangold 1997; Roeleveld 1998; Söller et al. 2000). Research in South Africa has mainly focused on the biology of the species. However, this has been confined to isolated investigations on the subtropical east coast (Smale & Buchan 1981) and the cold temperate southwest coast (Smith & Griffiths 2002), while data for the temperate southeast coast is lacking. McQuaid (1994) conducted laboratory trials on aspects of prey selection and feeding behaviour of *O. vulgaris*. Current exploitation of *O. vulgaris* consists of subsistence and recreational fisheries situated mostly on the east coast of South Africa. Artisanal fisheries on the Transkei coast in the Eastern Cape removed approximately 12.3 tons during 1994 - 1995. On the KwaZulu-Natal coast an estimated 12.9 tons of octopus were harvested during 1995 (Robertson & Fielding 1997). Recommendations were made for a small-scale pot fishery on the southwest coast (Smith 1999) using small vessels (< 5 tons) with minimum labour (2 persons), and different pot types of PVC pipe and old tyres, but neither the vessel or gear type was tested.

Octopus cyanea

Octopus cyanea is the most common reef-dwelling octopus in the Indo-west-Pacific (Roper et al. 1984), and occurs along the east African coast as far south as KwaZulu-Natal on the subtropical coast of South Africa. The species is found in intertidal and shallow subtidal waters (Roper et al. 1984; Roeleveld 1998), but little is known about its biology and population dynamics in southern Africa. *O. cyanea* is harvested intertidally for bait and food in KwaZulu-Natal and this exploitation could possibly be expanded into a small-scale artisanal fishery. During 1995, 12.9 tons of octopus were harvested on the KwaZulu-Natal coast; this may represent a mixed catch of *O. vulgaris* and *O. cyanea* (Robertson & Fielding 1997).

Aphrodoctopus schultzei

Aphrodoctopus schultzei is distributed from Lüderitz (26^{o}38'S, 15^{o}06'E) in Namibia to Tsitsikamma (34^{o}07'S, 23^{o}28'E) on the south coast of South Africa, but is most common west of Cape Point (34^{o}22'S, 18^{o}30'E). The biology of *A. schultzei* was described by Roper & Mangold (1991) and Smith (1999). This is a small species (mean mass 65 g), which occurs in intertidal and shallow subtidal waters to a maximum depth of about 18 m (Smith 1999). *A. schultzei* is currently not exploited (Smith pers. comm.), but could be used in the aquarium trade due to its small size.

Octopus magnificus

The distribution of *Octopus magnificus* ranges from Lüderitz (26^{o}38'S, 15^{o}06'E) in Namibia to Port Alfred (33^{o}35'S, 26^{o}57'E) on the southeast coast of South Africa. The depth distribution recorded for *O. magnificus* is 2 to 560 m, but is most abundant between 100 and 300 m (Villanueva et al. 1991). This is a large species with a mean mass of 2091 g (Villanueva 1993). It was described by Villanueva et al. (1991), and some biological work has been done by Villanueva (1993) and Smith (1999). *O. magnificus* is caught as a bycatch in the west coast hake trawl fishery, the south coast lobster trap fishery and south coast sole trawl fishery off South Africa (Villanueva 1993; Smith 1999). Bycatch from the west coast is generally reported, while that from the south coast is not (Smith 1999). Reported landings during the period 1979 -1997 varied between approximately 65 and 115 metric tons per year (Smith 1999). These quantities suggest that the species could be targeted through a direct fishery. *O. magnificus* is sold to local and international markets as a food and bait species, with most of the catch being exported to North America and Europe as bait (Smith 1999).

Veladona togata capensis

Veladona togata capensis is distributed along the east coast of South Africa and Mozambique (Roeleveld 1998). Not much is known about the biology and population in Southern Africa. It is currently a bycatch species in prawn trawls off the KwaZulu-Natal coast (Smale et al. 1993).

Target octopus species

The species that is the most likely candidate for a directed fishery in South Africa is *O. vulgaris*. It is the most common octopus occurring along the entire South African coast, and has been earmarked by industry as a target species for a potential fishery (Smith 1999). Despite the present focus on *O. vulgaris*, future possibilities should not preclude the potential for commercial exploitation of *O. magnificus*, or for artisanal and recreational exploitation of *O. cyanea* in KwaZulu-Natal.

AN OVERVIEW OF AVAILABLE INFORMATION ON THE BIOLOGY OF *OCTOPUS VULGARIS*

Taxonomy

The cephalopod genus *Octopus* comprises approximately 90 species (Nesis 1987), but the taxonomic status of many is still unclear. *Octopus vulgaris* consists of a large species complex distributed worldwide, which is currently under both morphological and molecular review (Söller et al. 2000). Preliminary molecular research by Hudelot (2000) indicates that major changes could occur in the classification of octopods. In addition, Roeleveld (1998) suggested (based on morphology) that the South African *O. vulgaris* also needed to be renamed.

With the increased fishery value of cephalopods, it has become important to solve global taxonomic problems relating to cephalopods. Taxonomic and phylogenetic studies on octopus have largely been based on morphology (Voss 1977; Roper & Voss 1983; Mangold & Hochberg 1991), however the ecological elasticity of cephalopods allows for swift adaptations in morphology, which are expressed phenotypically (Boyle & Boletzky 1996). Molecular techniques are now increasingly being employed to solve these taxonomic problems (De Los Angeles Barriga Sosa et al. 1995; Söller et al. 2000; Warnke et al. 2000).

Distribution

O. vulgaris was previously believed to have a worldwide distribution, but is now considered to occur in the Mediterranean and the eastern Atlantic only (Mangold 1997). A truly coastal species, it is found in the upper 100 m of the continental slope, with abundance decreasing down the slope (Guerra 1981). It mostly inhabits shallow rocky areas, but does occur on sand and muddy substrates in some regions (Mangold 1983).

Research

O. vulgaris is one of the most intensely studied cephalopod species worldwide (Mangold 1997). Studies on the biology and exploitation of this species have mainly taken place in the Mediterranean Sea and on the Saharan Bank, northwest Africa (Hatanaka 1979; Sato & Hatanaka 1983; Mangold 1983; Guerra 1981). Other studies conducted internationally have dealt with aspects of *O. vulgaris* physiology (Wells 1978), learning and behaviour (Boycott & Young 1955), nervous system (Young 1967, 1971), embryology (Neaf 1923, 1928;

Boletzky 1968, 1969), diet (Nigmatullin & Ostapenko 1976) and systematics (Mangold & Hochberg 1991).

Comparatively little work has been conducted on *O. vulgaris* in South Africa, although some research has been done on its biology (Smale & Buchan 1981; Smith 1999; Smith & Griffiths 2002) and diet (McQuaid 1994). Work by Smale & Buchan (1981) primarily focussed on feeding and growth rates, but also investigated the biology on a small subtidal reef in the subtropical KwaZulu-Natal region. Smith (1999) and Smith & Griffiths (2002) conducted field-based studies on the population biology of *O. vulgaris* in subtidal kelp beds along the cold temperate southwest coast. To date no research has been done on *O. vulgaris* in the warm temperate region of South Africa. A summary of the pertinent biological information is given in Table 1.

Table 1. Summary of biological information available on *O. vulgaris* in South Africa.

Biological feature	**Reference**	
	Smale & Buchan (1981) **(Subtropical)**	**Smith (1999), Smith & Griffiths (2002)** **(Cold temperate)**
Size range (mean)	58 - 3012 g (Unknown)	57 - 4625 g (1019 g)
Size at maturity	Female = 900g Male = 400g	Female = Unknown Male = 170g
Growth rate	5.2 % body weight per day	Unknown
Sex ratio F:M	0.5:1 (summer), 1:0.5 (winter)	0.6:1
Diet	Mussels, crabs	Crustaceans, abalone
Seasonality	Female migration inshore in winter	Mean size large in summer, small in winter

Population dynamics

The spatial distribution and population dynamics of octopuses is very diverse. The abundance and population size structure of *O. vulgaris* in the Mediterranean and in northwest Africa was shown to be highly variable (Mangold 1983; Guerra 1981), with migrations between inshore and deeper offshore areas related to spawning behaviour and temperature variations (Mangold & Boletzky 1973; Guerra 1981). Similar migration patterns were found on the east coast of South Africa (Smale & Buchan 1981) and in South Carolina (Whitaker et al. 1991). Smith (1999) noted a shallower depth distribution for juveniles than for larger animals on the west coast of South Africa. This was also found for *O. vulgaris* in Bermuda (Mather & O'Dor 1991) and for *O. dolfleini* in Canada (Hartwick et al. 1988), indicating the importance of spatial dynamics within populations. Further information on population dynamics and distribution can be gleaned from molecular studies. These can be used to determine whether more than one population exists within a fishing stock and whether spatial interaction between these stocks occurs.

Life history

The life history of *O. vulgaris* has been well studied (Neaf 1923, 1928; Itami et al. 1963; Mangold-Wirz 1963; Nixon 1969, 1971; Guerra 1979, 1981; Hatanaka 1979). *O. vulgaris* is a semelparous, large octopod with small eggs (2 - 3 mm) (Mangold 1983). The planktonic hatchlings weigh approximately 1.2 mg and have a mantle length of 1.7 mm (Mangold 1997). The duration of the planktonic stage is temperature-dependent, and has been found to vary between 33 - 40 days at 22 - 27 ^{o}C (Itami et al. 1963) and 50 - 60 days at 21 ^{o}C (Villanueva 1995). After 12 - 24 months of growth, the adults weigh 2 - 10 kg (Mangold 1997), with males maturing at 190 g and females at 1000 - 2000 g in the Mediterranean (Mangold & Boletzky 1973; Mangold 1983).

Mating occurs when the male transfers sperm into the body cavity of the female through a specialised hectocotylus arm. Spermatophores are stored in the female’s oviducal glands until spawning is initiated (Mangold-Wirz 1963). The female spawns once and lays between 100 000 and 500 000 eggs (Mangold 1983). The eggs are laid in sheltered dens, with the egg strings fixed to the substratum. Spawning occurs year-round (Wodinsky 1972). The female protects and cleans the eggs until they hatch, and normally dies shortly afterwards.

Growth

Cephalopods are short-lived animals with fast growth rates and high turnover of generations (Boyle & Boletzky 1996). Their growth is influenced by various factors such as water temperature, food availability, size and species (Forsythe 1984; Van Heukelem 1976; Mangold & Boletzky 1973; Borer 1971). The growth of octopods and loliginid squids occurs over two phases of the life cycle, the first being exponential and the second, logarithmic (Forsythe & Van Heukelem 1987). The duration of these phases is species-specific (Forsythe 1984) and temperature-dependent (Van Heukelem 1976). Large variation in growth between individuals has also been observed for many cephalopod species (Forsythe & Van Heukelem 1987; Van Heukelem 1976), including *O. vulgaris* (Mangold & Boletzky 1973; Smale & Buchan 1981). Such variation in growth has rendered length measurements insufficient for both cohort analysis and ageing of cephalopods (Forsythe & Van Heukelem 1987).

Traditional length-frequency analysis and other models used for growth estimates and ageing of finfish cannot be applied to cephalopods, as the underlying assumptions are not supported by cephalopod growth (Forsythe & Van Heukelem 1987; Jackson 1994). The debate on the difference between finfish and cephalopod growth and the applicability of models based on teleost growth to cephalopods is ongoing (Lipiński et al. 1998a; Jackson 1994; Jackson et al. 1997). Although it has been suggested that cephalopod age and growth could be estimated by similar models to those used for short-lived finfish species (Pauly 1998), this has been opposed by Forsythe & Van Heukelem (1987), Jackson (1994) and Jackson et al. (2000).

Age

In the past, age determination in cephalopods has focused on squid, primarily because of their major importance to fisheries worldwide and the readability of their statolith structure. Tetracycline, a chemical marker, has also been successfully used as an age validation method, by staining the statoliths of squids (Dawe et al. 1985; Lipiński et al. 1998b). With the increasing commercial importance of octopus it has become necessary to focus on octopus aging for stock assessment and management purposes. Despite work on the growth of octopus (Guerra 1979; Mangold & Boletzky 1973; Smale & Buchan 1981), few studies have attempted to determine octopod age directly (Raya & Hernández-González 1998; Hernández-López et al. 2001; Sousa reis & Fernandes 2003). Ring formation in octopus beaks and vestigial shells was investigated with beaks highlighted as a useful tool in octopus ageing and can be likened to the use of statoliths in squid ageing.

Trophic importance

Cephalopods play an important role in marine food webs. They are both predators of smaller fishes and invertebrates, and the prey of larger fishes and mammals (Smale 1996; Klages 1996; Clarke 1996). *O. vulgaris* feeds on a variety of prey including crustaceans, molluscs, other cephalopods and fishes (Nigmatullin & Ostapenko 1976; Guerra 1978; Hatanaka 1979; Smale & Buchan 1981). Caddy (1983) suggested that an inverse relationship exists between predatory fishes and octopus populations. Given that short-lived species such as cephalopods are widely believed to benefit from anthropogenic changes to faunal abundance, the relationship between cephalopods and their predators can be influenced by commercial exploitation of the predator (Clarke 1983). Several authors have suggested that octopus fisheries started in the Saharan Bank region as a consequence of overexploitation of seabream populations (Garcia Cabrera 1968; Bas et al. 1970; Caddy 1983; Caddy & Rodhouse 1998).

However, Balguerias et al. (2000) indicated that a combination of biological, oceanographic and economic factors, and not solely the overexploitation of fish, contributed to the increase in cephalopod catches in the Sahara Bank fishery.

Synthesis and identified information gaps

To adapt appropriate management measures (as set out in Chapter 2) specific information is required to understand the biology of a species. The availability of this basic knowledge in both international and South African literature is shown in Table 2. Although a large amount of information is available on *O. vulgaris* on an international level, this review has revealed critical shortcomings in the information available on *O. vulgaris* in South Africa.

- The taxonomic classification of the South African *O. vulgaris* is unclear; no research has been done on the genetic relatedness or population structure of *O. vulgaris* along the coast of South Africa.
- Biological information for *O. vulgaris* on the warm temperate **southeast coast** is lacking.
- No data is available on the fecundity, age, population dynamics (spatial dynamics), stock structure or recruitment of *O. vulgaris* along the **entire** South African coast.

Table 2. General **biological information** required for precautionary resource management and the availability of this information from both international and South African literature. Shaded areas indicate gaps in South African information. References are shown in superscript.

Biological information					
Management measure	**Required information**	**Available Internationally**	**Available South Africa**	**Notes**	**Reference**
Size limits	Size at maturity	Yes [1, 3, 10, 11]	Yes [12, 13]	*Only for warm subtropical – still needed for cold and warm temperate climates **Intertidal/ shallow subtidal only	[1]Mangold 1983 [2]Mangold-Wirz 1963 [3]Mangold & Boletzky 1973 [4]Mangold 1997 [5]Domain et al. 2000 [6]Robinson & Hartwick 1986 [7]Guerra 1981 [8]FAO 1997 [9]Guerra 1997 [10]Hatanaka 1979 [11]Wodinsky 1972 [12]Smale & Buchan 1981 [13]Smith 1999 [14]Caverivière et al. 2002 [15] Demarcq & Faure 2000
	Size at age	**No**	**No**		
	Growth rates	Yes [3]	*Yes [12]		
	Reproduction	Yes [1, 2, 4]	**No**		
	Natural mortality	Yes [14]	**No**		
	Yield per recruit	Yes [14]	**No**		
	Survival after capture and release	Yes [5, 6]	No		
Effort regulation	**Unit stock**	**No**	**No**		
	Migrations	Yes [3, 7]	**Yes [12, 13]		
	Recruitment	Yes [14, 15]	**No**		
Quota/TAC	**Abundance**	Yes [8, 9]	**No**		
	Habitat distribution	Yes [1, 4, 7]	**Yes [12, 13]		

GLOBAL OCTOPUS FISHERIES

Introduction

The global cephalopod catch consists mostly of the families Sepiidae (cuttlefish), Loliginidae (squid), Ommastrephidae (squid) and Octopodidae (octopus) (FAO 1997). Octopus and cuttlefish each contribute only 12% to the world cephalopod catch, which is dominated by squid (75 %) (Paust 1997). Octopus is caught using various methods, including trawling (Rathjen & Voss 1987), clay pots and traps (Whitaker et al. 1991; Sanchez & Obarti 1993), long lines using hooks (Voss 1988), by hand during SCUBA diving (Hartwick & Barriga 1997) and spearing (Young & Harman 1997). Large fisheries for *Octopus vulgaris* are concentrated on the northwest African coast, in the Mediterranean Sea and Japan (Hatanaka 1979; Mangold 1983, Takeda 1990), while small-scale fisheries exists in countries such as Mexico (Solis-Ramirez 1997), Canary Islands (Hernandez-Garcia et al. 1998), Chile (Defeo & Castilla 1998) and Hawaii (Young & Harman 1997). Experimental fisheries have also been attempted in several countries, among them Canada (Gillespie et al. 1998) and the USA (Whitaker et al. 1991). A review of fishery type, CPUE trends, fishing methods, management measures, market conditions, and environmental and anthropogenic influences on these octopus fisheries provides much-needed baseline information pertinent to the development of a new fishery.

Large fisheries

Northwest Africa

The fishery on the northwest coast of Africa is the largest trawl fishery for octopus worldwide, with the catch harvested by vessels from Spain, Korean Republic, Morocco and Mauritania and exported as frozen product to Japan (Guerra 1997). The fishery started during the 1960s when traditional finfish catches began to decline (Caddy 1983; Rathjen & Voss 1987) and showed a variable increase in catch, reaching 135 000 tons in 1994 (FAO 1997). Two stocks of *O. vulgaris* are exploited: a northern one on the Saharan Bank and a southern one off Cape Blanc, which is now considered overexploited (FAO 1997). Catches of the southern stocks declined during the late 1980s but returned to higher levels during the early 1990s, after fishing activity was reduced by 40% (FAO 1997). In the northern areas, management measures comprising a reduction of foreign vessels and a two-month closed season (FAO 1997) were implemented. During 2001, a second closed season was introduced and there was a further reduction of the Spanish fleet fishing in Moroccan waters (Anon. 2001).

Mediterranean

Octopus fisheries in the Mediterranean region are comprised of both pot and trawl fisheries. The Mediterranean pot fisheries have existed since classical times and currently account for approximately 36% of the annual octopus landings in the Spanish Mediterranean (Mangold 1983; Rathjen & Voss 1987; Sanchez & Obarti 1993). Catches in the Mediterranean have shown an increase in landings of most cephalopods in the last 40 years (FAO 1997), with *O. vulgaris* catches rising from approximately 2 000 tons in the 1950s to 20 000 tons during the 1990s (Guerra 1997).

In the western Mediterranean, octopuses (*O. vulgaris*) are caught in nearshore waters using pots (Sánchez & Obarti 1993) and further offshore by trawling (Quetglas et al. 1998; Sartor et al. 1998). The pot fishery catch peaks in early winter, when approximately 0.15 - 0.3 octopuses are caught per pot. Only large octopuses (>1 kg mass, >11 cm ML) are caught in this inshore pot fishery (Sánchez & Obarti 1993). In the trawl fishery, octopus represent 8 - 40% of the total catch (Quetglas et al. 1998; Sartor et al. 1998). The CPUE for the trawl fishery is highest during early summer (40 kg/h), and the largest animals are much smaller than those caught in the inshore pot fishery (Quetglas et al. 1998). This suggests that mature octopuses migrate for spawning and brooding purposes to the nearshore environment, where they become available to the pot fishery. Spanish demand for octopus increased substantially during the last decade, and most of the catch is consumed locally (Sánchez & Obarti 1993).

In Portuguese waters, octopus and other cephalopods are caught as a bycatch to finfish-directed trawling (Fonseca et al. 2002), yet they fetch approximately three times the price of fish. Although the minimum legal size for octopus is 0.75 kg, the legal trawl mesh size mostly retains octopus smaller than this.

Japan

Various octopus species are exploited in Japanese waters, with the most common, *O. vulgaris*, contributing 90% to the total octopus catch (Takeda 1990). Fishing methods include trawling, pots, long lines and angling. During 1980, pot fishing and trawling accounted for 49% and 27% of octopus caught in Japanese waters respectively. *O. vulgaris* is caught mostly at <100m depth in the Seto Sea, where landings decreased steadily from 14 166 tons during the 1960s to 6 422 tons during the 1980s (Takeda 1990). During the period 1983 - 1987, a five-year plan to protect and enhance spawning and nursery areas was implemented. It included introducing artificial and natural boulders and blocks to the substrate to protect and encourage spawning females. Other areas were spread with small stones to make the substrate more suitable for juveniles (Takeda 1990). The success of this intervention is not known.

Small-scale fisheries

Senegal

A small-scale fishery in Senegal started when *O. vulgaris* appeared in the commercial landings of traditional finfish fisheries in 1986 (Caverivière 1990). The fishery was established as an important commercial venture during 1989 (Caverivière 1994). This is a coastal fishery, which is exploited for both artisanal and industrial purposes. The main fishing gear used in the artisanal fishery is a jigging hook while the industrial fishery relies on trawlers (Diallo & Ortiz 2002). Fishing from industrial vessels is prohibited within six miles of the shore, while there is no restriction on the artisanal vessels. The fishing depth ranges between 10 and 100 m.

Catches in the artisanal fishery fluctuated between 2 and 8 metric tons between 1989 and 1994, while CPUE doubled in the same period. The fishing season varies, with peak activity occurring in spring (Feb. - May) in the northern area but in autumn (Jun. - Oct.) in the southern and central areas. The development of this fishery was dependent on international markets, with products initially being exported only to Asia and later also to Europe (Caverivière 1990). Currently all catches are sold on these markets (Dème et al. 1997). Management measures employed in this fishery include minimum size and closed seasons for octopus (Caverivière et al. 2002).

Mexico

Octopus (*Octopus maya*) fishing in Mexico began in 1949, but was a low-key coastal activity until 1970, after which catches increased from 1 500 tons to 9 000 tons in 1986 (Solís-Ramírez 1997). During the early 1980s, the mechanised fleet, which usually caught fish, started participating in hook and line fishing (drift fishing) for octopus. This led to increased octopus landings, so a series of new management measures were introduced. Although an open-access fishery, a strict fishing season was enforced, harvesting by diving and hooking was prohibited, a minimum legal size of 110 mm mantle length was implemented, and catch and effort data had to be submitted. Currently, the fishing fleet consists of two types of boats, namely artisanal (18 – 31 ft boats) and mechanised (40 - 72 ft boats). Each main vessel carries a number of smaller craft, usually one to three canoes in the artisanal fleet and five to seven boats in the mechanised fleet (Solís-Ramírez 1997). Fishing trips are limited to one day for artisanal boats, during which approximately 200 kg of octopus are landed, and 12 days for the mechanised fleet, when up to 11 tons are landed per trip. Octopuses in this fishery are only caught on hook and line. Some experimentation with natural- and lure-baited traps was conducted during the late 1960s to early 1970s, but this was not very successful (Solís-Ramírez 1997). Recently, the fishery in the Celestun region was seriously affected by a red tide that forced the octopus to move out of the fishing areas, causing a revenue loss of over 1 million USD (FIS Latino 2001).

Hawaii

Small-scale octopus fisheries exist in Hawaii, with *Octopus cyanea* and *O. ornatus* caught in both commercial and recreational fisheries, and as a bycatch in the lobster trap fishery (Young & Harman 1997). Fishing occurs throughout the year with no closed season or bag limit, but a minimum legal size of 0.45 kg is enforced. Octopuses are harvested by spearing in shallow waters and by using lures at depths of up to 240m. Fishing occurs during the day and night, with the largest catches being made during autumn. Commercial catches were about 2 268 kg during the early 1960s but by 1988 had increased to 18 144 kg, valued at 70 000 USD. Octopus landed as bycatch in the lobster fishery was worth approximately 50 000 USD during 1986 (Young & Harman 1997).

Canary Islands

The small-scale trap fishery in the Canary Islands targets demersal fish, with octopus caught as bycatch (Hernández-García et al. 1998). Fishing takes place at depths of 18 - 200 m from small boats (7 - 12 m), each deploying a total of 275 traps and hauling in about 50 traps per day. The soak time (time spent in the water) of the traps is about five days. The fishery started in 1980, when approximately 2 tons of octopus were landed. It peaked in 1982 with 21 tons and in 1995 with 25 tons, but at other times low catches (3 - 11 tons) persisted. This cyclical high and low CPUE has been linked to El Niño events affecting the region (Hernández-García et al. 1998).

Chile

Octopus mimus is harvested by both skin- and hookah-divers in Chile (Defeo & Castilla 1998), operating in waters of 5 – 20 m depth in shoreline coves. The fishery is an open-access one, regulated only by a closed season (Dec. – Mar.). It started in 1978 with landings of two tons a year and increased to approximately 4000 tons by 1983. During the period 1989 – 1991, landings decreased to 2500 tons per annum and increased again to 3700 tons in 1997. Export value of the 1997 catch reached 13.5 million USD (Defeo & Castilla 1998).

The octopus landings were influenced by environmental factors associated with ENSO (El Niño Southern Oscillation) events, such as sediment deposition in subtidal areas as a result of landslides. The catches were also influenced by short-term supply and demand locally and increased demand by foreign markets. All these factors can cause overexploitation and economic dissipation, and it was suggested that precautionary measures such as size limits, catch quotas and marine reserves be implemented (Defeo & Castilla 1998).

Canada

In Canada, *Octopus dofleini* was harvested recreationally and as a bycatch in other fisheries, yielding 18-50 tons per year until the early 1980s (Hartwick & Barriga 1997). The harvest increased rapidly after 1984 with the development of a commercial SCUBA dive fishery and reached approximately 206 tons in 1988, when divers harvested 10 - 73 kg/diver hour. With the introduction of individual vessel quotas in 1991, the landings decreased to 81 metric tons in 1995 (Gillespie et al. 1998). The commercial dive fishery now represents about half the annual landings of octopus in British Columbia with the remainder derived as bycatch in trawl and trap fisheries (shrimp, prawn and crab) and on hand- and long lines (Gillespie et al. 1998).

There has also been some experimental fishing with traps in the region. Pre - 2000, little management attention was given to the dive fishery and no minimum size limit, quotas, minimum escapements, biological sampling or closed season existed (Gillespie et al. 1998). During 2000 some management procedures were implemented to regulate the fishery. Fishers had to apply for a license, which was only awarded to those with a proven record in the fishery (Anon. 2000). Various license conditions were implemented and these included keeping detailed harvest logbooks, participating in biological sampling, using environmentally benign irritants, and adhering to closed fishing areas and seasonal closures (Anon. 2000).

California

Octopuses have been harvested in California since 1916. Originally most of the catches were incidental, except during 1930 – 1950 when an octopus trap fishery, using cone-shaped wicker baskets deployed at depths of 6 - 9 m, existed in the Monterey Bay area (Duffy 1997). Japanese, Chinese, Greek and Italian communities were the main consumers of octopus in this area. Landings were variable and ranged from 75 297 kg during 1924 to 453 kg in 1960, increasing again to 58 968 kg in 1980 (Duffy 1997). There are currently no regulations in place regarding octopus exploitation off the Californian coast.

Experimental fisheries

The potential for small-scale octopus fisheries have been investigated on an experimental basis in several regions worldwide, including Alaska, Canada, California, South Carolina and Florida.

Alaska

An octopus-directed pot fishery, targeting *Octopus dofleini*, was initiated in 1983 in southeast Alaska. All octopuses caught prior to 1982 were bycatch in the crab and shrimp fisheries (Paust 1997). The experimental fishery for *O. dofleini* consisted of three phases during which different gear types and fishing areas were tested. The gear types used in the experiment were wooden slat pots, ceramic and plastic pots, and PVC (polyvinyl chloride) pipe pots, and these were tested in both shallow inshore (<12.5 m) and offshore waters. The inshore areas were the least productive, with a catch efficiency of 1 - 4% (soak time 7 days). The offshore areas were more productive, and a CPUE of 30% was recorded using wooden slat pots during autumn and winter.

Canada

There have been various experimental fisheries using traps for *Octopus dofleini* in British Columbia, Canada (Gillespie et al. 1998). Adkins et al. (1980) tested wooden boxes, half-tyre pots, paint- and oilcans, and crab and prawn traps. Although 1 432 baited traps were deployed between depths of 7 and 66 m, only nine octopuses were caught. Hartwick et al. (1982) set trap lines inshore (6 - 19 m) and offshore (37, 55, 73 & 91 m) on the west coast of Vancouver. Optimal soak time was found to be 10 - 12 days, with wooden boxes and tyres the most effective. Inshore traps caught small animals (6 kg) at a CPUE of 0.03 kg/trap, with trap efficiency averaging 0.77% and peaking at 2.06 % during June. The offshore trapping was more productive at 6.56%, catching larger octopus (11 kg) at a higher CPUE of 0.46 kg/trap. Traps were more efficient during winter in deep offshore waters, and were ineffective in shallower areas where there is an abundance of natural dens.

Clayton et al. (1992) conducted another experimental trap fishery near Prince Rupert. Gear types tested were wooden boxes, ceramic eel traps and baited prawn mesh traps. Trapping efficiency was highest for prawn traps (23%) and wooden boxes (17%) and lowest (1%) for eel traps. Mean octopus size was larger in wooden boxes (11 kg) than in prawn traps (4.5 kg). However, the traps were tested on different bottom types at different times, and could therefore not be properly compared. Trap fishing was not considered a viable option and there is no significant octopus-directed trap fishery in Canada at present (Gillespie et al. 1998).

California

A small-scale octopus fishery on the Ventura - Santa Barbara coast in southern California was investigated as a supplemental fishery to existing crab and lobster fisheries (Rasmussen 1997). Octopus (*O. californicus* and *O. rubescens*) was a bycatch in halibut gill nets and hagfish traps. *O. californicus* and *O. rubescens* were mainly caught for human consumption. Various gear types were tested including hagfish traps (plastic, cylindrical), spruce boxes of various sizes, baited and unbaited traps, and four-inch pipes. Fishing took place on both hard and sandy/muddy bottom, at depths of 10 to 50 m. Pots were alternately placed on a longline (82 m) at 2.7 m intervals, with a surface buoy and anchor at each end. Each vessel deployed three lines, which were retrieved by a gillnet reel. Soak time was 24, 48 and 96 hours, respectively. Catch rates were found to vary with bottom structure. Pots on hard bottom were most successful, with one octopus caught in every six pots, compared to pots on muddy bottoms, which had a low catch rate of one octopus per 70 pots.

South Carolina

Research into the fishery potential of *O. vulgaris* was undertaken during 1984 - 1986 in the South Carolina area (Whitaker et al. 1991). Fishing occurred between 11 and 30 km offshore at a depth of 12 to 25 m, on hard bottom, low-profile reefs. Fishing gear consisted of double PVC pipe pots and single half-tire pots. The PVC pipe pots were plugged at one end and had diameters of 15.2 cm and 10.2 cm. The longline consisted of 15 pots comprising five of each pot type and placed 9 m apart. The line was anchored and had a surface buoy at each end. Each vessel had three longlines, which were retrieved by a hydraulic winch. Soak times varied between 6 - 10, 11 - 15 and 16 - 20 days.

No significant difference in catch rates among gear types was found. Soak time required for a catch rate per line of 60% was 6 - 10 days. The average catch rate was 27.8%, but catches decreased in the second year. The catch rates were highest in summer and autumn, and the largest octopuses were caught during late autumn and winter. The average size of octopuses caught was 0.90 kg, with larger diameter gear catching larger individuals. Small pots were most effective during summer when small octopuses were present, whereas larger pots were more effective during winter. Neither the leaching of cement plugs nor the colour of the pots seemed to deter octopuses from the pots, which were fouled within two weeks. Although the potential for a seasonal fishery during summer/autumn was identified, low prices attained for octopuses would have made this fishery only marginally profitable.

Florida

During the 1980s, an experimental fishery was conducted for *O. vulgaris* on the west coast of Florida, where it is caught as a pest bycatch species in the stone crab trap fishery (Roper 1997). The fishing gear consisted of double PVC pipe pots with a concrete plug in the middle, double PVC pipe pots closed at one end, and single tyre pots. The pots were alternately placed at 7.8 m intervals on a 625 m longline, with 60 pots per line. Soak times were 24, 48 and 96 hours, with a 10 day leaching time for all pots before fishing started. Two parallel lines were deployed at a depth of 3 m and then gradually moved deeper (7.8, 10.9, 18.8, 28 m). CPUE in terms of number of octopuses per pot ranged between 45 and 90%.

Fishing occurred between 1984 and 1985. Commercial fishermen running the experiment demonstrated little commitment and lost gear, and as a result no reliable data were obtained. The local market was also not strong enough to sustain an octopus fishery, and a commercial fishery never took place.

South Africa

The potential for a small-scale octopus fishery in South Africa was reviewed by Smith (1999). He assessed fishing methods, gear and markets, and recommended that a pot fishery would be the best suited for development in South Africa. This type of fishery could be operated in conjunction with existing fisheries such as the linefishery, rock lobster and abalone fisheries, because similar vessels (3-5 ton size) could be used. The fishing method would involve pots on longlines, as used in South Carolina (Whitaker et al. 1991), and Florida (Roper 1997). The pots would comprise PVC pipes (two diameters, single and double), and half-tire pots. Further recommendations were for the use of small vessels (less than 5 tons) operated by two people, with a hydraulic line-hauler used to deploy and retrieve pot lines. Much experimentation would be needed to determine the optimal fishing areas, pot types, soak times and depth. There is, however, no local demand for octopus so all catches would have to be exported (Smith 1999).

Synthesis and identified information gaps

It is evident that octopus fisheries are highly diverse and can be successful on both small and large scales. Even small-scale fisheries such as those found in Mexico and Chile are worth millions of USD in revenue (Solís-Ramírez 1997; Defeo & Castilla 1998). Nonetheless, there are various factors that influence the revenue of octopus fisheries and these include environmental (red tides, climatic events), anthropogenic (cholera epidemics), and market-related (stockpiling, demand) factors.

It is also apparent that establishing a new fishery is not straightforward and that many factors need to be considered during an experimental fishery. Most important is the competence of fishers, since productive pot fishing is highly dependent on the gear type used and the area being fished (Gillespie et al. 1998). Furthermore, a successful experimental fishing project would allow for diversification between fisheries, easing competition between fishers and relieving pressure on other resources. Specific information required on fisheries and economics in order to ensure successful and sustainable development, and its availability in both international and South African literature, are listed in Tables 3 & 4.

Table 3. Basic **fisheries information** required for sustainable development and management. Shaded areas indicate gaps in South African information. References are shown in superscript.

Fisheries information (Pot fisheries)				
Required	**Available Internationally**	**Available South Africa**	**Notes**	**Reference**
Fishery description	Yes [1, 2, 7]	*Yes [8]	*Theoretical, not implemented	[1]Guerra 1997
Fishing techniques	Yes [1-7]	*Yes [8]		[2]Whitaker et al. 1991
Vessel and gear type	Yes [1-7]	*Yes [8]		[3]Gillespie et al. 1998
Gear selectivity and efficiency	Yes [9]	**No**	Highly selective	[4]Paust 1997 [5]Rasmussen 1997
Catch rates	Yes [1-4, 6, 7]	**No**	Low	[6]Roper 1997
Environmental impacts	Yes [9]	**No**	Low	[7]Sanchez & Obarti 1993 [8]Smith 1999 [9]Bjordal 2002

Table 4. Basic **economic information** required for sustainable development and management of a fishery. Shaded areas indicate gaps in South African information. References are shown in superscript.

Economic information				
Required	**Internationally**	**South Africa**	**Notes**	**Reference**
Market demand	Known [1]	No demand [2]	High market demand	[1]Guerra 1997
Potential economic value of species	Known [1, 3, 4]	Known [2]	High, potential "cold rush" fishery	[2]Smith 1999 [3]Solís-Ramírez 1997
Expected catch rates	Known [Table 3:1-4, 6, 7]	Unknown	Low and variable	[4]Defeo & Castilla 1998
Cost of fishing	Not available	Unknown		
Profitability	Known [3, 4]	Unknown	High	

MANAGEMENT AND ASSESSMENT OF OCTOPUS FISHERIES

In managing cephalopod fisheries, it becomes imperative to learn from past experiences with finfish overexploitation (Lipiński et al. 1998a). It is important to balance the objectives of maximizing catch and minimizing the risk of depleting the resource. This has been done fairly successfully for various squid fisheries (Broziak & Macy 1996; Basson et al. 1996). However, little information is available on active assessment and management of octopus fisheries. Furthermore, Caddy (1983) suggested that both long-term and short-term measures are important in the management of cephalopod stocks. Some input and output management measures that have been implemented in cephalopod fisheries are discussed below.

Input controls

Most octopus fisheries are managed by input controls such as size limits, closed areas and closed seasons, and effort limitation (Caddy 1983; FAO 1997; Solís-Ramírez 1997). The main advantage of input controls is time- and cost-efficiency, because the need for short-term decision-making is reduced and exact knowledge of stock size is not required (Caddy 1983).

Size limitation

Size limitation has been implemented in Mexico, Hawaii and Senegal (Solís-Ramírez 1997; Young & Harman 1997; Caverivière et al. 2002). In pot fisheries, large-diameter pots have been shown to catch larger octopuses and vice versa (Whitaker et al. 1991). Setting a minimum or maximum pot size can thus effect size selection of octopus. Size selection for octopuses has also been achieved in trawling, by means of size-selective nets (Fonseca et al. 2002). This method is an easy and effective way to protect specific stages of a life cycle. Octopuses are hardy animals that survive well after capture and release if undersized animals were caught (Robinson & Hartwick 1986; Domain et al. 2000).

Time- and area closures

There are several advantages (Hall 2002) to time- and area closures and these include:

- Conceptual simplicity
- Stock protection
- Habitat protection
- Insurance against uncertainty.

Spatial and temporal variability is important in selecting closed areas and the timing of closed seasons. In terms of biology of the species, information on growth, reproduction and spatial patterns are needed. Life stages that may be vulnerable to fishing must also be identified (Gillespie et al. 1998). Closed areas must be large enough to protect the stock from collapsing in the event of overfishing (Hall 2002). They must therefore encompass different habitat types needed during the life cycle and also take migration into consideration (Lipiński et al. 1998a).

Closed seasons / time restrictions: Closed seasons are used in stock maintenance and recovery (Caddy 1983; FAO 1997) and have proved an efficient measure in some fisheries (FAO 1997). Closed seasons can be an effective management tool for species that have peak spawning aggregations and seasons, but *O. vulgaris* spawns throughout the year (Wodinsky 1972) and does not form spawning aggregations. Nevertheless octopuses are generally protected from fishing while brooding as they spawn eggs in a den or cave and do not forage during this period.

Closed areas: Areas such as no-fishing zones in inshore regions and Marine Protected Areas (MPAs) can be used in stock management to protect spawning stock to seed adjacent areas. A closed season and area in Morocco, instituted to protect juvenile cephalopods, has proven efficient in increasing catch rates (FAO 1997).

Restrictive licensing / limited licences

Limitations on vessel or licence numbers should be employed to control the increase in both access to the fishery and fishing capacity (fishing power) (Pope 2002). It is important that the licence conditions include restrictions on the vessel size, engine size or power, and on other technological advancements that might improve fishing capacity of the vessel or fleet (Pope 2002). If this is not done, effort levels will increase even though fleet size or licence numbers are kept constant. Information on the implementation of these restrictive measures is unavailable for octopus fisheries.

Gear limitation

Gear use can be limited in two ways, by specifying the type of gear (trawling, pots, hook and line, nets) or the number of gear allowed for use (i.e. number of pots or longlines). Ideally, fishing gear should adhere to the following (Bjordal 2002):

- Be highly selective for target species and size, with little or no impact on the habitat and other species
- Give high catch rates at the lowest cost
- Produce high-quality catches.

By restricting gear use to a particular type while limiting the number of gear allowed, effort can be reduced. Furthermore, by restricting gear to that with least impact on other species and the environment, environmentally friendly fishing can be accomplished. Gear-type restrictions have been implemented in some octopus fisheries (Solís-Ramírez 1997; Hartwick & Barriga 1997).

Output controls

Quota (catch controls)

Catch restrictions generally take the form of a total allowable catch (TAC), but can also include bag limits (normally for recreational fisheries). Quotas or TACs are generally set in terms of the number of tons allowed to be caught (Pope 2002), and information regarding stock size is needed in order to determine them. This information, which includes data such as habitat and population density estimates, is generally difficult to acquire (Pope 2002, Gillespie et al. 1998). The applicability of general finfish assessment models to cephalopods is highly disputed (Forsythe & van Huekelem 1987; Jackson et al. 1997; Lipiński et al. 1998a; Pauly 1998), so quotas are thought to be high-risk management options for cephalopods.

Other management measures

Short-term management measures may include temporary permits and variable timing of harvesting seasons (Caddy 1983). During periods of high biomass a number of temporary permits may be issued, while the harvesting season can be timed to deal with natural and anthropogenic influences. As an example, when a red tide event caused mass emigration and mortality of marine life in Mexico in 2001, harvesting was halted for a number of fisheries (FIS Latino 2001).

Assessment

There is a paucity of information on active fishery assessment methods used in cephalopod fisheries. In small-scale fisheries the stock state is generally assessed by monitoring catch rates, octopus size and effort levels, as in the Mexican fishery (FAO 1997; Solís-Ramírez 1997). Information on active stock assessment is only available for large octopus fisheries off Mauritania and Senegal (Demarcq & Faure 2000; Caverivière et al. 2002). These fisheries use environmental indicators to predict recruitment and future stock size. A strong link between upwelling intensity, retention processes and larval recruitment exists in this fishery (Demarcq & Faure 2000; Caverivière et al. 2002), with the recruitment success of *Octopus vulgaris* being largely dependent upon the seasonality and intensity of local upwelling.

The northwest African trawl fishery employs a combination of measures in the assessment of octopus and other cephalopod stocks. Catch rates were monitored and a recruitment index calculated by assessing the smallest size class caught. These data were combined with results from annual trawl surveys to provide indices of abundance and biomass (Bravo de Laguna (1989), in Gillespie et al. 1998). Production models were then used to estimate yield.

Various regulatory measures implemented in octopus fisheries worldwide are indicated in Table 5. Management measures, their implementation, operating costs, information needs and risks are summarized in Table 6 (Perry et al 1999).

Table 5. Management **measures implemented** in various octopus fisheries. References are shown in superscript.

Management measures	Octopus Fishery	Effectiveness of measure	Reference
Input control			
Size limit	Senegal[1]	Effective	[1]Caverivière et al. 2002
	Mexico[2]	Unknown	[2]Solís-Ramírez 1997
	Portugal[3]	Not effective	[3]Fonseca et al. 2002
Closed area	Canada[4]	Unknown	[4]Gillespie et al. 1998
	Morocco[5]	Effective	[5]FAO 1997
Closed season	Senegal[1]	[2, 4, 6] Unknown	[6]Defeo & Castilla 1998
	Mexico[2]	[1, 5]Effective	[7]Hartwick & Barriga 1997
	Chile[6]		[8]Anon 2001
	Canada[4]		
	Morocco[5]		
Restrictive licences	-	-	
Gear limitation	Mexico[2]	Unknown	
	Canada[7]		
Output control			
Quota	Morrocco[8]	Unknown	
Assessment measures			
Catch rate, size classes, effort levels	Mexico[2]	Unknown	
Stock size	Senegal[1]	Reasonable	
	Mauritania[1]		

Table 6. Management **measures** and potential **associated** costs, information **needs** and risks (Perry et al. 1999). References are shown in superscript.

Management measure	Implementation choices	Industry operating costs	Assessment information requirements	Risks
Size limits	Size limits	Minimal	Age at first reproduction, yield per recruit	Missed fishing opportunities
Effort controls	Effort limits	Low, stable	CPUE	Overfishing due to increase in catchability at low stock size
	Time/area closures	Highest	Dispersal and migration	Missed fishing opportunities
TAC/quota	Biomass from surveys	Minimal	Surveys	Missed fishing opportunities, or depensatory effects
	Biomass from production modelling	Low, variable	CPUE, catches, analysis	Overfishing due to hyperstability in CPUE index
	Biomass from removal experiments	Low, variable	Depletion fishing	Overfishing due to variance in estimates

Synthesis and identified information gaps

In the management and assessment of cephalopods, it is important to take a life cycle approach. Cephalopods have only one year-class, in contrast to finfish that have multi year-classes. They therefore use spatial distribution strategies to ensure survival (Lipiński et al. 1998a). Spatial variability is thus a major factor to consider during management.

Possible management measures to be implemented in the South African octopus pot fishery are limited licences, limitation on the type and number of pots to be used, minimum size limits and closed areas through existing MPAs.

REFERENCES

ADKINS B.E., GEE P.A. and BREEN P.A. 1980. Experimental octopus trap fishing in Barkley Sound, February-March 1997. *Fisheries and Marine Services Management Report* **1548**. 23 pp.

ANON. 2000. Octopus by dive: 2000 Experimental Harvest Guidelines. Canada, Fisheries and Oceans Canada. 15 pp.

ANON 2001. Fish Information and Services. Market reports. *Octopus vulgaris* (Morocco). May 2001. Retrieved May 2001 from: http://fis.com/fis/reports/reports.asp?1=e&specie=256&date=5/15/2001.

BALGUERÍAS E., QUINTERO M.E. and HERNÁNDEZ-GONZÁLEZ C. 2000. The origin of the Saharan Bank cephalopod fishery. *ICES J. Mar. Sci.* **57**: 15-23.

BAS C., MORALES E. and SAN FELIU M.J. 1970. Pesquerias de cefalopodos en el banco sahariano. *Publ. Tecn. Jun. Est. Pesca.* **9**.

BASSON M., BEDDINGTON J.R., CROMBIE J.A., HOLDEN S.J., PURCHASE L.V. and TINGLEY G.A. 1996. Assessment and management techniques for migratory annual squid stocks: the *Illex argentinus* fishery in the Southwest Atlantic as an example. *Fish. Res.***8**: 351-365.

BJORDAL A. 2002. The use of technical measures in responsible fisheries: regulation of fishing gear. In: A fishery manager's guidebook. Management measures and their application. Chapter 2. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 21-47.

BOLETZKY S. VON. 1968. Studies on the organogenesis of the circulatory system in *Octopus vulgaris* Lam. *Rev. Suisse Zool.* **75(4)**: 765-812.

BOLETZKY S. VON. 1969. Zum Vergleich der Ontogenesen von *Octopus vulgaris, O. joubini* und *O. briareus*. *Rev. Suisse Zool*. **76**: 716-726.

BORER K.T. 1971. Control of food intake in *Octopus briareas* Robson. *J. Comp. Physiol. Psych.* **75**(2): 171-185.

BOYCOTT B.B. and YOUNG J.Z. 1955. Memories controlling attacks on food objects by *Octopus vulgaris* Lamarck. *Pubbl. Staz. Zool., Napoli*. **27**: 232-249.

BOYLE P.R. and BOLETZKY S.V. 1996. Cephalopod populations: definition and dynamics. *Phil. Trans. R. Soc. Lond. B*. **35**: 1985-1002.

BROZIAK J.K.T. and MACY W.K. 1996. Growth of longfinned squid, *Loligo pealei*, in the northwest Atlantic. *Fish. Bull.* **94**: 212-236.

CADDY J.F. 1983. The cephalopods: Factors relevant to their population dynamics and to the assessment and management of stocks. *FAO Fish. Tech. Pap.* **231**. FAO, Rome. 416-452.

CADDY J.F. and RODHOUSE P.G. 1998. Cephalopod and groundfish landings: evidence for ecological change in global fisheries? *Rev. Fish Biol. Fish*. **8**: 431-444.

CAVERIVIÈRE A. 1990. Etude de la pêche du poulpe (*Octopus vulgaris*) dans les eaux côtières de la Gambie et du Sénégal. L'explosion démographique de l'été 1986. *Cent. Rech. Océanogr, Dakar-Thiaroye, Doc. Scient.* **116**. 42 pp.

CAVERIVIÈRE A. 1994. Le poulpe (*Octopus vulgaris*) au Sénégal: une nouvelle resource. In *L'évaluation des resources exploitables par la pêche artisanale sénégalaise*. (Ed M. Barry-Gérard, T. Diouf, & A.Fonteneau). Orstrom col. Colloques et séminaries, Paris. **2**: 245-256.

CAVERIVIÈRE, A., THIAM M. and JOUFFRE D. 2002. *Le pouple* Octopus vulgaris *Senegal et cotes nord-ouest africaines*. Paris: IRD Editions. pp 385.

CLARKE M.R. 1983. Cephalopod biomass-estimation from predation. *Mem. Natl. Mus. Victoria.* **44**: 95-107

CLARKE M.R. 1996. The role of cephalopods in the world's oceans. *Phil. Trans. R. Soc. Lond. B.* **351**: 979-1112.

CLAYTON W.E.L., BROADLEY T.A. and SUTHERLAND I.R. 1992. The evaluation of a productive and cost effective trap for the harvesting of the giant Pacific octopus (*Octopus dolfeini*). IEC Collaborative Marine Research and Development, Victoria, British Columbia. 23 pp.

DAWE E.G., O'DOR R.K., ODENSE P.H. and HURLEY G.V. 1985. Validation and application of an ageing technique for short-finned squid (*Illex illecebrocus*). *J. Northw. Atl. Fish. Sci*. **6**: 107-116.

DE LOS ANGELES BARRIGA SOSA I., BECKENBACH K., HARTWICK E.B. and SMITH M.J. 1995. The molecular phylogeny of five eastern North Pacific octopus species. *Molec. Phylogenet. Evol.* **4**: 163-174.

DEFEO O. and CASTILLA J.C. 1998. Harvesting and economic patterns in the artisanal *Octopus mimus* (Cephalopoda) fishery in a northern Chile cove. *Fish. Res.* **38**: 121-130.

DEMARCQ H. and FAURE V. 2000. Coastal upwelling and associated retention indices derived from satellite SST. Application to *Octopus vulgaris* recruitment. *Ocean. Acta*. **23**: 391-408.

DÈME M., DIALLO M., GUEYE B. and SALL A. 1997. Présentation des pêcheries nationals: cas du Sénégal. Gestion durable des resources halieutiques, *Projet européen Inco.* 22 p.

DIALLO M. and ORTIZ M. 2002. Estimation of a standardized index of abundance of octopus (*O. vulgaris*) from the Senegalese's artisanal fishery (1989-1994). In *Le pouple* Octopus vulgaris *Sénégal et cotes nord-ouest africaines*. (Ed. A. Caveriviere, M. Thiam & D. Jouffre). IRD Editions, Paris. p 223-232.

DOMAIN F., JOUFRE D. and CAVERIVIÈRE A. 2000. Growth of *Octopus vulgaris* from tagging in Senegalese waters. *J. Mar. Biol. Ass. U.K.* **80**: 699-705.

DUFFY J.M. 1997. California octopus fishery: Brief overview with notes on current harvest regulations. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 67-74.

FAO. 1997. Review of the state of world fishery resources: Marine fisheries. *FAO Fisheries Circular* **920**. FAO, Rome. 169 pp.

FIS LATINO. 2001. Fish Information and Services. World news. Red tide wreaks havoc. (August 2001). Retrieved October 2001 from: http://fis.com/fis/worldnews/worldnews. asp?1=e&special=search&id=19777.

FONSECA P., CAMPOS A. and GARCIA A. 2002. Bottom trawl codend selectivity for cephalopods in Portuguese continental waters. *Fish. Res.* **59**: 263-271.

FORSYTHE J.W. 1984. *Octopus joubini* (Mollusca: Cephalopoda): A detailed study of growth through the full life cycle in a closed seawater system. *J. Zool. Lond.* **202**: 393-417.

FORSYTHE R.W. and VAN HEUKELEM W.F. 1987. Growth. In: *Cephalopod life cycles*, Vol. 2 (Ed. P.R. Boyle). Academic Press, London. p 135–156.

GARCIA CABRERA R.C. 1968. Biologia y pesca del pulpo (*Octopus vulgaris*) y choco (*Sepia officianalis*) en agues del Sahara español. *Publ. Tecn. Jun. Est. Pesca.* **7.**

GILLESPIE G.E., PARKER G. and MORRISON J. 1998. A review of octopus fisheries biology and British Columbia octopus fisheries. *Canadian Stock Assessment Secretariat Research Document* **98/87**. Fisheries and Oceans Canada. 66 pp.

GUERRA A. 1979. Fitting a von Bertalanffy expression to *Octopus vulgaris* growth. *Inst. Invest. Pesq. Spain*. **43**: 319–326.

GUERRA A. 1981. Spatial distribution pattern of *Octopus vulgaris*. *J. Zool. Lond.* **195**: 133-146.

GUERRA A. 1997. *Octopus vulgaris*: Review of the world fisheries. 1989. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 91-97.

HALL S. 2002. The use of technical measures in responsible fisheries: area and time restrictions. In: A fishery manager's guidebook. Management measures and their application. Chapter 3. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 49-74.

HARTWICK E.B. and BARRIGA I. 1997. *Octopus dofleini*: Biology and fisheries in Canada. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 45-56.

HARTWICK E.B., TROTTER D.W.M and WALSH M. 1982. An experimental trap fishery operation for octopuses. Contract report to Dept. Fisheries Oceans, Canada. July 1982.

HARTWICK E.B., ROBINSON S.M.C., AMBROSE R.F., TROTTER D.W.M and WALSH M. 1988. Inshore-offshore comparison of *Octopus dofleini* with special reference to abundance, growth and physical condition during winter. *Malacol*. **29**: 57-68.

HATANAKA H. 1979. Studies on the fisheries biology of common octopus off the northwest coast of Africa. *Bull. Far Seas Fish. Res. Lab* **17**: 13-124.

HERNÁNDEZ-GARCÍA V., HERNÁNDEZ-LÓPEZ J.L. and CASTRO J.J. 1998. The octopus (*Octopus vulgaris*) in the small-scale trap fishery off the Canary Islands (Central-East Atlantic). *Fish. Res.* **35**: 183-189.

HERNÁNDEZ-LÓPEZ J.L., CASTRO-HERNÁNDEZ J.J. and HERNÁNDEZ-GARCÍA V. 2001. Age determined from the daily deposition of concentric rings on common octopus (*Octopus vulgaris*) beaks. *Fish. Bull.* **99**: 679-684.

HUDELOT C. 2000. Octopods molecular phylogeny. CIAC 2000: Cephalopod biomass and production. Abstracts. July 3-7, 2000. University of Aberdeen, Aberdeen, Scotland. p 93.

ITAMI K., IZAWA Y., MEADA S. and NAKANOSE T. 1963. Notes on the laboratory culture of octopus larvae. *Bull. Jap. Soc. Sci. Fish.* **29**: 514-520.

JACKSON G.D. 1994. Application and future potential of statolith increment analysis in squids and sepioids. *Can. J. Fish. Aquat. Sci.* **51**: 2612-2625.

JACKSON G.D., ALFORD R.A. and CHOAT J.H. 2000. Can length frequency analysis be used to determine squid growth? – An assessment of ELEFAN. *ICES J. Mar. Sci.* **57**: 948-954.

JACKSON G.D., FORSYTHE J.W., HIXON R.F. and HANLON R.T. 1997. Age, growth, and maturation of *Lolliguncula brevis* (Cephalopoda: Loliginidae) in the northwestern Gulf of Mexico with a comparison of length-frequency versus statolith age analysis. *Can. J. Fish. Aquat. Sci.* **54**: 2907-2919.

KLAGES N.T.W. 1996. Cephalopods as prey. 2. Seals. *Phil. Trans. R. Soc. Lond. B.* **351**: 1045-1052.

LIPIŃSKI, M.R., BUTTERWORTH D.S., AUGUSTYN C.J., BRODZIAK J.K.T., CHRISTY G., DES CLERS S., JACKSON G.D., O'DOR R.K., PAULY D., PURCHASE L.V., ROBERTS M.J., ROEL B.A., SAKURAI Y., and SAUER W.H.H. 1998a. Cephalopod fisheries: a future global upside to past overexploitation of living marine resources? Results of an international workshop, 31 August-2 September 1997, Cape Town, South Africa. *S .Afr. J. mar. Sci.* **20**: 463-469.

LIPIŃSKI M.R., DURHOLTZ M.D. and UNDERHILL L.G. 1998b. Field validation of age readings from the statoliths of chokka squid (*Loligo vulgaris reynaudii* d'Orbigny, 1845) and an assessment of associated errors. *ICES J. Mar. Sci*. **55**: 240-257.

MANGOLD K. 1983. *Octopus vulgaris*. In: *Cephalopod life cycles*. Vol. 1. Boyle, P.R. (Ed.) London, Academic Press. p 335-364.

MANGOLD K. 1997. *Octopus vulgaris*: Review of the biology. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. 85-90.

MANGOLD K. and BOLETZKY S.V. 1973. New data on reproductive biology and growth of *Octopus vulgaris*. *Mar. Biol.* **19**: 7–12.

MANGOLD K. and HOCHBERG F.G. 1991. Defining the genus *Octopus*: redescription of *Octopus vulgaris*. *Bull. Mar. Sci.* **49**: 665 pp.

MANGOLD-WIRZ K. 1963. Biologie des céphalopodes benthiques et nectoniques de la Mer Catalane. *Vie et Milieu* **13** (suppl.): 285 pp.

MATHER J.A. and O'DOR R.K. 1991. Foraging strategies and predation risk shape the natural history of juvenile *Octopus vulgaris. Bull. Mar. Sci.* **49**(1/2): 256-269.

MCQUAID C.D. 1994. Feeding behaviour and selection of bivalve prey by *Octopus vulgaris* Cuvier. *J. Exp. Mar. Biol. Ecol.* **177**: 187–202.

NEAF A. 1923. Die cephalopoden. *Fauna Flora Golf Neapal* **35A**(1): 149-863.

NEAF A. 1928. Die cephalopoden. *Fauna Flora Golf Neapal* **35B**(2): 1-375.

NESIS K.L. 1987. *Cephalopods of the world. Squids, cuttlefishes, octopuses and allies*. TFH Publications, New Jersey.

NIGMATULLIN, C.M., & OSTAPENKO, A.A., 1976. Feeding of *Octopus vulgaris* Lam. from the northwest Africa coast. *International Council for the Exploration of the Seas* **CM1976/K**. 15 pp.

NIXON M. 1969. The lifespan of *Octopus vulgaris*. *Proc. Malac. Soc. Lond*. **38**: 529-540.

NIXON M. 1971 Some parameters of growth in *Octopus vulgaris*. *J. Zool. Lond.* **163**: 277-284.

PAULY D. 1998. Why squid, though not fish, may be better understood by pretending they are. *S. Afr. J. mar. Sci.* **20**: 47-58.

PAUST B.C. 1997. Octopus marketing aspects with attention to the development of domestic (North American) food markets. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 135-139.

PERRY R., WALTERS C. and BOUTILLIER J. 1999. A framework for providing scientific advice for the management of new and developing invertebrate fisheries. *Rev. Fish Biol. Fish*. **9**: 125-150.

POPE J. 2002. Input and Output controls: the practice of fishing effort and catch management in responsible fisheries. In: A fishery manager’s guidebook. Management measures and their application. Chapter 4. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 75-93.

QUETGLAS A., ALEMANY F., CARBONELL A., MERELLA P. and SÁNCHEZ P. 1998. Biology and fishery of *Octopus vulgaris* Cuvier, 1797, caught by trawlers in Mallorca (Balearic Sea, Western Mediterranean). *Fish. Res.* **38**: 237-249.

RASMUSSEN A. 1997. Octopus, a fishermen's perspective. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 151-155.

RATHJEN W.F. and VOSS G.L. 1987. The cephalopod fisheries: a review. In: *Cephalopod Life Cycles*. Vol. 2. Boyle, P.R. (Ed.) New York, Academic Press. p 253-275.

RAYA C. and HERNÁNDEZ-GONZÁLEZ C. 1998. Growth lines within the beak micristructure of the octopus *Octopus vulgaris* Cuvier, 1797. *S. Afr. J. mar. Sci*. **20**: 135-142.

ROBINSON S. and HARTWICK E.B. 1986. Analysis of growth based on tag-recapture of the Giant Pacific octopus *Octopus dofleini martini. J. Zool. Lond*. **209**: 559-572.

ROBERTSON W.D. and FIELDING P.J. 1997. Transkei coastal fisheries resources. Phase 2: Resource utilization, development and tourism. *Oceanographic Research Institute Investigational Report* **4**. Oceanographic Research Institute, Durban.

ROELEVELD M.A.C. 1998. The status and importance of cephalopod systematics in southern Africa. *S. Afr. J. mar. Sci.* **20**:1-16.

ROPER C.F.E. 1997. Experimental Octopus Fisheries: Two Cases Studies. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 157-168.

ROPER C.F.E. and MANGOLD K.M. 1991. *Octopus schultzei* (Hoyle, 1910): A redescription with designation of *Afrodoctopus* new genus (Cephalopoda; Octopodinae). *Bull. Mar. Sci.* **49**(1-2): 57-72.

ROPER C.F.E. and VOSS G.L. 1983. Guidelines for taxonomic descriptions of cephalopod species. *Mem. natn. Mus. Victoria*. **44**: 49-63.

ROPER C.F.E., SWEENEY M.J. and NAUEN C.E. 1984. F.A.O. species catalogue. *Cephalopods of the world*. An annotated and illustrated catalogue of species of interest to fisheries. *F.A.O. Fish. Synop.* **125**(3): 277pp.

SÁNCHEZ P. and OBARTI R. 1993. The biology and fishery of *Octopus vulgaris* caught with clay pots on the Spanish Mediterranean coast. In: *Recent advances in fisheries biology*. Okutani, T., O'Dor, R.K. and Kubodera, T. (Eds.). Tokyo, Tokai University Press. p 477-487.

SATO T. and HATANAKA H. 1983. A review of the aessesment of Japanese distant-water fisheries for cephalopoda. *FAO Fisheries Technical Paper* **231**. FAO, Rome. 148-180.

SATOR P., BELCARI P., CARBONELL A., GONZALEZ M., QUETGLAS A. and SÁNCHEZ P. 1998. The importance of cephalopods to trawl fisheries in the western Mediterranean. *S. Afr. J. mar. Sci.* **20**: 67-72.

SMALE M.J. 1996. Cephalopods as prey. IV. Fishes. *Phil. Trans. R. Soc. Lond. B.* **351**: 1067-1081.

SMALE M.J. and BUCHAN P.R. 1981. Biology of *Octopus vulgaris* off the east coast of South Africa. *Mar. Biol.* **65**: 1-12.

SMALE M.J., CLARKE M.R., KLAGES N.T.W. and ROELEVELD, M.A.C. 1993. Octopod beak identification - Resolution at a regional level (Cephalopoda, Octopoda: South Africa). *S. Afr. J. mar. Sci.* **13**: 269-293.

SMITH C.D. 1999. Population biology and ecology of octopus in the southwestern Cape: A study towards the establishment of a small-scale octopus fishery. University of Cape Town. M.Sc. Thesis. 111 pp.

SMITH C.D. and GRIFFITHS C.L. 2002. Aspects of the population biology of *Octopus vulgaris* in False Bay, South Africa. *S. Afr. J. mar. Sci.* **24**: 185–192.

SOLÍS-RAMÍREZ M. 1997. *Octopus maya*: Biology and fishery in Mexico. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 105-113.

SÖLLER R., WARNKE K., SAINT-PAUL U. and BLOHM D. 2000. Sequence divergence of mitochondrial DNA indicates cryptic biodiversity in *Octopus vulgaris* and supports the taxonomic distinctiveness of *Octopus mimus* (Cephalopoda: Octopodidae). *Mar. Biol*. **136**: 29-35. *Bull. Mar. Sci.* **71(2)**: 1099–1103.

SOUSA REIS C. and FERNANDES R. 2003. Growth observations on Octopus vulgaris cuvier, 1797 from the Portuguese waters: growth lines in the vestigial shell as possible tools for age determination.

TAKEDA R. 1990. Octopus resources. *Mar. Behav. Physiol*. **18**: 111-148.

VAN HEUKELEM W.F. 1976. Growth, bioenergetics and lifespan of *Octopus cyanea* and *Octopus maya*. Ph.D. Dissertation, University of Hawaii. 224 pp.

VILLANUEVA R. 1993. Diet and mandibular growth *Octopus magnificus* (Cephalopoda). *S. Afr. J. mar. Sci*. **13**: 121-126.

VILLANUEVA R. 1995. Experimental rearing and growth of planktonic *Octopus vulgaris* from hatching to settlement. *Can. J. Fish. Aquat. Sci*. **52**: 2639-2650.

VILLANUEVA R., SÁNCHEZ P. and COMPAGNO-ROELEVELD M.A. 1991. *Octopus magnificus* (Cephalopoda: Octopodidae), a new species of large octopod from the Southeastern Atlantic. *Bull. Mar. Sci.* **49**(1/2): 39-56.

VOSS G.L. 1977. Present status and new trends in cephalopod systematics. *Symp. Zool. Soc. Lond.* **38**: 49-60.

VOSS G.L. 1988. White sails, cayucos and pulpos. Octopus fishing in the Yucatan. *Sea Front.* **34**: 348-353.

WARNKE K., SOLLER R., BLOHM D. and SAINT-PAUL U. 2000. Rapid differentiation between *Octopus vulgaris* Cuvier (1797) and *Octopus mimus* Gould (1852), using randomly amplified DNA. *J. Zool. Syst. Evol. Res*. **38**: 119-122.

WELLS M.J. 1978. *Octopus. Physiology and behaviour of an advanced invertebrate*. Chapman and Hall, London. 417 pp.

WHITAKER J.D., DELANCY L.B. and JENKINS J.E. 1991. Aspects of the biology and fishery potential for O*ctopus vulgaris* off the coast of South Carolina. *Bull. Mar. Sci.* **49**(1/2): 482-493.

WODINSKY J. 1972. Breeding season of *Octopus vulgaris*. *Mar. Biol*. **16**: 59-63.

YOUNG J.Z. 1967. The visceral nerves of octopus. *Phil. Trans. R. Soc. Lond.* **25**: 31-22.

YOUNG J.Z. 1971. The anatomy of the nervous system of *Octopus vulgaris*. Clarendon Press, Oxford. 690 pp.

YOUNG R.E. and HARMAN R.F. 1997. *Octopus cyanea* and *Octopus ornatus*: biology and fisheries in Hawaii. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 115-123.

PHASE 0: STEP 2 - INFORMATION GATHERING IN THE FIELD.

The gaps in the available information on *O. vulgaris* in South Africa were addressed during this phase. Research was conducted to investigate the biology, age and growth on the warm temperate coast as well as stock structure around the coast. The following chapters were written as separate scientific papers each covering a biological aspect, therefore some repetition from previous chapters was unavoidable.

- **CHAPTER 4:** Population biology of *O. vulgaris* on the temperate southeast coast of South Africa.

- **CHAPTER 5:** Age and growth assessment of *O. vulgaris* on the southeast coast of South Africa.

- **CHAPTER 6:** Population genetics of *O. vulgaris* around the South African coast.

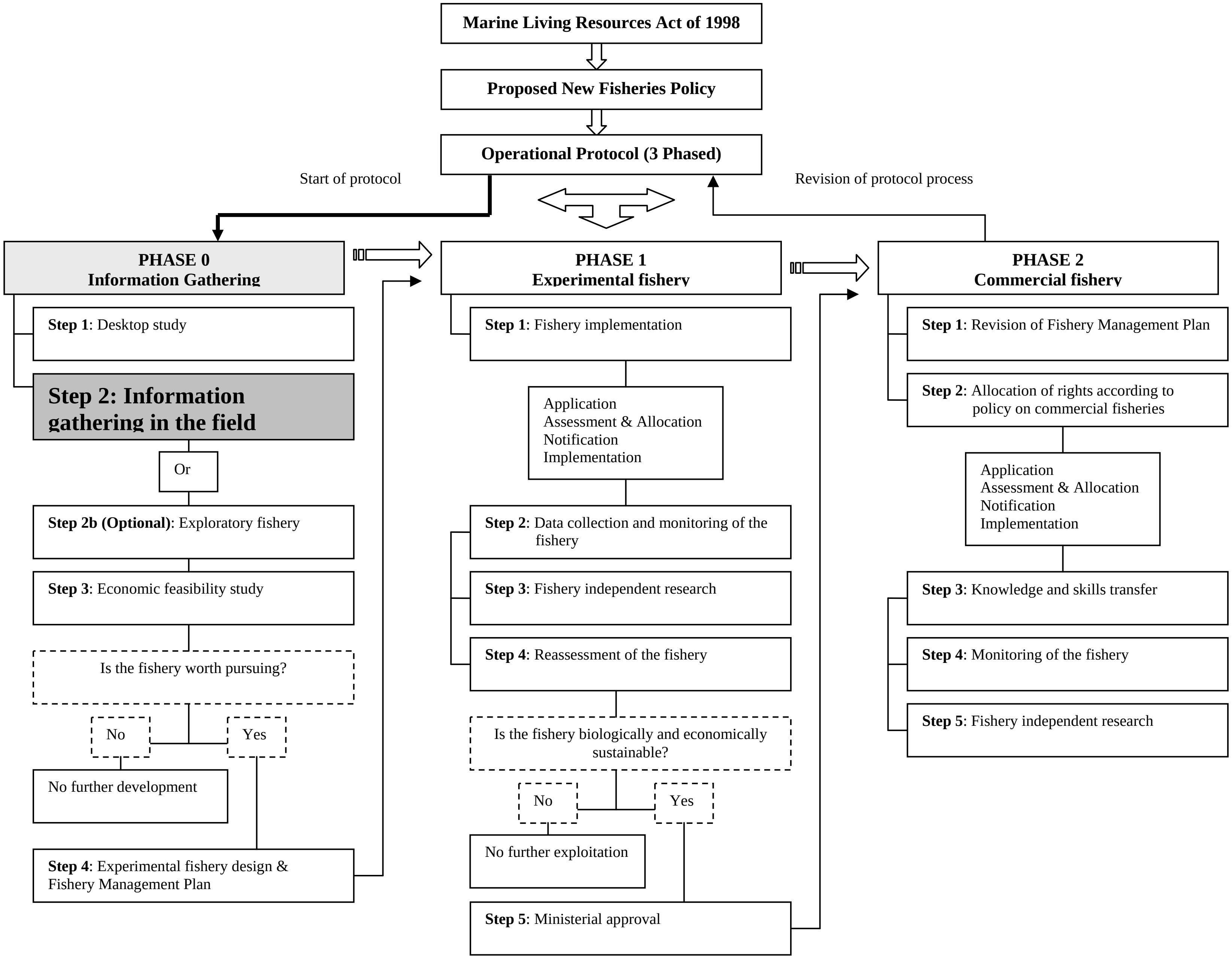

Figure B. Step 2: Information gathering in the field.

CHAPTER 4

POPULATION BIOLOGY OF *OCTOPUS VULGARIS* ON THE TEMPERATE SOUTHEAST COAST OF SOUTH AFRICA.

This work has been published in the *Journal of Marine Biological Association of the United Kingdom Vol. 83: 535-541.*

INTRODUCTION

The importance of biological information to understand the productive characteristics of a species for the implementation of appropriate management measures where pointed out in Chapter 2. The current chapter focuses on fishery independent data, by addressing gaps in the biological information in South Africa as pointed out in Chapter 3.

Octopus vulgaris Cuvier 1797 is one of the most intensely studied cephalopod species in the world (Mangold 1997), with research concentrated in the Mediterranean Sea and on the northwest African coast (Mangold & Boletzky 1973; Guerra 1979; Hatanaka 1979; Caverivière et al. 2002). This species was previously believed to have a global distribution; however it is now considered to occur in the Mediterranean and the eastern Atlantic only, but forms part of a larger cosmopolitan species complex (Mangold 1998).

The distribution of *O. vulgaris* in southern Africa ranges from Lüderitz on the coast of Namibia, to approximately Durban on the east coast of South Africa (Smale et al. 1993). Limited biological research has been conducted on the subtropical east coast (Smale & Buchan 1981) and the cold temperate southwestern coast (Smith & Griffiths 2002) of South Africa. Biological and ecological data on *O. vulgaris* on the warm temperate southeastern coast is lacking, although an isolated laboratory study on mussel predation by *O. vulgaris* has been carried out (McQuaid 1994). These three areas differ vastly in oceanographic climate, species diversity and zoogeography (Branch et al. 1994). Differences in water temperature and prey availability have been shown to influence octopus growth rates and size (Forsythe & Hanlon 1988; Forsythe 1993).

The intertidal stock of *O. vulgaris* along the South African coast is exploited by both recreational and subsistence fishermen, with the level of exploitation varying between the different regions (Clark et al. 2002). The octopus stock in the subtidal area is currently unexploited. This study was initiated to provide biological and ecological information on *O.*

vulgaris along the warm temperate southeastern coast of South Africa, which would supplement existing data for other regions. This baseline information will be used in the development of a proposed octopus fishery around the South African coast. The aim of this study was to describe the population structure, biology and distribution of *O. vulgaris* in both intertidal and subtidal areas.

MATERIALS AND METHODS

Study area

Intertidal collections were conducted around Algoa Bay, a large log-spiral bay situated on the southeast coast of South Africa (Schumann et al. 1987). The collection sites consisted mainly of rocky substrata and were located around Cape Recife, the headland at the western end of Algoa Bay (Fig. 1). Subtidal sites were located on various reefs in Algoa Bay, St Francis Bay and Tsitsikamma National Park (a marine reserve) (Fig. 1). A description of both the intertidal areas and subtidal reefs is given in Table 1. The water temperature in the study area is warm but fluctuating (12 - 24^{o}C) during summer and colder but more stable (14 - 18^{o}C) during winter months (Beckley 1988). The temperature fluctuations in summer are induced by localised upwelling, caused by prevalent easterly winds.

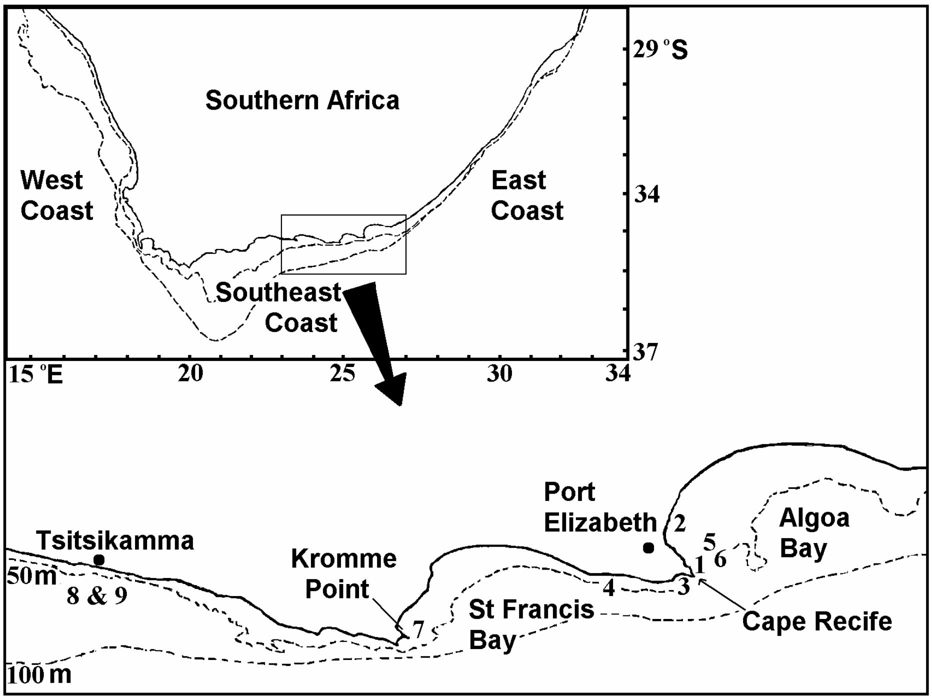

Figure 1. Geographical location of octopus collection sites on the southeast coast of South Africa.

Table 1. Descriptions of the intertidal and subtidal collection sites for *Octopus vulgaris*.

Site		Intertidal Area description
Algoa Bay	1	Sheltered low profile rock.
	2	Sheltered low profile rock.
	3	Exposed high profile rock.
	4	Exposed high profile rock.
Site		**Subtidal Reef description**
Algoa Bay	5	Medium to high profile, dense invertebrate cover, depth: 5 - 20 m.
	6	Low profile, sparse invertebrate cover, interspersed sand, depth: 15 - 20 m.
St Francis Bay	7	Boulder reef, seaweed cover, few invertebrates, depth: <8 m.
Tsitsikamma	8	High profile, dense invertebrate cover, depth: 15 - 30 m.
National Marine Park	9	Tidal gully, sparse invertebrate cover, interspersed sand, depth: <12 m.

Sampling techniques

Intertidal collections were conducted during spring low tides from January 1999 to February 2000. Searches were conducted for approximately three days per month, for every month (n = 25-35 per month). Total monthly effort was calculated from two people searching a set area (approximately 5800 m^2), in a two-hour period. Collections were mostly done during daylight hours (morning), with a few collections at night. A comparative study showed that den sites were located more effectively during the day.

Subtidal samples were collected during the day, by means of SCUBA (Self Contained Underwater Breathing Apparatus) diving, from June 1999 to November 2000. Collections were done on a seasonal basis, with 7-9 collections per season (n = 30-40 for each season) Octopuses were removed from their dens by squirting a mild dilution of copper sulphate ($CuSo_4$), an irritant, or chloroform, an anaesthetic, into the den. Specimens were euthanased in a 3% ETOH-seawater solution and frozen for later biological analysis.

Exposed (sites 3 and 4) and sheltered (sites 1 and 2) intertidal areas were compared over a six-month period, to investigate octopus densities.

Biological data collection

Total mass (TM), total length (TL), dorsal mantle length (DML), head width (HW) and gonad mass (GM) were recorded from thawed samples. The gonadosomatic index (GSI) was calculated as gonad mass as a percentage of total mass. Sex was determined by the presence of the spermatophoric groove and heterocotylus on the third right arm of the males (Mangold 1983). Female maturity was categorized according to Mangold (1987). Stage 1 (immature) refers to the ovary as small and white, Stage 2 (maturing) is characterised by a larger ovary and the oviducal glands are off-white in colour, Stage 3 (mature) refers to the presence of loose oocytes in the ovary and Stage 4 (spent) refers to the ovary as flaccid with few loose oocytes present. Males were classified as sexually mature by the presence of spermatophores in Needam's sac. Egg counts were done from egg strings collected from the dens. The egg strings were counted and measured, and the number of eggs per string determined from a subsample. This figure was then extrapolated to estimate the total number of eggs per female. Beaks were removed and soaked in fresh water for 3 - 7 days, after which they were rinsed and preserved in 10% formaldehyde. The diet was assessed by analysing stomach contents and den remains. Contents of the crop and stomach were removed, weighed and preserved in 10% formalin. Contents were washed through a 500-micron mesh sieve and prey species quantified by volume. Teleost prey was identified to the lowest taxon possible, using otoliths (Smale et al. 1995) and eggs found in the gut contents. Den remains were collected and preserved in 10% formaldehyde for later analysis. Gonads were removed and weighed. Den length, width and height were measured after removal of the octopus.

Statistical analysis

Morphometric and egg number:female mass (TM) relationships were analysed with GraphPad Prism® and Statistica (StatSoft®) software using linear and non-linear, least-square regression line or best-fit curve. The chi-square (χ^2) test was used to determine sex ratios (Zar 1984). Seasonal data (mean mass, GSI) were tested for normality and homogeneity of variance, transformed where necessary and tested using a two-way ANOVA (Statistica, StatSoft®). Den volume and octopus size were correlated using the Spearman rank correlation in GraphPad Prism® software. Biological parameters were measured for significant difference (one-way ANOVA) between sites within each area. No significant difference was found for any of the following parameters:

- Intertidal: TM (p = 0.288); TL (p =0.2152); ML (p = 0.1903); GSI (p = 0.2053)

- Subtidal sites: TM ($p = 0.051$); TL ($p = 0.089$); ML ($p = 0.065$); GSI ($p = 0.053$)

Data was also tested for the influence of subtidal reef type on morphometrics (TM, TL, ML, GSI) using a one-way ANOVA. TM data were then tested for interaction between reef type and season using a two-way ANOVA (Statistica, StatSoft®).

RESULTS

Density and distribution

A comparison between the exposed (sites 3 and 4) and sheltered (sites 1 and 2) areas showed that octopus were more abundant on low-profile rocky areas on the sheltered sites. Abundance in terms of mean number of octopus collected per hour was higher for the sheltered sites (3.4 ± 0.9 SD), compared to exposed sites (0.5 ± 0.2 SD). The distribution of octopus within sites was patchy and clumped in both the intertidal and subtidal regions.

In all, 300 octopuses weighing a total of 125.68 kg was removed from the intertidal area within one year. Intertidal densities were relatively low and ranged between 0.02 – 1 octopus/100 m^2 (mean 0.28 ± 0.08 SE), with density decreasing in the following year (personal observation). The effort for collecting 1 kg of octopus was approximately 1h search time per person. In the subtidal area, 147 octopuses weighing 168.34 kg were collected from a depth range of 3 - 30 m, at a search time of 1h 20 minutes for 1.1 kg octopus.

Significant differences in morphology (TM $p = 0.00058$; TL $p = 0.0017$; ML $p = 0.0008$; GSI $p = 0.0028$) were noted between low and high profile reefs. Furthermore, the TM was influenced by area and season. Individuals from medium- to high-profile reef with dense invertebrate cover during summer were significantly larger than the TM during winter on both low ($p = 0.000148$) and high profile reefs ($p = 0.0024$) (Fig. 2). Brooding females were more prevalent on medium-profile boulder reef (n = 7) than on high-profile reef (n = 2). Loose-boulder reef offered particularly good den habitat compared to solid-structure, high-profile reef (personal observation).

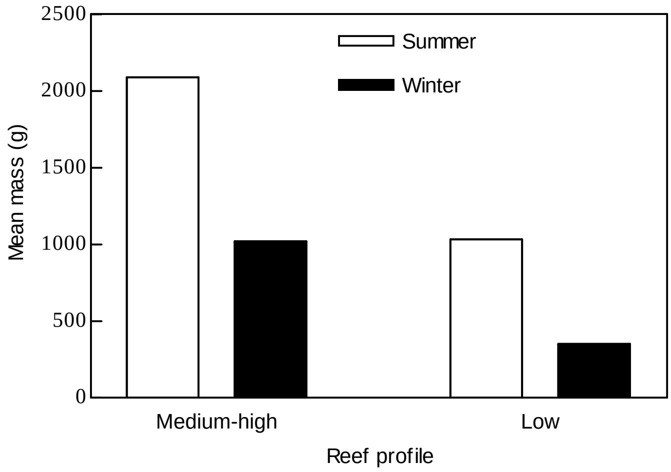

Figure 2. The difference between summer and winter mean mass for *O. vulgaris* found on two reef profiles sampled on the southeast coast of South Africa.

Den use and Diet

During intertidal collections 75% of the octopuses found were in dens and 25% were found exposed in rock pools. Octopus size was positively correlated (r = 0.83, $p < 0.0001$) with den volume (cm^3), with larger octopuses associated with larger den volume. Two different den types were observed; small octopuses (342.5 g ± 249.0 g SD) generally occupied holes sunk perpendicularly into the substrate, while larger octopuses (580.6 g ± 542.3 g SD) excavated dens beneath rocks and ledges. Of the specimens collected, 47% of intertidal (n = 141) and 41.5% of subtidal (n = 61) octopus had prey remains in the gut. Prey remains were only present at 11.92% of intertidal and 9.23% of subtidal dens. No distinct middens were found at the dens either intertidal or subtidally. The main prey items identified from stomach contents were crustaceans, teleosts and octopus (Fig. 3), the latter identified as *O. vulgaris* from beaks and partially digested flesh. Molluscs were most prevalent in the den remains, with the dominance in bivalves attributed mainly to *Venus vericosa* (Fig. 4). Teleosts found in the diet were identified to family level (Fig. 5). Small (<300 g) octopuses were found to eat Blenniidae and Gobiidae eggs attached to rock surfaces.

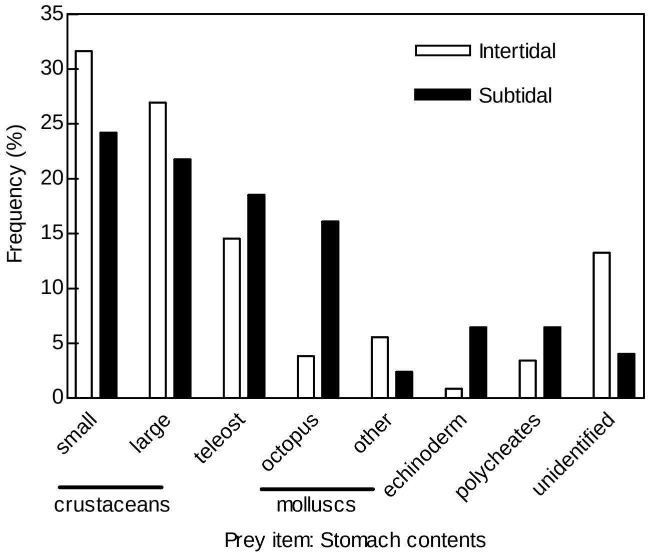

Figure 3. The frequency (of volume) of main prey items identified from the stomach contents of *O. vulgaris* collected on the on the southeast coast of South Africa.

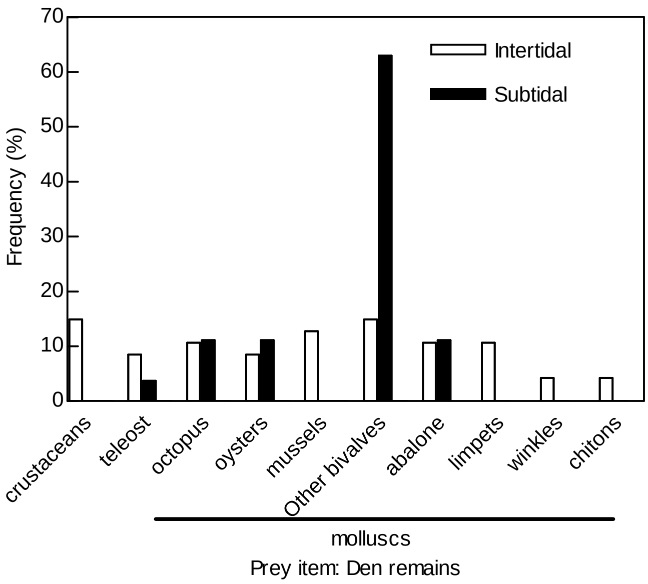

Figure 4. The frequency of occurrence of main prey items in the den remains of *O. vulgaris* collected on the on the southeast coast of South Africa.

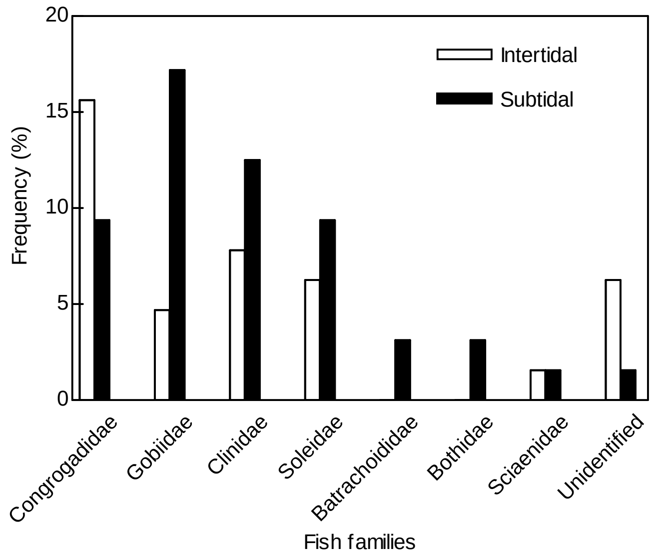

Figure 5. Teleosts families identified from otoliths and eggs found in the stomach contents of *O. vulgaris* collected on the southeast coast of South Africa.

Population biology

Sex ratio

Females were found to dominate the intertidal area (2:1 female to male ratio, $p > 0.05$), while there was no significant difference in the subtidal sex ratio (1:1, $p > 0.05$).

Morphometrics

The relationship between dorsal mantle length and total length was linear (TL = 5.02 (ML) + 54.03, $r^2 = 0.87$, n = 440, Fig. 6), while the dorsal mantle length and total mass relationship was best described by a power curve ($TM = 0.0038 (ML)^{2.58}$, $r^2 = 0.89$, n = 440, Fig. 7). The mean TM, TL, DML and GM for both inter- and subtidal specimens are presented in Table 2. There was no significant difference ($p > 0.05$) in mean mass between the sexes within a particular area. There was, however, a significant difference between the intertidal and subtidal mean mass ($p < 0.05$) in females and the intertidal and subtidal mean mass ($p < 0.05$) in males. Generally subtidal specimens had a significantly ($p < 0.05$) larger mean mass than the intertidal octopus. Differences were also apparent in the mass of the gonads, with the subtidal specimens having significantly larger ($p < 0.05$) gonads (Table 2).

Table 2. The total mass (TM), total length (TL), dorsal mantle length (DML) and gonad mass (GM) of *Octopus vulgaris* individually collected from intertidal and subtidal sites. Values are mean ± SE.

	Intertidal		
	Female (n =199)	**Male (n =101)**	**All (n =300)**
TM (g)	627.72 ±41.44	529.54 ±61.34	594.67 ±34.43
TL (mm)	567.05 ±11.59	515.15 ±18.40	549.57 ±9.96
DML (mm)	103.03 ±2.77	90.82 ±3.13	98.92 ±2.15
GM (g)	1.69 ±0.14	4.08 ±0.47	2.49 ±0.19
	Subtidal		
	Female (n =66)	**Male (n =81)**	**All (n =147)**
TM (g)	1302.93 ±169.27	931.05 ±102.63	1098.02 ±95.61
TL (mm)	641.64 ±27.78	608.33 ±24.71	623.29 ±18.45
DML (mm)	125.53 ±5.75	110.48 ±4.215	117.24 ±3.52
GM (g)	37.43 ±10.19	9.35 ±1.13	21.96 ±4.74

A clear linear relationship between gonad mass (GM) and total mass (TM) was found for male octopus both intertidally and subtidally (GM = 0.0102 (TM) - 0.76, r^2 = 0.94, n =181), with gonad mass increasing with total mass. Although intertidal (mainly immature) females gave a similar result (GM = 0.003 (TM) - 0.18, r^2 = 0.82, n =199), the combined intertidal and subtidal female sample showed a weak relationship (r^2 = 0.34). The subtidal females showed a large variation in the gonad–total mass relationship, with some small females having large gonads and vice versa.

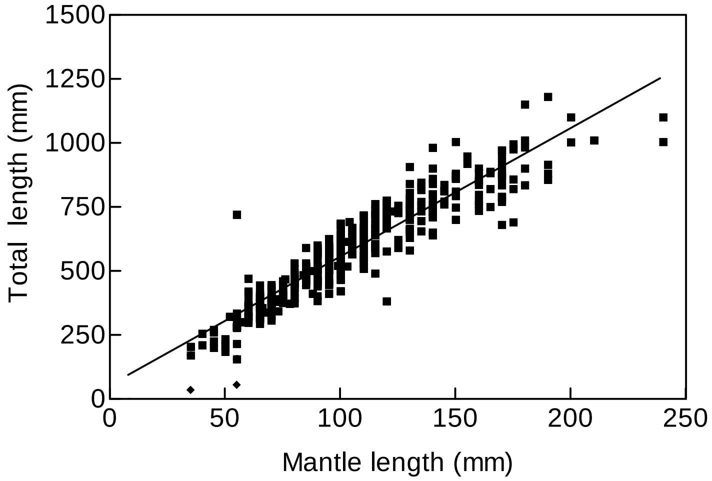

Figure 6. The linear relationship (TL = 5.02(ML) + 54.03, r^2 = 0.87, n = 440) between dorsal mantle length and total length of *O. vulgaris* collected on the southeast coast of South Africa.

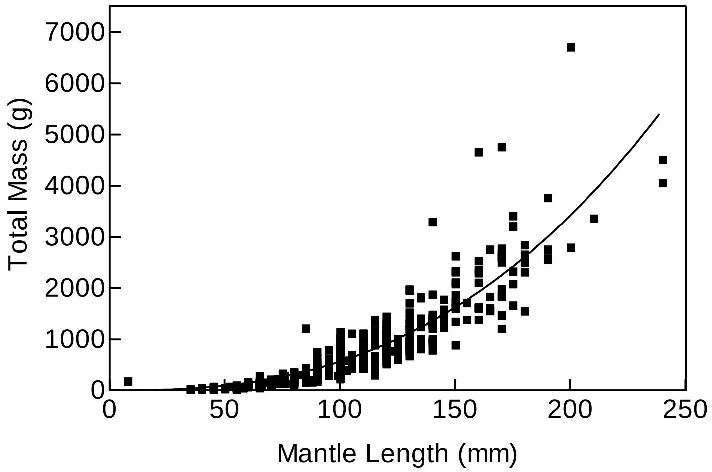

Figure 7. The dorsal mantle length and total mass relationship of *O. vulgaris* collected on the southeast coast of South Africa was best described by a power curve (TM = $0.0038(ML)^{2.58}$, r^2 = 0.89, n = 440).

Maturity

Male maturity stages ranged from juvenile to mature both intertidally and subtidally, with mature males found year-round. Intertidally, 62.4% (n = 63) of males were mature, with a mean size of 733.79 g ± 86.6 (SE), while subtidally, 75.3% (n = 60) of males were mature, with a mean size of 1246.98 g ± 127.01 (SE). All males larger than 190 g were mature, with the smallest mature male weighing 71.89 g.

Immature and maturing females were found both intertidally and subtidally, but no mature females were found in the intertidal region. Subtidal collections yielded 14 mature females without spawned eggs, nine brooding females and one spent individual. The brooding females, of which two individuals were mature and seven were spent, all had eggs present in the den. Six subtidal females had flaccid, degenerate bodies, indicating the possible end of the life span. Four of these were spent individuals, one was brooding but not spent, and one mature. The mean size of the mature females was 2425.92 g ± 314.9 (SE), with spawning probably taking place between 1000 - 3000 g total mass. Of these females, 50% were mature at approximately 1600 g. The smallest mature female collected weighed 405 g.

Gonadosomatic index (GSI)

The mean GSI was below 1% for both the intertidal and subtidal males (intertidal: 0.69% ± 0.032 (SE), n = 101, subtidal: 0.95% ± 0.053 (SE), n = 81) and the mainly immature intertidal females (0.26% ± 0.011 (SE), n = 199). The GSI for immature subtidal females was in the range 0.1 - 2.5% and for mature females 1.33 - 10.34% (mean 5.21 ± 0.72 (SE), n = 17).

Fecundity

The total number of eggs produced was estimated from seven spent females and ranged from 42133 to 789111. The mean number of eggs per egg string ranged from 602 to 2133 and the mean number of egg strings per individual ranged from 70 to 452. The mean length of the egg strings was 74.48 mm ± 0.76 (SE) and ranged from 36 to 114 mm. Both the number of eggs per egg string ($r^2 = 0.87$, $p < 0.05$, Fig. 8) and the total number of eggs ($r^2 = 0.78$, $p < 0.05$) were significantly related to the size of the female.

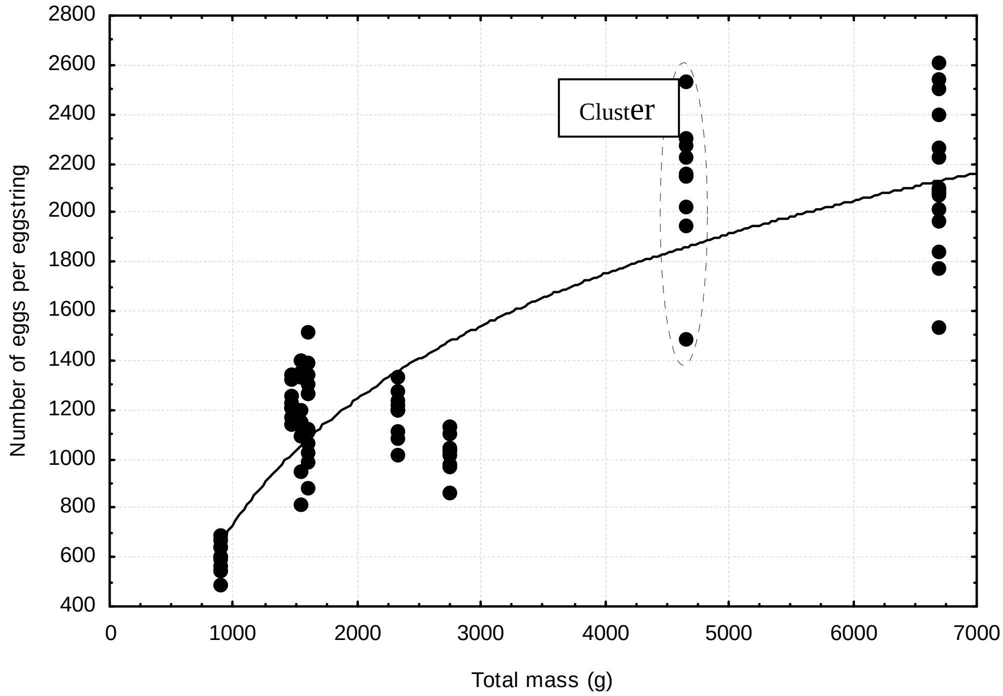

Figure 8. Number of eggs per string related to the total mass (g) of *O. vulgaris* females collected on the southeast coast of South Africa (Number=-4322.72 +1685.99*log10(mass)). Each cluster of points is data from one individual.

Seasonal trends

There was an interaction between the main effects of area and season on mean mass ($F_{(3,428)}$ = 6.7945, p = 0.00018). There was a three-way interaction between the main effects of area, season and sex on GSI ($F_{(3,428)}$ = 7.649, p = 0.00005). The post-hoc test showed that the subtidal females for the seasons of summer, autumn and spring were significantly different (p > 0.05) from the rest. Intertidal mean mass and GSI showed no difference between seasons. Seasonal mean mass for both intertidal and subtidal males and females is presented in Fig. 9. The mean intertidal and subtidal mass also differed significantly between summer ($p < 0.05$) and spring ($p < 0.05$).

Subtidal female GSI was significantly higher ($p < 0.05$) in summer (3.23%) than in winter (1.06%) (Fig. 9). Further evidence to support seasonality is given in the distribution of mature, brooding and spent females (Fig. 10). The number of mature and brooding females peaked during summer and autumn and was lowest during winter. There was no seasonal variation in the sex ratios, (p > 0.05 for all seasons) which remained 1:1 and 2:1 (female:male) for the subtidal and intertidal octopus respectively.

Incidences of possible mating (mature male and maturing female found in same or adjoining dens) were recorded on five occasions intertidally and five occasions subtidally, in all seasons.

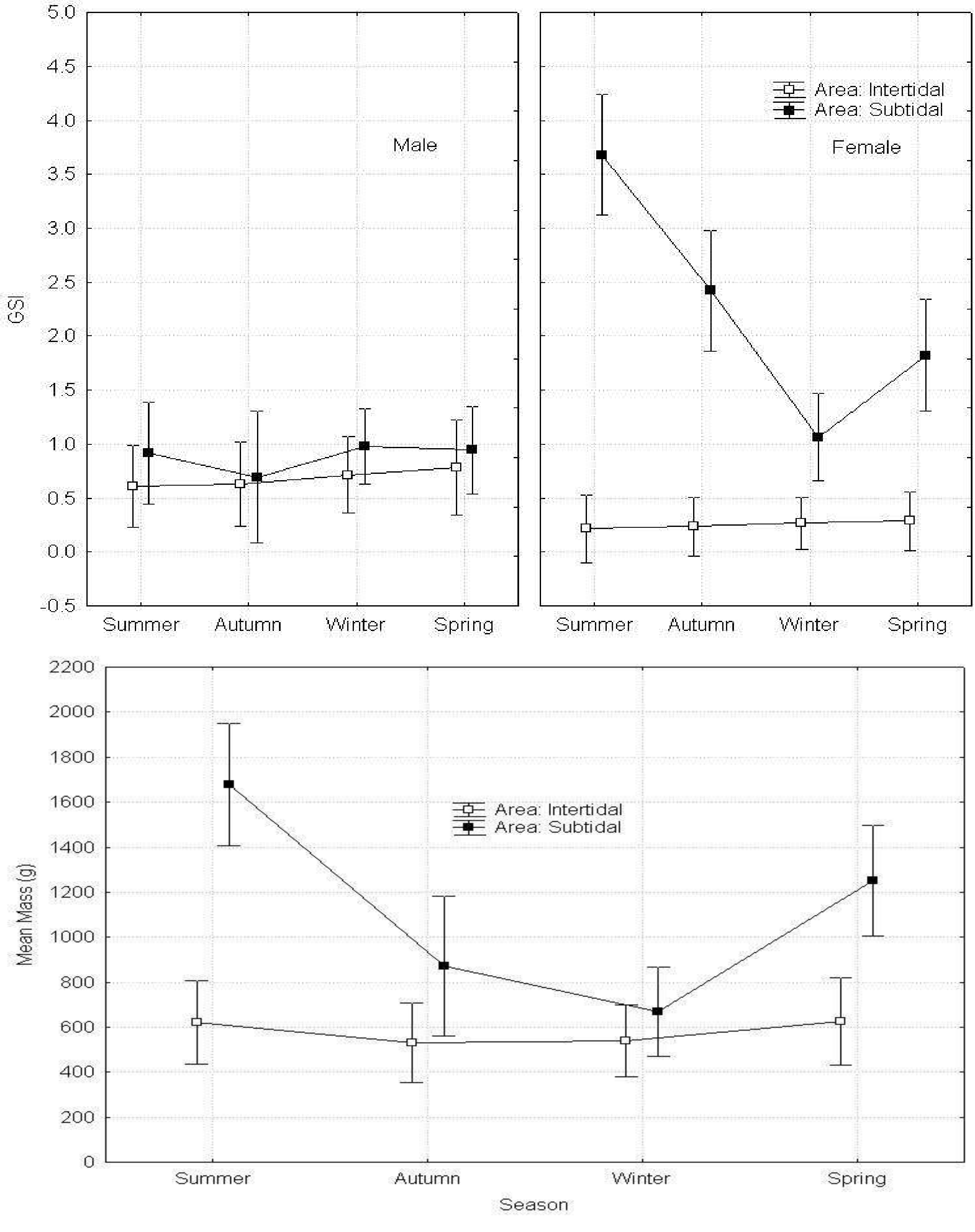

Figure 9. The mean mass (g) and mean gonadosomatic index (GSI) (%) for male and female *O. vulgaris* collected intertidally and subtidally per season on the southeast coast of South Africa.

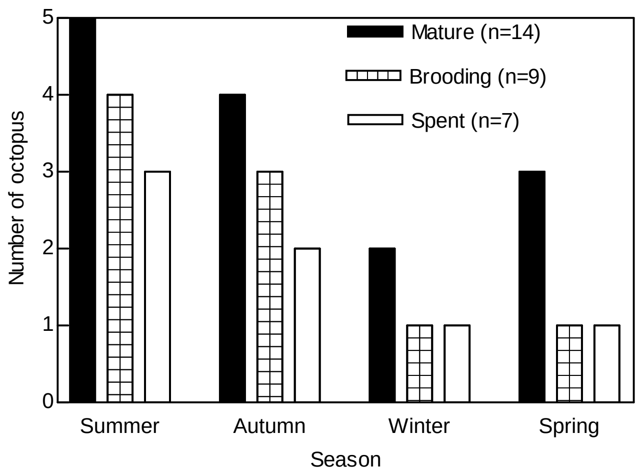

Figure 10. Seasonal distribution of mature, brooding and spent female *O. vulgaris* (Total n = 37% of all subtidal females) collected on the southeast coast of South Africa.

DISCUSSION

Important aspects of species biology relevant to the management of the fishery were addressed in this chapter. Reproductive characteristics, such as size at maturity and fecundity, and population dynamics in terms of spatial and temporal distribution and migrations, previously unknown were determined. This information is essential in the management of the species (Chaper 2).

Despite the possibility of a species complex in *Octopus vulgaris*, the dynamics and biology in southern Africa was found to be similar to that for *O. vulgaris* on the northwest coast of Africa (Mangold & Boletzky 1973; Hatanaka 1979) and the Mediterranean Sea (Sánchez & Obarti 1993). Octopuses tend to be opportunistic feeders that make use of a variety of prey items in different habitats (Mangold 1983). This is clearly reflected in *O. vulgaris* along the South African coastline, with the diet varying considerably between the different coastal regions. The brown mussel was the dominant prey item on the subtropical east coast (Smale & Buchan 1981), abalone and crustaceans comprised the bulk of prey on the southwest coast (Smith 1999), and crustaceans, teleosts and other octopuses dominated prey items on the southeast coast (this study). It was noteworthy that the fish taken were small and typical of reef areas. Regional variation in diet reflects differences in prey spectra available in different zoogeographic areas (Branch et al. 1994), and demonstrates behavioural plasticity that allows these predators to successfully exploit a wide variety of prey taxa. The prey species recorded in southern Africa fall within the range of prey observed in the Mediterranean (Nixon 1987) and northwest Africa (Nigmatullin & Ostapenko 1976; Hatanaka 1979; Caverivière 2002).

Morphometric descriptions are also very similar to studies on the subtropical east coast (Smale & Buchan 1981) and cool temperate southwest coast (Smith & Griffiths 2002) of South Africa, as well as the Mediterranean (Sánchez & Obarti 1993). The dynamics of the population appear to be dominated by the migration of maturing females to deeper subtidal areas, where they mature, spawn and brood. This hypothesis is supported by the fact that no mature or brooding females were found intertidally. Smale & Buchan (1981) and Smith (1999) also found evidence of such migration patterns amongst female octopuses. Similar distributions of mature *O. vulgaris* females were found on the northwest coast of Africa (Hatanaka 1979), in the Mediterranean (Sánchez & Obarti 1993) and in South Carolina (Whitaker et al. 1991). The difference between the size of intertidal and subtidal females on the South African coast suggests that younger, smaller individuals (small GM) inhabit the intertidal area, whereas larger and older individuals (larger GM) occur subtidally. However, this still needs to be validated by ageing studies (Chapter 5). The link between somatic and gonadal growth is restricted to the premature phase (Mangold 1983), and generally the correlation between body mass and gonad mass is better in males than in females, as was evident in this study. The cause of variation in size at maturity is still unknown, but many factors such as food, light, temperature, age and large variation in individual growth have been implicated (Mangold 1983). The specific influence of temperature on cephalopod growth and size has been illustrated by several authors (Forsythe & van Heukelem 1987; Forsythe 1993). A female hatching in spring will grow faster than one hatched during the previous winter, due to higher water temperatures, and will therefore reach a larger size at a younger age (Forsythe 1993). The influence of temperature is evident when comparing size at maturity for the temperate southeast coast and the subtropical east coast of South Africa. Males matured larger (400 g) and females matured smaller (900 g) on the east coast (Smale & Buchan 1981) compared to observations for males (190 g) and females (1600 g) on the southeast coast (this study). On the southwest coast of South Africa Smith & Griffiths (2002) and in the Mediterranean Mangold (1983), noted that male maturity was reached at approximately 170 g and 190 g respectively.

Male octopuses also differed in size between the intertidal and subtidal areas. This could indicate a migration of the older, larger males to the subtidal area to mate with mature, ready to spawn females. Migration to deeper waters in the cold season, possibly for reproduction, has been suggested from studies off northwest Africa (Caverivière 2002). A current study on the South African squid (*Loligo vulgaris reynaudii*) indicates that the last male to mate with a female substantially increases his success rate in paternity (Sauer in prep.). A similar strategy could be employed by *O. vulgaris* males. The sex ratios were maintained throughout the months sampled, which differed from findings by Smale & Buchan (1981) and Smith (1999).

Spawning peaked during autumn and winter on the subtropical east coast of South Africa (Smale & Buchan 1981). On the cold temperate southwest coast, the GSI peaked during spring and summer; however, no mature females were found (Smith 1999). This differs from the trend found on the warm temperate southeast coast, where the GSI peaked and mature females were more abundant in summer. Spawning of *O. vulgaris* in the Mediterranean was observed during summer (Mangold & Boletzky 1973), while spawning peaked during spring on the northwest African coast (Guerra 1979). The embryonic development of *O. vulgaris* can vary between 55 and 89 days at temperatures of 15 - 17^{o}C (Boletzky 1987; Caverivière et al. 1999) and the planktonic larval stage is estimated at approximately 60 days at 21^{o}C (Villanueva 1995). The southeast coast of South Africa has prevailing bottom temperatures of 15 - 17^{o}C (Oosthuizen 1999), and with peak spawning occurring in summer, the first settlement will probably peak late autumn to spring. During this period, the spawned females would have died and the decrease in mean mass between the seasons would be evident. Smith (1999) also observed this seasonal variation in size, but attributed this to lower water temperatures.

The fecundity calculated for the southern African *O. vulgaris* differs from that found in the Mediterranean. *O. vulgaris* in South Africa exhibited a wider range of between 42000 - 790000 eggs, compared to the Mediterranean where between 100000 and 500000 eggs are laid (Mangold 1983). The number of egg strings per female was similar at 70 - 452 (this study) and 100 - 400 (Mediterranean); however, the length of the egg strings differed from 74 mm (this study) to 100 mm (Mediterranean) (Mangold 1983).

At present, only the intertidal area on the South African coast is exploited for octopus. This study did not aim to estimate biomass; nonetheless, a variation in biomass in the intertidal component of the *O. vulgaris* population was noted. Intensive research collection during one year, plus increased disturbance of the rocky shore area by bait diggers and subsistence collectors the following year, may have resulted in lower octopus numbers in the area. However, anthropogenic effects on biomass cannot be proven in this study, and the reduction of biomass might have been due to natural fluctuations within the population. Although the intertidal population could be seen as a renewable resource (with the subtidal source replenishing the intertidal source), the combined exploitation of intertidal and subtidal areas could be detrimental to the octopus stock, as the overexploitation of one area will impact on the other. These two areas, which differ in locality and fishing activity, should thus be managed as one to ensure sustainable use of the octopus resource. Octopus fisheries worldwide have shown that careful planning is needed for a biological and economical sustainable fishery (Whitaker et al. 1991; Roper 1997; Defeo & Castilla 1998; Caddy 1999).

ACKNOWLEDGEMENTS

We thank the numerous people that assisted during the SCUBA diving collections. Special thanks to Dr Nadine Strydom (South African Institute for Aquatic Biodiversity) for field and editorial assistance and larval fish identification, Dr Warwick Sauer (Rhodes University) for editing a draft manuscript and suggestions throughout the project. The infrastructure for the project was provided by Bayworld (Port Elizabeth Museum) and funded by the National Research Foundation.

REFERENCES

BECKLEY L.E. 1988. Spatial and temporal variability in sea temperature in Algoa Bay, South Africa. *S. Afr. J. Sci.* **84**: 67–69.

BOLETZKY S.V. 1987. Embryonic phase. In *Cephalopod life cycles, Vol. 2* (ed. P.R. Boyle). Academic Press, London. p 5–31.

BRANCH G. M., GRIFFITHS C.L., BRANCH M.L. and BECKLEY L. E. 1994. *Two oceans: A guide to the marine life of southern Africa*. David Philip, Cape Town.

CADDY J.F. 1999. Fisheries management in the twenty-first centaury: will new paradigms apply? *Rev. Fish Biol. Fish.* **9**: 1–43.

CAVERIVIERE A. 2002. Elements du cycle de vie du pouple *Octopus vulgaris* des eaux senegalises. In *Le pouple* Octopus vulgaris *Senegal et cotes nord-ouest africaines*. (ed. A. Caveriviere et al.). IRD Editions, Paris. p. 105–125.

CAVERIVIÈRE, A., DOMAIN, F., and DIALLO, A., 1999. Observations on the influence of temperature on the length of embryonic development in *Octopus vulgaris* (Senegal). *Aquat. Liv. Res.* **12**: 151–154.

CAVERIVIERE A., THIAM M. and JOUFFRE D. 2002. *Le pouple* Octopus vulgaris *Senegal et cotes nord-ouest africaines*. Paris: IRD Editions.

CLARK B.M., HAUK M., HARRIS J.M., SALO K. and RUSSEL E. 2002. Identification of subsistence fishers, fishing areas, resource use and activities along the South African coast. *S. Afr. J. mar. Sci.* **24**: 425–438.

DEFEO O. and CASTILLA J.C. 1998. Harvesting and economic patterns in the artisanal *Octopus mimus* (Cephalopoda) fishery in a northern Chile cove. *Fish. Res.* **38**: 121–130.

FORSYTHE R.W. 1993. A working hypothesis of how seasonal temperature change may impact the field growth of young cephalopods. In *Recent advances in fisheries biology*. (Ed. T. Okutani et al.). Tokai University Press, Tokyo. p. 133–143.

FORSYTHE R.W. and VAN HEUKELEM W.F.1987. Growth. In *Cephalopod life cycles,* Vol. 2 (Ed. P.R. Boyle). Academic Press, London. p 135–156.

FORSYTHE R.W. and HANLON R.T. 1988. Effect of temperature on laboratory growth, reproduction and life span of *Octopus bimaculoides*. *Mar. Biol.* **98**:369–379.

GUERRA A. 1979. Fitting a von Bertalanffy expression to *Octopus vulgaris* growth. *Inst. Invest. Pesq. Spain*. **43**: 319–326.

HATANAKA H. 1979. Studies on the fisheries biology of common octopus off the northwest coast of Africa. *Bull. Far Seas Fish. Res. Lab* **17**: 13-124.

MANGOLD K. 1983. *Octopus vulgaris*. In *Cephalopod life cycles,* Vol. 1 (Ed. P.R. Boyle). Academic Press, London. p 335–364.

MANGOLD K. 1987. Reproduction. In *Cephalopod life cycles*, Vol. 2 (Ed. P.R. Boyle). p 157–200.

MANGOLD K. 1997. *Octopus vulgaris*: Review of the biology. In *Proceedings of the workshop on: The fishery and market potential of Octopus in California. University of Southern California, California, 31 August – 8 September 1989.* (Ed. M.A. Lang and F.G. Hochberg). Smithsonian Institution, Washington. p. 85–90.

MANGOLD K. 1998. The Octopodinae from the Eastern Atlantic Ocean and the Mediterranean Sea. In *Systematics and Biogeography of Cephalopods, Vol.2* (Ed. N.A. Voss et al.) Smithsonian Contributions to Zoology. **586**: 521-528.

MANGOLD K. and BOLETZKY S.V. 1973. New data on reproductive biology and growth of *Octopus vulgaris*. *Mar. Biol.* **19**: 7–12.

McQUAID C.D. 1994. Feeding behaviour and selection of bivalve prey by *Octopus vulgaris* Cuvier. *J. Exp. Mar. Biol. Ecol.* **177**: 187–202.

NIGMATULLIN C.M. and OSTAPENKO A.A. 1976. Feeding of *Octopus vulgaris* Lam. From the northwest Africa coast. *International Council for the Exploration of the Seas* **CM1976/K**. 15 pp.

NIXON M. 1987. Cephalopod diets. In *Cephalopod life cycles*, Vol. 2 (Ed. P.R. Boyle). Academic Press, London. p 201–219.

OOSTHUIZEN A. 1999. The effects of temperature on embryonic development and hatching success of squid (*Loligo vulgaris reynaudii*) eggs. M.Sc. thesis, University of Port Elizabeth, Port Elizabeth, South Africa.

ROPER C.F.E. 1997. Experimental Octopus Fisheries: Two Cases Studies. In *Proceedings of the workshop on: The fishery and market potential of Octopus in California. University of Southern California, California, 31 August – 8 September 1989*. (Ed. M.A. Lang, and F.G. Hochberg). Smithsonian Institution, Washington. p. 157–168.

SÁNCHEZ P. and OBARTI R. 1993. The biology and fishery of *Octopus vulgaris* caught with clay pots on the Spanish Mediterranean coast. In *Recent advances in fisheries biology*. (Ed. T. Okutani, R.K. O'Dor, and T. Kubodera). Tokai University Press, Tokyo. p. 477–487.

SAUER, W.H.H. in prep. Paternity determination in the squid *Loligo vulgaris reynaudii*. Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown, South Africa.

SCHUMANN E.H., ROSS G.J.B. and GOSHEN W.S. 1987. Cold water events in Algoa Bay and along the Cape south coast, South Africa, in March/April 1987. *S. Afr. J. mar. Sci*. **4**: 579–584.

SMALE M.J. and BUCHAN P.R. 1981. Biology of *Octopus vulgaris* off the east coast of South Africa. *Mar. Biol.* **65**: 51–12.

SMALE M.J., CLARKE M.R., KLAGES N.T.W. and ROELEVELD M.A.C. 1993. Octopod beak identification - Resolution at a regional level (Cephalopoda, Octopoda: South Africa). *S. Afr. J. mar. Sci.* **13**, 269–293.

SMALE M.J., WATSON G. AND HECHT T. 1995. Otolith atlas of southern African marine fishes. *Ichthyological monographs of the JLB Smith Institute of Ichthyology.* **No. 1**. 253 pp.

SMITH C.D. 1999. Population biology and ecology of octopus in the southwestern Cape: A study towards the establishment of a small-scale octopus fishery. M.Sc. thesis, University of Cape Town, Cape Town, South Africa.

SMITH C.D. and GRIFFITHS C.L. 2002. Aspects of the population biology of *Octopus vulgaris* in False Bay, South Africa. *S. Afr. J. mar. Sci.* **24**: 185–192.

VILLANUEVA R. 1995. Experimental rearing and growth of planktonic *Octopus vulgaris*. *Can. J. Fish. Aquat. Sci.* **52:** 2639–2650.

WHITAKER J.D., DELANCY L.B. and JENKINS J.E. 1991. Aspects of the biology and fishery potential for *Octopus vulgaris* off the coast of South Carolina. *Bull. Mar. Sci.* **49**: 482–493.

ZAR J.H. 1984. *Biostatistical analysis*, 2nd ed. Prentice-Hall inc, New Jersey.

CHAPTER 5

AGE AND GROWTH ASSESSMENT OF *O. VULGARIS* ON THE SOUTHEAST COAST OF SOUTH AFRICA.

INTRODUCTION

Management of cephalopod populations has become increasingly important with the rising demand placed on these resources because of the depletion of traditional finfish stocks. Central to many management strategies is the basic understanding of age and growth of a species. However, age determination of cephalopods has become a contentious issue, with clear divergence in the scientific literature (Lipiński et al. 1998a; Pauly 1998). Traditional length-frequency analyses based on von Bertalanffy growth curves assume slow asymptotic growth in cephalopods (Longhurst & Pauly 1987; Jarre et al. 1991). However, age research based on statolith increments and growth of cephalopods in the field and laboratory has shown logarithmic and exponential growth with a short life span (Forsythe & van Heukelem 1987; Jackson et al. 1997). Although there has been reluctance to accept proof of such growth in cephalopods (Pauly 1998), supporting evidence in many cephalopod species has become overwhelming (Forsythe & van Heukelem 1987; Jackson 1994; Lipiński et al. 1998b; Arkipkin 1995; Broziak & Macy 1996; Dawe & Beck 1997; Arkipkin & Laptikhovsky 2000; etc). Furthermore, comparative studies between the two age assessment methods proved that the application of asymptotic growth is incorrect and that length-frequency analysis based on von Bertalanffy cannot be applied to cephalopods (Jackson et al. 1997; Jackson et al. 2000).

Cephalopod age determination in the past has focused on squid, primarily because of their importance to fisheries worldwide and their statolith structure. However, octopus are increasingly exploited commercially (Roper et al. 1983), yet accurate age and growth assessment of octopus has so far eluded fisheries managers. Many studies have dealt with the growth of octopus (Mangold-Wirz 1963, Mangold & Boletzky 1973; Guerra 1979, 1981), but few have attempted to determine octopod age directly. The crystal structure of octopus statoliths is not conducive to ring or increment formation (Tait 1980). Some authors have reported on rings found in beaks; however, none attempted to use these structures in ageing of the animal (Clarke 1962; Nixon 1973; Smale et al. 1993). The first to investigate the periodicity of ring deposition in octopus beaks were Raya & Hernández-Conzález (1998). They postulated a one-day, one-ring deposition for *Octopus vulgaris*. The use of tetracycline as a stain in statoliths has provided support for the one-day, one-ring deposition hypothesis, and has been used successfully in squid (Hurley et al. 1985; Jackson 1990; Lipiński et al. 1998b) and sepioids (Jackson 1989).

This work investigates the suitability of using beak growth lines in the ageing of octopus, and attempts to validate the one-day, one-ring deposition hypothesis for *O. vulgaris* along the southeast coast of South Africa. This is essential information for the management of a species as referred to in Table 1 of Chapter 2, and identified in Table 1 & 2 of Chapter 3 as gaps in the South African and global information.

METHODS

Estimates of growth

Growth experiments were conducted on *O. vulgaris* (150 - 720 g) collected intertidally in Algoa Bay. The octopus were kept individually in glass tanks with lids, in an open circulating system, and fed daily on live *Perna perna*, a brown mussel found in their natural diet (Buchan & Smale 1981). Growth experiments were conducted at 18 ^{o}C, 22 ^{o}C and in the field (described below).

Four different treatments were conducted at 18^{o}C, namely two TC (tetracycline) experiments, one control experiment, and one PIT (passive internal transponder) tagging experiment. The second set of experiments, at 22^{o}C, consisted of three treatments, comprising two TC and one placebo experiment (Table 1). The octopus used in the TC experiments were anesthetized, and tetracycline (120 mg/ml) was injected into the mantle 2 - 3 times at various intervals during the experiment. The tetracycline dosage (12% concentration) was determined according to mass (pers comm. V. Bettencourt as used on *Sepia sp*. - Table 1). A pilot experiment was conducted to ascertain the viability of tetracycline, an antibiotic, as a chemical marker in *O. vulgaris* beaks. Four *O. vulgaris* with a mass between 150 and 300g were collected from the intertidal zone in Algoa Bay along the southeast coast of South Africa. The animals were anesthetized in 3% ETOH seawater mix (3 - 5 min) and then injected (into the 1 right arm) with 0.1 ml of tetracycline (120 mg/ml). All revived after approximately five minutes in fresh seawater. The octopus were kept as described above. The animals were euthanased in 3% ETOH seawater solution after 20 days. The beaks were removed, cleaned, and stored in 5 – 10 % formaldehyde, in the dark. The beaks were later checked for staining under a fluorescent light microscope. All four beaks, both upper and lower, were clearly marked by the tetracycline.

The control treatment group received no injections, while the placebo treatment was injected with sterile saline solution, following the same method as for the tetracycline injections. In the PIT treatment octopuses were tagged by subcutaneously injecting the tags (10 mm L x 1 mm D) in order to identify individuals. The tags were injected between the eyes of four individuals, and kept in the laboratory as above. This method was used successfully on *O. tetricus* and *O. maorum* both in the laboratory and field (Anderson & Babcock 1999).

The growth curve calculated for *O. vulgaris* in this study (Fig. 2) was based on the findings of Villanueva (1995), where *O. vulgaris* larvae were reared to 17 g in 60 days at a growth rate of 8%day^{-1}. Villanueva's (1995) growth rate was extrapolated for the next 30 days, with *O. vulgaris* attaining 171 g at the age of 90 days. Growth rates after 90 days were based on the growth rate (G) calculated in the laboratory and field during this study for the two different size classes of <600 g and >600 g.

Field growth

O. vulgaris with well-established den sites in the intertidal area were identified for use in field growth and age experiments. Octopus were removed from their dens, anesthetized as described above, weighed and injected with TC and PIT tags, before being released back into the den. This procedure took approximately seven minutes, with five minutes for anesthesia and approximately two minutes for weighing and injections. Octopuses were observed until they were fully revived (± 5 minutes) and had assumed their natural defensive positioning at the entrance of the den. The use of subcutaneous PIT tags ensured the identification of individual octopuses. Although 17 octopuses were tagged and TC-injected, only eight were retrieved. Two were retrieved after five days, four after 13 days and two after 14 days. Sea surface temperature during the field experiments is listed in Table 2.

Table 1. Tetracycline dosage (ml) allotted to the total mass (g) of *O. vulgaris.*

Total mass (g)	Tetracycline 120mg/ml (ml)
100-300	0.2
300-500	0.3
500-700	0.4
700-1000	0.5
1000-1500	0.7
1500-2500	0.8

Table 2. The growth experiments classified into treatments indicating the water temperature (mean ± SD) during the experiment, number of octopus (n) in each treatment and the duration of the experiment (days).

Treatment	Temperature (^oC)	N	Days
TC	17.78 ± 1.4	8	34
TC	18.71 ± 0.8	8	29
Control	18.93 ± 1.2	5	29
PIT	18.93 ± 1.2	4	21
TC	21.78 ± 1.8	8	24
TC	22.81 ± 0.3	4	24
Placebo	22.71 ± 0.6	3	21
Field 2000	17.13 ± 1.4	6	5, 13
Field 2002	17.03 ± 0.9	2	14

Age validation

The beaks of octopus collected for a population biology study by Oosthuizen & Smale (2003) along the southeast coast of South Africa were used in this age assessment study. *O. vulgaris* was collected both intertidally and subtidally in and around Algoa Bay. For sampling technique and biological data collection, see Oosthuizen & Smale (2003). The beaks were embedded in resin and sectioned, through the saggital plane (Fig. 1), with a double-bladed diamond otolith saw. The sections were mounted on slides and polished with Alpha Micropolish® Alumina No 2 (0.3 µm particle size), then etched with 33% hydrochloric acid for 10 hours. This method was successfully used on *O. vulgaris* by Raya & Hernández-González (1998). The sections were examined using a Nikon binocular microscope (100 - 300 x magnification) under oblique reflected light. Each growth line consisted of a successive light and dark band; dark bands were counted, and three repeated counts were done on each beak. Counts were discarded where more than 10% variation was observed. This is the standard cut-off value used in repeated counts ageing studies (Jackson et al. 1997; Jackson et al. 2000). The bands were counted along the margin of the section (Fig. 1) rather than along the Internal Rostral Axis (IRA) as defined by Raya & Hernández-González (1998). About 90% of the counts were done on upper beaks, as few lower beaks were readable. The similarity between upper and lower beaks could not be established conclusively, because both upper and lower beak counts could only be done for five beaks. The beaks of TC-injected octopus were processed by the same method, except for etching with hydrochloric acid. Beaks and the subsequent slides were stored in darkness to prevent fading of the TC fluorescence.

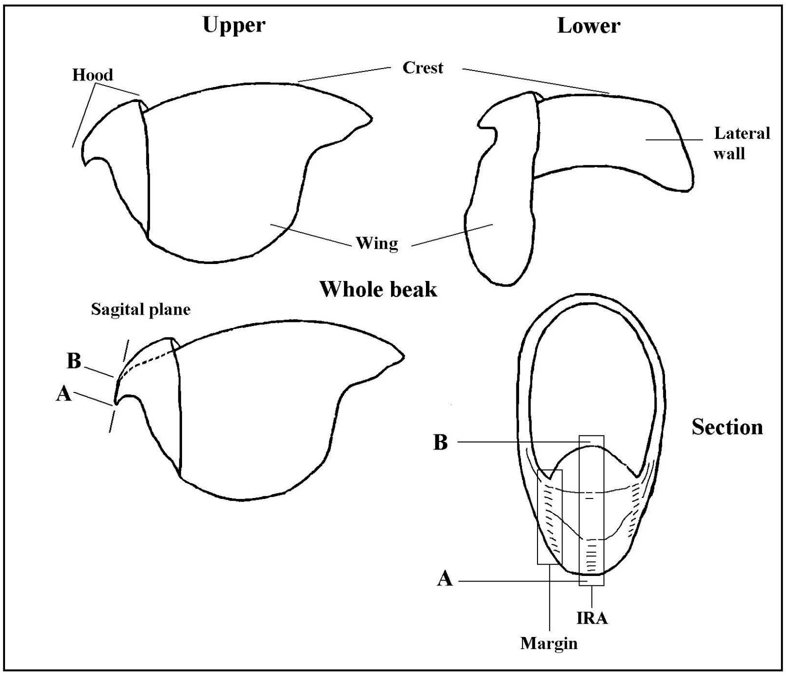

Figure 1. The upper and lower beaks of *Octopus vulgaris*, indicating the plane of sectioning. The section indicates two areas where bands were visible: the margin (used in this study) and the Internal Rostral Axis (IRA) as defined by Raya & Hernández-González (1998).

Statistical analysis

Growth

The instantaneous relative growth rate (G) (where $G = (\ln W_2 - \ln W_1/t_2 - t_1)*100$) (Forsythe & Heukelem 1987), also termed the Specific Growth Rate (SGR) (Robinson & Hartwick 1986), was determined for each octopus within each treatment. The growth rate (G) was tested for differences between treatments (TC, Control, PIT and Placebo) within each temperature with a one-way ANOVA. No significant differences were found between treatments within a temperature, and all data per temperature were lumped for further analysis. The growth rate (G) was then tested for interaction with size classes, <600 g and >600 g, and temperature by a two-factor ANOVA (Zar 1984). The growth curve was based on growth rates of planktonic to settlement larvae of *O. vulgaris* as determined by Villanueva (1995).

Age

Size-at-age curves were based on increment counts related to TM (total mass) for separate sexes, and the relationship was analysed with GraphPad Prism® software using both linear and non-linear regression best-fit curves. Increment counts were also related to maturity stages using a power curve.

RESULTS

Growth

Growth rate (G) between treatments

Growth was not influenced by TC treatment, PIT tags or Placebo injections. There was no significant difference (ANOVA, $p > 0.1$) in growth rate (G) between the two TC, control and PIT treatments at 18^{o}C, nor between the two TC and placebo treatments (ANOVA, $p > 0.1$) at 22^{o}C. Growth data within a specific temperature were therefore lumped for further analysis.

Weight gain

The mean weight gain over 21 and 30 days at 18^{o}C was 51.93% and 85.8% of body mass respectively. The mean weight gain over 21 and 25 days at 22^{o}C was 88.96% and 94.59% of body mass respectively. The mean weight gain over 13 days in the field was 12.13% of body mass. The percentage weight gain for 18^{o}C and 22^{o}C over a similar period (16, 15 days) was 18.54% and 34.45% respectively

Growth rate (G) between size classes and temperatures

There was a significant difference in growth rate (G) between temperature treatments (18 ^{o}C *vs*. 22 ^{o}C, $p = 0.000121$; 18 ^{o}C *vs*. Field, $p = 0.000304$; 22 ^{o}C *vs*. Field, $p = 0.00019$) and the two size classes <600 g and >600 g ($p = 0.000123$). Growth rate was highest at 22 ^{o}C and lowest in the field. The growth rate was also higher for the smaller size class of <600g (Table

3). *O. vulgaris* in the laboratory and field exhibited exponential growth between 100 – 1000 g total mass (Fig. 2). Few individuals were reared to larger than 1000 g.

Table 3. The relative instantaneous growth rate (Mean G ± SE) for the different size classes subject to three treatments.

Size class	Treatment		
	18 ^{o}C	22 ^{o}C	Field
150-600 g	2.05 ± 0.14 n=16	3.11 ± 0.22 n=10	0.97 ± 0.10 n=5
600-1200 g	1.32 ± 0.15 n=9	1.98 ± 0.14 n=5	0.70 ± 0.06 n=3

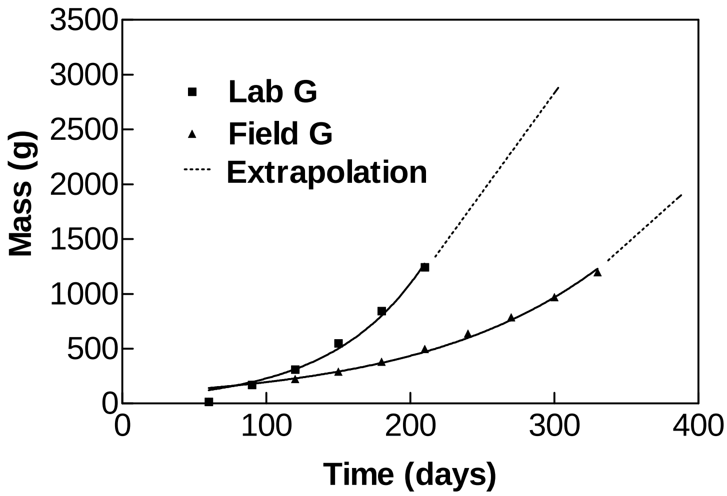

Figure 2. The growth curve for *O. vulgaris* based on the instantaneous relative growth rate (G) attained for both laboratory and field growth. The relationships are described by the following equations, $TM=47.88e^{0.016t}$, $r^2=0.98$, and $TM=87.59e^{0.008t}$, $r^2=0.99$, for laboratory and field respectively, where TM is total mass (g) and t is time (days).

Age assessment

Of 320 beaks sectioned and prepared, 60 were clear enough to record accurate counts. The upper beak was used in most cases; both beaks were counted for 5 individuals. The increments were most prominent along the margin of the section, with the Internal Rostral Axis in most cases unclear or with an incomplete increment sequence. The mean increment count, mass, sex and maturity stage for each specimen is presented in Appendix 3. The relationship between total mass (TM) and age in days (increments) was determined separately for the sexes. Neither linear nor non-linear models fitted the data well. In the case of males, the runs tests were not significant for deviations from either model (*p* = 0.426 linear; *p* = 0.637 non-linear), and similar r^2 values (r^2 = 0.75 linear; r^2 = 0.74 non-linear) were attained. Results for the females were alike with the runs tests not significant (*p* = 0.213 linear model; *p* = 0.071 non-linear model), and comparable r^2 values (r^2 = 0.24 linear model; r^2 = 0.2 non-linear model). The data were fitted with the non-linear model for illustration purposes (Fig. 4 & 5).

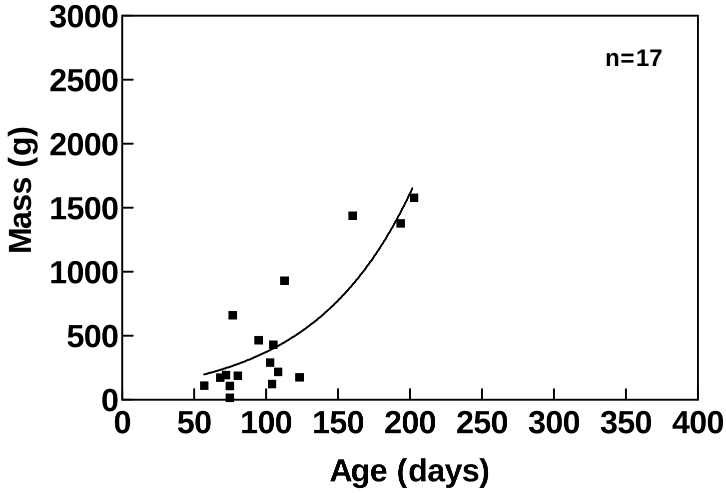

Figure 3. Growth curve based on beak increment counts for male *O. vulgaris* collected along the southeast coast of South Africa. TM=86.43$e^{0.015t}$, r^2=0.75, n=17.

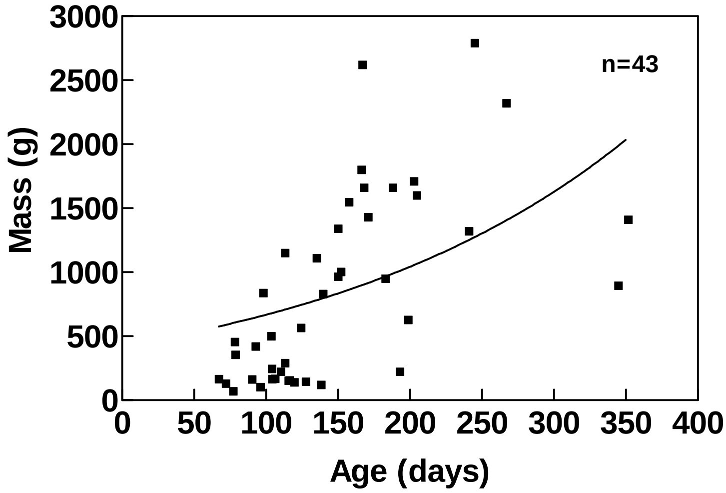

Figure 4. Growth curve based on beak increment counts for female *O. vulgaris* collected along the southeast coast of South Africa. TM=427.9$e^{0.005t}$, r^2=0.26, n=43.

The comparison of growth data and increment counts indicates variation between these data sets. The exponential growth observed for the species, was not fully supported by the age validation data (Fig. 5).

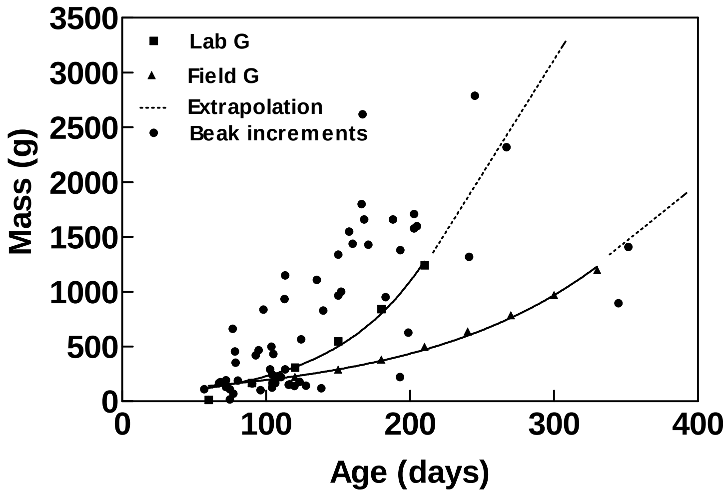

Figure 5. Size-at-age growth curve of *O. vulgaris* based on growth experiments and beak increment counts.

In general, the juvenile/immature intertidal octopus were the youngest and smallest, with the mature subtidal females being the oldest and largest (Figs. 6 & 7). The oldest individual was an intertidal maturing female at 352 days, the youngest an intertidal immature male at 57 days. A female weighing 2320 g was found brooding at 8.8 months, while a spent individual weighed 896 g at 11.4 months, suggesting a life span of 10 - 13 months. Large variation in size-at-age was observed between sexes as well as between maturity stages. Females generally reached an older age than males.

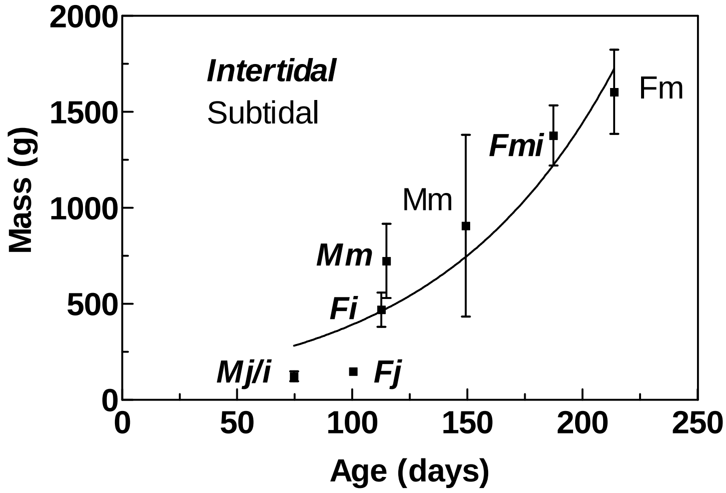

Figure 6. The mean counts for male and female *O. vulgaris* (mean mass ± SD) at different maturity stages. Bold/italic lettering indicate intertidally collected octopus. (TM = 106.7e $^{0.013t}$, r^2=0.96, n=60).

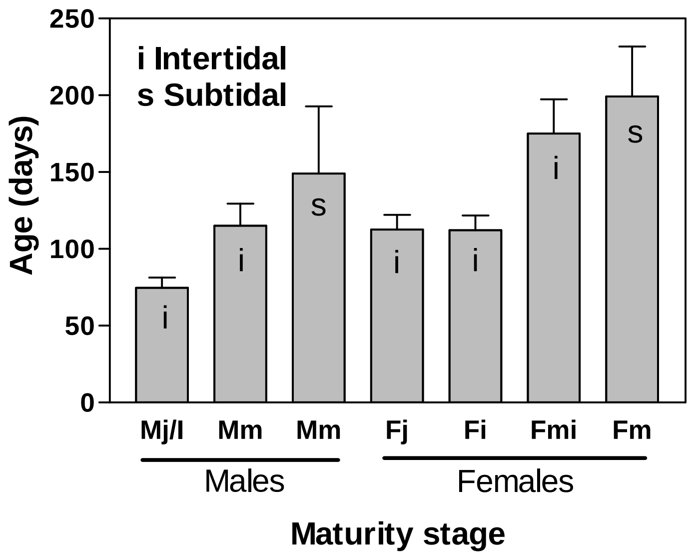

Figure 7. The mean age at different maturity stages of male and female *O. vulgaris* (I=immature, J=juvenile, MI=maturing, M=mature). Bars indicate standard deviation around mean age.

Tetracycline as a chemical marker in *O. vulgaris* beaks

Whole beaks

The tetracycline bands were more definite in whole beaks than in the sectioned beaks. Only TC dosages injected less than 20 days before termination were visible. TC bands were clearest on the wings and posterior end of the lateral wall. Various patterns of TC deposition were noted in the whole beaks. The TC was deposited in a line, but in some areas also across various increments and across strengthening formations in the beaks.

Both the upper and lower beaks of two small (190 - 400 g) laboratory-kept individuals, administered with two TC injections 13 and 5 days before termination, showed two clear lines of TC deposition (Fig. 8a). The lines were visible on the inside of the lateral wall (lower beak), on the posterior end of the hood, and on the outside of the wing area (upper beak). It was noted that these lines fused at the corner region of the wings, with the result that the growth increments were compressed (Fig. 8b). At the point where the two TC lines merged, the TC diffused across numerous growth lines and did not follow one particular increment.

A large individual showed only one deposition line after two TC injections; note the increment compression at the margin of the wing (Fig. 8c). Deposition of TC in strengthening formations in the beak was noted on the inner side of the wing (lower beak); however, the deposition line was not defined and formed jagged formations across growth increments (Fig 8d). Although the TC bands were clearly observed in these whole beaks, it was not possible to accurately count bands and correlate them with the number of days between injections.

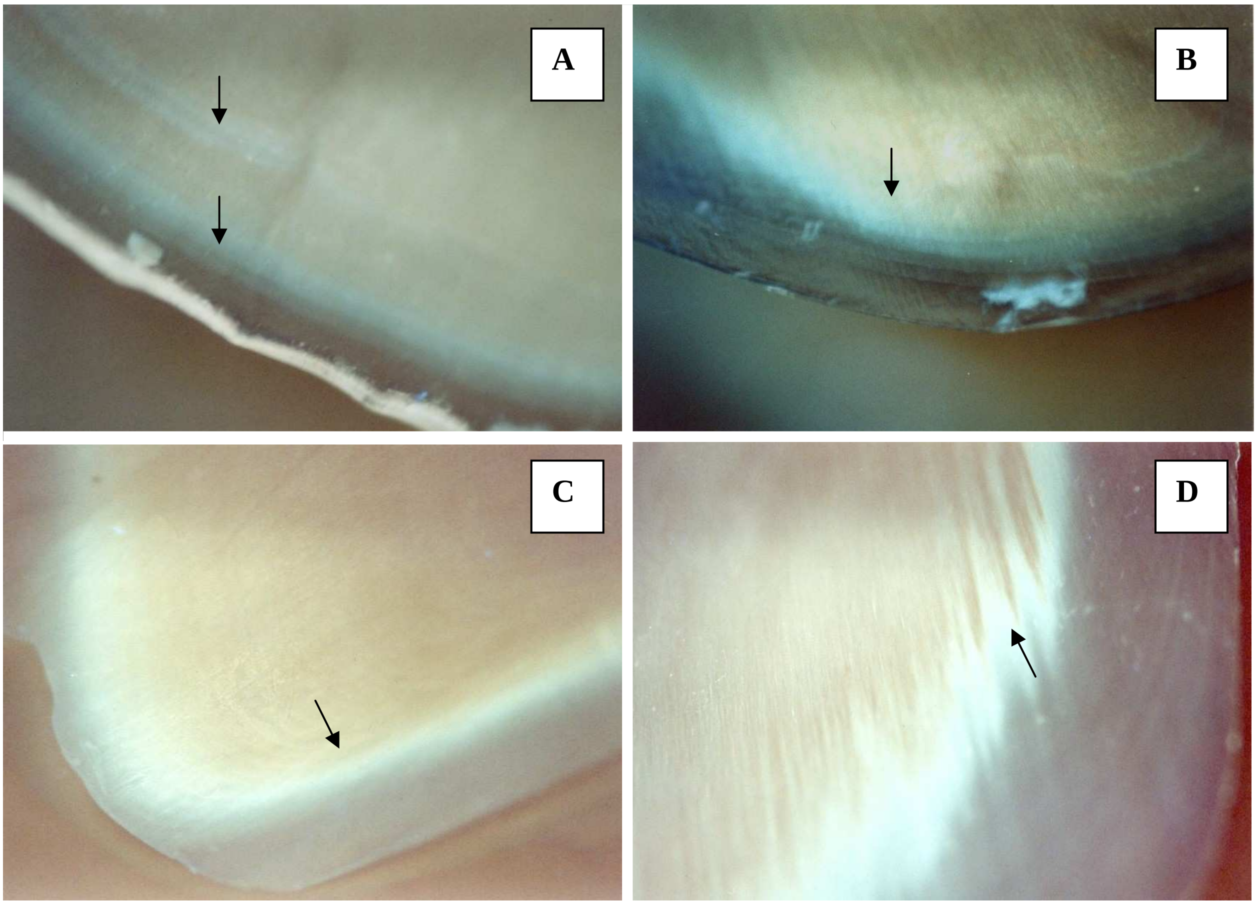

Figure 8 a-d. a) TC deposition lines on the outside of the anterior wing area of the upper beak. Male specimen, TM = 400 g. **b)** The fusion of two OTC lines noted on the margin of the anterior wing area of the upper beak. Female specimen, TM = 190 g. **c)** Increment compression at the posterior margin (inside) of the posterior crest wing. Male specimen, TM = 823 g. **d)** OTC deposited across various growth lines into strengthening formations in the anterior wing area. Female specimen, TM = 400 g.

Sectioned beaks

Only five (4 laboratory, 1 field) sectioned beaks showed clear deposition of TC. The increments between the TC lines could be related to the number of days between TC injections. It is suggested that *O. vulgaris* deposits daily bands in the beak. The TC bands are illustrated in Figures 9 & 10. The size and sex of the octopus and replicate increment counts for the beak sections are presented in Table 4.

Table 4. The increment counts related to days between TC injections and termination for *O. vulgaris* in both the field and laboratory.

Field/Lab Specimen	Sex	TM (g)	Up/Low beak	Days between TC 1 & 2	Days between TC 2 & Termination	Replicate increment counts	Mean ± SD	Fig
1.3 (lab)	F	1180	U L	-	15 15	15, 17, 15 14, 14, 15	16 ± 1.15 14 ± 0.58	9
4.4(lab)	F	990	L	6	2	6, 6, 6 2, 2, 2	6 ± 0 2 ± 0	
4.5(lab)	F	404	L	6	2	6, 7, 7 2, 3, 2	7 ± 0.58 3 ± 0.58	
4.6(lab)	F	590	U	6	2	6, 6, 6 2, 2, 2	6 ± 0 2 ± 0	10
F 8(Field)	F	628	U L	-	13 13	12, 12, 13 13, 12, 14	13 ± 0.58 12 ± 0.58	

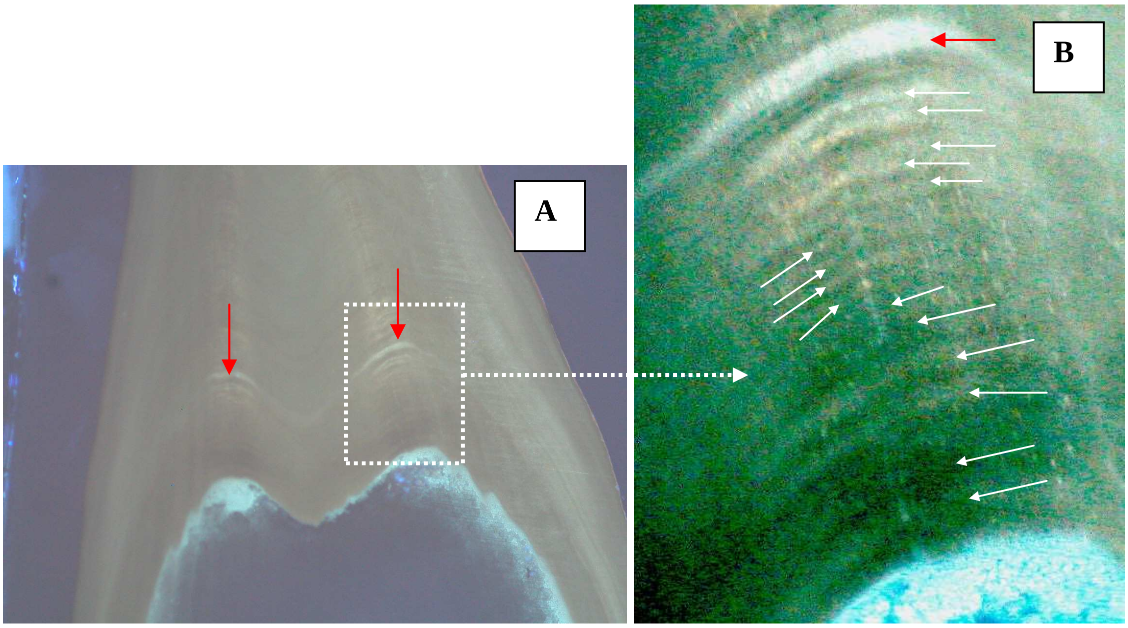

Figure 9 a & b. a) A section of the upper beak of *Octopus vulgaris*, indicating two margin areas where the tetracycline deposition lines (red arrows) were visible. **b)** The enlargement of the area on **a** indicating 15 days between the tetracycline line and end of the beak. Female specimen, TM = 1180g.

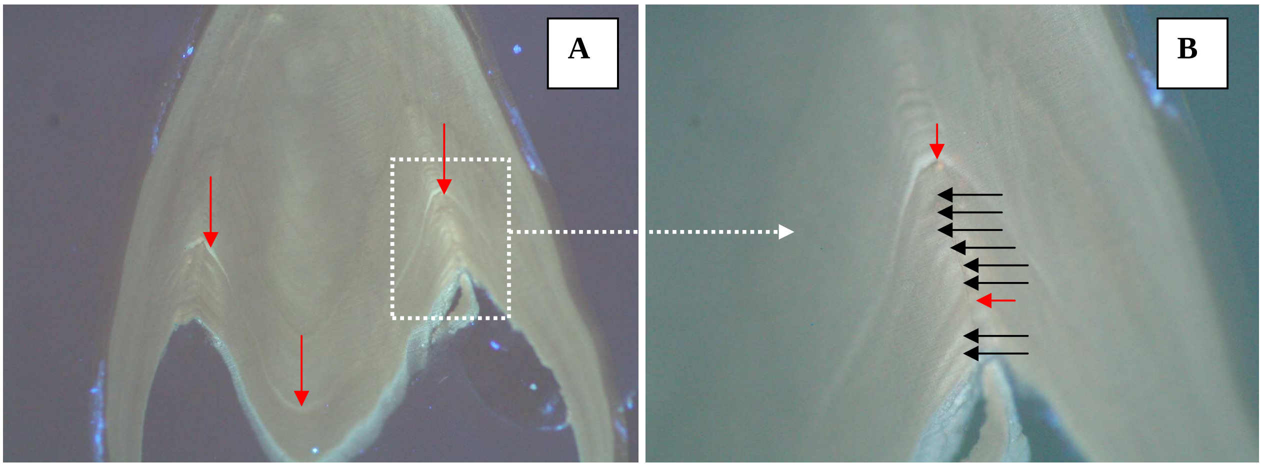

Figure 10 a-d. a) A section of the upper beak of *Octopus vulgaris*, indicating two marginal and one internal area where the tetracycline deposition lines (red arrows) were visible. **b)** The enlargement of the selected area on **a** indicating two tetracycline lines with six growth lines between them and another two before the end of the beak. Female specimen, TM = 590g.

DISCUSSION

The use of tetracycline as a marker in *Octopus vulgaris* beaks was successful, and supported the one-day one-increment deposition hypothesis for octopus in both the field and laboratory. Although n was low it provides sufficient evidence not to reject the one-ring one-day hypothesis. The variation between growth and increment age estimates suggests uncertainty in the general growth model for this species. Despite informative results from the observed growth, possible areas of uncertainty lie in the determination of field growth rates (very low n) and underestimates in the increment analysis. Notwithstanding these uncertainties the number of increments at size for *O. vulgaris* in South Africa was similar to that found by Raya & Hernández-Conzález (1998) for *O. vulgaris* on the northwest African coast.

Although similar sectioning and preparation methods for the beaks of *O. vulgaris* as Raya & Hernández-Conzález (1998) were followed, the percentage readable beaks obtained were low (18.8%). The difficulty lay in accurately sectioning the plane of contact between the hood and crest, and preparation of the section. Similar age validation studies on squid also found that statolith preparation posed a problem (Lipiński et al. 1998b). Furthermore, the success and visibility of tetracycline stains seem to be influenced by dosage, as smaller individuals more regularly had visible stains compared to larger individuals. The darker pigmentation of larger beaks might also have reduced tetracycline visibility. However, despite these difficulties the support for the one-day, one-increment hypothesis in squid statoliths could not be refuted (Lipiński et al. 1998b). It is suggested that the method used in this study be refined to ensure optimal preparation, in order to increase the number of readable beaks as well as the accuracy of reading.

O. vulgaris on the southeast coast of South Africa exhibited exponential growth between 100 - 1000 g. Exponential growth was also found for *O. vulgaris* in the Mediterranean (Mangold-Wirz 1963) and for *O. vulgaris* from 50 - 5000 g in Senegal (Domain et al. 2000). However, Forsythe & van Heukelem (1987) suggested that growth is more accurately described by two functions, namely exponential and logarithmic. The lack of accurate growth data for individuals larger than 1000 g in the present study could explain the failure to detect a logarithmic growth phase for *O. vulgaris* on the South African coast. The growth rate (G) of *O. vulgaris* at different sizes during this study (2.03 at and 1.32) was higher than those found by Mangold (1983) (1.45 and 0.94), but lower than those by Smale & Buchan (1981) (2.75 and 2.24) for similar-sized octopus. The growth rate was found to decrease with increase in weight, which has been noted before for *O. vulgaris* and various other octopus species (Smale & Buchan 1981; Hanlon 1983; Forsythe 1984; Boyle 1983).

The large difference in growth rate between laboratory and field results suggested that food and temperature may have played a role in growth, as was found by Van Heukelem (1976). Inherent variation in individual growth of specimens reared under identical conditions (Van Heukelem 1976; Forsythe 1984; Smale & Buchan 1981), as well as in the field (Domain et al. 2000), is also known to cause disparities in growth estimates. The influence of temperature on cephalopod growth and size has been illustrated by several authors (Forsythe & van Heukelem 1987; Forsythe 1993). A female hatching in spring will grow faster than one hatched during the previous winter, due to higher water temperatures, and will therefore reach a larger size at a younger age (Forsythe 1993). Furthermore, a small sample size and limited number of days at liberty might have biased results of field growth in this study. Domain et al. (2000) suggested that sufficient measurable growth of *O. vulgaris* in the field only occurred after 10 days at liberty.

The relationship between increments and maturity suggests that females can be mature and brooding by eight months, correlating with a life span of approximately 10 - 13 months. Other authors suggested similar life spans of 10 - 12 months in northwest Africa (Raya & Hernández-Conzález 1998), 12 - 14 months in Senegal (Domain et al. 2000) and 9 - 15 months on the east coast of South Africa (Smale & Buchan 1981).

Jackson et al. (1997) suggested that the use of statoliths has the most potential for generating growth models for cephalopods. He showed the margin of error in growth and life span estimates obtained using von Bertalanffy models compared to estimates from growth experiments and statolith increments. Statolith age-derived growth models have been successfully used in various squid fisheries (Arkipkin 1995; Broziak & Macy 1996; Dawe & Beck 1997; Arkipkin & Laptikhovsky 2000). The use of a growth model derived from both observed growth and beak age estimates for octopus in this study is a first. However, this model is not conclusive, with areas of uncertainty still needing to be addressed. The results provide preliminary size-at-age data to be used in the management of this species until conclusive evidence can be amassed through further research.

ACKNOWLEDGEMENTS

The infrastructure for this project was provided by Bayworld (Port Elizabeth Museum) and Rhodes University and funded by the National Research Foundation.

REFERENCES

ANDERSON T.J. and BABCOCK R.C. 1999. Subcutaneous electromagnetic tagging of benthic octopus: a preliminary evaluation. *Mar. Fresh. Res*. **50**: 225-227.

ARKIPKIN A.I. 1995. Age, growth, and maturation of *Loligo vulgaris* (Myopsida, Loliginidae) on the West Saharan Shelf. *J. Mar. Biol. Ass. U.K.* **27**: 593-604.

ARKIPKIN A.I. and LAPTIKHOVSKY V.V. 2002. Age, and growth of the squid *Todaropsis eblanae* (Cephalopoda: Ommastrephidae) on the north-west African Shelf. *J. Mar. Biol. Ass. U.K.* **80**: 747-748.

BOYLE P.R. 1983. *Eledone cirrhosa*. In: *Cephalopod life cycles.* Vol. 1. (Ed. Boyle, P.R.), Academic Press, London. pp.365-386

BROZIAK J.K.T. and MACY W.K. 1996. Growth of longfinned squid, *Loligo pealei*, in the northwest Atlantic. *Fish. Bull.* **94**: 212-236.

BUCHAN P.R. and SMALE M. J. 1981. Estimates of biomass, consumption and production of *Octopus vulgaris* Cuvier off the east coast of South Africa. *Investl. Rep. Oceanogr. Res. Inst. S. Afr*. **50**: 9 pp.

CLARKE M.R. 1962. The identification of cephalopod beaks and the relationship between beak size and total body weight. *Bull. Br. Mus. Nat. Hist. (Zool).* **8**: 419-480.

DAWE E.G. and BECK P.C. 1997. Population structure, growth and sexual maturation of the short-finned squid (*Illex illecebrocus*) at Newfoundland. *Can. J. Fish. Aquat. Sci.* **54**: 137-146.

DOMAIN F., JOUFRE D. and CAVERIVIÈRE A. 2000. Growth of *Octopus vulgaris* from tagging in Senegalese waters. *J. Mar. Biol. Ass. U.K.* **80**: 699-705.

FORSYTHE J.W. 1984. *Octopus joubini* (Mollusca: Cephalopoda): A detailed study of growth through the full life cycle in a closed seawater system. *J. Zool. Lond.* **202**: 393-417.

FORSYTHE J.W. 1993. A working hypothesis of how seasonal temperature change may impact the field growth of young cephalopods. In: *Recent advances in fisheries biology*. Okutani, T., O'Dor, R.K. and Kubodera, T. (Eds.). Tokyo, Tokai University Press. p 133-143.

FORSYTHE R.W. and VAN HEUKELEM W.F. 1987. Growth. In: *Cephalopod life cycles*, Vol. 2 (Ed. P.R. Boyle). Academic Press, London. p 135–156.

GUERRA A. 1979. Fitting a von Bertalanffy expression to *Octopus vulgaris* growth. *Inst. Invest. Pesq. Spain*. **43**: 319–326.

GUERRA A. 1981. Spatial distribution pattern of *Octopus vulgaris*. *J. Zool. Lond.* **195**: 133-146.

HANLON R. T. 1983. *Octopus cyanea*. In: *Cephalopod life cycles.* Vol. 1. (Ed. Boyle, P.R.), , Academic Press, London. pp. 293-310

HURLEY G.V., ODENSE P.H., O'DOR R.K. and DAWE E.G. 1985. Strontium labeling for verifying daily growth increments in the statolith if the short-finned squid (*Illex illecebrocus*). *Can J. Fish. Aquat. Sci.* **42**: 380-383.

JACKSON G.D. 1989. The use of statolith microstructures to analyze life history events in the small tropical cephalopod *Idiosepius pygmaeus*. *Fish. Bull.* **87**: 265-272.

JACKSON G.D. 1990. The use of tetracycline staining techniques to determine statolith growth ring periodicity in the tropical loliginid squids *Loliolus noctiluca* and *Loligo chinensis*. *Veliger*. **33**: 395-399.

JACKSON G.D. 1994. Application and future potential of statolith increment analysis in squids and sepioids. *Can. J. Fish. Aquat. Sci.* **51**: 2612-2625.

JACKSON G.D. and MOLTSHANISWKYJ N.A. 1999. Analysis of precision in statolith derived age estimates of the tropical squid *Photololigo* (Cephalopoda: Loliginidae). *ICES J. Mar. Sci.* **56**: 221-227.

JACKSON G.D., FORSYTHE J.W., HIXON R.F. and HANLON R.T. 1997. Age, growth, and maturation of *Lolliguncula brevis* (Cephalopoda: Loliginidae) in the northwestern Gulf of Mexico with a comparison of length-frequency versus statolith age analysis. *Can. J. Fish. Aquat. Sci.* **54**: 2907-2919.

JACKSON G.D., ALFORD R.A. and CHOAT J.H. 2000. Can length frequency analysis be used to determine squid growth? – An assessment of ELEFAN. *ICES J. Mar. Sci.* **57**: 948-954.

JARRE A., CLARKE M.R. and PAULY D. 1991. Re-examination of growth estimates in oceanic squids: the case of *Kondakovia longimana* (Onychoteuthidae). *ICES J. Mar. Sci.* **48**: 195-200.

LIPIŃSKI M.R., BUTTERWORTH D.S., AUGUSTYN C.J., BRODZIAK J.K.T., CHRISTY G., DES CLERS S., JACKSON G.D., O'DOR R.K., PAULY D., PURCHASE L.V., ROBERTS M.J., ROEL B.A., SAKURAI Y. and SAUER W.H.H. 1998a. Cephalopod fisheries: a future global upside to past overexploitation of living marine resources? Results of an international workshop, 31 August-2 September 1997, Cape Town, South Africa. *S. Afr. J. mar. Sci.* **20**: 463-469.

LIPIŃSKI M.R., DURHOLTZ M.D. and UNDERHILL L.G. 1998b. Field validation of age readings from the statoliths of chokka squid (*Loligo vulgaris reynaudii* d'Orbigny, 1845) and an assessment of associated errors. *ICES J. Mar. Sci*. **55**: 240-257.

LONGHURST A.R. and PAULY D. 1987. *Ecology of tropical oceans*. Academic press, San Diego. 608 pp.

MANGOLD K. 1983. *Octopus vulgaris*. In: *Cephalopod life cycles*. Vol. 1. Boyle, P.R. (Ed.). Academic Press, London. p 335-364.

MANGOLD K. and BOLETZKY S.V. 1973. New data on reproductive biology and growth of *Octopus vulgaris*. *Mar. Biol.* **19**: 7–12.

MANGOLD-WIRZ K. 1963. Biologie des céphalopodes benthiques et nectoniques de la Mer Catalane. *Vie et Milieu* **13**(suppl.): 1-285.

NIXON M. 1973. Beak and radula growth in *Octopus vulgaris*. *J. Zool. Lond.* **170**: 451-462.

OOSTHUIZEN A. and SMALE M.J. 2003. Population biology of *O. vulgaris* on the temperate south-eastern coast of South Africa. *J. Mar. Biol. Ass. U.K.* **83:** 535-541.

PAULY D. 1998. Why squid, though not fish, may be better understood by pretending they are. *S. Afr. J. mar. Sci.* **20**: 47-58.

RAYA C. and HERNÁNDEZ-GONZÁLEZ C. 1998. Growth lines within the beak microstructure of the octopus *Octopus vulgaris* Cuvier, 1797. *S. Afr. J. mar. Sci*. **20**: 135-142.

ROBINSON S. and HARTWICK E.B. 1986. Analysis of growth based on tag-recapture of the Giant Pacific octopus *Octopus dofleini martini. J. Zool. Lond*. **209**: 559-572.

ROPER C.F.E., LU C.C. and HOCHBERG F.G. 1983. Biology and resource potential of cephalopods. Workshop proceedings and recommendations. *Mem. Natn. Mus. Victoria*. **44**: 311 pp.

SMALE M.J. and BUCHAN P.R. 1981. Biology of *Octopus vulgaris* off the east coast of South Africa. *Mar. Biol.* **65**: 1-12.

SMALE M.J., CLARKE M.R., KLAGES N.T.W. and ROELEVELD M.A.C. 1993. Octopod beak identification - Resolution at a regional level (Cephalopoda, Octopoda: South Africa). *S. Afr. J. mar. Sci.* **13**: 269-293.

TAIT R.W. 1980. Aspects of the ecology and life history of *Octopus australis* Hoyle, from northern Port Phillip Bay. B.S. Thesis, Monash University, Clayton, Victoria, 77 pp.

VAN HEUKELEM W.F. 1976. Growth, bioenergetics and lifespan of *Octopus cyanea* and *Octopus maya*. Ph.D. Dissertation, University of Hawaii. 224 pp.

VILLANUEVA R. 1995. Experimental rearing and growth of planktonic *Octopus vulgaris*. *Can. J. Fish. Aquat. Sci.* **52**: 2639–2650.

ZAR J.H. 1984. *Biostatistical analysis*, 2nd ed. Prentice-Hall inc, New Jersey.

CHAPTER 6

POPULATION GENETICS OF *OCTOPUS VULGARIS* ON THE COAST OF SOUTH AFRICA.

INTRODUCTION

The identification of stock structure within a population is an important facet of both fisheries stock assessment and fisheries management (Begg et al. 1999). Failure to detect stock structures can lead to biological changes, influence productivity rates and cause loss of genetic diversity within a species (Altukhov 1981; Ricker 1981; Smith 1991). This in turn can lead to ineffective management as the underlying function of the population is not understood and the response of the stock to management measures cannot be predicted (Begg et al. 1999).

Recently, there have been significant advances made especially in the field of genetic stock identification (Begg et al. 1999). Genetic markers have increasingly been used in the identification of finfish stocks (Bartley et al 1992; Beacham et al. 1995; Imsiridou et al. 1998; Shaklee et al. 1999; Katsarou & Nævdal 2001; Smith et al. 2002; etc). By comparison, the use of genetic methods in cephalopod population studies has been low (Carvallo et al. 1992; Brierly et al. 1993; Norman et al. 1994; Shaw et al. 1999) and genetic studies on octopus specifically have focused mainly on phylogeny (De Los Angeles Barriga Sosa et al. 1995; Bonnaud et al. 1997; Söller et al. 2000; Warnke et al. 2000).

Although *Octopus vulgaris* is one of the most intensively studied cephalopod species, it is still undergoing taxonomic revision. Long considered to be globally distributed, it is now considered to be restricted to the Mediterranean and Eastern Atlantic through morphological description (Mangold & Hochberg 1991; Mangold 1997). Recently species previously classified as *O. vulgaris*, have been separated form the *O. vulgaris* complex and described as a separate species through genetic studies (Warnke et al. 2000).

Molecular analyses of octopus phylogeny have focussed on allozymes, and mitochondrial DNA (mtDNA) (gene coding regions: COI, COII, COIII, 16s rRNA etc.). Studies on octopus, and *O. vulgaris* in particular, have focussed on the COIII gene region of mtDNA (Barriga Sosa et al. 1995; Bonnaud et al. 1997; Söller et al. 2000; Warnke 1999a), with DNA sequences available from individuals from several regions including South Africa. Given that the taxonomic classification of the South African species is uncertain (Roeleveld 1998), it is essential to determine the phylogenetic status as well as population structure of the species, because a proposed fishery for *O. vulgaris* planned in the near future.

The objectives of this study were firstly, to investigate the genetic variation within South African *O. vulgaris* at the mtDNA COIII region, to determine population structure and secondly, to determine the phylogenetic relatedness of South African and Mediterranean *O. vulgaris.*

METHODS

Sample collection

O. vulgaris were collected intertidally and by SCUBA diving from various sites around the South African coast (Fig. 1). Approximately 3 - 5 cm of arm tip was removed from each specimen, where after the octopus was released. The samples were preserved in 95% ETOH. The number of samples collected per site is indicated in Table 1.

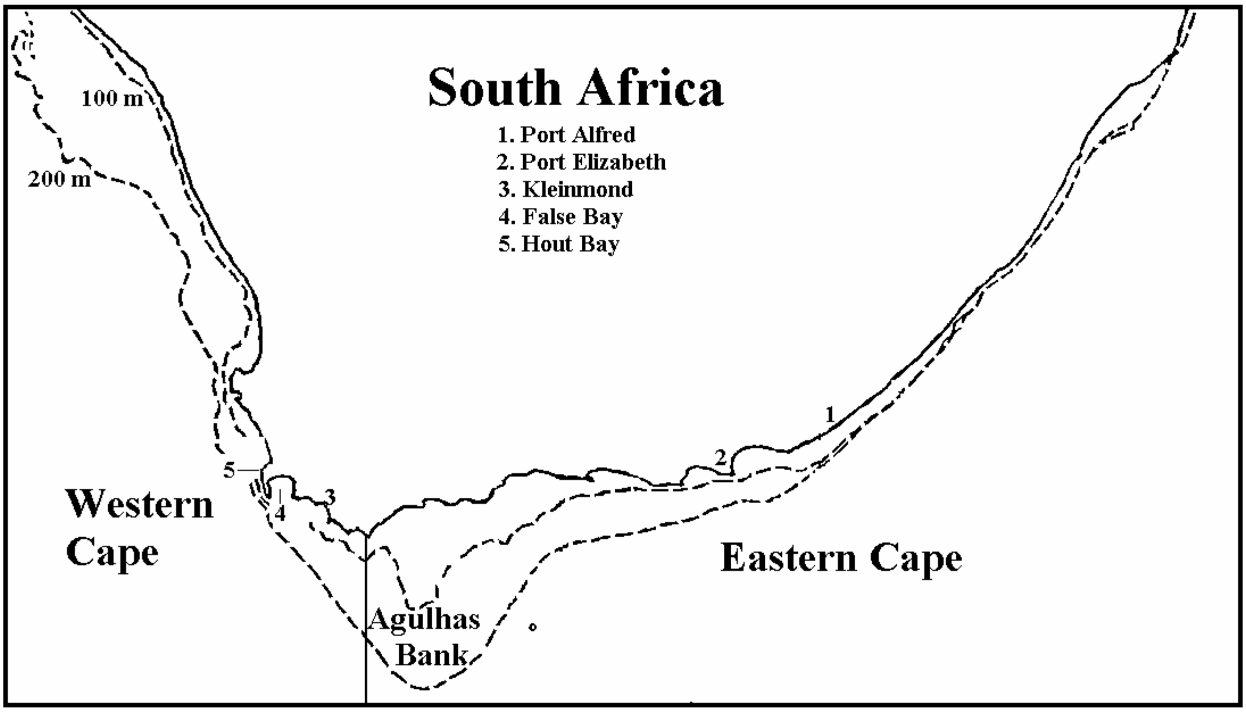

Figure 1. Collection sites of *Octopus vulgaris* around the South African coast.

Table 1. Number of tissue samples of *Octopus vulgaris* collected per region and site.

Region	Site	Number
Eastern Cape	Port Alfred	10
	Port Elizabeth	11
Western Cape	Kleinmond	5
	False Bay	4
	Hout Bay	5

DNA extraction, PCR and Sequencing

The total genomic DNA was extracted using a Qiagen DNeasy® Tissue Kit, after addition of the ATL Buffer and proteinase K the tissue was incubated overnight at 55^{o}C before the protocol was completed. The elute was tested on agarose gel to determine DNA yield.

Initial primers were designed (Prof R. Kirby, Rhodes University) to amplify 700 base pairs (bp) of the COIII region, however, no products were amplified. A second set of primers was then designed (M. Jivaji, Rhodes University) to match conserved regions within the COIII sequences available in Genbank for *O. vulgaris*. A 380 bp segment of the COIII region of mitochondrial DNA was amplified using the polymerase chain reaction (PCR) with these specific designed primers: mtDNA forward 5´-ACCATAATTCAATGATGACGTGATATT-5´ and mtDNA reverse 5´-AAATAGAAAATGATGCTTCTATATATTCTAA-3´ supplied by Inqaba Biotech (Pretoria, South Africa). The PCR reactions were set up in 25µl reaction volume, containing: 2.5µl 10x NH_4 Buffer, 2.5µl 50mM $MgCl_2$, 2.5µl BSA, 2.0µl 100mM dNTPs, 1µl primer (3.2 pmol), 0.4µl Taq (BIOTAQ^{TM} DNA Polymerase) and 1 - 5 µl DNA. Thermal cycling was hot started (96^{o}C for 5 min, held at 85 ^{o}C while Taq was added) followed by five cycles of 93^{o}C (50 sec), 45^{o}C (50 sec) and 72^{o}C (1 min), followed by 28 cycles of 93^{o}C (50 sec), 50^{o}C (30 sec) and 72^{o}C (1 min). The last step of 72^{o}C was prolonged for 5 minutes (Söller et al. 2000). The amplified product was cut out of agarose gel and purified using a Promega Wizard® SV Gel and PCR Clean-up System. DNA was sequenced in one direction (forward) using BigDye® Terminator v3.1 Cycle Sequencing Kit and run on a ABI 3100 Genetic Analyser (PE AppliedBiosystems).

Data analysis

Sequences from 21 samples from the Eastern, and 14 samples from the Western Cape was compared to determine whether different populations exist along the South African coast.

Sequences were aligned using ClustalW in BioEdit (Hall 1999) with further modifications by eye. Analyses were carried out with both 595 bp region (Published sequences only) and the 380 bp region (published plus sequence from this study).

Phylogenetic inference was made using maximum parsimony (MP), maximum likelihood (ML) and distance based methods in PAUP* 4.0b10 (Swofford 1998) and MEGA version 2.1 (Kumar et al. 2001). Distance analysis was performed using neighbour joining (NJ), assuming a Kimura two-parameter and HKY85 model (Hasegawa et al. 1985) of sequence evolution. For MP analysis a heuristic search algorithm, with tree-bisection, branch swapping and random sequence addition was used. Insertions and deletions were treated as missing data in all tree construction, and confidence was assessed by 1000 bootstrap resamplings for distance, parsimony and maximum likelihood approaches. *Loligo vulgaris reynaudii* (EMBL/Genbank accession number: X97960) was used as an out-group to root all trees.

RESULTS

Sequence comparisons

No sequence variation was observed between individuals from the same region or between individuals from the eastern (n = 21) and western Cape (n = 14) regions. All sequences conformed to a single haplotype. Lack of variation within and between east and west coast samples prohibited further population genetic analysis.

The sequence obtained in this study was an exact match to a previous *O. vulgaris* COIII sequence from False Bay, South Africa and from Tristan da Chuna lodged by Warnke (1999b) in Genbank (Accession numbers SA: AJ250487, TdC: AJ250477). The South African COIII sequence from the present study was compared to a range of *O. vulgaris* and other octopus species COIII sequences lodged in the EMBL/Genbank database (Table 2). The 380 bp COIII region of *O. vulgaris* sequenced in this study is illustrated in figure 2.

Table 2. Abbreviations, origin and accession numbers of DNA sequences for the various species compared.

Species	Abbreviation	Origin	Accession number
Octopus vulgaris	*O. v.1*	South Africa, this study	-
	O. v. 2	South Africa	AJ250487
	O. v. 3	Tristan da Cunha	AJ250477
	O. v. 4	Senegal	AJ250476
	O. v. 5	Mediterranean	AJ012121
	O. v. 6	Taiwan	AJ250479
	O. v. 7	Venezuela	AJ250478
	O. v. 8	North Brazil	AJ012123
	O. v. 9	North Brazil	AJ012124
	O. v. 10	Costa Rica, Caribbean	AJ012126
	O. v. 11	Costa Rica, Caribbean	AJ012127
	O. v. 12	Costa Rica, Pacific	AJ012125
Octopus mimus	*O. m.1*	Costa Rica, Pacific	AJ250480
Octopus mimus	*O. m.2*	North Chile	AJ012128
Octopus bimaculoides	*O. o.*	USA, California	AJ250482
Octopus bimaculatus	*O. a.*	USA, California	X83100
Octopus dolfeini	*O. d.*		X83103
Loligo vulgaris reynaudii	*L. r.*		X97960

Figure 2. The 380 bp COIII region of *O. vulgaris* sequenced in this study, aligned and compared to octopus COIII sequences from other regions.

O. v. 5 (Mediterranean)	1	TCGAGAAAGTACATTTCAAGGTTTCCACACATCCAAAGTA	40
O. v. 1 (S.A. This study)	1	....	40
O. v. 2 (South Africa)	1	....	40
O. v. 3 (Tristan da Cunha)	1	....	40
O. v. 4 (Senegal)	1	....	40
O. v. 6 (Taiwan)	1	.....................C...........T......	40
O. v. 7 (Venezuela)	1	C.......................T..T............	40
O. v. 8 (North Brazil)	1	C........A..............T..T.....T.....C	40
O. v. 9 (North Brazil)	1	C........A..............T..T.....T.....C	40
O. v. 10 (Costa Rica, Caribbea	1	C........A..............T..T.....T..G..T	40
O. v. 11 (Costa Rica, Caribbea	1	C........A..............T..T.....T..G..T	40
O. v. 12 (Costa Rica, Pacific)	1	C........A..............T..T.....T..G..T	40
O. m. 1 (Costa Rica, Pacific)	1	C........A..............T........T..G..T	40
O. m. 2 (North Chile)	1	C........A..............T..T.....T..G..T	40
O. o. (USA, California)	1	.........A..............T..T.....T......	40
O. a. (USA, California)	1	.........A...........C..T..T............	40
O.d.	1	.........A.....C.....A..T.....TA.T.....T	40
Loligo (X97960)	1	C........A...........C.A...T...CTA.....C	40
O. v. 5 (Mediterranean)	41	TATAATGGCCTTCGATGAGGTATAATACTTTTTATTATTT	80
O. v. 1 (S.A. This study)	41	......................................C.	80
O. v. 2 (South Africa)	41	......................................C.	80
O. v. 3 (Tristan da Cunha)	41	......................................C.	80
O. v. 4 (Senegal)	41	....	80
O. v. 6 (Taiwan)	41	.............................C..........	80
O. v. 7 (Venezuela)	41	........T....................C..........	80
O. v. 8 (North Brazil)	41	.....C..AT.A.................C..........	80
O. v. 9 (North Brazil)	41	.....C..AT.A.................C..........	80
O. v. 10 (Costa Rica, Caribbea	41	........GT.A............................	80
O. v. 11 (Costa Rica, Caribbea	41	........GT.A............................	80
O. v. 12 (Costa Rica, Pacific)	41	........GT.A............................	80
O. m. 1 (Costa Rica, Pacific)	41	........GT.A............................	80
O. m. 2 (North Chile)	41	........GT.A............................	80
O. o. (USA, California)	41	........AT.A....................C.......	80
O. a. (USA, California)	41	.....C..AT.A............................	80
O.d.	41	........GT.A.................A......G.A.	80
Loligo (X97960)	41	.CGTTA..TA.A...AT...G...G.TT.A.....C.CC.	80
O. v. 5 (Mediterranean)	81	CAGAAGTATGTTTCTTTTTTGCTTTCTTTTGAGCCTATTT	120
O. v. 1 (S.A. This study)	81	..................................T.....	120
O. v. 2 (South Africa)	81	..................................T.....	120
O. v. 3 (Tristan da Cunha)	81	..................................T.....	120
O. v. 4 (Senegal)	81	..................................T.....	120
O. v. 6 (Taiwan)	81	....	120
O. v. 7 (Venezuela)	81	....	120
O. v. 8 (North Brazil)	81	.......T.....T...........T........T.....	120
O. v. 9 (North Brazil)	81	.......T.....T...........T........T.....	120
O. v. 10 (Costa Rica, Caribbea	81	.............T....................T.....	120
O. v. 11 (Costa Rica, Caribbea	81	.............T....................T.....	120
O. v. 12 (Costa Rica, Pacific)	81	.............T.....G.....T........T.....	120
O. m. 1 (Costa Rica, Pacific)	81	.............T...........T........T.....	120
O. m. 2 (North Chile)	81	.............T.....G.....T........T.....	120
O. o. (USA, California)	81	.............T..C........T........A.....	120
O. a. (USA, California)	81	.............T...........T........G.....	120
O.d.	81	.....A.T.....T..C.....C..T........T..C..	120
Loligo (X97960)	81	.C...........T...G.......T........T.....	120
O. v. 5 (Mediterranean)	121	CCATAGTAGTTTAGCTCCTAATATAGATATTGGATCATGT	160
O. v. 1 (S.A. This study)	121	T..C....................................	160
O. v. 2 (South Africa)	121	T..C....................................	160

```
O. v. 7 (Venezuela)          241 ...T..............T..................... 280
O. v. 8 (North Brazil)       241 ...T..T...........T..C...T...........A.C 280
O. v. 9 (North Brazil)       241 ...T..T...........T..C...T...........A.C 280
O. v. 10 (Costa Rica, Caribbea 241 .........A........T....................C 280
O. v. 11 (Costa Rica, Caribbea 241 .........A........T....................C 280
O. v. 12 (Costa Rica, Pacific) 241 ......T..A........T......T...........A.C 280
O. m. 1 (Costa Rica, Pacific)  241 ......T..A........T......T...........A.C 280
O. m. 2 (North Chile)        241 ......T..A........T......T...........A.C 280
O. o. (USA, California)      241 ......T........T..T..................A.. 280
O. a. (USA, California)      241 ......T...........T..................A.C 280
O.d.                         241 ...T..A........T.....C..........GA...A.A 280
Loligo (X97960)              238 .A.A..A...............CG.A.T...C.CGG.A.. 277

O. v. 5 (Mediterranean)      281 TTAAAATCCGCAACTCACTCTATAATTATTACTATTTCCT 320
O. v. 1 (S.A. This study)    281 ........................................ 320
O. v. 2 (South Africa)       281 ........................................ 320
O. v. 3 (Tristan da Cunha)   281 ........................................ 320
O. v. 4 (Senegal)            281 ........................................ 320
O. v. 6 (Taiwan)             281 ........................................ 320
O. v. 7 (Venezuela)          281 ....................C................... 320
O. v. 8 (North Brazil)       281 C................T....................T. 320
O. v. 9 (North Brazil)       281 C................T....................T. 320
O. v. 10 (Costa Rica, Caribbea 281 C................T.........G.......C.... 320
O. v. 11 (Costa Rica, Caribbea 281 C................T.........G.A.....C.... 320
O. v. 12 (Costa Rica, Pacific) 281 C................T.........G.M.....C..T. 320
O. m. 1 (Costa Rica, Pacific)  281 C................T...........C.....C..T. 320
O. m. 2 (North Chile)        281 C................T.........G.A.....C..T. 320
O. o. (USA, California)      281 C...................C.....C.....C..C.... 320
O. a. (USA, California)      281 C............................C..C..C.... 320
O.d.                         281 .....TC.A..T.T...........C...C..C..CA.A. 320
Loligo (X97960)              278 CAC.T.GAAT.T..C..A..C...GCAT.G..G...ATT. 317

O. v. 5 (Mediterranean)      321 TAGGATTTTATTTTACAATCCTTCAAATATTAGAATATAT 360
O. v. 1 (S.A. This study)    321 ...................T.................... 360
O. v. 2 (South Africa)       321 ...................T.................... 360
O. v. 3 (Tristan da Cunha)   321 ...................T.................... 360
O. v. 4 (Senegal)            321 ........................................ 360
O. v. 6 (Taiwan)             321 ....G.................C............G..... 360
O. v. 7 (Venezuela)          321 ...................T..C................. 360
O. v. 8 (North Brazil)       321 ..........C...............G.GA.......... 360
O. v. 9 (North Brazil)       321 ..........C..C............G.GA.......... 360
O. v. 10 (Costa Rica, Caribbea 321 .............C........C................. 360
O. v. 11 (Costa Rica, Caribbea 321 .............C.......................... 360
O. v. 12 (Costa Rica, Pacific) 321 .............C.......................... 360
O. m. 1 (Costa Rica, Pacific)  321 .............C.......................... 360
O. m. 2 (North Chile)        321 .............C.......................... 360
O. o. (USA, California)      321 ..........C........T..A................. 360
O. a. (USA, California)      321 ..........C........T..C................. 360
O.d.                         321 .................T.TT.A......A.......... 360
Loligo (X97960)              318 ....TACA..C..C...T.T......GCTGA.......T. 357

O. v. 5 (Mediterranean)      361 AGAAGCATCATTTTCTATTT 380
O. v. 1 (S.A. This study)    361 .................... 380
O. v. 2 (South Africa)       361 .................... 380
O. v. 3 (Tristan da Cunha)   361 .................... 380
O. v. 4 (Senegal)            361 .................... 380
O. v. 6 (Taiwan)             361 .................... 380
O. v. 7 (Venezuela)          361 .................... 380
O. v. 8 (North Brazil)       361 .................... 380
O. v. 9 (North Brazil)       361 .................... 380
```

```
O. v. 10 (Costa Rica, Caribbea  361 ..................C. 380
O. v. 11 (Costa Rica, Caribbea  361 ..................C. 380
O. v. 12 (Costa Rica, Pacific)  361 ..................C. 380
O. m. 1 (Costa Rica, Pacific)   361 ..................C. 380
O. m. 2 (North Chile)           361 ..................C. 380
O. o. (USA, California)         361 .................... 380
O. a. (USA, California)         361 ...G................ 380
O.d.                            361 T.................C. 380
Loligo (X97960)                 358 ...G..TC.G.....C..C. 377
```

Phylogenetic trees

The tree construction methods of neighbour joining and maximum parsimony revealed similar topology for both the 380 bp and 595 bp regions (Fig. 3 & 4, 380 bp region shown only). Four distinct clusters were visible. The South African and Tristan da Cunha haplotypes fell within the Mediterranean cluster also containing Senegal, Taiwan and Venezuela. A second cluster consisted of the *O. vulgaris/O. mimus* complex from Costa Rica and North Chile, while the last two groups were formed by *O. vulgaris* from North Brazil and *O. bimaculatus/bimaculoides* from California. All these clusters were supported by high bootstrap values (92 - 100%).

Average sequence divergence was calculated within and between groups (Table 3 & 4: Mediterranean group: *O. v.* 1-7; Costa Rica group: *O. v.* 10, 11 & *O. m.* 1, 2; North Brazil group: *O. v.* 8, 9 and *O bimaculatus/bimaculoides* group). *O. vulgaris* from South Africa displayed less sequence divergence from Senegal (0.79%) and Mediterranean (1.32%) individuals compared to *O. vulgaris* from other regions (4.21 - 4.47%).

Table 3. Mean percentage (%) sequence divergence within the Mediterranean group.

	Mediterranean		**South Africa**		**Senegal**		**Taiwan**	
	380 bp	595 bp	380 bp	595 bp	380 bp	595 bp	380 bp	595 bp
Mediterranean	-							
South Africa	1.32	1.51	-					
Senegal	0.53	0.17	0.79	0.67	-			
Taiwan	3.16	2.86	4.21	3.87	3.68	3.36	-	
Venezuela	3.68	3.53	4.47	3.85	4.21	3.53	5.26	4.03

Table 4. Mean percentage (%) sequence divergence for each group.

	380 bp	**595 bp**
Mediterranean	3.131	2.738
Costa Rica	2.527	2.318
Brazil	0.26	0.19
California	16.59	16.47

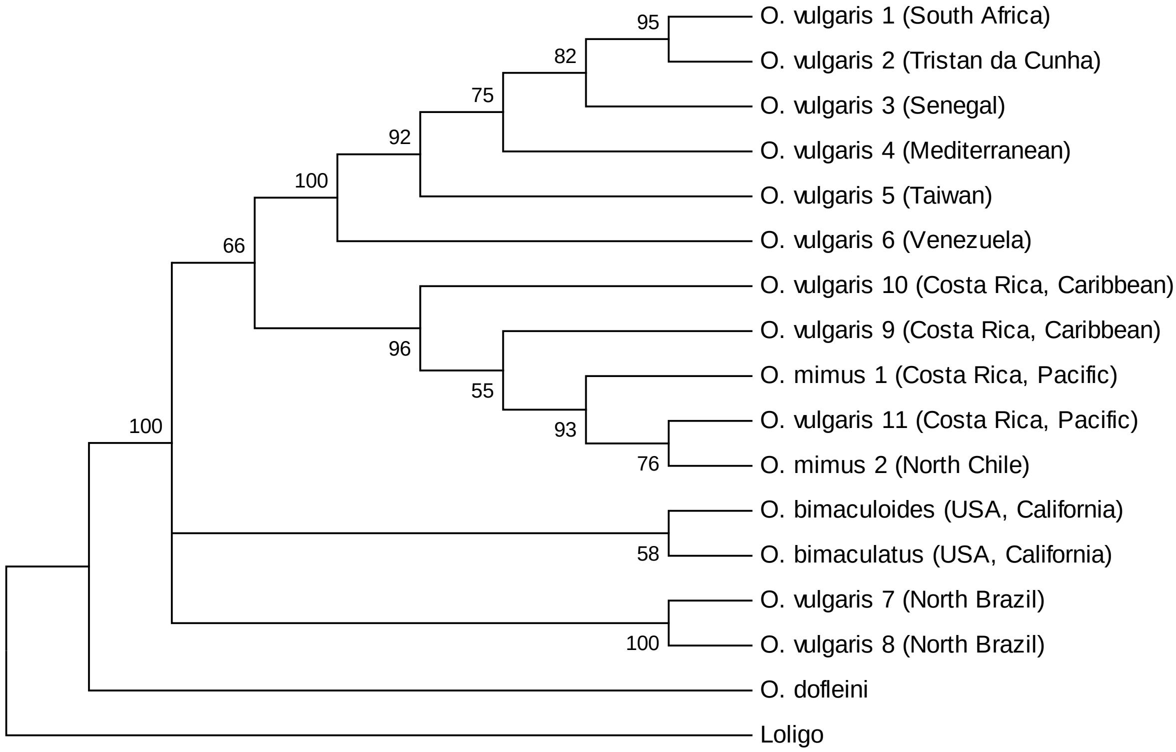

Figure 3. Maximum parsimony tree (in Mega, Branch & bound) constructed from aligned *Octopus vulgaris* and a range of other octopus species mtDNA COIII sequences. (Bootstrap values (%) after 1000 replications).

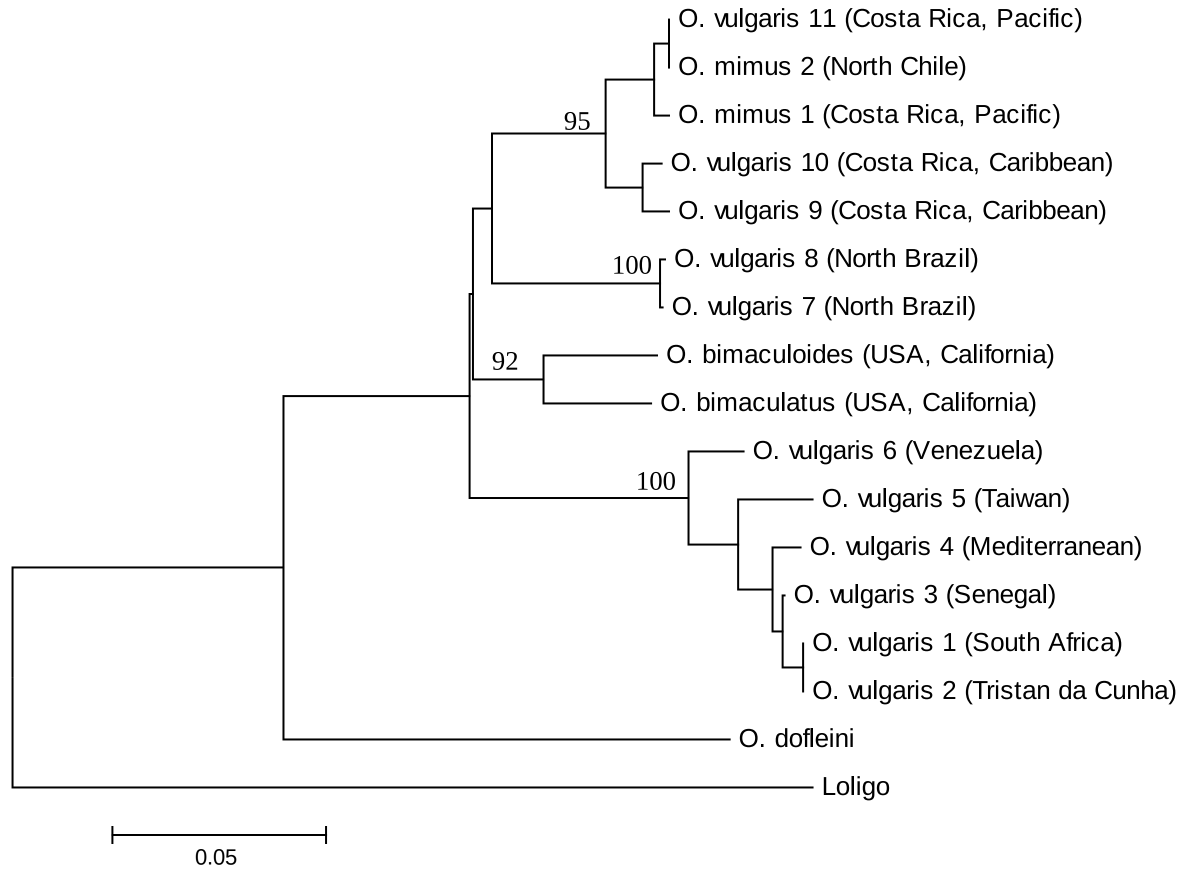

Fig. 4 Neighbour Joining (assuming Kimura-2 parameter model) tree constructed from aligned *Octopus vulgaris* and a range of other octopus species mtDNA COIII sequences in Mega. (Bootstrap values (%) after 1000 replications). Scale bar indicates branch length.

Distance matrixes using Kimura-2 parameter (Table 5) and Jukes- Cantor, HKY 85 (data not shown) models produced similar values. This distance data also support the close relation (0.01 - 0.0 = no divergence) between the South African, Tristan da Cunha, Senegal and Mediterranean sequences.

Table 5. Pairwise distances between haplotypes based on the Kimura-2 parameter model. Haplotype designations as in Table 2.

		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**
1	**Loligo**																	
2	**Ov 5**	0.38	-															
3	**Ov 1**	0.36	0.01	-														
4	**Ov 7**	0.36	0.04	0.04	-													
5	**Ov 11**	0.35	0.10	0.10	0.09	-												
6	**Ov 10**	0.35	0.12	0.12	0.10	0.01	-											
7	**Ov 12**	0.34	0.14	0.14	0.12	0.03	0.03	-										
8	**Ov 9**	0.32	0.13	0.13	0.11	0.08	0.09	0.08	-									
9	**Ov 8**	0.33	0.12	0.13	0.11	0.09	0.09	0.08	0.00	-								
10	**Om 2**	0.34	0.14	0.14	0.12	0.03	0.03	0.00	0.08	0.08	-							
11	**O d**	0.36	0.23	0.22	0.22	0.20	0.20	0.20	0.20	0.20	0.20	-						
12	**Ov 4**	0.37	0.01	0.01	0.04	0.10	0.11	0.13	0.12	0.12	0.13	0.22	-					
13	**Ov 6**	0.37	0.03	0.04	0.04	0.11	0.11	0.14	0.14	0.13	0.14	0.23	0.03	-				
14	**Om 1**	0.34	0.13	0.13	0.12	0.03	0.03	0.01	0.08	0.08	0.01	0.19	0.12	0.13	-			
15	**Oo**	0.35	0.12	0.12	0.10	0.09	0.09	0.09	0.09	0.09	0.09	0.18	0.12	0.12	0.09	-		
16	**Oa**	0.34	0.12	0.12	0.11	0.09	0.09	0.09	0.09	0.08	0.09	0.19	0.12	0.13	0.09	0.05	-	
17	**Ov 3**	0.36	0.01	0.00	0.04	0.10	0.12	0.14	0.13	0.13	0.14	0.22	0.01	0.04	0.13	0.12	0.12	-

DISCUSSION

No distinction could be made between *Octopus vulgaris* collected on the east and west coasts of South Africa on the basis of genetic variation in the COIII region. These data do not, therefore, refute the hypothesis of a single *O. vulgaris* genetic population around the coast. *O. vulgaris* has planktonic larvae, and oceanographic studies along the South African coast have suggested that the dispersal of ichthyoplankton may occur over a large scale (Roberts & van den Berg in press.). Population genetic studies on several other species around the South African coast have shown no genetic variation between west and east coasts. Most of these studies were conducted on demersal teleosts (Grant et al. 1987; Leslie & Grant 1990) and benthic invertebrates (Lombart & Grant 1986) with planktonic eggs and larvae, indicating free movement of larvae between the west and east coast.

Molecular genetic analysis of cephalopods have however, been hampered by low levels of variability (Shaw et al. 1999). The COIII region examined here might be too conserved, i.e. there is not enough genetic variation present to show differences between populations and other methods such as microsatellite DNA markers should be explored to investigate population structures. Microsatellite markers are now available for octopus and have been used in a population study on octopus in northwest Africa (Greatorex et al. 2000; Murphy et al. 2002). Genetic variability detected by the microsatellites indicated that more than two genetically distinct populations exist of the northwest coast of Africa (Murphy et al. 2002). Microsatellites were also successfully employed to distinguish population structuring in squid (*Loligo forbesi*) where other techniques such as mtDNA and allozymes failed to detect differences (Shaw et al. 1999). The South African *O. vulgaris*, based on data from this study should be treated as a single population for fishery management purposes until more in depth genetic research can be conducted.

Phylogenetically the South African *O. vulgaris* is closely related to *O. vulgaris* from Senegal (0.79 % divergence) and the Mediterranean (1.32 % divergence). These results are similar to that found by Warnke et al. (2000) and Söller et al. (2000). Warnke et al. (2000) further postulated that populations from France, Senegal, South Africa, Tristan da Cunha and Venezuela are from the same taxon. However, the high sequence divergence (this study, 3.16-5.26%) between the Mediterranean (including South Africa, Senegal) and Taiwan and Venezuela might support conclusions drawn from morphological data by Mangold & Hochberg (1991) and Mangold (1997), which indicated a Mediterranean and eastern Atlantic distribution only. Nevertheless, further taxonomic classification of octopus should take in consideration morphology, reproductive and molecular data to ensure an all rounded approach to systematic analyses.

ACKNOWLEDGEMENTS

I would like to thank Dr Paul Shaw (Royal Holloway, University of London) for advice during this study and comments on a draft of this work, and the staff and students of the Department of Biochemistry, Microbiology and Biotechnology (Rhodes University) for their help and support to a novice in the molecular field. In particular, Mez Jivaji and William Modisakeng. This project was funded by Rhodes University.

REFERENCES

ALTUKHOV Y.P. 1981. The stock concept from the viewpoint of population genetics. *Can. J. Fish. Aquat. Sci*. **38**: 1523-1538.

BARTLEY D.M., BENTLEY B., OLIN P.G. and GAL G.A.E. 1992. Population genetics structure of the coho salmon (*Oncorhynchus kisutch*) in California. *Cal. Fish. Game* **78**: 88-104.

BEACHAM T.D. WITHLER R.E. and GOULD A.P. 1995. Biochemical genetic stock identification of chum salmon (*Oncorhynchus keta*) in southern British Columbia. *Can. J. Fish. Aquat. Sci*. **42**: 437-448.

BEGG G.A., FRIEDLAND K.D. and PEARCE J.B. 1999. Stock identification and its role in assessment and fisheries management: an overview. *Fish. Res.* **43**: 1-8.

BONNAUD, L., BOUCHER-RODONI R. and MONNEROT M. 1997. Phylogeny of cephalopods inferred from mitochondrial DNA sequences. *Mol. Phylogenet. Evol.* **7**: 44-54.

BRIERLY A.S., RODHOUSE P.G., THORPE J.P. and CLARKE M.R. 1993. Genetic evidence of population heterogeneity and cryptic speciation in the ommastrephid squid *Martialia hyadesi* from the Patagonian shelf and Antarctic Polar Frontal Zone. *Mar. Biol.* **116**: 593-602.

CARVALLO G.R., THOMPSON A. and STONER A.L. 1992. Genetic diversity and population differentiation of the shortfin squid *Illex argentinus* in the south-west Atlantic. *J. Exp. Mar. Biol. Ecol.* **158**: 105-121.

DE LOS ANGELES BARRIGA SOSA I., BECKENBACH K., HARTWICK E.B. and SMITH M.J. 1995. The molecular phylogeny of five eastern North Pacific octopus species. *Molec. Phylogenet. Evol.* **4**: 163-174.

GREATOREX E.C., JONES C.S., MURPHY J., KEY L.N., EMERY A.M. and BOYLE P.R. 2000. Microsatellite markerz for investigating population structure in *Octopus vulgaris* (Mollusca: Cephalopoda). *Mol. Ecol.* **9**(5):641

GRANT W.S., LESLIE R.W and BECKER I. 1987. Genetic stock structure of southern African hakes, *Merluccius capensis* and *M. paradoxus*. *Mar. Ecol. Prog. Ser*. **41**: 9-20.

HALL, T.A. 1999. BioEdit: a user-friendly biological sequence alignment editor and analysis program for Windows 95/98/NT. *Nucl. Acids. Symp. Ser*. **41:** 95-98.

HASEGAWA M., KISHINO H. and YANO T. 1985. Dating of the human-ape splitting by a molecular clock of mitochondrial DNA. *J. Mol. Evol.* **21**: 32-38.

IMSIRIDOU A., APOSTOLISDIS A. P., DURAND J-D., BRIOLAY J., BOUVET Y. and TRIANTAPHYLLIDIS C. 1998. Genetic differentiation and phylogenetic relationships among Greek Chub *Leuciscus cephalus* L. (pisces, Cyprinidae) populations as revealed by RFLP analysis of mitochondrial DNA. *Biochem. Sys. Ecol.* **26**: 415-429.

KATSAROU E. and NÆVDAL G. 2001. Population genetics of the roughhead grenadier, *Macrourus berglax* L., in the North Atlantic ocean. *Fish. Res.* **51**: 207-215.

KUMAR S., TAMURA K. and NEI M. 2001. MEGA: Molecular evolutionary genetics analysis, Ver. 1.01. Pennsylvania State University, University Park.

LESLIE R.W. and GRANT W.S. 1990. Lack of Congruence between genetic and morphological stock structure of the Southern African anglerfish *Lophuis vomerinus*. *S. Afr. J. mar. Sci*. **9**: 379-398.

LOMBART A.T. and GRANT W.S. 1986. Biochemical population genetics of the black mussel *Choromytilus meridionalis. S Afr. J. Zool.* **21**(2): 131-135

MANGOLD K. 1997. *Octopus vulgaris*: Review of the biology. In: Proceedings of the workshop on: *The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (eds). Smithsonian Institution, Washington. 85-90.

MANGOLD K. and HOCHBERG F.G. 1991. Defining the genus *Octopus*: redescription of *Octopus vulgaris*. *Bull. Mar. Sci.* **49**: 665 pp.

MURPHY J.M., BALGUERÍAS L.N. and BOYLE P.R. 2002. Microsatellite DNA markers discriminate between two *Octopus vulgaris* (Cephalopoda: Octopoda) fisheries along the northwest African coast. *Bull. Mar. Sci.* **72**(1): 545-553.

NORMAN J., MURPHY J.M., PIERCE G. and BOYLE P.R. 1994. Preliminary molecular genetic analysis of stock structure in the squid *Loligo forbesi* (Steenstrup). *ICES Shelfish Committee C. M. 1994/K.* **23**: 8 pp.

RICKER W.E. 1981. Changes in the average size and average age of Pacific salmon. *Can. J. Fish. Aquat. Sci*. **38**: 1636-1656.

ROBERTS M.J. and VAN DEN BERG, M. in press. ADCP measured currents along the Tsitsikamma coast (South Africa) and potential transport of squid paralarvae and ichthyoplankton. *Afr. J. mar. Sci.*

ROELEVELD M.A.C. 1998. The status and importance of cephalopod systematics in southern Africa. *S. Afr. J. mar. Sci.* **20**:1-16.

SHAKLEE J.B., BEACHAM T.D., SEEB L. and WHITE B.A. 1999. Managing fisheries using genetic data: case studies from four species of Pacific salmon. . *Fish. Res.* **43**: 45-78.

SHAW P.W., PIERCE G.J. and BOYLE P.R. 1999. Subtle population structuring within a highly vagile marine invertebrate, the veined squid *Loligo forbesi*, demonstrated with microsatellite DNA markers. *Mol. Ecol*. **8**: 407-417.

SMITH P.J., FRANCIS R.I.C.C. and MCVEAGH M. 1991. Loss of genetic diversity due to fishing pressure. *Fish. Res.* **10**: 309-316.

SMITH P.J., ROBERTSON S.G., HORN P.L., BULL B., ANDERSON O.F., STANTON B.R. and OKE C.S. 2002. Multiple techniques for determining stock relationships between orange royghy, *Hoplostethus atlanticus*, fisheries in the eastern Tasman Sea. *Fish. Res.* **58**: 119-140.

SÖLLER R., WARNKE K., SAINT-PAUL U. and BLOHM D. 2000. Sequence divergence of mitochondrial DNA indicates cryptic biodiversity in *Octopus vulgaris* and supports the taxonomic distinctiveness of *Octopus mimus* (Cephalopoda: Octopodidae). *Mar. Biol*. **136**: 29-35.

SWOFFORD D.L 1998. PAUP: Phylogenetic analysis using parsimony, Ver. 4.0d64. Smithsonian Institution, Washington DC.

WARNKE K.1999a. Diversität des Artenkomplexes *Octopus cf vulgaris* Cuvier, 1797 in beziehung zu seiner Verbreitung an der Ost- und Westküstes Lateinamerikas. PhD thesis Universität Bremen, Shaker Verlag, Aachen.141pp.

WARNKE K.1999b. AJ250487, AJ250477. Direct submission to Genbank database, 20-OCT-1999, Biotechnology & Mol. Genetics (FB2-UFT), University of Bremen / Center for Tropical Marine Ecology, Leobener Str., Bremen, 28359, GERMANY.

WARNKE K., SOLLER R., BLOHM D. and SAINT-PAUL U. 2000. Rapid differentiation between *Octopus vulgaris* Cuvier (1797) and *Octopus mimus* Gould (1852), using randomly amplified DNA. *J. Zool. Syst. Evol. Res*. **38**: 119-122.

CHAPTER 7

PHASE 0: STEP 3 - ECONOMIC FEASIBILITY OF AN EXPERIMENTAL OCTOPUS FISHERY IN SOUTH AFRICA.

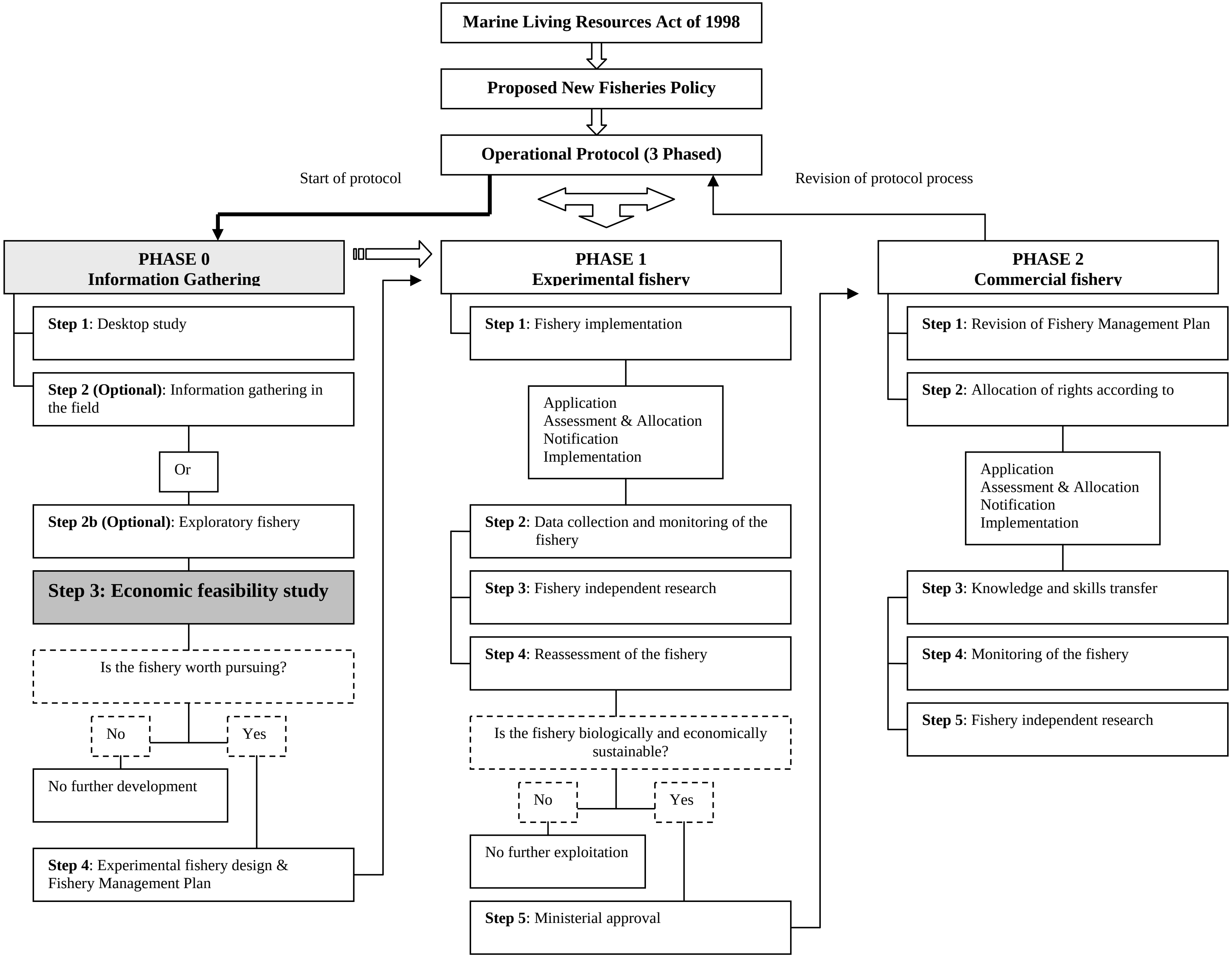

Figure C. Step 3: Economic feasibility study of proposed fishery.

CHAPTER 7

PHASE 0: STEP 3 - ECONOMIC FEASIBILITY OF AN EXPERIMENTAL OCTOPUS FISHERY IN SOUTH AFRICA

INTRODUCTION

Fisheries exist because they provide social and economic benefits to society, and the way in which a fishery is managed will impact, either positively or negatively, on those benefits (Cochrane 2002). The aim of creating new fishing opportunities in South Africa is to achieve economic growth within coastal areas, focussing on small- and medium-enterprise development; and thereby create employment opportunities, develop human resources and enhance transformation in the fishing sector (Britz et al. 2001). It is important for the fisheries manager to have an understanding of the underlying economic and social factors, to fully comprehend the impact that the management of the resource has on these factors (Cochrane 2002).

Economic and social analysis of a fishery should be presented, in the same fashion as biological and ecological data, for the management decision-making process. In establishing new fisheries it is important to have knowledge of the following factors (as identified in Chapter 2) to determine the economic feasibility of a fishery:

- Vessel and gear type
- Fishing techniques
- Gear selectivity
- Expected catch rates
- Local and international markets
- Cost of fishing.

This knowledge is not only necessary for the fishery manager responsible for the formulation of an experimental fishery, but also for the prospective fisher, who must submit a business plan as part of the permit application process. Pre-empting the economic viability of the resource will thus help to develop and manage the fishery sustainably from its inception. This chapter focuses specifically on the economic feasibility of the proposed octopus pot fishery. *Octopus vulgaris* was identified by industry as the target of a possible commercial venture. Subsequently, it was determined to be a species well suited to the proposed venture in terms of geographic and depth distribution, biology, marketability and demand (Guerra 1997; Smith 1999; Chapter 3).

The aim of this work was to describe the fishing activity and calculate the minimum CPUE for various fishing operation scenarios to determine the economic feasibility. It is important to note that this is only an **estimated** minimum CPUE, based on assumptions that cannot be confirmed until the fishery starts. Furthermore, this economic analysis also needs to be assessed by stakeholders with experience in the operation of a fishery.

DESCRIPTION OF THE PROPOSED FISHERY

Vessel type

The proposed fishery should be compatible with other existing fisheries to prevent both user conflict and capital expenditure at the start of the new fishery. Vessels in the existing fisheries fleet should thus be suitable for use in the new fishery. Vessels sizes of 3 - 5 tons were suggested by Smith (1999) because similar vessels are used in existing fisheries such as the linefishery, the rock lobster fishery, the hake-directed handline fishery, and the squid fishery. These fisheries occur mainly along the west, southwestern, southern and southeastern Cape coasts. Similar sized vessels were also used in other experimental octopus fisheries (Whitaker et al. 1991). The South African vessels in the specified size class vary from small 5 - 8 m (chukkies, skiboats) to medium 14 - 25 m length (deckboats) vessels (Smith 1999). Furthermore, the vessels should be fitted with an echosounder, a GPS plotter and a line-hauler. This equipment will enable the accurate determination of depth, fishing substrate, fishing areas, and location and retrieval of fishing gear. It was recommended by Smith (1999) that only two to three crewmen is needed for such a fishing operation.

This study will focus on two different sized vessels, a 14 m deckboat (Fig. 1) powered by two 285 hp inboard diesel engines and a smaller 8 - 10 m wooden “chukkie” (Fig. 2) with a six-cylinder diesel engine. These smaller vessels only operate in the west and southwestern Cape regions, generally out of small harbours, while the larger vessels are found around the entire coast. For the purpose of this study, three crewmen and one skipper will operate the deckboat, while only two crewmen and a skipper will operate the chukkie.

Gear type

Smith (1999) recommended pot fishing on longlines for the South African experimental fishery. This is also the method that has been used most commonly in other experimental octopus fisheries (see Chapter 3). The fishing gear consists of long lines with a number of pots (unbaited, no hooks) attached at intervals. The lines are anchored and buoyed at each end. The pots could consist of PVC pipe and tire pots either closed off in the middle or at one end (Fig. 3). These are similar in structure to those described by Whitaker et al. (1991). The specific structure in terms of length of the line and number of pots per line, as well as soak times, will be at the discretion of the individual fisher.

For the purpose of this study, two configurations of gear and soak times were compared. The first consisted of a large number of short lines, with a short soak period, while the second comprised few but longer lines with a longer soak period (Table 1). Pots used in this study consisted of PVC pipes, approximately 50 cm in length and 11 cm in diameter (Whitaker et al. 1991; Smith 1999).

Figure 1. The larger deckboat (14 - 25 m) vessel to be used in the octopus pot fishery.

Figure 2. Chukkies, the smaller (8 - 10 m) wooden vessels moored in a small boat harbour in the southwestern Cape.

Figure 3. Octopus pots consisting of PVC pipe (111 mm and 150 mm diameter) and half tires, closed off in the middle.

Fishing activity

The operational area for this fishery will be from Saldanha on the west coast to East London on the east coast, due to the wide continental shelf area along this stretch of coast. Octopus occurs to a depth of approximately 200 m, with abundance decreasing with increasing depth. The fishing depth range will therefore probably be 10 - 100 m, on relatively flat-profile bottom.

The smaller vessels only have the capacity to make day trips, so fishing activity will involve a number of traps being deployed and hauled each day. This might not apply to the larger vessels with capacity for multi-day trips, and these might engage in other fishing activities before and after gear deployment and retrieval. However, for the purpose of this study, fishing operations and cost calculations are limited to a daily fishing operation (see economic assumptions below regarding other fishing activities). Fishing days per month were calculated as follows (A detailed description of these fishing operations is presented in Table 1):

- There are approximately 20 days available to fishing per month, the rest allows for bad weather and vessel maintenance.
- Fishing operation 2 deploys all pots (900 year 1; 1950 year 2) on 6 lines (year 1) and 13 lines (year 2) for a seven day soak time (3 cycles of 7 days = 21 days). All lines are deployed and retrieved during only four sea going days (i.e. 4 fishing days)
- Fishing operation 1 deploys all pots (1000 year 1; 2000 year 2) on 40 lines (year 1) and 80 lines (year 2) for a four day soak time (4 cycles of 4 days = 16 days). Ten lines are deployed each day for the first 12 days (12 sea going days) and during the last four days, lines are only retrieved (4 sea going days; i.e. 16 fishing days).

Octopus will either be iced or frozen at sea, depending on the vessel type. The only processing required is removal of the beak and internal organs. Octopus will be exported directly by the fisher or sold to an intermediate for this purpose.

Gear selectivity

Pot fishing is a passive fishing method and highly selective towards the target species, so no bycatch is expected (Bjordal 2002).

Table 1. A description of the two different fishing operations employed in this study.

Fishing and gear design	Fishing operation 1	Fishing operation 2
No. of pots		
Year 1	1000	900
Year 2	2000	1950
Gear configuration Year 1	40 lines (220m each) with 25 pots per line	6 lines (1050m each) with 150 pots per line
Gear configuration Year 2	80 lines (220m each) with 25 pots per line	13 lines (1050m each) with 150 pots per line
Pot type	Single PVC closed in the middle	Single PVC closed in the middle
Fishing trips	Daily, deploying 10 lines a day,	Daily, deploying 6 lines
Soak time	4 days	7 days
Fishing days/month	16	4

EXPECTED CATCH RATES

Other experimental fisheries for octopus reported variable but low catch rates (Table 2). Catch rate is defined as the number of octopus caught per number of pots. The average size of octopus caught in South Carolina was 0.90 kg, with larger diameter pots catching larger individuals (Whitaker et al. 1991). Similar size classes are caught on the Senegalese coast (Diallo 2002). Biological studies on *O. vulgaris* around the South African coast indicate a mean size of approximately 1 - 1.2 kg. Seasonal variation is evident, with the mean octopus size during winter (600 g) being substantially smaller than in summer (1,5 – 2 kg) (Smith 1999; Chapter 3, Oosthuizen & Smale 2003). The expected catch rate for this study was set at 30%, with large individuals caught in summer and smaller octopus caught in winter.

Table 2. Catch rates from other octopus pot fisheries.

Fishery	Catch rate	Reference
†South Carolina	27.8 %,	Whitaker et al. 1991
†West Coast of Florida	45 - 90 %	Roper 1997
†Spanish Mediterranean	6 - 40 %	Sánchez & Obarti 1993
*Canada: Barkley Sound	0.63 %	Adkins et al. 1980
*Canada: Vancouver Island	0.26 - 8.44 %	Hartwick et al. 1982
*Canada: Prince Rupert	1.88 - 23.62 %	Clayton et al. 1992
*Alaska	21 %	Paust 1997

†Similar sized species to *O. vulgaris*.
*Large octopus species

MARKETS

Prospective fishermen and import/export companies were interviewed to collect market-related information. Information on octopus imports, exports and local supply are given in Appendix 4.

Local market

A very small local market exists for octopus and the only local species traded and consumed is *Octopus magnificus*. This large octopus is supplied by wholesalers, mostly to the Portuguese and Greek communities based predominantly in Gauteng and Cape Town (approximately 4 tons/month). Only *O. magnificus* is exported from South Africa, while imported octopus (from India and Asia) consists of “baby octopus” (sp. unknown). This product is mostly used in seafood restaurants. *O. vulgaris* is rarely traded, and generally only consumed by subsistence fisheries.

International market

The *O. magnificus* bycatch from the Namibian and South African west coast hake trawlers and south coast rock lobster traps are bought by local businesses and exported mainly to Portugal and Spain with some going to the United States and Belgium (approximately 170 tons/year). This species is frozen into 5 – 10 kg blocks and shipped to the various markets. The average ex-vessel price is R8 - 13/kg while the market price is R 14 – 18 /kg.

Markets for *O. vulgaris* exist in various countries, including Australia, Japan, Korea, Spain and Portugal (Fisheries Information Services 2001). These are large commercial/agricultural markets that sell fresh and frozen seafood, meat, fruit and vegetables, as well as other agricultural products. Octopus is generally graded into different sizes and usually sold frozen. Different grades (sizes) fetch different prices. An estimation of price, size ranges and product form of *O. vulgaris* sold on the European (Mercabana, Spain), Japanese (Tsujiki), and Australian (Sydney) markets are presented in Table 3. The Japanese market showed a slow but stable increase in price over the last year, while the Australian market showed high variability in price. The European market was fairly stable.

Table 3a. Examples of sizes, product forms and price of octopus sold on the European Market (Mercabarna – frozen octopus – 11/9/2002; Fisheries Information Services (2002)). 1 EUR = ± R 10.

Octopus Origin	Product Size	Product form	Price (EUR/kg)	Price (R/kg)
Morocco	0.5 kg	whole	7.15	71.5
Morocco	1 kg	whole	8.11	81.1
Morocco	2.5 kg	whole	8.71	87.1
Morocco	3 kg	whole	10.22	102.2
Morocco	4-5 kg	whole	12.02	120.2
Tunisia	1 kg	whole	6.61	66.1
Tunisia	2.5 kg	whole	6.91	69.1
Tunisia	3 kg	whole	7.66	76.6
Tunisia	4-5 kg	whole	8.71	87.1

Table 3b. Examples of sizes, product forms and price of octopus sold on the Japanese Market (– frozen octopus – 11/9/2002; Fisheries Information Services (2002)). 1 JPY= ± R 0.069

Octopus Origin	Product Size	Product form	Price (JPY/kg)	Price (R/kg)
Morocco	0.2-0.3 k g	gutted	640	44.60
Morocco	0.3-0.5 kg	gutted	705	48.58
Morocco	0.5-0.8 kg	gutted	775	53.48
Morocco	0.8-1.2 kg	gutted	795	54.86
Morocco	1.2-1.5 kg	gutted	950	65.55
Morocco	1.5-2 kg	gutted	1000	69.00
Morocco	2-3 kg	gutted	1050	72.45
Morocco	3-4 kg	gutted	1150	79.35

Table 3c. Examples of sizes, product forms and price of octopus sold on the Australian Market (Sydney– frozen octopus – 11/9/2002; Fisheries Information Services (2002)). 1 AUD = ± R6.5

Octopus Origin	Product Size	Product form	Price (AUD/kg)	Price (R/kg)
Unknown	Medium	Unknown	4.95	32.18
	Large		6.21	40.37
	3-4 kg		5.19	33.74

Cost estimation

Costs were determined at present price (September 2002, in Rands). All items were priced individually, while general running expenses were determined from vessel owners and the Economic and Sectoral Study conducted on the South African linefish industry (Mather et al. 2002).

ECONOMIC SCENARIOS

Capital stock requirement was assessed for two different economic scenarios firstly, when the vessel and all necessary gear are purchased at the beginning of the fishery (Full Capital Outlay, FCO) and secondly, when a pre-owned vessel is used (Use of Existing Vessel, UEV). These scenarios were extrapolated into eight options for the two different fishing operations, and costing sheets and the minimum CPUEs were calculated for these. Cashflow statements for year 1 and 2 and break-even analysis (year 1 - 5) were only calculated for the most cost-effective options (KPMG Aiken & Peak 1992; Longenecker et al. 2000). The eight economic scenarios identified for the fishery are as follows:

Option 1a. FCO, deckboat and gear purchased at beginning of fishery, Fishing operation 1.

b. UEV, pre-owned deckboat used, gear purchased at beginning of fishery, Fishing operation 1.

Option 2a. FCO, chukkie and gear purchased at beginning of fishery, Fishing operation 1.

b. UEV, pre-owned chukkie used, gear purchased at beginning of fishery, Fishing operation 1.

Option 3a. FCO, deckboat and gear purchased at beginning of fishery, Fishing operation 2.

b. UEV, pre-owned deckboat used, gear purchased at beginning of fishery, Fishing operation 2.

Option 4a. FCO, chukkie and gear purchased at beginning of fishery, Fishing operation 2.

b. UEC, pre-owned chukkie used, gear purchased at beginning of fishery, Fishing operation 2.

The assumptions on which cost calculations were based are listed below:

Assumptions

- 11 months of fishing, 1 month contingency (vessel maintenance).
- 10 % increase in all costs and market prices per year (inflation).
- Year 1: Fishing with a minimum number of pots (900 or 1000). Permit conditions specify minimum number of pots to be used during year one. It must be assumed that some fishermen might use the only minimum number of pots during year one.
- Gear maintenance during Year 1 is the cost of replacing approximately a third of the gear. This is estimated, as the real rate of gear loss is unknown.

- Year 2: Fishing with maximum number (1950 or 2000) of pots (Gear restrictions will include a maximum number of pots used).
- Gear maintenance during Year 2 is the cost of replacing approximately two-thirds of the gear.
- Crew increase by one in Year 2, because of increased gear and fishing activity, Salary structure: Skipper = R5000/m, 1 Crew = R2500/m. Increase because of an increase in the number of pots handled.
- Fishing days per month do not increase, only increased activity during each fishing day.
- Fuel consumption increases by 20% in Year 2 because of increased activity. The fuel consumption of Fishing operation 2 is approximately half that of Fishing operation 1 (R7500 / 2). Increase because of an increase in the number of deployment and retrieval of more lines.
- Vessel insurance approximately 3% of vessel value.
- Administration costs of the smaller vessel (chukkie) are approximately half that of the larger vessel (deckboat).
- The permit fee of the smaller vessel (chukkie) is approximately half that of the larger vessel (Deckboat).
- Protective clothing of the smaller vessel (chukkie) is approximately a quarter that of the larger vessel (Deckboat).
- If only a six-month fishery, costs will be shared by other fishing activities.
- Assume that deck space on the chukkie is not prohibiting in the number of pots fished.
- Catch rates were based on rates attained in other experimental fisheries (Whitaker et al. 1991).
- Catch size composition (500 g vs. 1 kg) was based on biological data from both South Africa (Smith 1999; Oosthuizen & Smale 2003) and elsewhere (Whitaker et al. 1991; Diallo 2002).
- Whole catch is exported to the European market.
- Export and packaging costs were estimated at R 10 /kg. (probably overestimated).

A description of the quantity and cost of the two gear designs used in the different fishing operations is presented in Table 4. The gear cost for Fishing operation 1 was approximately double that of Fishing operation 2. A small number of longer-length lines, with more pots per line, are more cost-effective than a large number of short lines, with fewer pots per line. The gear and fishing design also has implications for fuel use, since Fishing operation 1 required 16 sea days per month compared to four sea days per month for Fishing operation 2. A summary of total costs and estimated CPUE needed to cover costs is presented in Table 5. The use of an existing vessel (UEV) with Fishing operation 2 was the most cost-effective economic scenario for both vessel types.

Table 4. A description of the quantity and cost for the gear designs used in the two different fishing operations.

Fishing operation 1		**Description**	**Quantity**		**Cost**
40 lines (220m each)	pots	1000 x UPVC 30cm length, 15cm diam.	300m	@R64/m	19200
1000 pots (25/line)	lines: drop	Ploypropl6mm, 220m coil	40 coils	@ R553/coil	22120
	main	10mm, 220m coil	40 coils	@ R220/coil	8800
	buoys	250mmx4/line	160 buoys	@ R168/bouy	26880
	anchors	20kgx2/line	80 anchors	@ R380/anchor	30400
	cement	10kg bag	10 bags	@ R40/bag	400
	LL clips	0	1000 clips	@R9/clip	9000
Total gear cost					**116800**
Fishing operation 2			**Quantity**		**Cost**
6 lines (1100m each)	pots		270m		17280
900 pots (150/line)	lines: drop		29		16037
	main		29		6380
	buoys		20		3360
	anchors		10		3800
	Cement		10		400
	LL clips		900		8100
Total gear cost					**55357**

Table 5. Summary of the total costs (Rands) and estimated CPUE (in kg per year) needed to cover expenses. These estimates were based on European market prices (Fisheries Information Services 2002). The different scenarios in the experimental octopus fishery are as follows: FCO - Full capital outlay, UEV - Utilize existing vessel, FO - Fishing operation. (See Appendices 5-8 for detailed costing). A total of 11 fishing months per year, with the costs and CPUE given for the first six months of year 1 and 2, due to the different fishing operations that occurs during these years. CPUE 1 = where catch consist of 500 g size class sold at R71.5/kg. CPUE 2 = where catch consist of 1 kg size class sold at R81.5/kg.

Option						**Deckboat**			
		Year		**1**		**2**	**3**	**4**	**5**
1a	**FCO, FO 1**	**Months**	6	11	6	11	11	11	11
	Total Costs (Rands)		**606,948**	**1,213,896**	**657,542**	**1,315,084**	**1,292,641**	**1,274,970**	**1,264,001**
	CPUE 1 (kg)		9,869	19,738	10,692	19,440	17,515	15,947	14,681
	CPUE 2 (kg)		8,489	16,978	9,196	16,721	15,066	13,717	12,627
1b	**UEV, FO 1**								
	Total Costs (Rands)		**236,948**	**473,896**	**321,542**	**643,084**	**688,641**	**738,970**	**796,001**
	CPUE 1 (kg)		3,853	7,706	5,228	9,506	9,331	9,243	9,245
	CPUE 2 (kg)		3,314	6,628	4,497	8,177	8,026	7,950	7,952
3a	**FCO, FO 2**								
	Total Costs (Rands)		**561,837**	**1,123,676**	**591,879**	**1,183,762**	**1,153,841**	**1,128,386**	**1,107,845**
	CPUE 1 (kg)		9,136	18,271	9,624	17,498	15,635	14,114	12,867
	CPUE 2 (kg)		7,858	15,716	8,278	15,051	13,448	12,140	11,067
3b	**UEV, FO 2**								
	Total Costs (Rands)		**191,837**	**383,676**	**255,879**	**511,762**	**549,841**	**592,386**	**639,845**
	CPUE 1 (kg)		3,119	6,239	4,161	7,565	7,450	7,409	7,431
	CPUE 2 (kg)		2,683	5,366	3,579	6,507	6,408	6,373	6,392
						Chukkie			
		Year		**1**		**2**	**3**	**4**	**5**
2a	**FCO, FO 1**	**Months**	6	11	6	11	11	11	11
	Total Costs (Rands)		**205,322**	**413,076**	**251,029**	**507,165**	**505,329**	**505,953**	**509,282**
	CPUE 1 (kg)		3,339	6,717	4,082	7,497	6,847	6,328	5,915
	CPUE 2 (kg)		2,872	5,777	3,511	6,448	5,890	5,443	5,088
2b	**UEV, FO 1**								
	Total Costs (Rands)		**112,822**	**228,076**	**167,029**	**339,165**	**354,329**	**371,953**	**392,282**
	CPUE 1 (kg)		1,835	3,709	2,716	5,014	4,801	4,652	4,556
	CPUE 2 (kg)		1,578	3,190	2,336	4,312	4,130	4,002	3,919
4a	**FCO, FO 2**								
	Total Costs (Rands)		**185,352**	**370,706**	**221,639**	**443,343**	**440,780**	**440,319**	**442,171**
	CPUE 1 (kg)		3,014	6,028	3,604	6,553	5,973	5,507	5,136
	CPUE 2 (kg)		2,592	5,185	3,100	5,637	5,137	4,737	4,417
4b	**UEV, FO 2**								
	Total Costs (Rands)		**92,852**	**185,706**	**137,639**	**275,343**	**289,780**	**306,319**	**325,171**
	CPUE 1 (kg)		1,510	3,020	2,238	4,070	3,927	3,831	3,777
	CPUE 2 (kg)		1,299	2,597	1,925	3,501	3,377	3,296	3,248

Cash flow statements for the first two years and a break-even analysis of the most feasible scenarios (Options 3 & 4) are given in Appendices 9-12. Both FCO and UEV are shown for comparison.

Sensitivity analysis

The sensitivity of the Net Profit (before tax) to variations in CPUE (15%), market prices (15%), and costs (10%) was determined for five years. The sensitivity of the net profits of the most economical scenarios (Options 3 & 4) is presented in Figures 4 - 6. The change in CPUE and market price had the most noticeable effect on Net Profit.

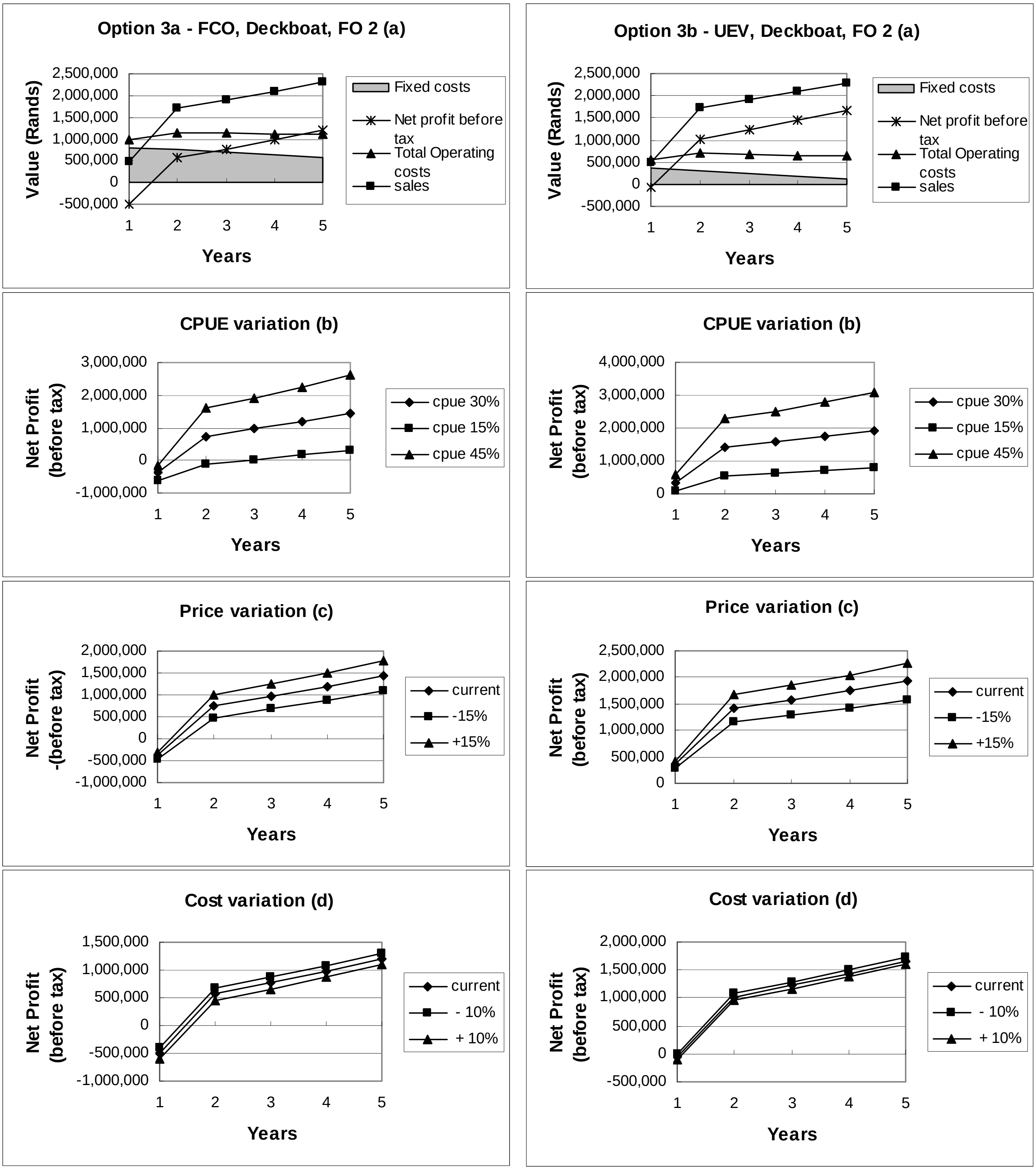

Figure 4. Option 3 a (Full capital outlay, deckboat, employing fishing operation 2) & **b** (Use of existing vessel, deckboat, employing fishing operation 2). Break-even analysis a) and sensitivity analysis of the Net Profit (before tax) to b) CPUE, c) Price and d) Costs.

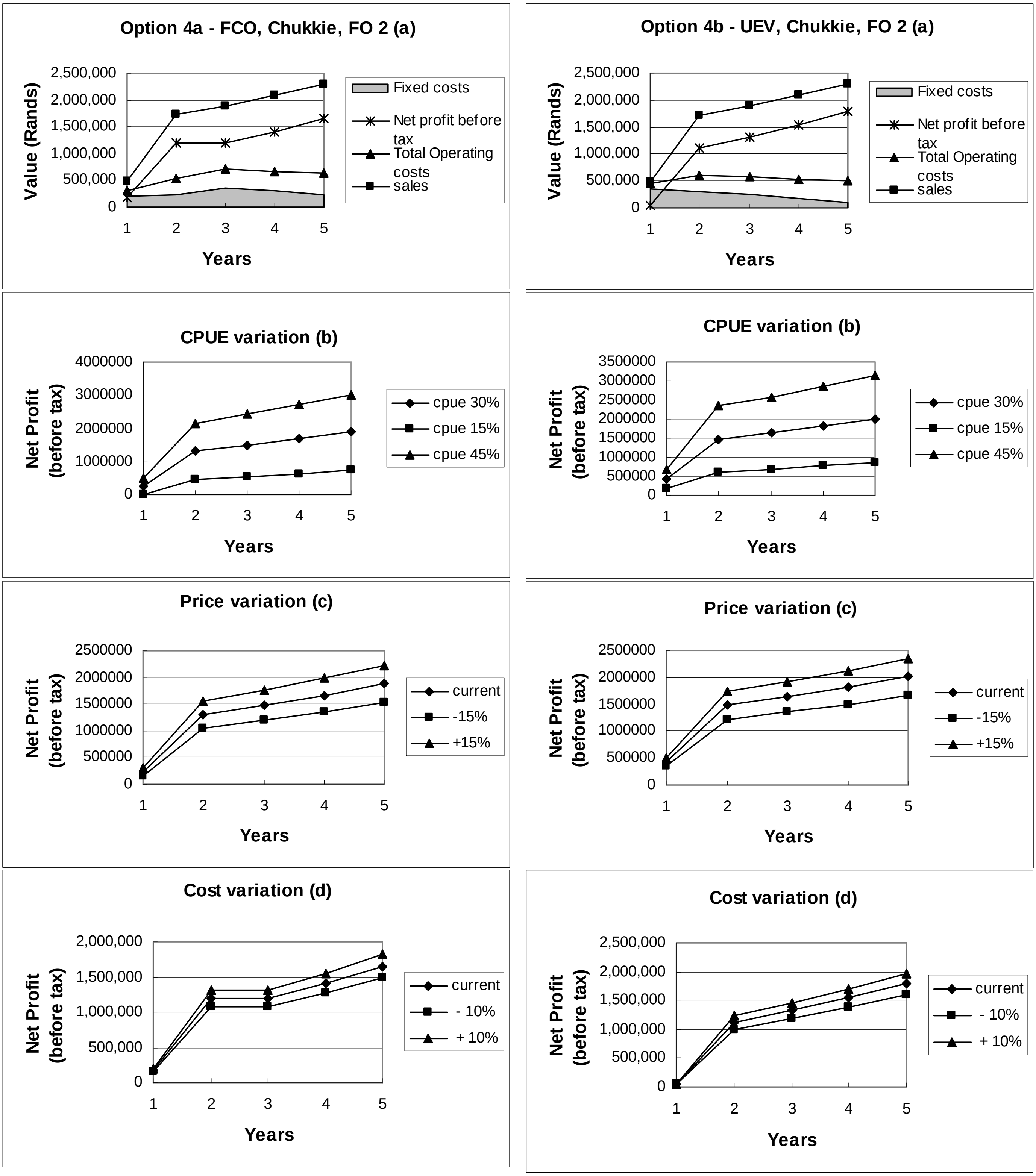

Figure 5. Option 4 a (Full capital outlay, chukkie, employing fishing operation 2) & **b** (Use of existing vessel, chukkie, employing fishing operation 2). Break-even analysis a) and sensitivity analysis of the Net Profit (before tax) to b) CPUE, c) Price and d) Costs.

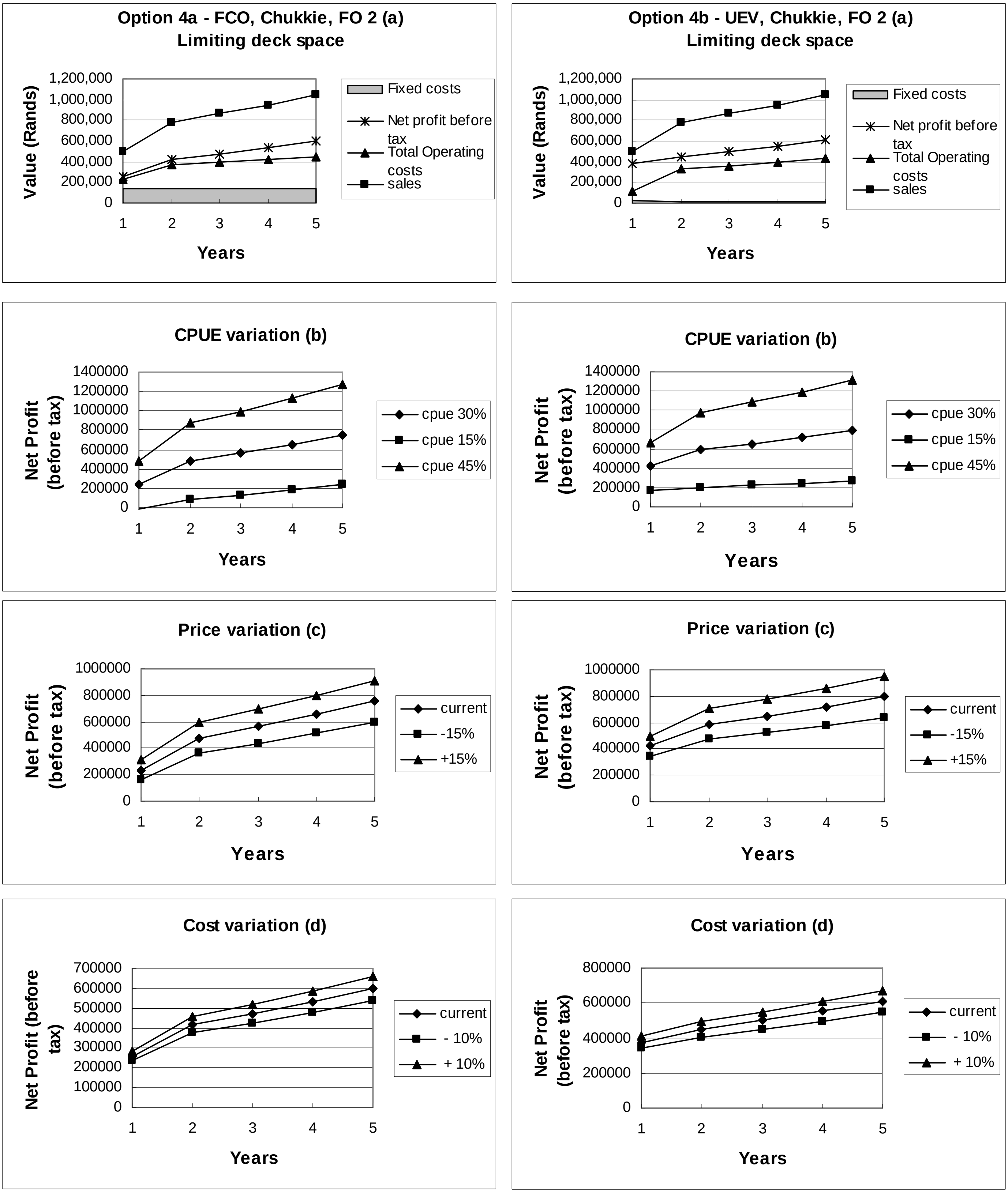

Figure 6. Option 4 a & **b**, Chukkie deck space is limiting. Break-even analysis a) and sensitivity analysis of the Net Profit (before tax) to b) CPUE, c) Price and d) Costs.

RECOMMENDATIONS

This economic appraisal indicates that the pot fishery could be viable if a catch rate of approximately 30% can be attained. All existing vessels (UEV) employing the second fishing operation were considered profitable, breaking even within the first year. The minimum CPUE for the chukkie, operating in the west or southwestern Cape was estimated at 2.6 – 4.1 tons/year, depending on the fishing operation. Assuming that deck space did not prohibit the number of pots carried, the smaller vessels made a profit of R1.5 million after five years. For the deckboat, the minimum CPUE was estimated at 5.4 - 7.6 tons/year, with a profit margin (before tax) of approximately R1.5 million. The options where new vessels were purchased at the beginning of the fishery were not feasible, with the deckboat FCO option being least profitable and only breaking even in the third year. Where deck space was prohibiting, the smaller vessels would be less profitable at R 400000-450000. It is therefore recommended that only wholly owned vessels adhering to the second fishing operation are considered for the experimental fishery.

Comments from prospective fishers

Indications from prospective fishers are that the octopus stock will probably only support a seasonal fishery and will be supplemental to other fisheries during their off-seasons. Fishers in the southwestern Cape mainly target migratory linefish during summer. In winter they target the already overexploited reef fish species and see the octopus resource as a welcome supplement. In the Eastern Cape, fishermen who target squid and hake on handline might consider moving to octopus during the off-seasons (mainly winter). The most accessible market will probably be Europe, to which local fishermen are already exporting squid (pers.comm. M. Craig, Robberg Seafoods).

NOTE: If proven to be viable on a seasonal basis, the rights-holding in other fisheries should be considered. If the octopus fishery only proves viable on a seasonal basis, consideration should be given to allocating the participants rights in other fisheries, where participants are involved in other fishing activities. However, these rights should fall within the envisaged TAC or effort for the other fishery, and not be extra allocations. This will be a means of diverting effort away from over-subscribed fisheries.

Factors influencing commercial success

It is evident from the literature (Chapter 3) that octopus fisheries can be successful on various scales. Nonetheless, there are various factors that influence the revenue of octopus fisheries. These include environmental, anthropogenic, and market-related factors. For example, upwelling was indicated as the key environmental factor influencing the abundance of both larvae and adult octopus in Senegal (Demarcq & Faure 2000). In Mexico, a red tide during 2001 forced octopus to move out of the fishing areas, causing a revenue loss of over 1 million USD (FIS Latino 2001). Furthermore, *Octopus mimus* landings in Chile were influenced by both environmental factors such as ENSO events and anthropogenic effects such as landslides and cholera epidemics. The most prominent market-related factors to impact an octopus fishery were oversupply and stockpiling. This led to large price drops and strained international relations between Morocco, the supplier, and Japan, its largest importer of octopus (Wyman & Chiba 2001 a, b). Octopus fisheries are thus vulnerable to a range of issues, and fluctuations in both catch and market demand can be expected.

It is important that these risks be taken into account when preparing a business plan for this type of fishery. The economic constraints that will have practical implications in the establishment of an octopus fishery were identified as follows:

- The vessel type must be chosen according to economic viability (i.e. wholly owned vessels only)
- Large capital outlay is required for fishing gear and operations.

Furthermore, the fluctuating nature of the markets and stock might well dictate a mixed quota fishery to make this a feasible venture. This information must be identified before the start of the experimental fishery, so that these limitations can be incorporated into the experimental design. It will also direct the requirements for the fishery, and serve as a guideline to assess and compare the business plans of applicants. The business plan submitted by the prospective fisher will differ from this study, but the financial analysis should be similar. A structure of a proposed business plan for prospective fishers is outlined in Appendix 1.

ACKNOWLEDGEMENTS

I would like to thank Hans Erstadt for his input at the start of the project. Mr B Holmes and Craig Smith (Marine and Coastal Management) for information on fishing operations, Mr M. Craig (Robberg Seafoods) for comments on markets and exporting, Mr Tremain Wesson (Business Partners) for comments on a draft of this work and Prof T. Hecht (Rhodes University) for the use of the deckboat photograph.

REFERENCES

ADKINS B.E., GEE P.A. and BREEN P.A. 1980. Experimental octopus trap fishing in Barkley Sound, February-March 1997. *Fisheries and Marine Services Management Report* **1548**. 23 pp.

BJORDAL A. 2002. The use of technical measures in responsible fisheries: regulation of fishing gear. In: A fishery manager's guidebook. Management measures and their application. Chapter 2. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 21-47.

BRITZ P.J., SAUER W.H.H., MATHER D., OELLERMAN L.K., COWLEY P.D., TER MORSHUIZEN L. and BACELA N. 2001. Baseline study of the utilization of living marine resources in the Eastern Cape. Dept. Ichthyology and Fisheries Science, Rhodes University, Grahamstown. 103 pp.

COCHRANE K.L. 2002. The use of scientific information in the design of management strategies. In: A fishery manager's guidebook. Management measures and their application. Chapter 5. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 95-130.

CLAYTON W.E.L., BROADLEY T.A. and SUTHERLAND I.R. 1992. The evaluation of a productive and cost effective trap for the harvesting of the giant Pacific octopus (*Octopus dolfeini*). IEC Collaborative Marine Research and Development, Victoria, British Columbia. 23 pp.

DEMARCQ H. and FAURE V. 2000. Coastal upwelling and associated retention indices derived from satellite SST. Application to *Octopus vulgaris* recruitment. *Ocean. Acta* **23**(4): 391-408.

DIALLO M. 2002. Fréquences de poids des poulpus capturés par la pêche artisanale sénégalaise. (1996-1998). In *Le pouple* Octopus vulgaris *Sénégal et cotes nord-ouest africaines*. (ed. A. Caveriviere, M. Thiam & D. Jouffre). IRD Editions, Paris. p 159-168.

FIS LATINO. 2001. Fisheries Information Services. World news. Red tide wreaks havoc. (August 2001). Retrieved October 2001 from: http://fis.com/fis/worldnews/worldnews.asp?1=e&special=search&id=19777

FISHERIES INFORMATION SERVICES 2001. Fisheries Information Services. Market reports. Retrieved May 2001 from http://fis.com/

FISHERIES INFORMATION SERVICES 2002. Fisheries Information Services. Market reports. Retrieved September 2002 from http://fis.com/

GUERRA, A. 1997. *Octopus vulgaris*: A review of the world fishery. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution. Washington. p 91-98.

HARTWICK E.B., TROTTER D.W.M and WALSH M. 1982. An experimental trap fishery operation for octopuses. Contract report to Dept. Fisheries Oceans, Canada. July 1982.

KPMG AIKEN and PEAT. 1992. *Starting and running your own business*. Small Business Development Corporation Publications.

LONGENECKER J.G., MOORE C.W. and PETTY J.W. 2000. *Small business management: An entrepreneurial emphasis*. New York, 11th ed. South-Western College Publishing.

MATHER D., BRITZ P.J., HECHT T. and SAUER W.H.H. 2002. An economic and sectoral study of the South African fishing industry, Vol 1: Economic and regulatory principles, Survey results, Transformation and socio-economic impact. Report prepared for Department of Environmental affairs and Tourism, Marine and Coastal Management. Rhodes University, Grahamstown, South Africa.

OOSTHUIZEN A. and SMALE M.J. 2003. Population biology of *O. vulgaris* on the temperate south-eastern coast of South Africa. *J. Mar. Biol. Ass. U.K.* **83:** 535-541.

PAUST B.C. 1997. Octopus marketing aspects with attention to the development of domestic (North American) food markets. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 135-139.

ROPER C.F.E. 1997. Experimental Octopus Fisheries: Two Cases Studies. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution, Washington. p 157-168.

SÁNCHEZ P. and OBARTI R. 1993. The biology and fishery of *Octopus vulgaris* caught with clay pots on the Spanish Mediterranean coast. In: *Recent advances in fisheries biology*. Okutani, T., O'Dor, R.K. and Kubodera, T. (Eds.). Tokyo, Tokai University Press. p 477-487.

SMITH C.D. 1999. Population biology and ecology of octopus in the southwestern Cape: A study towards the establishment of a small-scale octopus fishery. University of Cape Town. M.Sc. Thesis. 111 pp.

WHITAKER J.D., DELANCY L.B. and JENKINS J.E. 1991. Aspects of the biology and fishery potential for O*ctopus vulgaris* off the coast of South Carolina. *Bull. Mar. Sci.* **49**(1/2): 482 - 493.

WYMAN, J. and CHIBA H. 2001a. Fisheries Information Services. Market reports. West African frozen octopus. Retrieved March 2001 from: http://fis.com/fis/reports/reports.asp?1=e&specie=256&date=3/7/2001

WYMAN, J. and CHIBA H. 2001b. Fisheries Information Services. Market reports. Report from Japan on Moroccan octopus. Frozen octopus from West Africa. Retrieved October 2001 from: http://fis.com/fis/reports/reports.asp?1=e&specie=256&date=10/11/2001

CHAPTER 8

PHASE 0: STEP 4 - PROPOSED FISHERY MANAGEMENT PLAN AND EXPERIMENTAL DESIGN FOR THE OCTOPUS POT FISHERY

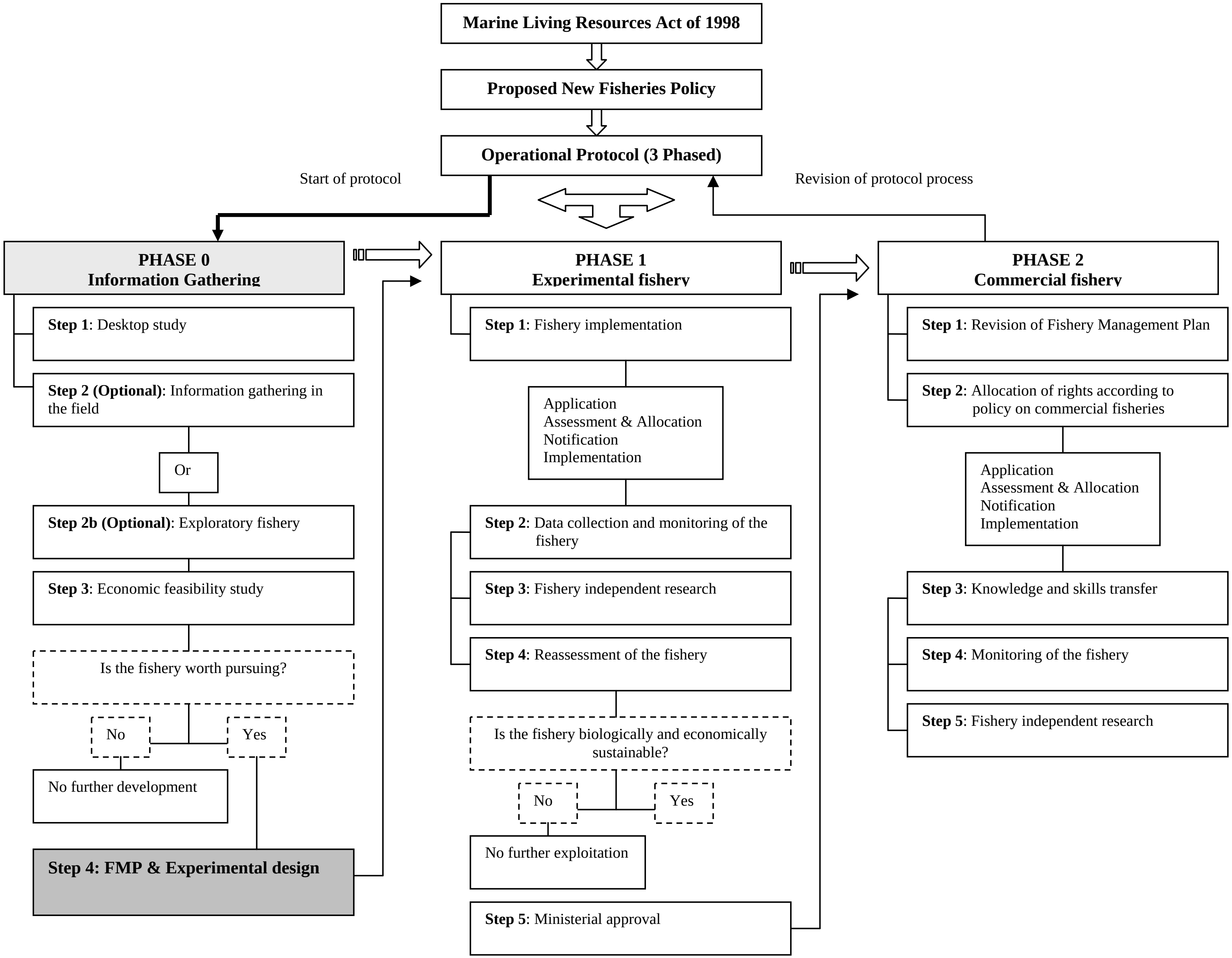

Figure D. Step 4: Fishery Management Plan and design of experimental fishery.

CHAPTER 8

PHASE 0: STEP 4 - PROPOSED FISHERY MANAGEMENT PLAN AND EXPERIMENTAL DESIGN FOR THE OCTOPUS POT FISHERY

PROPOSED FISHERY MANAGEMENT PLAN FOR THE OCTOPUS POT FISHERY

The structure of this Fishery Management Plan (FMP) follows international trends, and is based on FMPs of other developing fisheries (Anon 1996; Halmarick 1999) and fisheries management literature (Cochrane 2002a, b; Die 2002).

DESCRIPTION OF RESOURCE

Octopus vulgaris is a fast-growing, short-lived mobile benthic cephalopod species. The subtidal resource of this species is virtually unexploited in South Africa, and is therefore considered to be a virgin stock. Intertidally, subsistence and recreational fisheries exploit the resource at a low level. No information is available on the subtidal abundance of the resource, but the biology and distribution in intertidal and shallow subtidal areas has been well studied (Smale & Buchan 1981; Smith 1999; Smith & Griffiths 2002; Oosthuizen & Smale 2003).

GOAL

- To ensure biological, ecological and economic sustainable development of the octopus resource.

MANAGEMENT OBJECTIVES

- Biological objectives
    - To establish biological characteristics of the fished stock and to sustain a viable population for future exploitation.
- Economic objectives
    - Economically efficient commercial production, through experimentation with fishing gear, vessels and areas.
- Social objectives
    - The sustainable development of an experimental fishery to provide a possible new commercial opportunity within the fishing sector that could provide prospect for employment, human resource development and transformation.

- Governance objectives
    - o Management according to the principles of the Proposed New Fisheries Policy (Chapter 2):
        - Ecological Sustainable Development
        - Precautionary Principle
        - Responsible fishing
        - Scientific integrity.
    - o Compliance targets achieved and monitored.
    - o Enforcement of regulatory measures.

EXPERIMENTAL DESIGN FOR THE OCTOPUS POT FISHERY

Duration of experiment

Permits should be allocated for four to five years to ensure a solid scientific outcome and to encourage investment and commitment from the prospective fishers.

Number of vessels/permits

The fishing area along the South African coast can be divided into four regions, namely the west, southwest, south and southeast coasts (Fig. 1). Two possible operating ports were identified in each region (Table 1), except on the west coast where the geographical distribution of *O. vulgaris* is limited in the north. It is recommended that two licences be issued per port to ensure replication and statistical viability within an area. This translates to a total of 14 licences along approximately 1500 km of coastline

Table 1. The number of proposed experimental permits for different regions along the coast.

Coastal region	Operating Ports	No of licenses
West	Saldanha	2
Southwest	Houtbay	2
	Kleinmond/Hermanus	2
South	Struisbaai	2
	Mosselbay/Plettenberg Bay	2
Southeast	Port Elizabeth	2
	East London	2
Total	**7**	**14**

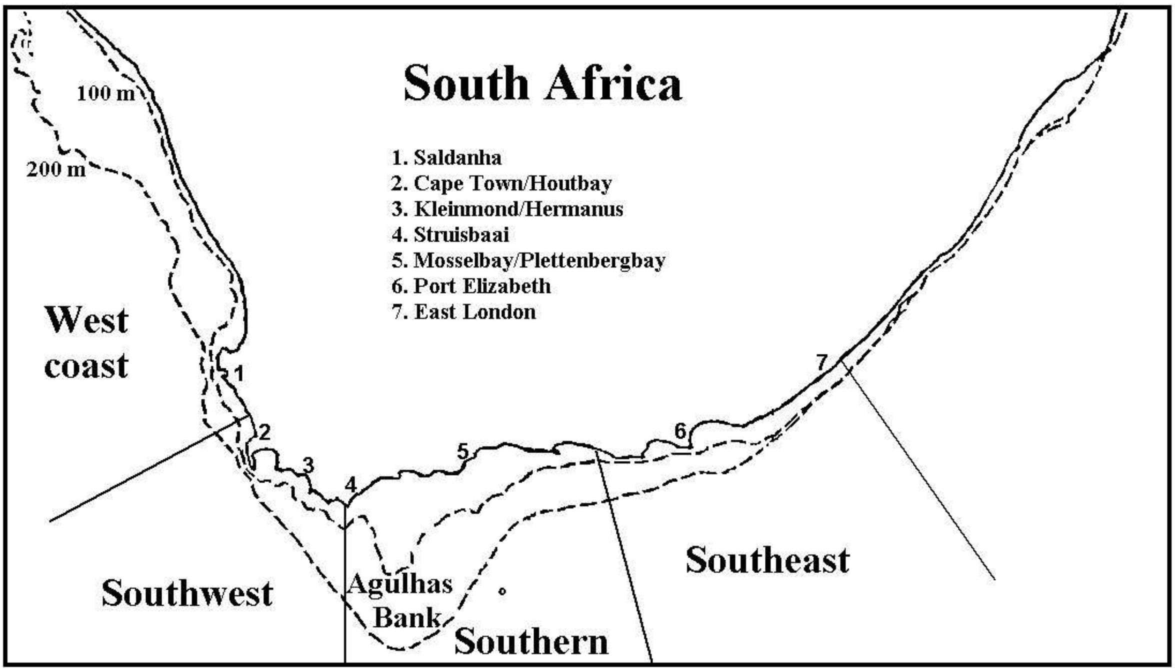

Figure 1. The four regions along the South African coast in which the proposed experimental fishery will occur.

Vessel type

The economic feasibility study suggested that larger deckboats would be more profitable than smaller chukkies with prohibiting deck space. However, most vessels operating out of Struisbaai, Kleinmond, Hermanus, Houtbay and Saldanha are chukkies. Traditional low-income fishing communities inhabit these areas and even a small amount of extra income will result in economic input in the local area. It is therefore recommended that licenses be given to both types of vessels. Using two vessel types should not bias the results from the experiment, as the CPUE will be assessed according to the numbers of pots fished.

Gear type

As identified in Chapter 3, fishing gear will consist of pots on longlines. It is important to test different pot types and sizes in order to determine the effects on catch rate and mean octopus weight caught between seasons, areas and depth. The biology of *O. vulgaris* suggests that different sized octopus will be available to the fishery during different seasons on the southwest and southeast coast of South Africa (Smith 1999; Oosthuizen & Smale 2003). This is supported by catch data from other experimental fisheries, which showed that the catch rate of a particular pot size varied with season (Whitaker et al. 1991).

The following pot types are suggested for use in the experimental fishery:

- Half-tire pots, plugged at one end
- PVC single, plugged at one end or middle, diameter 10 and 15 cm
- PVC double, plugged at one end or middle, diameter 10 and 15 cm
- Or variations thereof.

Gear configuration

The economic feasibility study indicated that it is cheaper to operate longer-lines with more pots, than shorter lines with fewer pots. Therefore, the suggested gear configuration is as follows:

- Total line length of approximately 1050 m, with 150 pots per line
- Thirty of each pot type on each line
- One of each type, approximately 7 m apart, alternately along the line.

EXPERIMENTAL APPROACH TO THE OCTOPUS POT FISHERY

To achieve the information required from this experimental fishery, three parallel experimental approaches are suggested:

- **A rigid scientific fishery experiment**, comprised of fishing with a specified number of lines, according to a set paradigm. This will allow for the determination of:
  - Potential yield
  - Distribution
  - Catch rates
  - Collection of biological information as identified in Table 1 in Chapter 2, and Table 2 in Chapter 3.
- **An exploratory approach**, where fishers are given the freedom to experiment with gear configuration, soak times, depths, areas etc. This will allow for:
  - Optimisation of fishing techniques
  - Assessment of octopus distribution beyond experimental areas.
- **Fishery-independent research**, including tagging experiments to determine movement and distribution. This will allow for:
  - The collection of growth, distribution and migration data.

1) Experimental fishing (Fishery-dependent research)

Aim

- To determine biomass, distribution and biology of the exploited section of the population.
- To compare the effect of pot type, area, depth and season on CPUE and mean mass.

Operation

Six lines (900 pots) should be used exclusively for experimental purposes. All six lines should be fished simultaneously, but with three lines each at two different depths (e.g. 10 m and 30 m). Pots should soak for seven days and be retrieved on the eighth day. This should be repeated three times per month, weather-permitting, for two years (two seasonal cycles), after which the data and experimental design should be revised.

Data collection

Fishery observers should be onboard when experimental lines are set and retrieved. However, practical implications might limit the number of trips observed. They should collect CPUE data and information on area (GPS position), depth, bottom profile and composition (e.g. sand, shale in pots) where possible. They should also collect biological data on a subsample (5%, or minimum of 20 individuals) of the catch. This should occur on each vessel in each area.

Statistical analysis

All data should be tested for normality and equal variances and transformed if necessary. The effect of pot type on CPUE and mean octopus mass will be tested by a one-way ANOVA or nonparametric Kruskal Wallis test, depending on the data. CPUE and mass will also be compared between areas and depth by a two-way ANOVA. Biological data should be analysed using methods described in Smith (1999) and Oosthuizen and Smale (2003), including the chi-square test for sex ratios and linear and nonlinear regressions for morphometric data.

2) Exploratory fishing (Fishery-dependent research)

This will be conducted in addition to the experimental fishing.

Aim

- To allow fishers to use their fishing experience and knowledge to explore different pot types and gear configurations.
- To explore different areas and bottom types.
- To explore processing, value-adding and markets.

Operation

The milestones set in the business plans submitted by fishers with their applications should be used to assess the progress of the fishery. Fishers should adhere to these milestones to ensure a timely start to both experimental and commercial fishing and compliance with the specified fishing operations.

A specified maximum number of pots (± 1000) will be used exclusively for commercial fishing purposes. Fishers will be prohibited from deploying commercial lines within one nautical mile of experimental lines.

Data collection

All fishers should be required to complete a logbook and submit data on a monthly basis. Information required will include CPUE, area, depth, effort, total mass caught, processing, export and financial data. All information received by the Department will be considered confidential.

Statistical analysis

This will be similar to that stated for the experimental fishery, depending on the data quality.

3) Fishery-independent research

Tagging experiments

Aim

- To investigate the movement and distribution patterns of *O. vulgaris.*
- To investigate growth in the field.

Operation

License-holders should be required to tag and release a percentage of their catch.

Data collection

All tagged octopus recaptured should be weighed and their area of recapture recorded before being released.

MANAGEMENT STRATEGY

The management strategy for the octopus fishery will comprise input controls based on effort regulation. The application of standard stock assessment models will not be attempted for the octopus resource at this stage. Information required for management by quota is onerous with the application of traditional predictive models not being suitable for cephalopod assessment (Lipiński et al. 1998; Jackson et al. 1997).

Suggested management measures and rationale

The management measures discussed below were identified from Chapter 2 and 3 as best possible options for the octopus fishery. Each regulation and an alternative approach are described.

Regulation 1: Restrictive licensing

Restriction of the number (14, with I per vessel) of experimental permits issued, together with restrictions on vessel size (<25m) and engine capacity (<285 hp).

Rationale: Restrictive licensing is a precautionary measure to prevent early overexploitation and overcapacity in the fishing fleet (Caddy 1999; Perry et al. 1999). Even when vessel numbers are stable, it is important to include restrictions to limit the growth of fishing capacity due to increasingly large vessels with longer ranges and better fishing technology (FAO 1995; Pope 2002).

Regulation 2: Gear limitation

Gear will be limited to a specific type, i.e. pots (unbaited, with no hooks) on longlines, and will also be restricted to a maximum number of 2000 per licence.

Rationale: This gear type is highly selective for the target species, and there is no bycatch. The pots simply present a hiding place for octopus, and any other animals in the pot at the time of retrieval will be able to escape. The loss of gear presents negligible effects on the environment, as no ghost-fishing can occur, pots foul within two weeks and lines disintegrate within a few months; indeed, lost gear will enhance octopus habitat. This type of fishing gear fulfils the requirements for ideal fishing gear as established by the Code of Conduct for Responsible Fisheries (FAO 1995)

Regulation 3: Size limit

A minimum size limit of 200g.

Rationale: Size limits should be imposed as a precautionary measure based on biological data. *O. vulgaris* females can store sperm until they are mature (1000 - 1500 g), and once spawned are protected from fishing due to their brooding behaviour. Males mature at approximately 190g in the proposed fishing area (Smith 1999; Oosthuizen & Smale 2003), so it is recommended that a minimum size limit of at least 200 g be set to ensure male maturation. However, if the fishery were to expand, size restriction should be determined on a regional level, since the climatic conditions along the coast differ (temperate Western and Eastern Cape, and warm subtropical KwaZulu-Natal) and therefore influence growth and size at maturity (Smale & Buchan 1981; Oosthuizen & Smale 2003).

Regulation 4: *Refugia (area closures)*

No fishing will be allowed in existing marine protected areas.

Rationale: *O. vulgaris* has a larval stage that is planktonic for up to two months. Significant movement can occur during this period (Roberts & Van den Berg in press), ensuring dispersion of larvae and seeding of other areas. Area closures should be implemented as a precautionary conservation measure against uncertainty (Hall 2002). MPAs along the South African coast include the Tsitsikamma National Park (southeast coast) and De Hoop (southwest coast) plus several smaller reserves along the west and southwest coast. Historically, few MPAs exited from Tsitsikamma towards the east, however, the Minister of Environmental Affairs and Tourism recently declared more reserves in this area. Existing MPAs should thus suffice as a closed area management strategy for the octopus fishery.

PERFORMANCE INDICATORS TO MEASURE ACHIEVEMENT OF OBJECTIVES

Performance indicators and target/limit reference points for the biological and economic objectives are given in Table 2. Similar indicators and reference points have been used in other invertebrate fisheries (Gorfine et al. 2001).

Table 2. Possible biological and economic performance indicators and target/limit reference points to be used in the octopus pot fishery.

	Criteria to be measured	**Management objective**	**Performance indicator**	***Limit reference point**
Biological	Sustainability of octopus stocks	Productive capacity sustained into future with low risk	Annual catch /CPUE	Annual catch/CPUE at 70% of first 3 years catch
		-	Size classes	Minimum size
Economic	Economic efficiency	Commercial production to be economically efficient	Fishery profit • Net income per fisher • Net tonnage exported	Fishery profit at 70% of first 3 years profit
	Catching efficiency	Commercial production to be economically efficient	Commercial catch per unit effort (CPUE)	N/A

***Note:** These are suggestions only, and should be analysed and adjusted as the fishery proceeds.

Biological: A time-series of catch is necessary to achieve the biological reference point.

Economic: Economic benchmarks must be set according to both the fisher's business plan and the economic projections made by management (economic feasibility study). The economic achievements by the fishery in terms of income/profitability per fisher and sales/tonnage exported must be compared to these.

ADMINISTRATION PROCESS

Code of Conduct agreement

This should be a signed contract agreement between the Department and the prospective fisher and should include the following:

- Permit conditions
- Code of conduct for experimental fishers stipulating requirements such as:
    - Adherence to experimental design
    - Accurate collection and reporting of data
    - Observer assistance
    - Willingness to attend workshops
    - Presentation of business plans
    - Disciplinary procedures, amongst others.

Notification

Permit-holders will be notified in writing and through personal communication regarding any changes in the management regulations and/or permit conditions.

Penalties

Strict penalties will be applied to fishers who transgress any permit condition or management regulation. These will range from fines for the less-serious incidents to the loss of permits for serious offences.

Reviewing and amendment

Situations within fisheries change through time and it is important for management plans to accommodate these changes. It is thus necessary to review management strategies and measures periodically, so as to be able to react to and provide for these changes within the fishery (Die 2002). Changes in biological stock or in the socio-economic status of the fishery might occur, necessitating a review of the management plan. The management plan itself should provide guidance on the review process and strategy, and should include recommendations on large reviews as well as small changes such as urgently needed short-term measures (Die 2002).

Monitoring and compliance

This will be enforced by MCM and should be thorough and comprehensive, but flexible. Control measures to be implemented before, during and after the fishing operation are listed below (Bergh & Davies 2002).

Before fishing:

- Departure sites limited to specified harbours only.
- Vessel inspections to ensure compliance with regulations e.g. vessel size, engine power, gear type and number.

While fishing:

- Logbooks to be filled in, with strict penalties enforced for incomplete data or late submission.
- Observer programmes to be used for implementing continuous monitoring and data collection.
- Vessel Monitoring Systems to track the real-time movement of vessels, in order to prevent fishing in restricted areas and to validate reported data on fishing areas.

During landing:

- Landing sites limited to specified harbours only.
- Vessel inspections to collect logbook data and monitor catch composition and mass.

MANAGEMENT CONSIDERATIONS FOR OTHER OCTOPUS EXPLOITATION IN SOUTH AFRICA

Recreational fisheries: *Octopus vulgaris, O. cyanea, A. schultzei*

Recreational fishers may collect octopus for consumption or bait, as per Department (MCM) recreational bag limits. Since it is illegal to sell recreational catches, no octopus sales should result from this sector.

Subsistence / small-scale commercial fisheries: *Octopus vulgaris, O. cyanea, Afrodoctopus. schultzei*

Subsistence fishers operate in the intertidal area only. Subsistence fishers should be allowed to collect daily bag limits for own use, but not for sale. However, a number of small-scale commercial permits could be allocated to coastal communities. Catches could be sold to individuals, restaurants, fish shops and processing factories. Management options for the exploitation of octopus by this sector were identified by Cockcroft et al. (2002). They include effort control, closed areas, bag limits and harvest/fishing method restrictions. Furthermore, recording catches are important in monitoring variability within these fisheries. The development and management of the subsistence sectors should follow the recommendations made by Harris et al. (2002). In addition, community education in terms of basic biology, ecology and conservation is essential in creating custodianship over the resource. This was also identified as a key factor necessary in communities involved in co-management in South Africa (Hauck & Sowman 2001)

Commercial bycatch: *Octopus magnificus*

Closer monitoring and assessment of *O. magnificus* bycatch is needed, as no programme is currently in place to collect distribution and catch data for this species. The Department should institute enforced bycatch reporting on both geo-referenced catch data and regular biological collection through observers. This information is essential and could indicate whether a directed fishery would be plausible. The interaction with crustacean fisheries is known but the direct economic impact cannot be determined. Exploitation of these stocks could possibly benefit both crustacean and octopus fisheries (Boyle 1997).

SYNTHESIS

The work presented here is a theoretical approach to an experimental fishery and FMP design. It provides a basis for the implementation of the fishery; however, the practical realisation of such implementation will have financial, institutional and time costs that were not accounted for here. Nevertheless, this study does outline important factors to be considered in the development and management of the octopus fishery, as well as octopus exploitation in general, in South Africa. Furthermore, it should be subject to scrutiny from both management (MCM) and stakeholder bodies.

ACKNOWLEDGEMENTS

I would like to thank Mr Craig Smith (Marine and Coastal Management), for the use of the draft permit conditions and information on fishing operations.

REFERENCES

ANON. 1996. Fishery management plan, regulatory review and final environmental impact statement for the Queen Conch resources of Puerto Rico and the United States Virgin Islands. Caribbean Fishery Management Council, San Juan, Puerto Rico.

BERGH P.E. and DAVIES S. 2002. Fishery monitoring, control and surveillance. In: A fishery manager's guidebook. Management measures and their application. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. 231 pp.

BOYLE P.R. 1997. Octopus interactions with crustacean fisheries. In: *Proceedings of the workshop on: The fishery and market potential of Octopus in California*. Lang, M.A. and Hochberg, F.G. (Eds). Smithsonian Institution. Washington. 125-129.

CADDY J.F. 1999. Fisheries management in the twenty-first century: will new paradigms apply? *Rev. Fish Biol. Fish*. **9**: 1-43.

COCHRANE K.L. 2002a. Fisheries management. In: A fishery manager's guidebook. Management measures and their application. Chapter 1. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 1-20.

COCHRANE K.L. 2002b. The use of scientific information in the design of management strategies. In: A fishery manager's guidebook. Management measures and their application. Chapter 5. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. p 95-130.

COCKROFT A.C., SAUER W.H.H, BRANCH G.M., CLARK B.M, DYE A.H. and RUSSEL E. 2002. Assessment of resource availability and suitability for subsistence fishers in South Africa, with a review of resource management procedures. *S.A.J.mar.Sci.***24**: 489-501.

DIE D. 2002. Design and implementation of management plans. In: A fishery manager's guidebook. Management measures and their application. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. 231 pp.

FAO. 1995. Code of Conduct for Responsible Fisheries. FAO, Rome. 41p.

FAO. 1996. Precautionary approach to capture fisheries and species introduction. *FAO Technical guidelines for responsible fisheries* No. **2**. FAO, Rome. 54 pp.

GORFINE H.K., TAYLOR B.L. and WALKER T.I. 2001. Triggers and targets: What are we aiming for with abalone fisheries models in Australia? *J. Shellfish Res*. **20**(3): 803-811.

HALL S. 2002. The use of technical measures in responsible fisheries: area and time restrictions. In: A fishery manager's guidebook. Management measures and their application. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. 231 pp.

HALMARICK L. 1999. Developing new fisheries in Western Australia. A guide to applicants for developing fisheries. *Fisheries Management Paper* **130**. Fisheries Western Australia, Perth, Australia. 40 pp.

HARRIS J.M., BRANCH G.M., CLARK B.M, COCKROFT A.C., COETZEE C., DYE A.H., HAUCK M., JOHNSON A., KATI-KATI L., MASEKO Z., SALO K., SAUER W.H.H, SIQWANA-NDULO N. and SOWMAN M. 2002. Recommendations for the management of subsistence fisheries in South Africa. *S. Afr. J. mar. Sci* .**24**: 503-523.

HAUCK M. and SOWMAN M. 2001. Coastal fisheries co-management in South Africa: an overview and analysis. *Mar. Pol.* **25**: 173-185.

JACKSON G.D., FORSYTHE J.W., HIXON R.F. and HANLON R.T. 1997. Age, growth, and maturation of *Lolliguncula brevis* (Cephalopoda: Loliginidae) in the northwestern Gulf of Mexico with a comparison of length-frequency versus statolith age analysis. *Can. J. Fish. Aquat. Sci.* **54**: 2907-2919.

LIPIŃSKI, M.R., BUTTERWORTH D.S., AUGUSTYN C.J., BRODZIAK J.K.T., CHRISTY G., DES CLERS S., JACKSON G.D., O'DOR R.K., PAULY D., PURCHASE L.V., ROBERTS M.J., ROEL B.A., SAKURAI Y., and SAUER W.H.H. 1998. Cephalopod fisheries: a future global upside to past overexploitation of living marine resources? Results of an international workshop, 31 August-2 September 1997, Cape Town, South Africa. *S . Afr. J. mar. Sci.* **20**: 463-469.

OOSTHUIZEN, A. and SMALE, M.J. 2003. Population biology of *O. vulgaris* on the temperate south-eastern coast of South Africa. *J. Mar. Biol. Ass. UK.* **83:**535-541

PERRY R., WALTERS C. and BOUTILLIER J. 1999. A framework for providing scientific advice for the management of new and developing invertebrate fisheries. *Rev. Fish Biol. Fish*. **9**: 125-150.

POPE J. 2002. Input and output controls: the practice of fishing effort and catch management in responsible fisheries. In: A fishery manager's guidebook. Management measures and their application. *FAO Fisheries Technical Paper*. No **424**. FAO, Rome. 231 pp.

ROBERTS M.J. and VAN DEN BERG, M. in press. ADCP measured currents along the Tsitsikamma coast (South Africa) and potential transport of squid paralarvae and ichthyoplankton. *Afr. J. mar. Sci.*

SMALE M.J. and BUCHAN P.R. 1981. Biology of *Octopus vulgaris* off the east coast of South Africa. *Mar. Biol.* **65**: 1-12.

SMITH C.D. 1999. Population biology and ecology of octopus in the southwestern Cape: A study towards the establishment of a small-scale octopus fishery. University of Cape Town. M.Sc. Thesis. 111p.

SMITH C.D. and GRIFFITHS C.L. 2002. Aspects of the population biology of *Octopus vulgaris* in False Bay, South Africa. *S. Afr. J. mar. Sci.* **24**: 185–192.

WHITAKER J.D., DELANCY L.B. and JENKINS J.E. 1991. Aspects of the biology and fishery potential for *Octopus vulgaris* off the coast of South Carolina. *Bull. Mar. Sci.* **49**(1/2): 82- 493.

CHAPTER 9

SYNTHESIS AND RECOMMENDATION

DEVELOPMENT OF NEW FISHERIES IN SOUTH AFRICA - THE WAY FORWARD

A new policy was formulated in this study for the standardised and sustainable development of new fisheries in South Africa. A holistic approach to the development and management of a new fishery was presented. The policy provided a step-by-step operational protocol for fisheries development based on principles of precaution, responsible fishing and sustainability (FAO 1995, 1996). Implementation of the protocol was demonstrated using the octopus fishery as a case study and aspects such as basic biology, population structures, economic assessment, experimental design and management measures were included. Furthermore, this study provided essential baseline information required before the octopus fishery could proceed. The development framework was designed to be versatile and can be applied to any type of fishery development in South Africa.

Recently advocated precautionary approaches to fisheries management instilled the importance of conservation of stocks to ensure future use (FAO 1995; Caddy 1999, 2000). Nevertheless, even with the best of intentions, many developing fisheries still follow the boom and bust route. For example, the orange roughy fishery off Namibia collapsed (within six years of implementation) despite the early recognition of controlled fishery development, stakeholder input and support, a precautionary scientific approach, risk analysis and novel management ideas (Boyer et al. 2001). This experience in fishery development highlights the importance of gaining enough biological knowledge and imposing a precautionary approach in implementing a new fishery. The policy and protocol developed here should become a standardized management tool, not only in South Africa, but could be used by fishery managers throughout Africa. Many countries, particularly in Africa, lack capacity in the fisheries management sector and can benefit from such predefined management tools.

The need for change in fisheries management, both globally and in South Africa, has paved the way for implementing new sustainable fishing practices. Institutional structures now need to be put into place to achieve this. By adopting an operational protocol and providing resources for practical implementation, Marine and Coastal Management (Dept.

Environmental Affairs and Tourism, South Africa) should realise the goal of sustainable development of marine resources. In order to reach Government objectives of long-term, socio–economic benefits through sustainable utilization of marine resources, policy on experimental fishing needs to be steadfast. Government must also commit to human resource development, through skills transfer and capacity building, before the commercial fishery commences. These efforts must, however, be applied at all levels of the South African fishery sector, from large industrial fishing companies to subsistence fishers, if Government is to demonstrate a commitment to co-management of marine resources.

REFERENCES

BOYER D.C., KIRCHNER C.H., MCALLUSTER M.K., STABY A. and STAALSEN B.I. 2001. The orange roughy fishery of Namibia: Lessons to be learned about managing a developing fishery. *S. Afr. J. mar. Sci.* **23**: 205-221.

CADDY J.F. 1999. Fisheries management in the twenty-first centaury: will new paradigms apply? *Rev Fish Biol. Fish.* **9**: 1-43.

CADDY J.F. 2000. The Code of Conduct for Responsible Fisheries as a basis for evaluating fisheries research: a suggested operational procedure. *Fish.Res*. **48**: 205-211.

FAO. 1995. Code of Conduct for Responsible Fisheries. FAO, Rome. 41p.

FAO 1996. Precautionary approach to capture fisheries and species introduction. *FAO Technical guidelines for responsible fisheries* No. **2**. FAO, Rome. 54 pp.

APPENDICES

APPENDIX 1: BUSINESS PLAN OUTLAY FOR PROSPECTIVE FISHERS

BUSINESS PLAN

The business plan examines the environmental and economic implications of undertaking the proposed fishing venture. It should confirm that the proposal has commercial potential and that the applicant is in a position to undertake the venture. It must detail how the applicant intends to go about the business of developing the fishery resources in question. The greater the detail provided by the applicant, the more effectively the proposal can be assessed and the more easily the risks can be assessed. The business plan should include the following information:

- **Summary**: This should be a synopsis of the contents of the plan and reiterate the main points of the proposal.
- **Operational Plan**: This should provide a description of the venture, including the physical or equipment requirements and additional support structures needed. It should include detail on:
    - Estimated annual catch, including details of how these estimates were made.
    - Proposed initial harvesting strategy, including information on fishing gear and equipment.
    - Quality control and food safety measures
    - Output markets, including potential processing and distribution
    - Proposed landing ports and reasons for using them
    - Proposed area of operation defined by latitudes and longitudes or other parameters (e.g. depth.)

- **Environmental impact**: Applicants should specify the potential impact, if any, of the fishing venture on the environment, e.g. the seafloor, reefs and water quality. Impacts and mitigating measures should be described and significance of impacts noted.

- **Benefits to State or community**: Direct employments benefits and flow-on, better utilization of resource, increased exports etc.

- **Market research and analysis**: The objective of market research is to establish that a market exists for the proposed venture. It should include a summary of Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis of the markets.
    - Locality of markets: local and/or international
    - Distribution methods: it should include assumptions which support market projections
    - Sales forecast: This must indicate the projected sales and revenue expected over the first three to five years.

- **Milestones:** Realistic milestones should be included in the plan. They will allow for objective assessment of the monitoring of the venture. Milestones should include major events and a time schedule for them: e.g. a schedule for purchasing and setting up gear, commencement of fishing, reaching a target level of revenue. Applicants must realise that they will be judged against these milestones, and performance will influence the continuation of their permits.

- **Risk analysis:** This should include the identified risks, occurrence likely-hood, impact and contingency plans. Risk factors can include the collapse of the stock, bad weather, market failures and a bad fishing season.

- **Financial documentation:** Financial statements for the new venture are projections based on operating and market assumptions. It should include the following:
    - Start-up projections,
    - Profit and loss statement
    - Cash flow.
    - Balance sheet
    - Break-even analysis

APPENDIX 2: GUIDELINES TO ASSESSMENT PROCEDURES IN NEW FISHERIES

ASSESSMENT TOOLS

These guidelines are based on assessment procedures used in Western Australian developing fisheries (Halmarick 1999). These do not form an indisputable/obligatory basis for assessment but can be used as tools to assist in the decision making process and (where relevant) can be adapted to suit local needs. A point system could be developed where each section and accompanying details can be rated on an importance scale, ensuring equality within assessments.

- **Overall application package**
  - Completeness in terms of
    - Fees, forms and business plan.
  - Extent of completeness.
    - Extensive, satisfactory, unsatisfactory.

All anticipated/potential effects listed below will be assessed in terms of pros and cons over short and longer terms, to determine the net effect.

- **Anticipated/potential biological effects**
  - Potential impact on target stocks, related stocks and habitats.
- **Anticipated/potential economic effects**
  - Anticipated financial profile.
    - Extent of growth, market factors, dependence of profits on stock status.
  - Potential development impact.
    - Within local region, provincial, national level.
  - Feasibility of business plan.
    - Complexity, ease of administration, likelihood of success.
- **Anticipated/potential political and social effects**
  - Extent of interaction or impact on other fisheries, industries and stakeholders
- **Anticipated/potential administrative / regulatory effects**
  - Administrative requirements
    - Start-up, intra-annual and annual needs
  - Monitoring requirements
    - Compliance needs (minimal or intensive)

- Enforcement needs (occasional or ongoing)

Further issues, which could be included:

- Commitment of the fisher to the development process,
- Commitment and willingness to transform, including knowledge and skills transfer and capacity building (with commencement of the commercial fishery).

APPENDIX 3: AGE ASSESSMENT IN *O. VULGARIS*

Table A. The increment counts, mass, sex and maturity stage for each *O. vulgaris* specimen. e=eggs, i=immature, j=juvenile, m=mature, m1-m3=maturing, s=spent, U=upper beak, L= lower beak.

Specimen number		Counts		Mean	SD	TM	Sex	Maturity
				Intertidal Juvenile/immature				
144	133	139	143	**138.3**	**5.0**	120	f	i
134(U)	115	110	115	**113.3**	**2.9**	292	f	i
(L)	115	115	115	**115.0**	**0.0**			
136	189	200	190	**193.0**	**6.1**	223	f	i
189	110	99	103	**104.0**	**5.6**	245	f	i
59	120	110	110	**113.3**	**5.8**	1150	f	i
21	98	93	103	**98.0**	**5.0**	839	f	i
116	102	106	103	**103.7**	**2.1**	501	f	i
1	71	85	80	**78.7**	**7.1**	355	f	i
27	93	93	92	**92.7**	**0.6**	422	f	i
45	79	77	79	**78.3**	**1.2**	457	f	i
17	120	124	129	**124.3**	**4.5**	566	f	i
286	74	81	77	**77.3**	**3.5**	72.04	f	j
140	125	117	117	**119.7**	**4.6**	142	f	j
150	104	110	105	**106.3**	**3.2**	169	f	j
129(U)	115	119	113	**115.7**	**3.1**	154	f	j
(L)	108	119	113	**113.3**	**5.5**			
132	76	74	66	**72.0**	**5.3**	132	f	j
156(U)	119	135	129	**127.7**	**8.1**	145	f	j
(L)	120	129	123	**124.0**	**4.6**			
158	116	118	115	**116.3**	**1.5**	156	f	j
159	110	111	110	**110.3**	**0.6**	224	f	j
120	100	110	103	**104.3**	**5.1**	167	f	j
121	90	90	91	**90.3**	**0.6**	164	f	j
126	66	69	67	**67.3**	**1.5**	167	f	j
2	94	99	95	**96.0**	**2.6**	103	f	j
122	70	77	69	**72.0**	**4.4**	195	m	i
124	70	66	68	**68.0**	**2.0**	176	m	i
125	52	61	58	**57.0**	**4.6**	113	m	i
139	100	105	107	**104.0**	**3.6**	127	m	j
142	67	75	82	**74.7**	**7.5**	18	m	j
190	75	73	76	**74.7**	**1.5**	111	m	j
				Intertidal Maturing				
163	150	150	150	**150.0**	**0.0**	967	f	m3
172	245	240	238	**241.0**	**3.6**	1320	f	m3
174	175	170	168	**171.0**	**3.6**	1430	f	m3
175	150	152	154	**152.0**	**2.0**	1003	f	m1
180	170	158	173	**167.0**	**7.9**	2620	f	m1
182	180	189	180	**183.0**	**5.2**	952	f	m2
183	135	133	138	**135.3**	**2.5**	1110	f	m2
194	136	149	134	**139.7**	**8.1**	830	f	m1
199	350	355	350	**351.7**	**2.9**	1410	f	m2
197	165	165	169	**166.3**	**2.3**	1800	f	m1
196	195	199	214	**202.7**	**10.0**	1710	f	m2

127	75	83	83	**80.3**	**4.6**	192	m	m
3	103	103	102	**102.7**	**0.6**	293	m	m
58	99	90	95	**94.7**	**4.5**	468	m	m
66	102	111	112	**108.3**	**5.5**	221	m	m
26	75	79	76	**76.7**	**2.1**	664	m	m
53	116	106	116	**112.7**	**5.8**	934	m	m
181	160	165	155	**160.0**	**5.0**	1440	m	m
195	195	199	214	**202.7**	**10.0**	1580	m	m
Subtidal Mature								
191(U)	208	189	199	**198.7**	**9.5**	629	f	m1
(L)	203	204	203	**203.3**	**0.6**			
203	350	340	344	**344.7**	**5.0**	896	f	s
210	190	185	189	**188.0**	**2.6**	1660	f	m
212	155	145	150	**150.0**	**5.0**	1340	f	m
213	207	197	210	**204.7**	**6.8**	1600	f	m
216	268	260	273	**267.0**	**6.6**	2320	f	e
218	250	240	245	**245.0**	**5.0**	2790	f	m
205(U)	159	155	159	**157.7**	**2.3**	1549.7	f	e
(L)	166	166	163	**165.0**	**1.7**			
8	165	166	173	**168.0**	**4.4**	1660	f	m
185	197	190	193	**193.3**	**3.5**	1380	m	m
76	100	110	105	**105.0**	**5.0**	434	m	m
280	116	128	126	**123.3**	**6.4**	178.09	m	m

APPENDIX 4: MARKET RELATED INFORMATION ON OCTOPUS TRADING.

Table B. Prospective fishers and companies interviewed telephonically, the import, export or local supply of octopus is indicated.

Category	Deal in Octopus	Import	Export	Local	Location
Prospective Fisher	Will export directly				PE
Prospective Fisher	Will sell to exporter				Struisbaai
Prospective Fisher	Will export directly				Plettenberg Bay
Producer/Export Co	Very little	n	n	y	Plettenberg Bay
Import/Export Co	Yes	y	y	n	Cape Town
Import/Export Co	Yes	y	y	y	Cape Town
Producer/Import Co	Yes	-	y	n	Cape Town
Wholesaler	No	-	-	-	Cape Town
Producer/Import Co	No Reply	-	-	-	Cape Town
Import/Export Co	Yes	n	y	n	Cape Town
Producer/Import Co	No Reply	-	-	-	Cape Town
Import/Export Co	Yes	y	y	y	Cape Town
Retailer	Yes	n	n	y	Cape Town
Wholesale/Import Co	Used to	n	n	y	Pretoria

APPENDICES 5-8: Detailed costing of fishing operations. *These are available from the author, on request.*

APPENDIX 5:

Option 1a. FCO, deckboat and gear purchased at beginning of fishery, Fishing operation 1

1b. UEV, pre-owned deckboat used, gear purchased at beginning of fishery, Fishing operation 1.

APPENDIX 6:

Option 2a. FCO, chukkie and gear purchased at beginning of fishery, Fishing operation 1.

b. UEV, pre-owned chukkie used, gear purchased at beginning of fishery, Fishing operation 1.

APPENDIX 7:

Option 3a. FCO, deckboat and gear purchased at beginning of fishery, Fishing operation 2.

b. UEV, pre-owned deckboat used, gear purchased at beginning of fishery, Fishing operation 2.

APPENDIX 8:

Option 4a. FCO, chukkie and gear purchased at beginning of fishery, Fishing operation 2.

b. UEC, pre-owned chukkie used, gear purchased at beginning of fishery, Fishing operation 2.

APPENDICES 9-12: Cash flow statements for the first two years and a break-even analysis of the most feasible scenarios. *These are available from the author, on request.*

APPENDIX 9:

Option 3a. FCO, deckboat and gear purchased at beginning of fishery, Fishing operation 2.

APPENDIX 10:

Option 3b. UEV, pre-owned deckboat used, gear purchased at beginning of fishery, Fishing operation 2.

APPENDIX 11:

Option 4a. FCO, chukkie and gear purchased at beginning of fishery, Fishing operation 2.

APPENDIX 11a:

Option 4a. Limited deckspace, FCO, chukkie and gear purchased at beginning of fishery, Fishing operation 2.

APPENDIX 12:

Option 4b. UEC, pre-owned chukkie used, gear purchased at beginning of fishery, Fishing operation 2.

APPENDIX 12a:

Option 4b. Limited deckspace, UEC, pre-owned chukkie used, gear purchased at beginning of fishery, Fishing operation 2.