Development and Management of the Southern Ocean Krill Fishery

Jacqueline Kay Foster
BSc. and B.Ant.St. (Hons)

Submitted in fulfillment of the requirements for the
Degree of Doctor of Philosophy

University of Tasmania

Submitted June 2011

Declaration of Originality

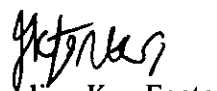
This thesis contains no material which has been accepted for a degree or diploma by the University or any other institution, except by way of background information and duly acknowledged in the thesis, and to the best of the candidates knowledge and belief no material previously published or written by another person except where due acknowledgement is made in the text of the thesis, nor does the thesis contain any material that infringes copyright.

Jacqueline Kay Foster

June 2011

Statement of Authority of Access

This thesis may be made available for loan and limited copying in accordance with the *Copyright Act 1968.*



Jacqueline Kay Foster

June 2011

Statement of Co-authorship

These publications were produced and submitted for consideration to the Commission for the Convention on the Conservation of Antarctic Marine Living Resources, as part of this thesis:

Appendix 1

Foster, J., Nicol, S and Kawaguchi, S. (2007). Information on krill in reports from the CCAMLR Scheme of International Observation and its utility for management. CCAMLR WG-EMM-07/22.

Contributions:

Jacqueline Foster (33%) Stephen Nicol (33%) So Kawaguchi (33%)

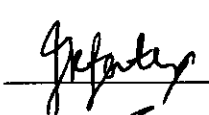
Appendix 2

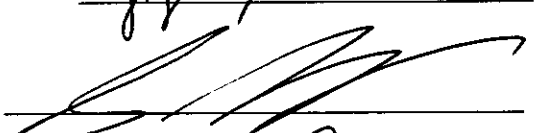
Foster, J., Nicol, S and Kawaguchi, S. (2009). The use of patent databases to detect trends in the krill fishery. SC-CAMLR-XXVIII/BG/15.

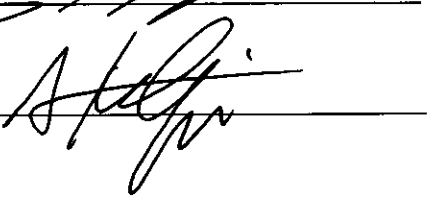
Contributions:

Jacqueline Foster (33%) Stephen Nicol (33%) So Kawaguchi (33%)

We, the undersigned, agree with the above stated proportioning of work undertaken for the above manuscripts which contributed to this thesis:

Candidate: Jacqueline Foster 

Author: Dr Steve Nicol 

Author: Dr So Kawaguchi 

Statement of Ethical Conduct

The research associated with this thesis abides by the International and Australian cods on human and animal experimentation, the guidelines by the Australian Government's Office of the Gene and Technology Regulator and the rulings of the Safety Ethics and Institutional Biosafety Committees of the University (H9460).

Jacqueline Kay Foster

June 2011

Abstract

There has been increasing concern amongst the scientific community and those responsible for the management of the Antarctic krill fishery that the harvesting of this species will soon increase to unprecedented levels. This concern has been prompted by numerous factors including, but not limited to, increased and diversified participation in the fishery, advances in technology, the rapid decline of global fish stocks and an ever-increasing global population. This study examined the development and current management of the fishery for Antarctic krill (*Euphausia superba*) in the Southern Ocean with a view to identifying and recommending possible future management strategies to deal with new directions in the industry.

The Commission for the Conservation of Antarctic Marine Living Resources aims to manage the krill fishery in line with its precautionary and ecosystem based approach to management In order to fulfil its objectives and allow for orderly development of the fishery, it is necessary for it to be kept informed about the economic drivers. However, currently, there is very limited knowledge available to the Commission on the nature of the marketplace for Antarctic krill.

This study used data from the Commission, the United Nations Food and Agriculture Organisation, publicly available patent libraries, published literature, industry participants and commodities marketplace to investigate the management and development of the krill fishery.

Mechanisms used by the Commission to track the development of the fishery to date, and new tools developed in this study to detect likely future trends in the fishery, indicated that not only is interest in the fishery increasing in terms of participation and investment, but the marketplace for krill has expanded, with a number of new markets (including pharmaceuticals and nutraceuticals) likely to expand considerably in coming years.

The principal finding of the study was that the krill fishery has been exempted from many of the tighter regulatory controls that other fisheries in the Southern Ocean were subjected to. However, to ensure that the development of the fishery is consistent with its approach to management, and accounts for this fishery's recent rapid development, the Commission will need to adopt tighter regulatory controls including, but not limited to, mandatory observer coverage for all krill fishing vessels, more rigorous application of the existing vessel monitoring system's reporting requirements and allocation of catch limits across smaller management units to mitigate against overfishing in important predator foraging grounds.

The Commission has already acted on several of the outcomes and subsequent recommendations from this study that had been submitted to its Working Group on Ecosystem Monitoring and Management and the Scientific Committee as background papers. For example, the Commission ordered a review of the observer program, which has since led to more detailed information both in the observers' notification reports and in the notification form (on gear specifications). In addition, the Commission adopted the use of the patent database developed during this study as a tool for tracking interest and possible developments in the fishery.

Acknowledgements

There are many people and institutions who must be thanked for giving their generous support in the form of both time and money and without whom this research would not have been possible.

Thanks must go to my supervisorial team of Associate Professor Marcus Haward, Dr Julia Jabour, Dr Steve Nicol and Dr So Kawaguchi. I have often been told by PhD students, both past and present, that I must surely have had the most supportive supervisorial team they have ever seen! My sincerest thanks to these people who have made my PhD journey an entirely smooth and rewarding experience.

Thanks must also go to the following: Graeme Broxam from Intellectual Property Australia who provided invaluable guidance and feedback in constructing the krill patent database; Dr Dietrich Blome and Ludolf Koehler from Marine Bio Products GmbH in Bremerhaven, Germany for giving their valuable time to discuss their enterprises and share their knowledge; Jon Ervik and Associates of Bergen, Norway, for giving their time to discuss their operations, plans and research; Dr Bettina Meyer from the Alfred Wegener Institute for Polar and Marine Research (AWI) in Bremerhaven, Germany for hosting me at the Institute whilst I conducted research across northern Europe; and staff at the CCAMLR Secretariat in Hobart for giving their time to respond to my queries and offer advice during my research.

This study was funded by the University of Tasmania (UTAS) and the Antarctic Climate and Ecosystems Cooperative Research Centre (ACE CRC). I would also like to thank the Institute for Marine and Antarctic Studies (IMAS) (formerly the Institute for Antarctic and South Ocean Studies, IASOS) Policy Program for their support for conference attendance and associated travel. Thanks must also go to the Australian Antarctic Division (AAD) for their in-kind support and hosting of me as a student and to the Association of Polar Early Career Scientists (APECS) for their conference funding support.

Table of Contents

Figures

Chapter One

Chapter Two

Chapter Three

Chapter Four

Chapter Five

Tables

Acronyms

APFZ	Antarctic Polar Front Zone
CCAMLR	Convention on the Conservation of Antarctic Marine Living Resources
CDS	Catch Documentation Scheme
CEMP	CCAMLR Ecosystem Monitoring Program
CPUE	Catch per Unit Effort
DHA	Docosahexaenoic Acid
EBM	Ecosystem Based Management
EPA	Eicosapentaenoic Acid
EPO	European Patent Office
FAO	Food and Agricultural Organisation
FCR	Feed Conversion Ratio
FIFO	Fish-In-Fish-Out
GFC	Global Financial Crisis
GYM	Generalised Yield Model
IFFO	International Fishmeal and Fish Oil Organisation
IPC	International Patent Classification
INPADOC	International Patent Documentation Centre
IP	Intellectual Property
IUU	Illegal, Unreported and Unregulated
KYM	Krill Yield Model
MPA	Marine Protected Area
MSC	Marine Stewardship Council
MSY	Maximum Sustainable Yield

OPEC	Organisation of the Petroleum Exporting Countries
PUFA	Polyunsaturated Fatty Acid
R&D	Research and Development
RFMO	Regional Fisheries Management Organisation
SC-CAMLR	Scientific Committee for CCAMLR
SCIC	Standing Committee on Implementation and Compliance
SSMU	Small Scale Management Unit
TASO	Technical Group for At-Sea Operations
UNCED	United Nations Conference on Environment and Development
USPTO	United States Patent and Trademark Office
VMS	Vessel Monitoring System
WG-DAC	Working Group on the Development of Approaches to Management
WG-EMM	Working Group on Environmental Monitoring and Management
WG-IMALF	Working Group on Incidental Mortality Associated with Longline Fishing
WG-KRILL	Working Group on Krill
WHO	World Health Organisation

Chapter One: Introduction

1.1 The Problem

There has been increasing concern amongst the scientific community, as well as those responsible for the management of the Antarctic krill fishery, that harvesting of this species in the Southern Ocean will soon increase to unprecedented levels. This concern is prompted by numerous factors including, but not limited to, increased and diversified participation in the fishery, the rapid decline of global fish stocks and an ever increasing global population. The Commission for the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) (the Commission) is tasked with managing all Southern Ocean fisheries, including the krill fishery, consistent with both a precautionary and ecosystems approach to management. In order for the CCAMLR Commission to fulfil its objectives and allow for orderly development of the krill fishery, it is necessary for the Commission to be up to date on the economic drivers of the fishery. However, currently, there is very limited knowledge available to the Commission to inform it of the nature of the marketplace for Antarctic krill. To allow the Commission to progress in the management of this keystone species, tools must be identified to allow it to track the development of the fishery.

1.2 Overview

Antarctic krill, *Euphausia superba*, is the largest and most abundant Euphausiid (krill) species occurring in the Southern Ocean (Everson, 1977) (Figure 1). Worldwide there are 86 known species of Euphausiids (Baker *et al.*, 1990), with six of these occurring in the waters around continental Antarctica (Everson, 1977). Antarctic krill, referred to herein as "krill", grow to a maximum length of 65mm, and weight of 2g, over their 2-5 year life-span (Nicol and Endo, 1997) (Figure 2) and swarm in large aggregations in the surface layers of the Southern Ocean during the austral summer (Sidhu *et al.*, 1970). Together with its relatively large size, it was this surface swarming characteristic that made *Euphausia superba* an attractive commercial species, above other high protein zooplankton that had been investigated (Sidhu *et al.*, 1970).

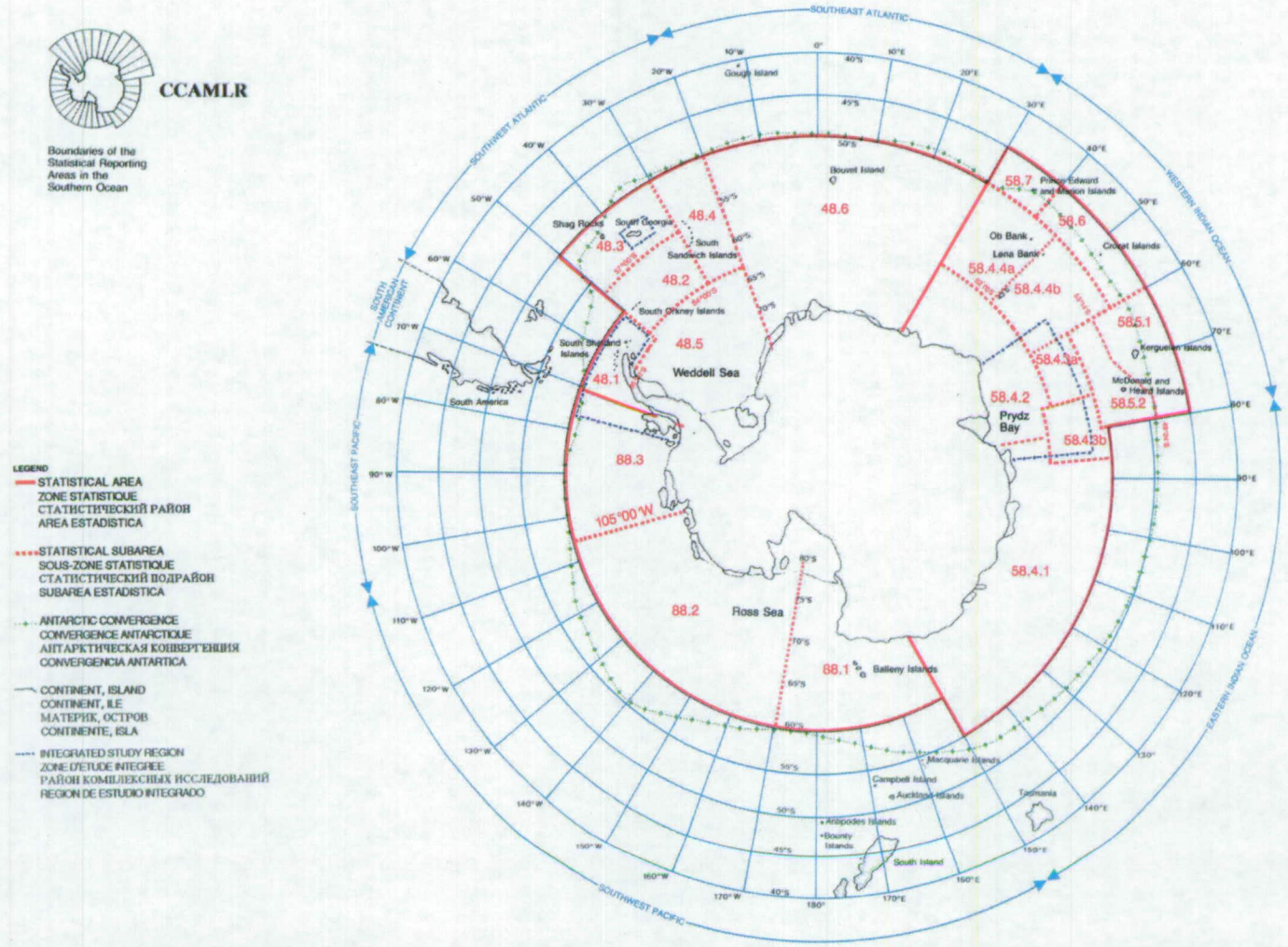


Figure 1: FAO Southern Ocean Statistical Areas (CCAMLR, 2009a).

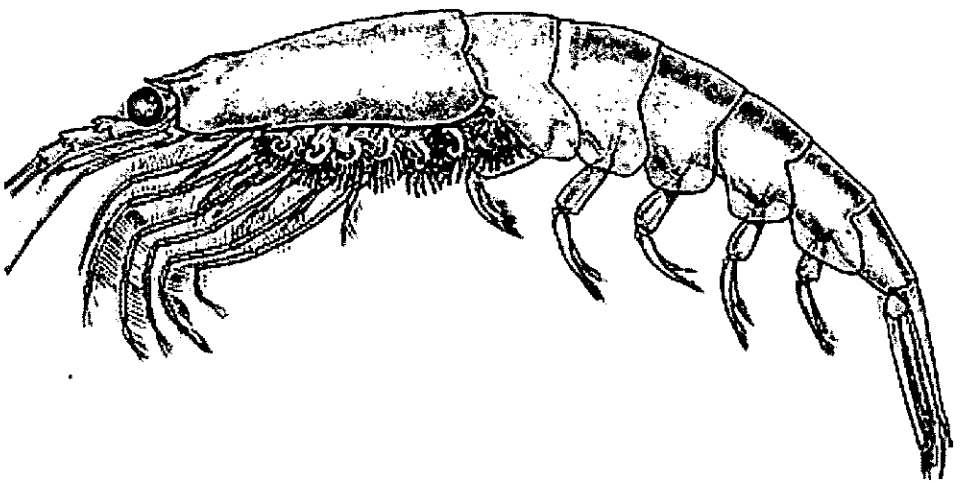


Figure 2: *Euphausia superba* (FAO, 2009).

Krill has long been recognised as holding a key position in the Antarctic ecosystem (Figure 3), due to the reliance of fish, seals, penguins, whales and seabirds on it as a primary food source (Marr, 1962; Mackintosh, 1973; Miller and Hampton, 1989; Miller, 2002). Given this role in the food chain and their distribution and behaviour, krill are considered to occupy a similar trophic level in the Southern Ocean ecosystem as small pelagic fish species do in other ecosystems around the world (Fréon *et al.*, 2005). Biomass estimates for the species have varied from 14 to 7000 million tonnes (Miller and Hampton, 1989), with most recent estimates placing biomass in the range of 60-420 million tonnes (Siegel, 2005). The distribution of krill around the Antarctic continent is generally defined by physical features, namely the Antarctic Polar Front Zone (APFZ) (Everson, 2000); the continental shelf; and the pack ice zone (Nicol *et al.*, 2000).

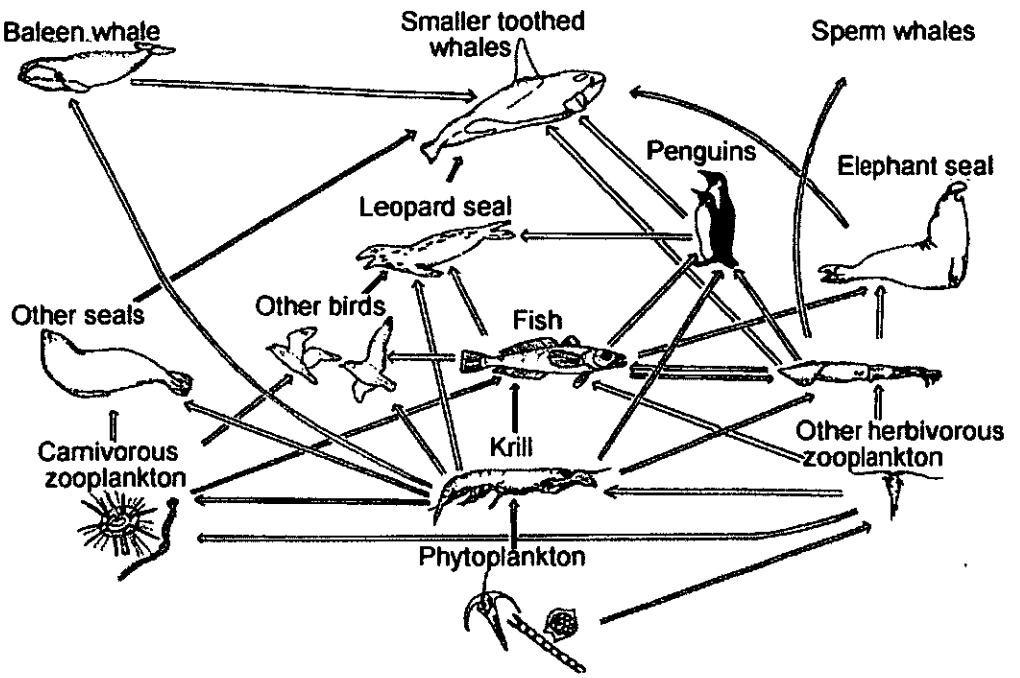


Figure 3: Simplified Antarctic food web (Cool Antarctica, 2008).

The fishery for *Euphausia superba* (Antarctic krill) has been operating commercially in the Southern Ocean since the late 1960s, with the idiosyncrasies of the fishery regularly documented (Eddie, 1977; Budzinski *et al*, 1985; Miller, 1991; Nicol and Endo, 1997; Kawaguchi and Nicol, 2007; Kock, 2007). Catches of krill have exhibited a number of phases and fluctuations since the beginning of commercial harvesting.

In response to the initial development of the krill fishery, CCAMLR was adopted in 1980 as an international regime tasked with managing the harvest of krill and other Southern Ocean marine resources. There had been concerns expressed by Antarctic Treaty Consultative Parties over increasing landings of krill in the 1970s (Frank, 1983; Edwards and Heap, 1981) and the effect that a dramatic reduction in the size of krill stocks would have on populations of krill predators, including penguins, seals, whales, fish and seabirds (Howard, 1989). The result of their concern was the adoption of CCAMLR in 1980 and its entry into force two years later.

CCAMLR has been called the "krill convention" (Nicol, 1991; Fernholm and Rudback, 1989) due its predominant focus on ensuring the precautionary management of Southern Ocean krill stocks. However, the depletion of Antarctic fish stocks, including those of rockcod (*Notothenia gibberifrons*) and icefish (*Champsocephalus gunnari*) (Howard, 1989), attracted the Commission's early attention, as these fisheries coincided with the initially rapid rise in landings of krill. The early krill fishery subsided in the 1990s, but not before the first steps towards krill management were enacted. In recent years, the attention of the Commission has been drawn to emerging issues, in particular the Illegal, Unreported and Unregulated (IUU) fishing of Patagonian Toothfish.

In recent years there has been much discussion within the Commission surrounding the prospect of increased catches of krill, to a level not yet seen in the fishery. Events which have raised these concerns include fishing notifications from CCAMLR fishing Members indicating new entrants into the fishery; new vessels and countries entering the fishery and higher predicted catches; marketing of new krill-based products; increased investment by companies operating in the krill market in krill fishing-related capital and Research and Development (R&D); and a global decrease in fish stocks which have traditionally been used for fish meal and fish oils. As a result of these events the focus of the Commission has once again been drawn back to addressing issues surrounding the management of the krill fishery. This renewed focus has been adopted to ensure that management decisions are truly precautionary, taking into full account the ecosystem approach. Both the precautionary and ecosystem approaches are management strategies which CCAMLR pioneered and on which the Commission bases all its fisheries management decisions.

Successful precautionary management of a resource logically requires information not only on the state of the resource, but also on the state of the market of the resource. Having access to this information enables managers to actively manage the resource in a precautionary manner, rather than reacting to overexploitation once it occurs which has been the case in many of the overexploited fisheries of the world. The exploitation of the Patagonian toothfish in CCAMLR waters provides an example of this. Although the Commission had

been responsible for the management of toothfish stocks since its inception, it wasn't until the impact of IUU fishing was brought to the Commission's attention in the mid 1990s that active management of the fishery, through the introduction of a suite of new Conservation Measures, occurred. Whilst CCAMLR-sanctioned science addresses the issue of the state of krill stocks, little attention has been paid to the state of the market for krill. Several circumstances have prohibited the kinds of analyses regularly undertaken on traditionally traded fish commodities being undertaken on krill.

First, there has been little trade of krill in traditional fish markets and research in this thesis suggests that, in the past, krill has been traded directly from supplier to buyer in a very demand-driven relationship. What is currently known about the market for krill has resulted primarily from analysis of past trends in harvests, the limited trade that has occurred in traditional market places and the activities of the traditional fishing countries in terms of participation in the fishery. Secondly, in the past five years in particular, there has been a diversification in fishery participants, fishing technologies, markets, product technologies and supply and demand regimes.

As will be discussed in this thesis, this diversification has resulted in information becoming more accessible from a once closed market. Companies new to operating in the fishery are placing shareholder information, R&D projects and newly patented technologies into the public domain. New products developed by these companies can also be tracked more easily in the market place due to an increase in this publicly available information. Such information is making it easier to track trends in the markets for krill and thus to provide some useful data for predictions of future developments.

Predictions on the future direction of the krill fishery will be useful for the Commission to assist it in determining the necessary rate of development of its management approaches. Given that krill stocks in the Southern Ocean represent one of the few underexploited marine stocks in the world, it seems probable that increased exploitation will eventuate. Information on the potential rate of

increase of exploitation of krill is essential for the Commission to ensure that there is an orderly development of this fishery.

1.3 An Overview of the Antarctic Krill Fishery

The history and development of the krill fishery has been reviewed and documented in numerous publications (e.g. Nicol *et al.*, 2011; Kawaguchi and Nicol, 2007; Nicol and Endo, 1997; Miller, 1991; Budzinksi *et al.*, 1985; McElroy, 1984). As such, only a brief overview of key aspects of the history of the fishery is presented here.

Throughout the history of CCAMLR, the krill fishery has consistently been the largest by-weight fishery in the Southern Ocean. The commercial fishery for Antarctic krill has operated in the Southern Ocean since the early to mid 1970s (Nicol and Endo, 1997), developing since this time in what has been described as a "phased" manner (Nicol and Endo, 1997; Eddie, 1977) (Figure 4). The early years of the fishery were characterised by low catches, primarily aimed towards research and product development (Grantham, 1977) with Soviet (from the 1961/62 season) and Japanese vessels (from the 1972/73 season) initiating exploration. In the late 1970s and early 1980s there was an explosion in effort, with total catches reaching heights not seen since. This period of high catch rates, primarily taken by countries including USSR, Japan, Poland, Germany, Taiwan, Spain and Chile, represented the move of the fishery from the experimental to commercial phase (Nicol and Endo, 1997).

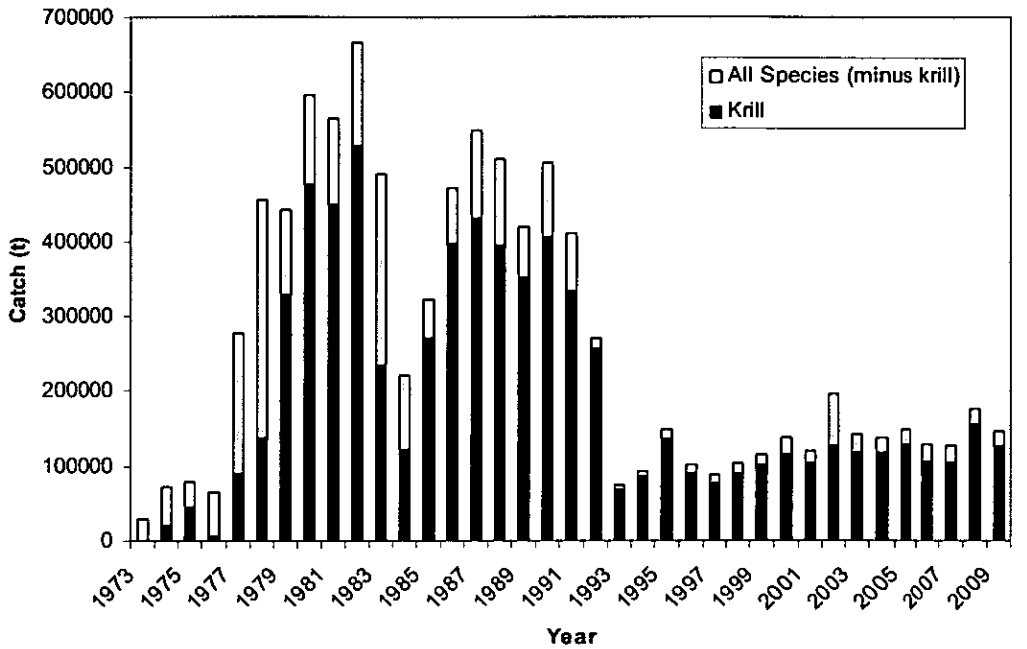


Figure 4: Catch of krill and all fisheries (including krill) in the Southern Ocean (CCAMLR, 2010).

After this explosion in catch there was a period of sharp decline in the fishery in the mid-1980s, attributed to "technical difficulties" (Nicol and Endo 1997). These difficulties are often associated with the discovery of high fluoride levels in the exoskeleton of the krill, rendering them unfit for human consumption (Soevik and Breakkan, 1979) and with processing technologies and marketability of resulting products (Budzinski *et al.*, 1985). Further development of processing techniques was undertaken and catches quickly recovered into 1990 before once again declining rapidly in 1991 to pre-experimental phase levels. The decline occurred at the same time as the break-up of the Soviet Union and saw catches of distant water, low value products decline for those countries once part of the Soviet bloc (Nicol and Endo, 1997). Since the mid 1990s, the krill fishery has exhibited a small and steady increase in krill landings to a current catch of approximately 125 823 tonnes in 2009.

The catch of the early exploratory fishery was generally used in scientific research and experiments, often aimed at developing harvesting and processing techniques (Nicol and Endo, 1997; Eddie, 1977). Once the fishery began to develop into the 1970s, catches were used mainly in R&D for food products for

human consumption with a small amount of interest in development of fish meal for animal feed (Eddie, 1977). Into the 1980s the scope for use of krill broadened dramatically with interest in the composition of krill in terms of protein, enzymes and lipids, chitin and chitosan as well as further interest in krill as a direct food product and as an alternative to traditional fish meal and animal feed meals (Budzinski *et al.*, 1985).

Since the mid-1990s, the fishery has been concentrated in Area 48 in the waters surrounding the Antarctic Peninsula islands including South Georgia, South Sandwich, South Orkney and South Shetland Islands. Over time, the fishery has been dispersed between all the FAO (Food and Agricultural Organisation) Statistical Areas in the Southern Ocean (Figure 5) however the fishery has always been primarily located in the Atlantic Sector (89% of total catch).

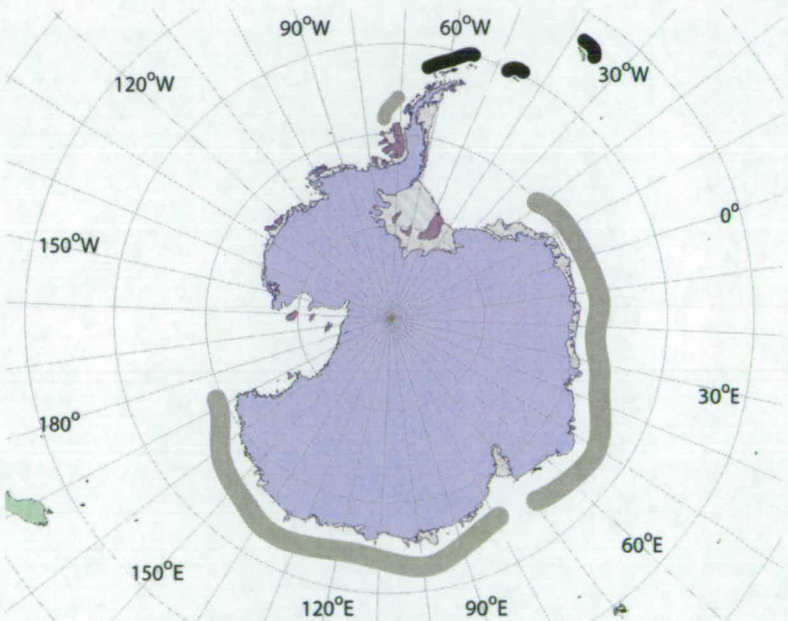


Figure 5: Location of existing (black) and past (grey) Antarctic krill catches (Kawaguchi and Nicol, 2007).

1.4 Management of the Krill Fishery

The Convention on the Conservation of Antarctic Marine Living Resources (the Convention) was signed in Canberra in 1980, concluding negotiations of the Antarctic Treaty Consultative Parties that had commenced in 1977 (Constable *et*

al., 2000; Miller *et al.*, 2004). It entered into force in 1982 and currently has 25 Members who have a role in decision making and nine States party to the Convention who participate in the lead up to the decision making process. CCAMLR was negotiated primarily in response to concerns that fishing for krill was going to increase rapidly and that there was no system in place to regulate the fishery (Edwards and Heap, 1981). CCAMLR is responsible for the conservation of all living resources (with the exception of seals and whales which are managed by other instruments), both targeted and dependent and associated species, in the Southern Ocean (CCAMLR, 2009a), which has been defined for this purpose as the 32.9 million square kilometres of ocean between the Antarctic Polar Front and the continent (CCAMLR, 2009a; Nicol and Endo, 1997), referred to here in as 'the Area'. The Area is further divided for management purposes into areas based on the FAO Statistical Areas (see Figure 1).

CCAMLR is unique in its approach to regulation of resources in that it adopts both a 'precautionary' and 'ecosystem approach' to fisheries management (CCAMLR, 2009a; Miller, 2002). Principle 15 of the Rio Declaration of 1992, made at the United Nations Conference on Environment and Development (UNCED) codified the precautionary approach for the first time at the global level. Principal 15 states that:

> In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation (UNCED, 1992).

In the CCAMLR context, the precautionary approach allows that decisions taken should have a low risk of long-term adverse effects, an important factor when working with scientific information that has a degree of uncertainty (Kock, 2000). CCAMLR was a pioneer in the world of Regional Fisheries Management Organisations (RFMOs) in taking an ecosystem approach to resource management (de la Mare, 2009). The ecosystem approach works differently to

the conventional 'single species' approach taken by most fisheries management bodies in that it does not only focus on the management of the target species but also on dependent and related species, such a predators of the target species. Article II (3) of the Convention set outs the remit for taking an ecosystem approach to the management of Southern Ocean resources:

> 3. Any harvesting and associated activities in the area to which this Convention applies shall be conducted in accordance with the provisions of this Convention and with the following principles of conservation:
>
> (a) prevention of decrease in the size of any harvested population to levels below those which ensure its stable recruitment. For this purpose its size should not be allowed to fall below a level close to that which ensures the greatest net annual increment;
>
> (b) maintenance of the ecological relationships between harvested, dependent and related populations of Antarctic marine living resources and the restoration of depleted populations to the levels defined in subparagraph (a) above; and
>
> (c) prevention of changes or minimisation of the risk of changes in the marine ecosystem which are not potentially reversible over two or three decades, taking into account the state of available knowledge of the direct and indirect impact of harvesting, the effect of the introduction of alien species, the effects of associated activities on the marine ecosystem and of the effects of environmental changes, with the aim of making possible the sustained conservation of Antarctic marine living resources.

It is important to note that whilst CCAMLR's primary aim is the conservation of species; the Convention includes the harvesting and rational use of these resources in its definition of conservation (Article II.2) (CCAMLR, 2009a).

The Commission implements management directives through Conservation Measures (the functions of which are set out in Article IX of the Convention),

which are adopted in a consensus decision making process (Article XII) by Commission Members. In this case, consensus means the absence of formal objection and is reached when Members have negotiated acceptable outcomes and language (Turner *et al.*, 2008). Currently, the krill fishery is managed through a series of Conservation Measures. These Measures relate to aspects of operation of the fishery including precautionary catch limits, gear restrictions, data reporting, notification of intent to fish, minimisation of incidental mortality, observer deployment in limited areas and measures for exploratory fisheries. A full discussion of Conservation Measures which regulate the krill fishery, and their history, is presented in later discussions.

In order to provide Members with best-available scientific information on which to base management decisions, the Convention establishes a Scientific Committee (Article XIV) to act as a consultative body to the Commission. The Scientific Committee advises the Commission on harvesting levels and other management measures developed through consultation and the application of advanced scientific techniques. It provides a forum for consultation and cooperation on the collection, study and exchange of information necessary for the Commission to exercise its functions.

In turn, the Commission must take full account of the recommendations and advice of the Scientific Committee (Article IX.4) in the development of measures to implement the principles of conservation embodied in the Convention. Over time, the Scientific Committee has deemed it necessary to establish working groups to help inform its recommendations to the Commission. Currently, the Working Group for Ecosystem Monitoring and Management (WG-EMM) (an amalgamation of the former Working Groups for Krill [WG-Krill] and CCAMLR Ecosystem Monitoring Program [CEMP]) aids the Committee to advise the Commission on krill harvesting and ecosystem assessment (SC-CAMLR-XVIII, 7.41).

1.5 Research Design

This thesis utilises several different methods of research, both qualitative and quantitative. The investigation of the marketplace for krill and the Commission's management of the fishery use mainly qualitative methods. The description and analysis of tools for detecting trends in the fishery use quantitative methods. The research methods are generally described within the relevant chapters.

For continuity and comparability purposes, all catch and trade data for the krill fishery and competing commodities were taken from the CCAMLR Statistical Database, the FAO FishStat Plus (universal software for fishery statistical time series) and FAO industry bodies including Globefish, the FAO centre for international fish trade information. Where this is not the case, it has been specified.

However, due to the limited availability of information on direct market prices for krill and krill-related products, as discussed throughout this study, information on the marketplace for krill was gathered from a variety of sources. These included published academic literature, online marketplace, company annual reports and online sites, fish markets and trade press. The raw data for many of the figures taken from company annual reports and online sites is not publicly available due to it being 'commercial in confidence'. Therefore it has been possible to only present copies of the resulting figures, rather than the preferred but unobtainable primary information.

Information for the review of the management of the krill fishery used information from CCAMLR Commission, Scientific Committee and various Working Group reports. In addition to reviewing information contained within these reports, published literature was also used to identify commentary on the management of the fishery. This information was collated to provide a comprehensive overview. Permission to access Observer Reports for the review of the CCAMLR Scheme of International Scientific Observation was obtained from CCAMLR Members, in line with CCAMLR's Rule of Access requirements.

The krill patent database was constructed from searches of the European Patent Office (EPO) online database and the United States Patent and Trademark Office (USPTO) online database. Information from the two patent sources was combined and treated as one database for the purposes of this research. All patents were cross-checked between the two databases to ensure no duplication or over representation occurred. The final database was constructed and analysed primarily using the same methods employed by Nicol and Foster (2003).

Interviews with industry participants were conducted in Germany and Norway in 2007. In addition to providing information on the development of the krill fishery these interviews also dealt with some issues and topics identified by the interview subjects as 'commercial in confidence'. Under the terms of the ethics guidelines approved for this research and accepted by the interview subjects no 'commercial in confidence' information is included in this thesis. Only information accessible in the public domain that was discussed during these interviews has been included. These interviews, and the broader research underpinning this thesis were conducted in line with the University of Tasmania's Human Research Ethics (Ethics Minimal Risk) guidelines for project H9460 including submission of annual reports on the progress of research.

1.6 Aims and Objectives

1.6.1 Aims

The overall aim of this thesis is two-fold. Firstly, this thesis aims to provide an up-to-date overview of the CCAMLR Commission's management of the Southern Ocean krill fishery. Secondly this thesis aims to identify tools which can be used to examine future trends in the Southern Ocean krill fishery.

1.6.2 Objectives

The objectives of this study are:

a) To examine the Commission's management of the krill fishery to date, including an overview of discussions surrounding management of the krill fishery;

b) To track the management of the fishery by the Commission through examination of management measures adopted to regulate the fishery, identifying and constructing the framework for management that has been developed in line with the Commission's precautionary and ecosystem approaches to management;

c) To examine the validity of recent suggestions of a potential increase in the Southern Ocean krill fishery and identify the likelihood of an increase in the fishery in coming years;

d) To develop indices to track drivers of newly emerging krill markets, including information from fisheries participants, patent databases and trends in the supply and demand for competing commodities, and to analyse the usefulness of the information which can be obtained from tracking these drivers;

e) To use these tools to comment on likely future trends in the fishery by combining them with information directly from CCAMLR on the management of the fishery; and

f) To outline the current direction of the krill fishery, to speculate on its possible future direction, and to provide recommendations on how this information could be incorporated into future decisions on the management of the krill fishery.

1.7 Scope and Limitations

This thesis analyses past and current trends in the Southern Ocean krill fishery with the aim of using trends in catch, participation, management decisions, competing commodity prices and patent information to identify suitable tools for predicting future trends in the fishery. This thesis does not aim to analyse the effectiveness of the management of the fishery to date. An analysis of regime effectiveness has not yet been carried out for CCAMLR in the context of the management of the krill fishery. Such an analysis will, however, be useful in the

future once the krill catch trigger levels have been reached broadly across the fishery and consistently over time. The trigger level was only reached for the first time in 2010, and then only for one subarea, providing insufficient data for a meaningful analysis. Once the fishery is established, there will be more data on the fishery itself, the ecosystem responses, and the management provisions used by CCAMLR. For these reasons, an analysis of CCAMLR effectiveness is outside the scope of this current thesis.

In line with this approach, no consideration is given to the CCAMLR Performance Review undertaken in 2008. This thesis does, however, aim to review how the fishery has been managed in line with CCAMLR's management approach. Any discussions surrounding regime effectiveness are outside the scope of this study. When analysing the management of the fishery, consideration is given only to Conservation Measures which have been adopted and are legally binding on Members. This study does not give any consideration to Resolutions which are not legally binding, although their value as expressions of soft law is acknowledged.

This study does not aim to draw conclusions on the quantitative nature of future trends in the fishery; only qualitative assessments of possible trends are made. This thesis does not aim to comment on the *rate* of development of the krill fishery but, rather, aims to comment on the likely *direction* that the krill fishery will take when it does expand. Any discussion on the rate at which the krill fishery is likely to expand would require economic modelling. However economic and other data on tonnages, quantities being processed into different products and destination markets is simply not available for the krill fishery – points that underpin the novel approaches for tracking developments in the fishery that are examined in this thesis. Avenues for accessing economic data from fishery participants were investigated in the early stages of this research in recognition of the important role they could play. However, due to 'commercial in confidence' constraining the release of sensitive information to third parties, a thorough financial investigation was not possible. The lack of consistently collected and published economic information on the krill fishery and its products has therefore precluded a value chain analysis.

It is obvious that this study was limited by the 'commercial in confidence' nature of much of the information held by the commercial krill industry. A small amount of information was obtained in interviews with industry participants, but this was also subject to similar constraints by the same 'commercial in confidence' and may not be referenced in entirety or may be have been completely excluded from the published thesis.

This thesis also does not look at inter-industry issues but, rather, aims to assess the general development of the krill industry. As such, detailed consideration of issues that exist between industry participants is not relevant in this study.

The krill fishery and its management are constantly developing. To allow this thesis to be as up to date as possible, information from CCAMLR meetings up to the Commission and Scientific Committee Meetings of 2009 is included in the overview of the management of the fishery. The krill patent database is updated to, and including, March 2009. It must be noted that there is a time lag between when patents are lodged and when they appear in the public domain. As such, whilst patents may appear in the public online patent database that have been lodged in 2009, or earlier, they may not appear in the database presented here.

1.8 Justification

A key strategy of CCAMLR is to avoid overharvesting of the krill resource and allow for an orderly development of the fishery. This cannot occur without reliable information on which to make assessments of potential trends in the fishery. Over the past eight years, the Commission has repeatedly asked for information on the economics of the krill fishery because this information can be used to predict potential catch increases.

Information requested has ranged from market prices (SC-CAMLR-XVIII, paragraph 2.7), product information (SC-CAMLR-XVIII, paragraph 2.7; SC-CAMLR-XX, paragraph 2.4) and market drivers (SC-CAMLR-XVII, paragraph 2.6; SC-CAMLR-XXI, paragraph 4.11), to full economic analyses (SC-CAMLR-XX, paragraph 2.4). Most recently, at the 2008 meeting of the Commission, new Resolution (27/XXVII) was adopted, urging Members:

To introduce into their domestic law, and use accordingly, an appropriate tariff classification in order to improve knowledge of the volume and trade of Antarctic krill.

At the 2000 Meeting of the Commission the need for information from the krill fishery on market prices for krill products was noted. It was considered by the Scientific Committee at this stage that information on krill prices from markets where large amounts of krill were frequently traded was still not available.

Detailed research on the potential market for Antarctic krill has been very limited with the last in-depth discussion on the topic appearing in FAO Technical Papers of the late 1970s and mid-1980s. Limited discussion has taken place since (again, in FAO Technical Papers, this time in the mid-1990s) but now, with a recent increase in interest in the krill fishery and a logical increase in demand for krill to follow, the need for a current analysis of the potential market for krill is necessary.

1.9 Outline of Thesis

The following is an outline of the structure and content of this thesis:

1.9.1 Chapter Two: The Krill Marketplace

This Chapter will investigate the evolution of the marketplace for krill and krill-derived products, including the involvement of various companies in fishing and R&D. After examination of what makes krill a competitive product, likely market niches for krill and krill-related products are identified. The development of krill and krill-related products, up until the present day, is discussed to give context discussion on the niches that these products are likely to fill in the present day, and future, marketplace. This Chapter concludes by identifying the gaps that exist in information from the marketplace that make it difficult to track the market for krill.

1.9.2 Chapter Three: Management of the Krill Fishery

This Chapter will investigate the management of the krill fishery to date and address the question of how well the Commission is placed to deal with an

increase in krill catches. This will be done by examining both the level of attention the Commission has given to the issue of management of the krill fishery and the management measures which have been adopted to regulate the krill fishery. By doing so, this Chapter will identify how these measures fit with CCAMLR's ecosystem-based and precautionary approaches to management. A case study of the CCAMLR Scheme of International Scientific Observation will be used to illustrate both how effective the Commission's management of the krill fishery is and to identify shortcomings.

1.9.3 Chapter Four: Current Tools for Detecting Trends in the Krill Fishery

Chapter Four will identify the tools the Commission currently has for detecting trends in the krill fishery, including catch and notification data, as well as the krill patent database which was developed as part of this study and was adopted by the Commission at the 2009 meeting as a tool for tracking the krill fishery. The key information which can be provided by these tools will be identified and analysed to provide indications of likely future trends in the krill fishery in terms of the marketplace and participation.

1.9.4 Chapter Five: Other Indicators for Detecting Trends in the Krill Fishery

Given the emerging markets for krill and krill-related products that have been identified in Chapters Two and Four, this Chapter will identify tools that can be used as indicators for future developments in the krill fishery. Both commodities that are likely to compete with krill in the marketplace, and the raw materials that comprise these commodities, will be identified. Trends in sales and supply of fishmeal and fish oils and trends in supply/availability of the small pelagic fish species which are representative of the species which make up these products will be examined. Comments on the usefulness of these tools for use by the Commission will be discussed.

1.9.5 Chapter Six: Conclusions

Chapter Six will present final conclusions that have resulted from this research and comment, based on these conclusions, on the likely orderly development of the krill fishery into the future.

Chapter Two: The Krill Marketplace

2.1 Introduction

The United Nations Population Division estimates that by the year 2020 the world population will be 7.7 billion, almost double the population of 1970. By 2050, the world population will have exceeded nine billion. As world population continues to grow, there is increasing pressure placed on the world's natural resources to contribute to the global food supply. Fish stocks contribute significantly to world food supplies with world fisheries production, both aquaculture and capture (Tacon and Metian, 2008), supplying 110 million tonnes of food fish to the global population in 2006, equivalent to approximately 16.7kg per person (FAO, 2008). Both capture and aquaculture fisheries place significant pressure on fish stocks, with direct fishing pressure on wild stocks and the requirement for fishmeal as a protein-rich food source for farmed stocks.

The global average annual growth in the aquaculture sector between 1990 and 2004 was 9.4% (Hasan *et al.*, 2007), placing extra strain on capture fisheries to provide fish meal and fish oil for feeds. The fish-in-fish-out ratio describes the amount of wild fish it takes to produce a tonne of farmed salmon (Jackson, 2006). Whilst the fish-in-fish-out (FIFO) ratio has decreased from 1995 to 2006 (Tacon and Metian, 2008), indicating that use of fish in aquaculture production is becoming more efficient, the continued growth in the aquaculture places enormous pressure on wild fish stocks to provide raw product for inclusion in fish meals and animals feeds..

There has been a clear acceleration in global aquaculture production for the major groups of marine species (Figure 6) with freshwater fish (including salmon) and crustaceans showing the largest growth. At the same time, global capture production figures (Figure 7) indicate a levelling off in the amount of wild fish being landed globally. The disparity between trends in aquaculture and wild capture fisheries production is concerning, particularly given the aforementioned reliance on aquaculture production on wild fish stocks for feed.

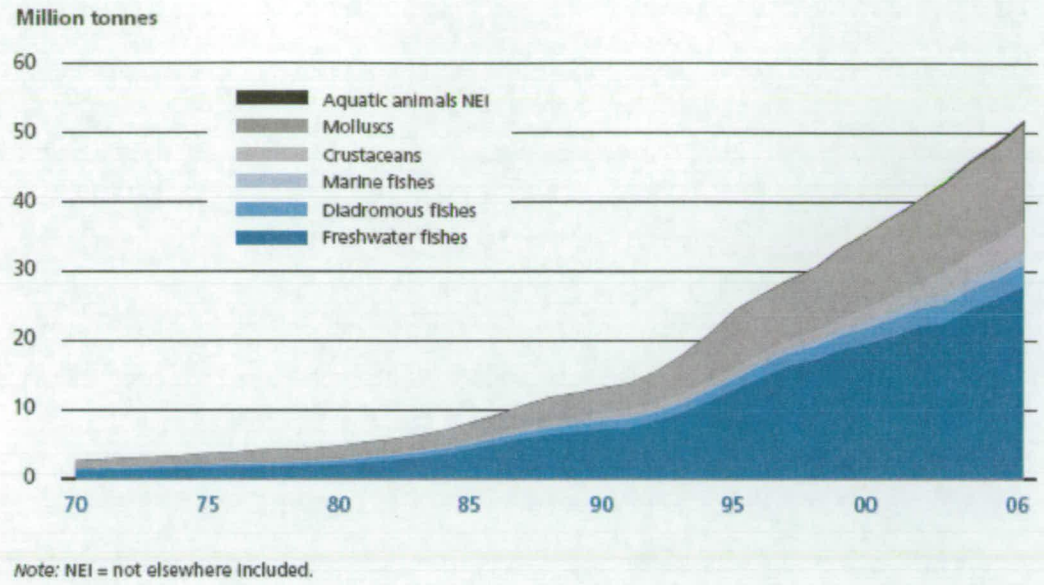


Figure 6: Trends in world aquaculture: major species groups (FAO, 2008).

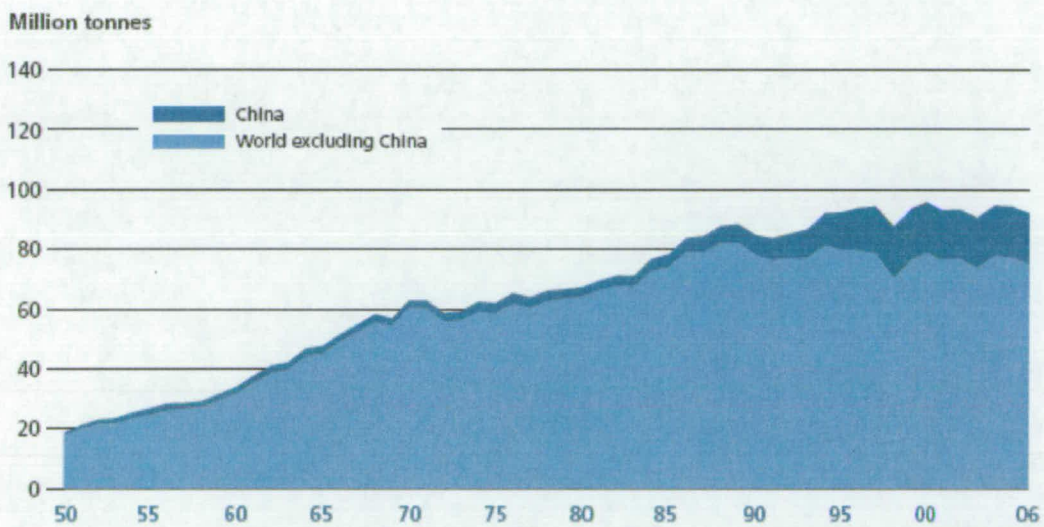


Figure 7: World capture fisheries production (FAO, 2008).

Also contributing significantly to world food supplies are protein-rich resources such as meat, dairy and eggs. The livestock producing these resources also require protein-rich feed, mostly sourced from corn and other grains, soy and fish meals. The demand for livestock products is on the increase with the FAO (2004) predicting an increase in global meat production from 233 million tonnes in 2000 to 300 million tonnes in 2020.

In addition to growth in demand for protein-rich resources to contribute to world food supplies, there is also an increasing demand for diet supplements from marine oils (Arthi, 2009; Nutraingredients, 2004; Shahidi and Wanasundara, 1998), rich in Omega-3 fatty acids. These Omega-3s have numerous health benefits with over 8000 research publications supporting health benefit claims associated with them (Nichols and Nelson, 2007).

Coinciding with increasing world population and increases in demand for commodities such as fish, meat, dairy and fish/marine oil supplements, there has been a decrease in global fish stocks (Pitcher, 2008; Naylor *et al.*, 2000). As the world population expands past 7 billion (predicted to occur by 2015) its reliance on aquaculture grown fish species as a vital protein source will also continue to increase (Naylor *et al.*, 2000). In 2007, more than half the fish stocks monitored by the FAO were classed as fully exploited (no room for further expansion), and 19% were classed as overexploited (no possibilities in the short or medium term for further expansion) (FAO, 2008) (Figure 8). As fish has been a major source of protein for hundreds of years we face a dilemma in where this protein will be sourced from as these fish stocks continue to disappear. There is also increasing concern over the sourcing of oils for the burgeoning nutraceutical markets and the effects this will have on fish stocks already under immense pressure (Tou *et al.*, 2007; Shahidi and Wanasundara, 1998).

With such a shift in the availability of, and demand for, protein (Czeczuga, 1984) and Omega-3 rich resources, it is no wonder that there has been speculation that the krill fishery will soon increase in size (SC-CAMLR-XVI, paragraph 2.5) to help fill the niche left by this growing deficit (Nichols, 2007). Antarctic krill is considered an underexploited FAO fish stock (Maguire *et* al., 2006) and thus can be considered to make up part of the 2% of stocks monitored by the FAO classed as underexploited (stocks that are currently harvested but could withstand an increased level of harvest) (FAO, 2008). The current krill catch in Antarctic waters is 150 000 tonnes a year and the precautionary catch limit on the Antarctic krill fishery is some 7 million tonnes (CCAMLR figures) so the potential for increase is considerable.

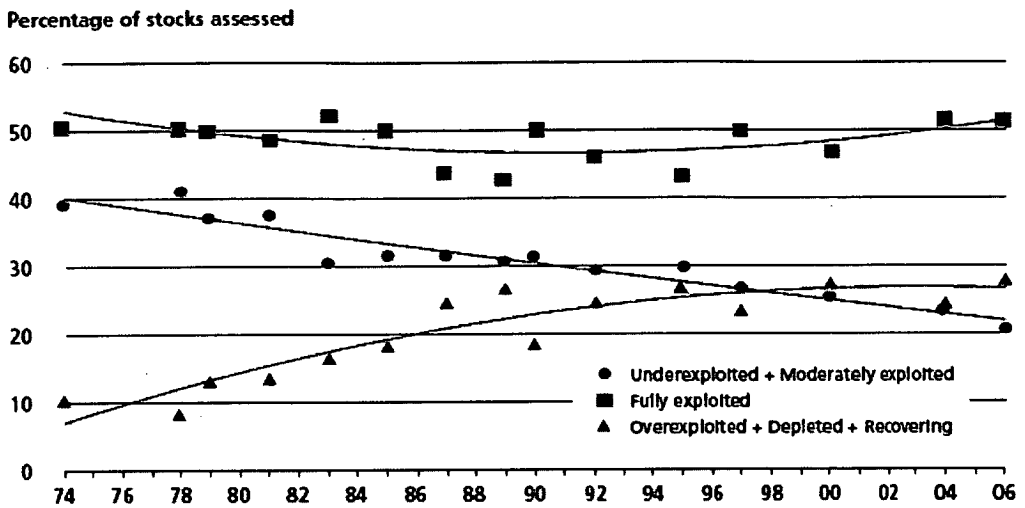


Figure 8: Global trends in the state of world wild marine stocks from 1974 to 2006 (FAO, 2008).

In response to continual shifts in the availability of, and demand for, seafood resources, the operation of the commercial krill fishery has altered markedly since its inception in the 1970s. The biochemical composition of krill and advances in processing technologies means that the market for krill-based products has been diversifying over the past decade (Nicol and Foster, 2003). This diversification in products has also seen new participants and investment in the marketplace.

This Chapter will examine the marketplace for krill, both in a historical and present day context. By examining the properties that make krill a saleable product, it is possible to explore the niches that krill products have occupied in the past, and are likely to occupy in the future. Identification of market participants, their investments in R&D technologies and their market projections is vital in establishing a knowledge base for examining the marketplace for krill.

2.2 The Biochemical Composition of Krill

Since the inception of the fishery, the potential marketplace for krill has not been single-product focussed. It has always been recognised that the potential market would be based around a diverse range of products (Nicol and Foster, 2003; Budzinski *et al.*, 1985; Grantham, 1977) aimed at utilising as much of the

harvested resource as possible, in order to offset the large costs associated with such a distant-water fishery (McElroy, 1980). As such, early research into krill focussed heavily on determining krill's biochemical composition. It was quickly identified that krill's protein, chitin, pigmentation and unique fatty acid and enzyme properties would direct the future market potential of products in the industry. Numerous studies have been conducted to determine the gross biochemcial composition of krill.

The biochemical composition of Antarctic krill differs from that of other marine species. A study by Güner *et al* (1998) looked at the composition and mineral content of nine commercially important small and medium pelagic fish species. On average, these species contained less protein (14.1-25.1%) than krill (49.0-66.3%) (Sidhu *et al.*, 1970; Zhu and Wang, 1989) on a dry weight basis, but overall had similar levels of other minerals. In terms of lipid content, Nichols *et al* (1998) found that krill had a total fatty acid content of 1631mg/100g (w.w) whilst small pelagic species such as pilchards (*Sardinops neopilchardus*) and sardine (*Dussumieria elopsoides*) contained only 662mg/100g and 679mg/100g respectively.

2.2.1 Protein

Protein is an essential component of human dietary requirements as dietary proteins are digested by enzymes (known as proteases) to deliver essential amino acids to the body. These essential amino acids cannot be synthesised by the body and therefore diet plays an essential role in ensuring sufficient quantities are available for use in metabolic processes. A diet deficient in protein can lead to growth failure, loss of muscle mass, decreased immunity, weakening of the heart and respiratory system, and death (Harvard, 2009). Protein is also an essential component of animal diets for the same reasons and inclusion of high-protein components in aquaculture and agriculture feeds has always been a primary focus of the marketing of such products.

Human dietary sources of protein have traditionally come from red meat, legumes, nuts, soy products and, particularly in third world and developing countries, where subsistence fishing still has an important role, seafood. In 2006

the FAO reported that, overall, fish products provided over 2.9 billion people with approximately 15% of their animal protein intake, whilst the fish proteins contributed 18.5% of total animal protein intake in 2005 (FAO, 2008). This figure may be even higher if the un-recorded contribution of subsistence and small-scale fisheries is accounted for.

Krill has long been considered as an excellent alternative source of protein to replace the protein the world's population has been deriving from traditional fish stocks that are now in decline (Budzinski *et al.*, 1985; Oehlenschläger and Schreiber, 1981; Siebert *et al.*, 1980). The protein that can be derived from krill is generally considered to be of high quality due to the sufficient presence of all nine essential amino acids which are considered by the FAO and the World Health Organisation (WHO) to be necessary requirements for human adults to maintain good health (Gigliotti *et al.*, 2008).

2.2.2 Chitin/Chitosan

Chitin is a tough polysaccharide found in the exoskeleton of arthropods, including insects, crabs, shrimps, and lobsters (Heffernan, 1987), built of various minerals and chitin, bound together by proteins (Budzinski, 1985). Chitin can make up to 40% of the dry weight of the krill exoskeleton (or 4% of the total dry weight of the krill) (Yanase, 1981) and can therefore provide a potentially plentiful byproduct. In the traditional processing of rolling krill for a meat product, the exoskeleton has usually been a waste product but is increasingly seen as valuable commodity in its own right, with research into the quality of the waste product being undertaken by Polish researchers in the early 1980s (Naczk *et al.*, 1981) and more recently (Tou *et al.*, 2007).

Chitin is the main source of production of chitosan, which is used in a number of applications, such as a flocculating agent, a wound healing agent and a delivery vehicle for various pharmaceuticals. A number of publications have focussed on the utilisation of krill for these purposes (Bustos *et al.*, 2003). Due to their high biomass and current underutilisaiton, krill are the major producers of chitin in the world's oceans and the fishery for Antarctic krill is potentially a large source of chitin for industry (Nicol and Hosie, 1993).

2.2.3 Pigmentation

Crustaceans, including crabs, shrimp and krill commonly have noticeably orange and/or red pigmented exoskeletons. The primary pigment in Antarctic krill that gives this colour is astaxanthin, although other carotenoid pigments are also found in the exoskeleton (Nicol *et al.*, 2000). Given consumer demand for orange and reddish coloured fish meat in species of salmon, trout and sea bream, it has been suggested that extracts from krill could be used as an addition to feed for aquaculture raised commercial species (Nicol *et al.*, 2000; Savage and Foulds, 1987). Research into the addition of marine crustacean, in particular krill, derived pigments to aquaculture feed to improve colouration in farmed species has become more common over the past decade (Kalinowski *et al.*, 2007; Suontama, *et al.*, 2007; Moretti *et al.*, 2006; Floreto *et al.*, 2001).

In the past, synthetic colourants have been used for pigmentation of aquaculture species but consumer demand for more natural products is increasing (Moreira *et al.*, 2006). Given the "natural" and "pristine" tags increasingly being used to describe the species in the media (ColdSea, 2009; FIS, 2009), and the amount of research that has been conducted on the inclusion of Antarctic krill in the feed for commercially farmed marine species, it is likely that there will be increasing focus on the use of Antarctic krill for this purpose.

2.2.4 Fatty Acids

As early as 1970 it was recognised that, as well as being an excellent source of protein, krill could also be a source of oil for consumption by humans and animals (Sidhu *et al.*, 1970). This conclusion was considered valid only if necessary further developments of suitable technologies for harvesting and processing took place.

Fish oils have been at the centre of large amounts of R&D in fish processing, feed, functional food and nutra- and pharmaceutical markets over the past 15 years. The Omega-3 and Omega-6 properties of seafood have long been recognised as having health benefits (Fereidoon and Wanasundara, 1998) including prevention and treatment of arthritic conditions, cardiovascular disease, PMS and facial appearance. Omega-3 is particularly important, because it is used

to build the structure of vital parts of the body such as brain cells, which is why these fatty acids are referred to as 'essential fatty acids'. Where plants can convert fatty acids between 3 and 6 chain types, animals are unable to do this and as such must get both types from their diet. As such, the level of these fatty acids in seafood will be dependent on their diet.

Eicosapentaenoic acid (EPA) and docosahexaenoic (DHA) fatty acids are both highly unsaturated fatty acids, most beneficial in terms of regulating blood pressure and clotting, immune function, allergic response and reproduction and gastric response (IFFO, 2008a). EPA and DHA fatty acids are the types found most commonly in the marine environment where they are produced by algae and transferred through the food chain where they are incorporated into the lipids of marine fish and mammals (Fereidoon and Wanasundara, 1998). They are most common in cold water species where less saturated fatty acids remain liquid at colder temperatures.

Additionally, setting krill oil apart from regular fish oils is the linkage of the EPA and DHA fatty acids to phospholipids. This linkage means that movement of the fatty acid molecules across intestine walls occurs more readily, increasing the bioavailability of the fatty acids to the consumer (Duan *et al.*, 2010).

2.2.5 Enzymes

The enzymes contained within krill's digestive gland have, until only recently, caused significant issues for the processing and spoilage of catch. Once the animal dies, the powerful hydrolytic enzymes contained in the cepthalothorax rapidly begin to degrade the body tissue (Nicol *et al.*, 2000), resulting in the rapid spoiling of catch once it is hauled on board a vessel (Grantham, 1977). However, the possibility of these enzymes having practical applications in food, animal feed and pharmaceutical industries was recognised in the early developmental stages of the fishery (Budzinski *et al.*, 1985).

The hydrolytic enzymes derived from Antarctic krill, in particular the proteases, carbohydrases, nucleases and phospholipases (Nicol *et al.*, 2000) have wide ranging uses in different medical applications. Applications include treatment of

spinal injuries (Melrose *et al.*, 1995) and necrotic wounds (Karlstam *et al.*, 1991) and in clinical drug applications (Nicol *et al.*, 2000).

2.2.6 Summary

As the krill fishery has progressed over time, so has research into potential applications of krill. Once lauded for its potential as a raw food protein source and addition to animal feed, the biochemical properties of krill are now considered useful in a much broader range of products. Based on these biochemical properties of krill, given the broad range of potential applications, and its various competitive advantages, being from the "pristine" Antarctic waters, free from contaminants and being extracted from what is currently considered a sustainable fishery, the potential marketplace for krill could be quite diverse. It is important to consider the historical state of the marketplace for krill in order to appreciate the driving forces behind the commercial krill fishery into the future.

2.3 Historical State of the Market for Krill

Due to the relatively small-scale operations of the krill fishery on a world scale (krill accounts, by weight, for only 0.15% of total world capture fisheries since the beginning of the commercial fishery in 1973, FAO Fishstat Plus, 2007), there has been very little publicly available research undertaken on krill in terms of actual and potential market analysis. It is inevitable that companies who have been investing in associated R&D have commissioned market reports by qualified institutions however, such reports are almost always subject to strict commercial-in-confidence conditions. Indeed, since the early to mid-1980s there has almost no market analysis information on the krill fishery in the public domain.

Most of the publicly available information on market potential is the result of research reports published in the very early developmental stages of the fishery. Any projections or inferences on the future on the market for krill are based solely on the potential of krill as a useful product and not on the competitiveness of krill in the marketplace in terms of pricing.

With the initial interest in the commercial fishery in the 1970s the FAO commissioned a series of Fisheries Technical Papers (Budzinski *et al.*, 1985; Eddie, 1977; and Grantham, 1977) addressing the harvesting, utilisation and possibilities of processing and marketing products made from Antarctic krill. Much of the information on the initial development of krill-based products comes from these early papers and some early publications in scientific journals.

2.3.1 Early Krill Product Development

The early days of the krill fishery were dominated by two distinct phases, the initial experimental and exploratory phase and the developmental phase. The initial experimental and exploratory phase of the fishery in the mid 1970s saw small catches taken by Russian, Japanese and German vessels. Due to the experimental nature of harvesting and processing techniques at the time, these catches were used for exploration of products for test marketing, with the nutritional value of the products being a high priority (Sidhu *et al.*, 1970). These products included krill meal for animal feed, krill protein paste, frozen cooked whole krill, dried krill, minced muscle and tail meats, all for human consumption (Oehlenschläger and Schreiber, 1981; Eddie, 1977).

As the fishery developed, the number of countries participating in the fishery increased, with countries including Spain, Norway, Poland, Taiwan and the UK (amongst others) all taking experimental catches. This phase of the fishery was very much a development phase (Eddie, 1977) with various trials and analyses of newly developed products taking place, particularly focussing on saleable, high quality products (Lyubimova, 1973). Products for animal feed and human consumption were priorities at this time (Siebert *et al.*, 1980; Rehbein, 1980).

This development of, and further investigations into, saleable products continued throughout the 1980s and early 1990s. However, in the mid 1980s product development research stalled for several years when the industry encountered what is now referred to as 'the fluoride problem' (Nicol and Endo, 1997; Budzinski *et al.*, 1985). High levels of fluoride that exist in the exoskeleton, particularly in the carapace (Soevik and Braekkan, 1979) stalled the use of krill in animal feeds (Yoshitomi *et al.*, 2007) and human products due to health

concerns associated with the accumulation of fluoride in the bones and tissues which can be toxic at high levels (Adelung *et al.*, 1987). This problem was eventually overcome with research undertaken into ways to decrease and/or mitigate the quantity of fluorine that would be included in the end product as a result of the inclusion of krill as an ingredient (Tenuto-Filho, 1999; Tenuto-Filho, 1993; Budzinski *et al.*, 1985).

Solving of 'the fluoride problem' allowed the development of new processing techniques and the continued development of the fishery. This development continued until 1992 when catches once again plummeted due to the break up of the Soviet Union (discussed in Chapter One). In terms of the development of the fishery and krill products, this meant that the costs associated with operation in the distant-water fishery which, in terms of market participation, had yet to establish a reliable economic return and were too big a burden for the nations which had, until this point, dominated catch-share.

As a result, the fishery for krill stalled and participants looked towards the development of higher value, lower yield products, a situation which was predicted to occur in the various FAO-commissioned Technical Papers of the late 1970s and mid 1980s.

2.3.2 Market Prices

Actual market prices for krill and krill products have been very difficult to obtain. The main reason for this is the unusual circumstance that surrounds the fishery. This situation historically saw countries fishing for the resource, conducting experimental development of products (Eddie, 1977) and selling the products, all within their own borders. The market for krill was not a worldwide one until much later in the fishery's history and as such, market prices have not been widely published.

In 1977, Grantham hypothesised that the initial phase of the krill fishery would see competition for a place in the market, not for the resource, a situation which is highly unusual in commercial fisheries. This hypothesis was based on the relative abundance of krill (biomass estimates at the time ranged from 60 to 5000

million tonnes; Voronia, 1983 and Lyubimova *et al.*, 1979) and the low demand for the product in the marketplace at that time (Grantham, 1977).

In the early 1980s, McElroy from the Centre for the Economics and Management of Aquatic Resources at the University of Portsmouth in the UK also produced some discussion papers on the market and economics of the krill fishery (McElroy, 1982a and 1981a and b). McElroy's main theory on the potential of the fishery was based on the recovery of the baleen whales and the impacts this would have on krill stocks (McElroy, 1984). McElroy's primary conclusions were that:

- Large initial catches in the fishery were taken at a time when there was virtually no market for the krill product;
- It was likely that the fishery would possibly develop in a similar manner to the blue whiting fishery (as a vast resource attracting a large amount of technological effort, it could be continually fished for meal whilst a food-based fishery would develop alongside it – largely dependent on the continued interest of the USSR); and
- The market for krill-based products was relatively unknown (both in size and price) but there would be a potentially lucrative market for certain krill products.

Based on indicative values from the market place at the time (tail meat $1600-2500/t at production of 60 000t/year and krill meal $300-400/t for volumes less than 500 000t/year), McElroy produced a summary schematic of where he envisioned the market for krill would be concentrated, and at what economic scale (Figure 9). McElroy's graph implied that the demand for krill meal could possibly increase exponentially, up to 1 250 000 t into the 1990s, whilst the demand for other krill products, including whole, minced and tail meats, would be limited to between 10 000 and 100 000 t (Figure 9).

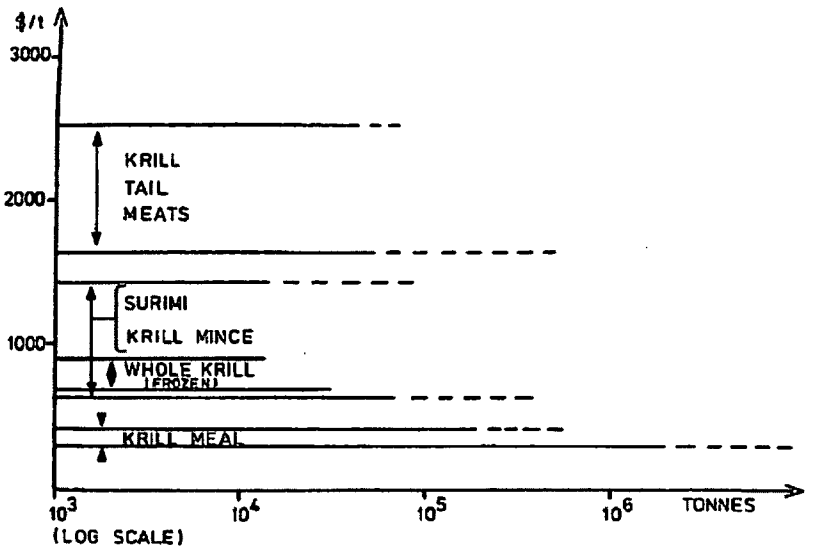


Figure 9: Potential market for krill products into the 1990s (McElroy, 1980).

Various other prices for different krill product have been published inconsistently over the years with little reference made to where the prices have actually emanated from, or citing figures as having come from 'industry sources' (Table 1). Additionally, prices given for krill product have often not verified the price as being for Antarctic krill, or have used a similar species to make extrapolations on the price of Antarctic krill, and therefore haven't necessarily provided a true representation of the market price for the Antarctic krill product. For example, Grantham (1977) had used prices for smallest grade brown shrimp, Norwegian shrimp and the Japanese-fished North Pacific krill to give representations of approximate price for Antarctic krill.

Table 1: Various market prices given for krill and krill products in the developmental stage of the fishery.

Year	Product	Country	Price	Reference
1996	Whole, frozen krill	Australia	~US$0.24/kg	Nicol and Endo, 1997
1996	Frozen tail meat	Australia	~US$7.03/kg	Nicol and Endo, 1997
1977	Canned, roller peeled meat	Chile	US$3.20/kg	Grantham, 1977
1977	Block frozen meals	Chile	US$1.00-1.10/009kg	Grantham, 1977
1977	Canned paste	Russia	US$2.00-2.80/kg	Grantham, 1977
1977	Block frozen paste	Russia	US$1.60/kg	Grantham, 1977

Note: Some prices in this table were converted to US$ using the currency converter for historic exchange rates at www.fxtop.com to allow for easier comparison across products.

2.3.3 Summary

The FAO-commissioned Technical Papers drew some basic conclusions on the future market for krill, and the future of a commercial krill industry, recognising that there were problems with accessing actual market prices due to commercial-in-confidence conditions:

- Product development would be largely dependent on developments in processing technologies;
- Bringing krill into the mainstream, in terms of market acceptance, would be a challenge;
- Products would largely be for human consumption, helping to fulfil the world's protein requirements;
- Products would mainly emanate from, and be consumed in, developed countries;
- The future for krill lies in high-quality, low-volume products; and
- There would be high investment costs associated with operating in the industry.

With patchy, and often unreliable, information being provided on market prices over the early stages of the fishery, commentary on the precise nature of the market price for krill or krill product over this time was rare. Only assumptions and broad price ranges were available based on un-checked prices and extrapolations. Assumptions were made on the general direction of the market and what factors would shape the future of the market, and expectations for the future of the marketplace were high (McElroy, 1982b). Consequently, few of the predictions on the future of the fishery based on these assumptions have eventuated.

2.4 Current State of the Market for Krill

The current focus of the market for krill has been developing over the past 10 to 15 years. After initially focusing on the use of krill for animal feeds and human consumption as a food product, in the late 1990s the focus of R&D shifted to the use of krill in products designed to treat human medical conditions and to

enhance human health. However, R&D interest has, at the same time, remained high in the area of using of krill as a value-adding ingredient for use in meal for animal feeds. The publication of research aims and results in scientific journals means that this research is very accessible and, combined with information readily available from market participants, means there is a much more reliable and broader scope of information on which to base assessments of the current marketplace for krill and krill products.

2.4.1 Market Niche

Krill's current role in the marketplace is rapidly evolving. Over the past decade there has been an increase in interest in the fatty acid, pigmentation and enzymatic properties of krill and how they can be utilised in the pharmacaeutical/nutraceutical and fish meal markets. Additionally, research also continues into the application of krill and its byproducts across various aspects of the food market, in particular the creation of functional foods (foods with health promoting additives). Scientific investigations into krill's usefulness as a product for these purposes is widely available in scientific journals and can be used to identify the current market niches that krill is likely to fill.

The utilisation of krill in pharma- and nutraceutical products has only recently begun to evolve in terms of research into practical applications with commercial potential. The health benefits associated with marine oils in general have been recognised for several centuries (Nichols, 2007). However, research into the competitive advantages of marine oils from cold water environments, and in particular Antarctic krill, is a more recent phenomenon.

Research has shown that high fatty acid properties of krill oil make it effective in the treatment of autoimmune murine lupus (Chandrasekar, *et al.*, 1996), cardiovascular disease (Batetta *et al.*, 2009; Bunea *et al.*, 2004) and arthritis (Deutsch, 2007). Other research indicates that properties of krill, including its enzymes, antioxidant astaxanthin and chitin, make it effective in the treatment of liver disease (Tandy *et al.*, 2009) and maintenance of general health and well being (Bridges *et al.*, 2010). It is the increased bioavailability of the Omega-3 and Omega-6 fatty acids that makes krill oil a superior treatment for

cardiovascular disease and other health conditions, compared to regular fish oils (Kidd, 2009).

In 2004 the European market for EPA and DHA products was valued at approximately US$194 million with more than three-quarters of these oils being from marine based sources (Nichols and Nelson, 2007). A market report accessed by Nichols and Nelson (2007) predicted that the market for these products would increase at average rates of 8% until 2010. However, whilst the market for the use of fish oils in nutraceutical products is high in value, it remains relatively small in volume, estimated to represent only 5-6% of total world fish oil production (Nichols, 2007).

Considering that oils with high levels of Omega-3 command a premium price in the market (Nichols, 2007), the future use of krill oil in pharma- and nutraceutical products looks to provide a lucrative investment for participants in this market.

In order to ensure that humans are receiving sufficient quantities of Omega-3 through their diets, to meet standards set by the WHO, extensive research has been conducted into enhancing the quantities of these Omega-3 that already occur naturally in dietary sources, such as eggs, dairy and other food products.

In a study aimed at creating egg products enhanced with Omega-3 during the processing stage of production, Kassis *et al* (2010) found that those eggs treated with krill oil had a much higher Omega-3 content that those treated with plant, algae and fish derived Omega-3 (Kassis *et al.*, 2010).

Krill oil and chitosan have also been tested to increase the nutritional value and shelf life of various fish fillet products (Duan *et al.*, 2010). This research determined that a krill oil mixture which included chitosan, could be used to increase Omega-3 content and shelf life of various fresh lean fish.

With an expected increase in demand for fish meals and marine byproducts and their limited availability due to dwindling fish stocks, maintenance of the

economic viability of aquaculture is resulting in investigations into the supplementation of currently used proteins and additives with lower cost alternatives that, most importantly, aren't as limited in terms of availability (Yoshitomi *et al.*, 2007; Davis and Arnold, 2000). Krill is most commonly used as a high value additive to aquaculture feeds (Floreto *et al.*, 2001) rather than the primary ingredient however, some research has focused on determining the properties of 100% krill meal in comparison to other, more commonly used fish meals (Giogios *et al.*, 2009). There are several areas of research that have focused on the use of krill as a value-adding ingredient: protein concentrations, food uptake and attractability, colouration, growth and Omega-3 concentrations. More indirectly, krill has been often been used as a general feed alternative or additive in feed substitution experiments (Kofuji *et al.*, 2006; Smith *et al.*, 2005b; Kim *et al.*, 2005; Samocha *et al.*, 2004).

Numerous experiments have shown that krill meal has a nutritional value equal to, or surpassing, that of regular fish meals (Yoshitomi *et al.*, 2007; Karlsen *et al.*, 2006; Opstad *et al.*, 2006; Gaber, 2005) when used as a substitute in the diets of various farmed species including Atlantic cod, Atlantic salmon and Pacific white shrimp. In these experiments, nutritional value is determined based on observed growth and survival rates, elemental (e.g. protein, fatty acid) composition and feed uptake rates. Due to the increasing price of fish meals, producers are constantly striving to improve the uptake of feeds to minimise feed wastage and provide better economic returns (Smith *et al.*, 2005a).

The production of fish meals and oils is closely linked with one being a byproduct of the other (Nichols, 2007). Given proven benefits of utilisation of krill meal and oils (the addition of fish oil to meals is used to boost Omega-3 content of farmed species, IFFO, 2008b) in fish meals, and the decline of traditional sources of these meals and oils, krill, as a product source, is well placed to satisfy demand in a market niche that will be under increasing pressure as fish stocks continue to decline.

There is increasing speculation in the pharma- and nutrceutical markets that the protein and fatty acid characteristics, in particular, of krill, as well as its current

underutilisation as a resource, will offer a sustainable alternative source in the marketplace (Bridges *et al.*, 2010). Combined with the recognition of krill as a useful source of various nutrients and compounds used as value-adding ingredients of fish meals and the continuing interest in the use of krill for human consumption, particularly in the area of functional foods, the expansion of the possibilities for krill in the marketplace appear to be very promising.

2.4.2 Market Participation

There has been an increase and diversification in countries and companies participating in the Southern Ocean krill fishery over the past decade. Traditional krill fishing nations, such as Japan and Poland have maintained relatively stable catch rates over the life of the fishery but have not been visible in the marketplace for krill-based products. In recent years companies from nations that have not traditionally fished in Antarctic waters have entered the krill marketplace and this fact has been at the centre of much of the speculation over the predicted increase in the krill fishery. This will be discussed further in Chapter Four when tools for predicting trends in the fishery are identified, tested and discussed.

This Chapter, however, considers only the current participants in the marketplace for krill, that is, those companies who are driving R&D into the commercialisation of krill as a product and who are, as a result, investing in the diversification of the krill fishery. These companies publish a large amount of information, in particular financial reports, on their open access websites for shareholders and interested parties. The websites of two relative newcomers to the krill market, the Norwegian based Aker BioMarine (www.akerbiomarine.com) and the Canadian based Neptune Technologies and Bioressources (www.neptunebiotech.com), offer a significant amount of information on product R&D, financial operating costs and planned future market developments. There are also several other, less established, companies that have recently began operating in the market, providing somewhat more limited information on these matters.

Given the new direction the fishery appears to be taking (i.e. diversification of participants and participation of non-fishing nations, as identified through the use of the Patent Database tool discussed in Chapter Four), the information provided by such companies may provide additional insight to assist with monitoring the development of the fishery.

2.4.2.1 Aker BioMarine

Aker BioMarine is a subsidiary company of the Norwegian seafood giant, Aker, initially called Aker Seafoods Antarctic AS. Aker BioMarine (herein referred to as Aker), primarily a biotechnology company, began its initial foray into krill harvesting in January 2004 using a factory trawler, the *F/T Atlantic Navigator*, a vessel flagged to Vanuatu. Aker's interest in harvesting krill grew from three primary observations. Firstly, that the Southern Ocean krill biomass represented a large unexploited biomass, one of the last such fisheries in the world. Secondly, an expectation that there would, in the near future, be a shortage of fish meal and fish oil for use in the aquaculture and pharmaceutical/health markets. Finally, that Antarctic krill offered excellent potential as an ingredient in aquaculture, pharmaceutical and health markets (Aker, 2010a).

Aker's current products emanating from its krill fishing activities are Superba™ krill oil and Qrill™ krill meal. Superba™ is oil sourced from krill to be used in the market for human consumption. Aker markets this product primarily based on the oil's Omega-3 phospholipid and astaxanthin content, and the ability of these components to benefit human physical and mental health. Qrill™ is meal and oil made from krill for use in the aquaculture feed market. Initial research and marketing focussed on the use of Qrill™ in shrimp feeds, based on an increase in growth rate, a decrease in feed conversion ratio (FCR) and an overall reduction in costs for the producer for shrimp fed meal containing Qrill™. The high protein levels, Omega-3 phospholipids, antioxidant astaxanthin and natural colourant/carotenoid properties are now used to market use of Qrill™ for broader application in the aquaculture feed market.

Aker has had a clear direction for their krill harvesting activities since the inception of the company. Aker's plans centred around three major stages of

development: initial focus on products for use in animal nutrition and health (Qrill™ meal and oil), the movement towards development of products for use in human nutrition and health products (Superba™ oil) and lastly, branching into active pharmaceutical ingredients (Superba™ oil).

Initially, Aker recognised several hurdles to utilising the krill resource, namely problems associated with operating in such a distant-water fishery, a lack of suitable technology in terms of suitability of and capacity for processing, the rapid deterioration of krill due to enzymatic processes and market confidence in a predictable supply. These concerns are not new to the industry, often having been cited as primary reasons why the fishery had not developed further (Kawaguchi and Nicol, 2007; Nicol *et al.*, 2000; McElroy, 1984).

Aker's development of what has become known as the 'continuous pumping method' of trawling has helped the Company overcome issues surrounding spoilage and damage of catch, as well as fishing efficiency. The patented technology (WO2005004593) (Figure 10) consists of a regular trawl apparatus for gathering seafood/biomass with a conveying hose or pipe for delivering it onboard the vessel using an air lift system. This technology means that krill are brought onboard the vessel with minimal damage to the catch by the crushing that occurs when a regular trawl net is hauled onboard. Once onboard the vessel the catch is stored in large holding tanks containing seawater and then moved into the processing plant as required, providing a continuous supply of catch to the onboard processing plants. This technology has the added benefit of meaning that the trawl net does not have to be hauled onboard in order to retrieve the catch, thereby allowing the vessel to trawl continuously when in a good fishing ground. The limiting factor in terms of output from this fishing method is the capacity of processing equipment to keep pace with the amount of krill being pumped onboard.

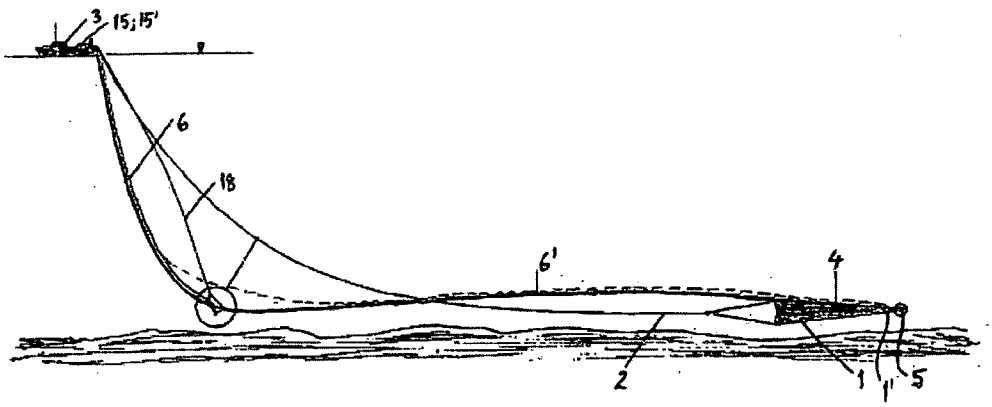


Figure 10: Aker's patented continuous pumping system (as presented in patent WO2005004593).

Aker has recently obtained Marine Stewardship Council (MSC) certification for their "Eco-Harvesting" krill fishing activities (Aker, 2010a). This certification is awarded to fisheries that undertake their harvesting operations in an environmentally sustainable manner with the MSC program ultimately aiming to influence the choices consumers make with regards to selecting products that originate from sustainable fisheries (MSC, 2010). Aker uses this certification as a marketing tool that sets its Qrill™ and Superba™ products apart from competitor's products as Aker is currently the only company with the certification for their krill fishing activities. The certification was awarded on the basis of Aker's 100% observer coverage, vessel monitoring system (VMS) and real-time reporting procedures on their harvesting vessels as well as their science and research contributions (Aker, 2010a). However, the awarding of the MSC to Aker's krill fishing operations has not been without controversy. Jacquet and Pauly (2010) have raised concerns that the certification process overlooked reports from the scientific community that krill stocks are declining and ignored the unsustainable use of krill in fishmeal.

Aker has published, on their website, a large amount of information pertaining to their operations. With Aker being at the forefront of the recent marketing push for krill oil and meal, this information provides insight into the intentions of one of the major players in both the fishery and the marketplace for krill. Quarterly reports for investors, including projections, product disclosure information and

general information on the company itself, all provide avenues for the collection of data that can be used to assess Aker's level of investment and potential future involvement in the fishery. Additionally, the market reports commissioned and purchased by Aker for inclusion in their reporting also give access to valuable market-research that is otherwise inaccessible.

Aker's primary products, Superba™ and Qrill™, compete for market share in the pharma- and nutraceutical and fish meal markets. As with any company that is significantly investing in new products, Aker has conducted a substantial amount of research into the market potential for these products. Prior to the launch of these products in 2008, Aker presented information on projected markets for these products in its Fourth Quarter Report for investors (Aker, 2007). Research from a market report by Frost and Sullivan in 2005, accessed by Aker and displayed in this publicly available quarterly report, indicated the potential increase in demand for Omega-3 concentrates in the nutraceutial market (Figure 11) - the primary market to be targeted by Aker in their launch of the Superba™ product. This figure indicated that the demand for Omega-3 concentrates, both in dietary supplement and functional food markets, would increase by US$613million and US$805million respectively, across US, European and Asian markets from 2002 to 2010.

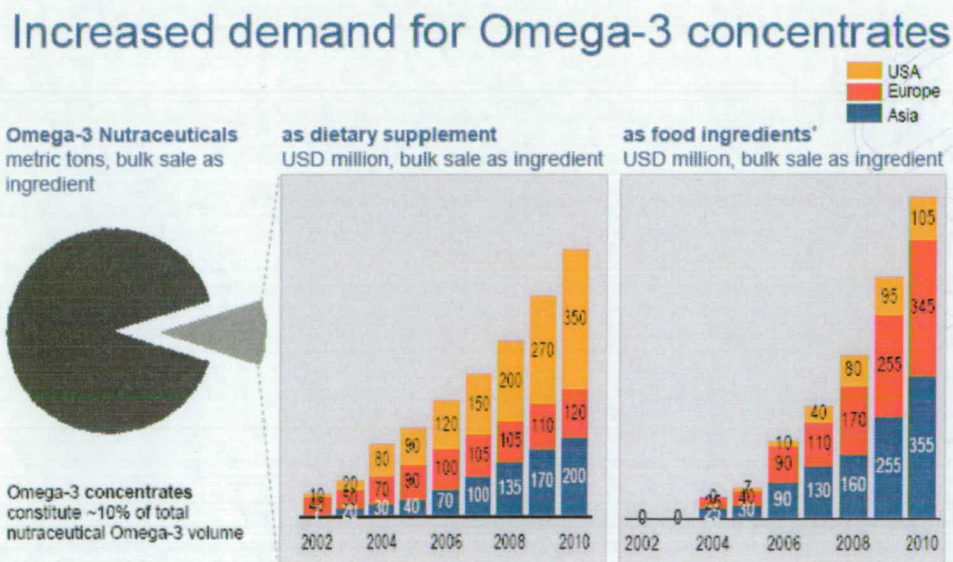


Figure 11: Aker Biomarine's projections for growth in demand for Omega-3 concentrates, from Frost and Sullivan market report (Aker, 2007; original data unavailable).

Additionally, in their Third Quarter Report presentation for 2009, Aker provided information on the Omega-3 market in the US, obtained from Euromonitor International, indicating that the value of the Omega-3 market in the US had increased by 32% from 2003 to 2008 (Figure 12). At a time when Aker was looking to the launch of their Omega-3 rich krill oil product, market information such as this would have been instrumental in building confidence in investors. However, this market reports is not publicly available and can only be accessed upon payment of a fee.

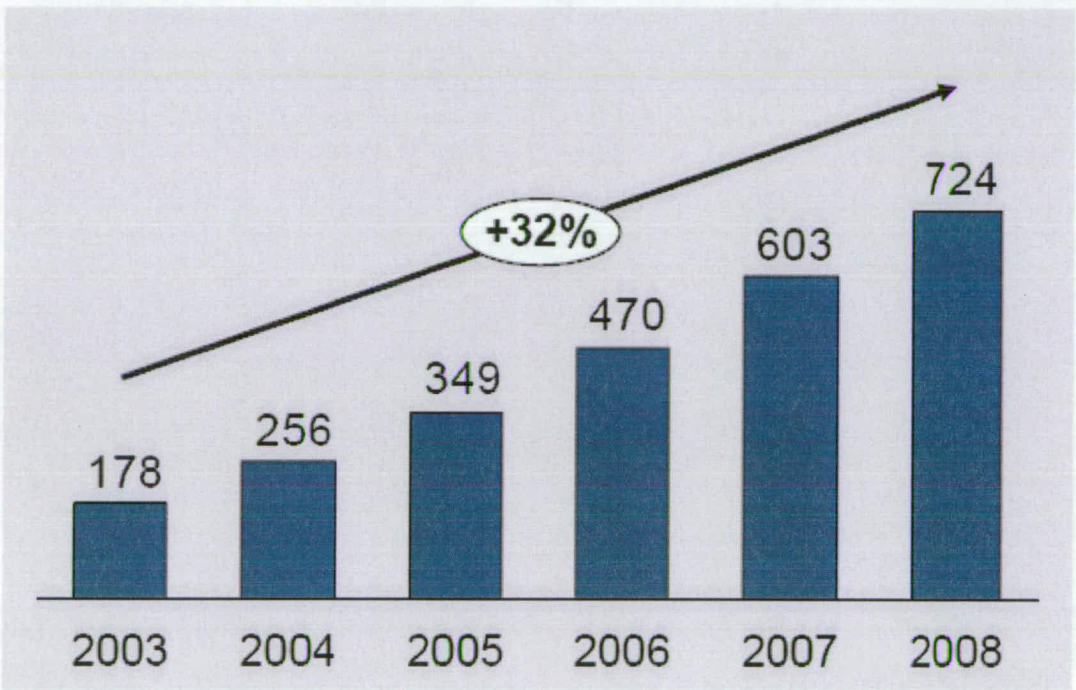
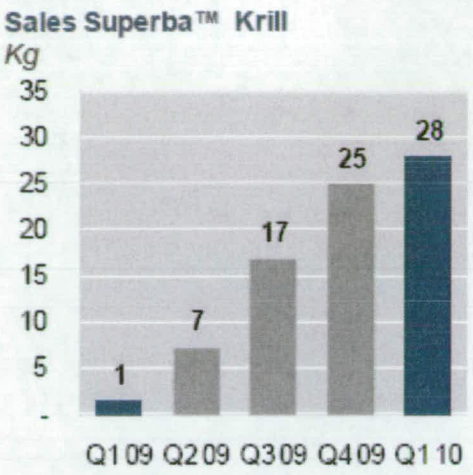


Figure 12: US Omega-3 market 2003 to 2008, US retail value in USD (Aker, 2009b; original data unavailable).

Aker's current participation in the market can be partly monitored through the sales figures for their two primary products. Latest figures from the First Quarter Report (Aker, 2010b) indicate growth in sales of both products over the past quarter (Figures 13 and 14). In particular, growth in sales of Superba™ have shown a steady increase since the launch of the product in late 2008 (Figure 16). Both demand and prices paid for the Qrill™ product have increased from 2009 and 2010 comparable reporting times, by 130% and 20% respectively (Aker, 2010b).



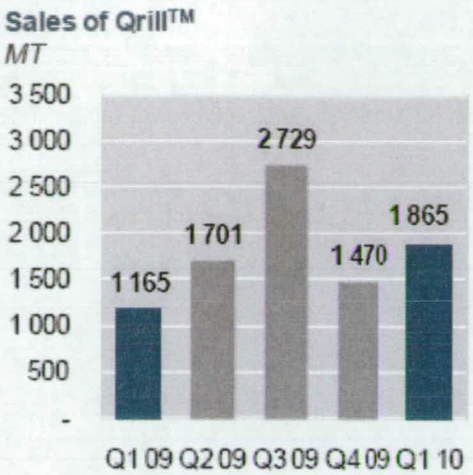


Figure 13: Sales of Superba™ (Aker, 2010b). Figure 14: Sales of Qrill™ (Aker, 2010b).

With 2010 first quarter revenues up by NOK 32 million from the same reporting period in 2009, largely attributed to the Superba™ product, the outlook for Aker's krill products looks positive. Recent expansion from US to European markets and a recent agreement with distributors in Taiwan and China also suggest a positive outlook for demand for Aker's krill-based products.

2.4.2.2 Neptune Technologies and Bioressources, Inc.

Neptune Technologies and Bioressources, Inc. (Neptune), is a Canadian company founded in 1998 and based in Montreal. The primary mission of the company is to extract oceanic biomass, particularly from underutilised resources, and maximise the value of this biomass in the nutraceutical, cosmetic and pharmaceutical markets (Hamovitch, 2001). The company's involvement in these different product markets is based on their primary product, Neptune Krill Oil, NKO®. A patented technology, Neptune OceanExtract™, a cold extraction process using frozen krill, is used to extract the oils from the krill resource delivering oil that is high in essential nutrients, fatty acids and is free of preservatives (Hamovitch, 2001).

Neptune has two primary subsidiaries that facilitate the research, development and production of products for the pharmaceutical market for the treatment of cardiovascular disease and neurological health, whilst Neptune itself concentrates on products for the nutraceutical markets. These two subsidiaries,

Acasti Pharma and NeuroBioPharm are in the early stages of development, both utilising Neptune's NKO® oil product. Acasti Pharma, operating since early 2008, is currently negotiating with companies in the market for pharmaceuticals for functional foods, over the counter and prescription drug applications for the treatment of cardiovascular disease (Neptune, 2010a). NeuroBioPharm, operating since late 2008, is developing its treatments for the same applications based on the fatty acid and astaxanthin antioxidant properties of the NKO® for the treatment of neurological and cognitive diseases (Neptune, 2010a).

Neptune also has plans to branch into the nutrigenomics market using its established extraction technique and NKO® and related products. Nutrigenomics, part of the nutraceutical market, is the study of how food and its base components affect gene expression i.e. how the body responds to functional foods at a biomolecular level (NuGO, 2010). These functional foods can be used in the prevention of genetic disorders and are based on expanded knowledge of the human genome (Neptune, 2008).

Neptune's place in the market for krill is established based on pharma- and nutraceutical applications with no focus on production of any meal product. Whilst Aker published information on market trends freely on their website and in their publicly available publications, Neptune does not do this to the same extent. Rather, Neptune gives limited information on the basis for the evolution of their products into their current markets and focuses more on the basis for their product's market potential and the development of their products into the future.

As with Aker, Neptune accessed the 2005 Frost and Sullivan market report on the Analysis of the Global Omega-3 Polyunsaturated Fatty Acid (PUFA) Market. As such, their entry into the nutraceutical market was based on similar information to Aker. This information primarily points to the estimation that the worldwide Omega-3 market would reach over US$1.4 billion by the end of 2010 (Neptune, 2010a). In terms of Omega-3 enriched food, estimates from a report by market researcher Mintel, revealed that product launches in this market doubled from 120 to 250 from 2005 to 2006 with enrichment being mainly of dairy,

beverage, egg and nutrition bar products. Additional information from Datamonitor research in 2004 claimed that the worldwide market for nutraceutical products was valued at US$127.8 billion in 2003.

The markets for functional foods are acknowledged as being difficult to estimate, given the relatively new marketplace for them. Neptune has based estimations of this market on the potential for 25% of the total US food market being available for use for nutraceutical products (Neptune, 2010a). Based on this assumption, total market potential would amount to more than US$100 billion in the US and US$200 billion in Europe, based on 2004 figures (Neptune, 2010a).

Neptune currently has an annual production capacity of 100 000kg NKO®. With an increase in demand for this product (with an estimated increase in annual production to between 120 000 and 130 000 kg to satisfy demand), Neptune is undertaking updates and expansions to its manufacturing facilities. It is projected that a similar increase in production will continue until the end of the 2011 fiscal year (March 2011) (Neptune, 2010b).

In terms of revenue generated from sales, figures in the 2009 Annual Report (Neptune, 2009) indicate a continual increase in total sales from 2007 to 2009 from US$8.2 million to US$11.75 million respectively (Neptune, 2010b).

Neptune reports that clinical trials for functional food applications with Yoplait and Nestlé are expected to be completed by the end of 2010 and are expected to significantly increase Neptune's profits from this section of the nutraceutical market.

The source of Neptune's krill is not known. Canadians do not fish in the Southern Ocean so the assumption is that the krill is imported. There is also considerable uncertainty about what happens to krill once it is caught, making a value chain analysis impossible. Nevertheless, with expansion taking place in the company's production capacity to deal with increases in demand and sales, new distribution agreements, the formation of subsidiaries to focus on new markets and continuing success of clinical trials, it is fair to say that the future for

Neptune looks positive. Based on the Company's current direction it is likely that their krill fishing operations may increase in the coming years to keep up with demand for their products.

2.4.2.3 Other Participants in the Krill Marketplace

Another company operating in the pharma- and nutraceutical product market, Enzymotec, founded in 1998, originated in Israel and entered the marketplace for krill oil in 2007. With several recent advancements in its R&D for krill oil products, Enzymotec is aiming to be competitive in krill oil markets using its novel lipid formulations. Very little information is currently available on this company but recent news releases (Heller, 2010) reporting on Enzymotec's recent success in obtaining novel food status in Europe for its kill oil product, point towards an increased participation in the marketplace in the near future. Enzymotec is primarily targeting its krill oil product towards use in dietary supplements, functional foods, clinical and advanced infant nutrition supplements (Enzymotec, 2010).

A company which is beginning its operation in both the nutraceutical and feeds market is the Norwegian company Krillsea Group. Krillsea undertook major alterations to the vessel *Thorshøvdi* in order to equip it to fish for, and process on board, krill in the Southern Ocean and holds one of the four Norwegian krill fishing permits. Krillsea is producing products including Krill Meal Pellet (to be used in food and feeds), Krill Concentrate (for use in food and feeds), Krill Shell Powder (for use in feeds or as a raw material) and Natural Krill Oil (for use in the pharma- and nutraceutical markets) (KrillSea, 2010).

Neither of Enzymotec nor KrillSea has yet undertaken any extensive marketing of their products in the worldwide marketplace, as Aker and Neptune have done over the past few years. As such, there is very little publicly available information on the operations of these companies in the marketplace. Given the information accessible through the higher profile companies, it will be prudent to track the development of these companies into the future.

2.4.2.4 Summary

Given that companies such as Aker and Neptune are two of the major drivers of demand for high quality krill from the krill fishery, the tracking of information accessible through investor reports and product R&D data that is freely available from their websites is an invaluable way to source information on the current and future market for krill. Demand and sales figures available from both companies suggest that their requirement for krill resource will increase in the coming years.

The demand for raw krill product from Aker alone accounts for a high proportion of annual krill catches. Aker produced approximately 10 000MT of krill meal for the 2009/2010 financial year (Aker, 2010c). Given conversion factors of 7.6-10 for krill to krill meal (CCAMLR, 2009b) based on the above production figures, Aker would have required approximately 76 000 to 100 000 tonnes of raw krill product from the fishery. Given the krill catch for 2009 was 125 823 tonnes, Aker would have required, at the least, over half of the krill catch in 2009 to meet production requirements. Whilst this is only a rough estimate it does indicate the importance of emerging companies, such as Aker and Neptune, in the development of the fishery.

The entry of other companies, such and Enzymotec and Krillsea Group, into the krill pharma- and nutraceutical and feed markets also suggests a growth in the demand for the krill resource in the coming years.

2.4.3 Market Prices

Although there is now more information publicly available on krill product prices than in previous phases of the fishery and more information on drivers of the market for krill, there still remains a huge void in information on raw krill product in the marketplace. Whilst the fishery and market participants discussed above present information on their krill products, information on where they source their raw krill product from, and at what price, is absent. Also absent is information on krill meal trading prices, whereas information on krill oil pharma- and nutraceutical products is readily available online. In order to determine current market prices for krill, two examples of information on raw krill product and krill oil product prices will be examined.

Historically, direct information on quantities and prices of krill traded in the market place has been difficult to obtain. In terms of reporting this information to the Commission, nations have traditionally claimed that the commercial-in-confidence nature of this information is too important for companies, and thus their representative governments, to disclose in any public or published arena (SC-CAMLR-XIX, paragraph 2.6).

There is some limited information available from both the Tokyo and Sydney Fish Markets, however, which shows that the trading of krill in these traditional marketplaces has been, at best, patchy (Figure 15). This information was obtained directly from the markets and is not publicly available. A limited sample of the information from the Sydney Fish Market was submitted to the Scientific Committee in 2000, giving a price for krill traded between 1992 to 1999 ranging from A$2.65 to A$6.91 (SC-CAMLR-XIX, paragraph 2.5). It must be noted that this market information may not necessarily represent trading of Antarctic krill (*Euphausia superba*) but represents "krill" as a group.

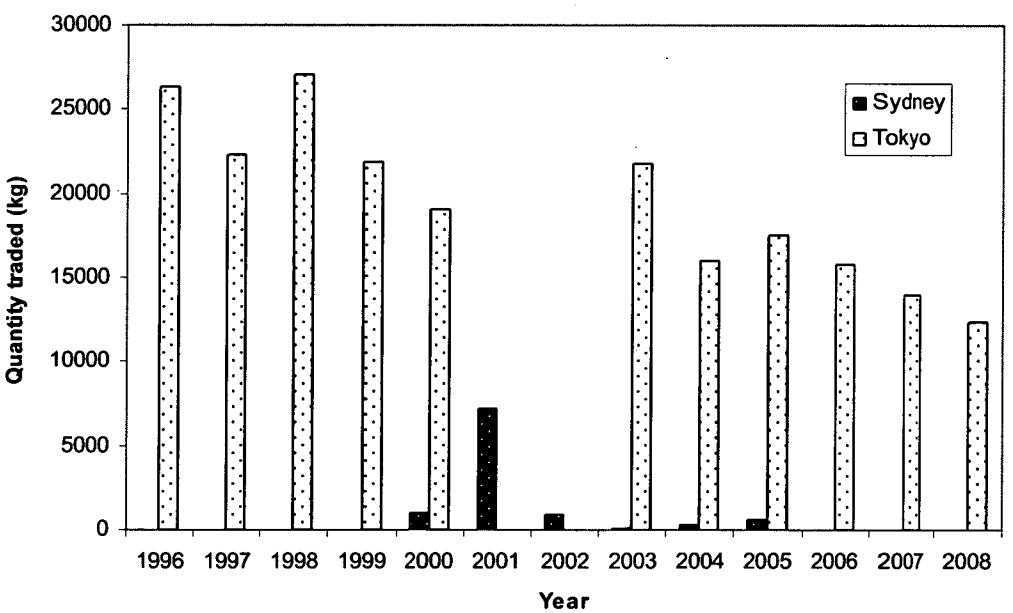


Figure 15: Amount of krill sold in the Sydney and Tokyo Fish Markets from 1996 to 2008 (Sydney Fish Market, 2006 and Tokyo Metropolitan Central Wholesale Market, 2008). Note the absence of data from the Tokyo Market for 2001 and 2002.

From these fish markets, very limited information is also available on the prices that krill is traded for. It must be noted that the actual prices for traded krill, presented here in different currencies, are not important. Rather, it is the trends in the prices that is important. Figures 16 and 17 indicate the fluctuations in market prices for krill in the Sydney and Tokyo fish markets. As can be seen, prices have fluctuated considerably in the two markets, and the trends in price exhibited are dissimilar to each other. It is not possible to draw any correlations *between* markets.

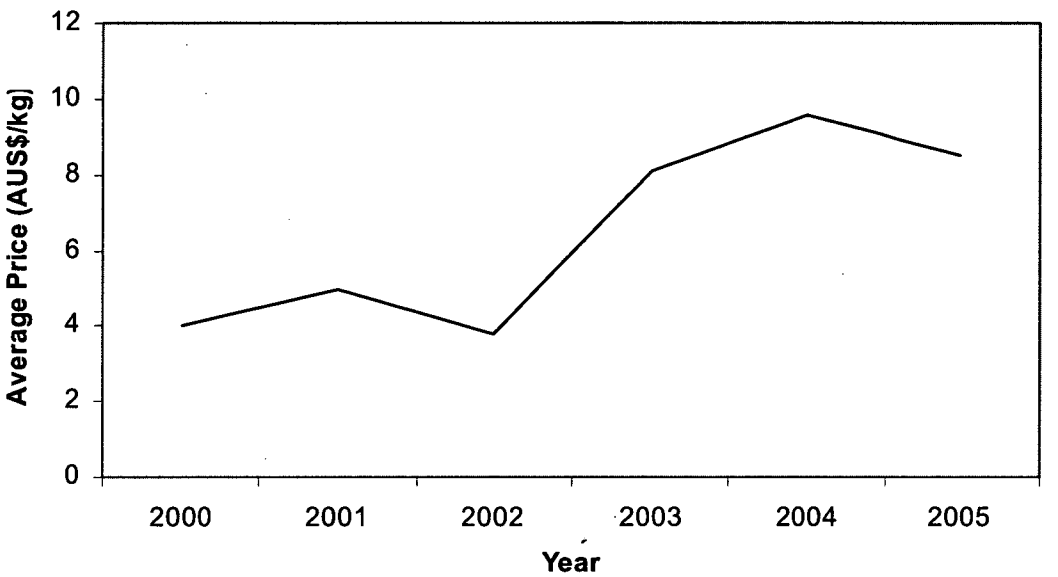


Figure 16: Average price of krill sold in the Sydney Fish Market from 2000 to 2005 (Sydney Fish Market, 2006).

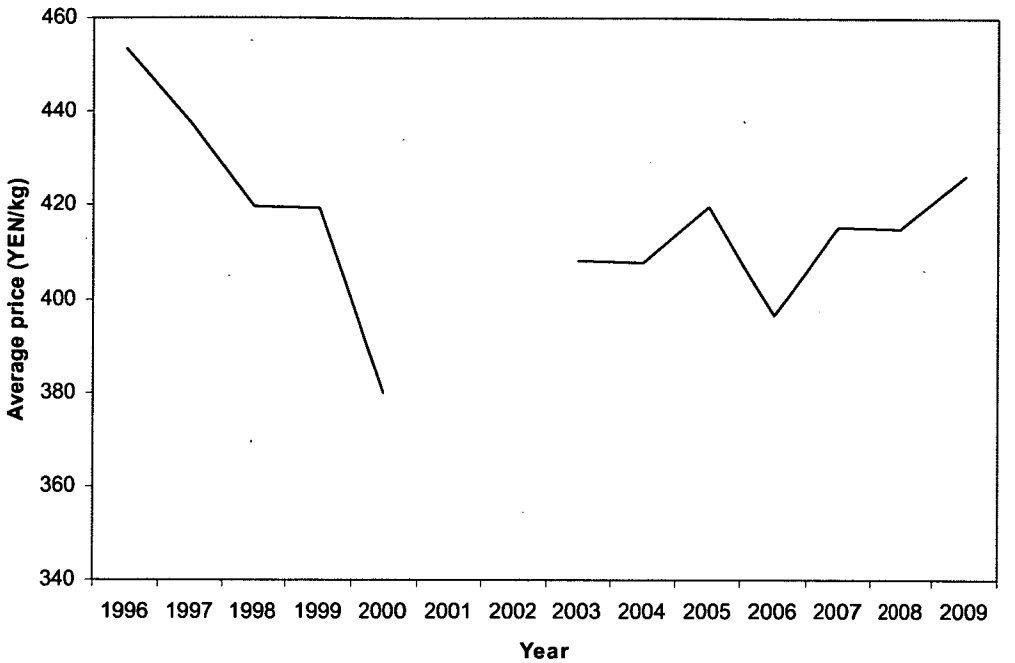


Figure 17: Average price of krill sold in Japan from 1996 to 2009. Note the absence of data for 2000 and 2001 (Tokyo Metropolitan Central Wholesale Market, 2008).

The trends between the quantity of krill traded and the average price per traded kilogram *within* the markets can be compared, as in Figures 18 and 19. In the Sydney market, as the quantity of krill traded dropped dramatically, the average price per kilogram increased just as dramatically, as would generally be expected in a normal supply and demand relationship.

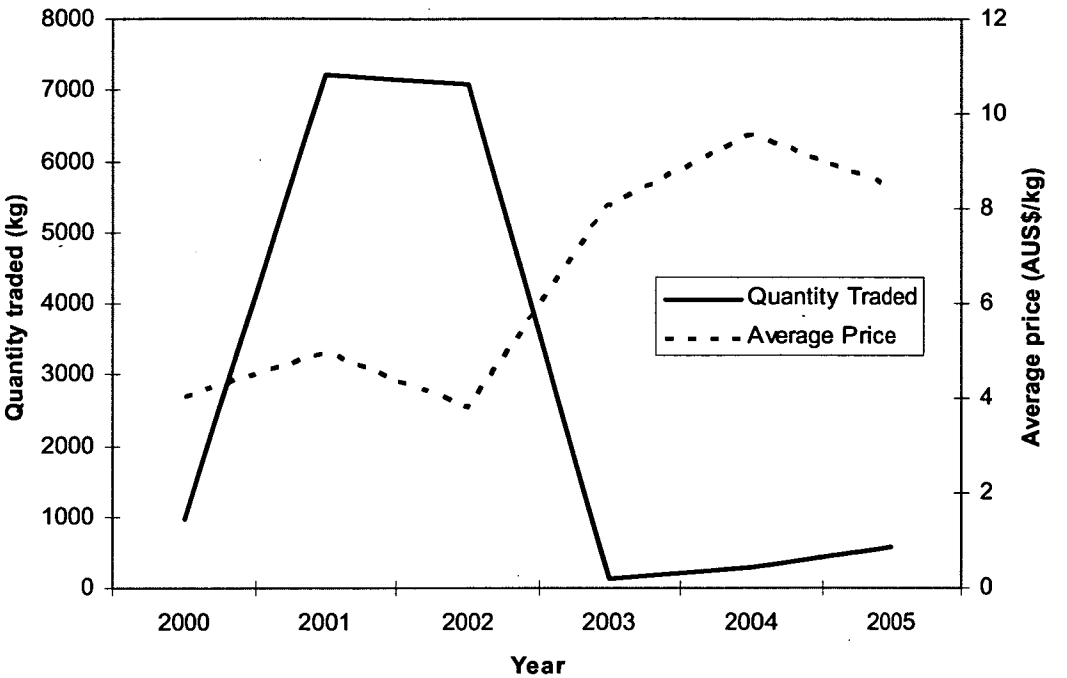


Figure 18: Quantity of krill traded and average price per kilogram in the Sydney Fish Market from 2000 to 2005 (Sydney Fish Market, 2006).

In the Tokyo market, however, there does not appear to be any obvious relationship between the quantity traded and average price. In some instances the relationship appears to be negative, and at other times inverse. The irregularity of the relationships suggests that this data is not useful for detecting trends in any supply and demand scenario.

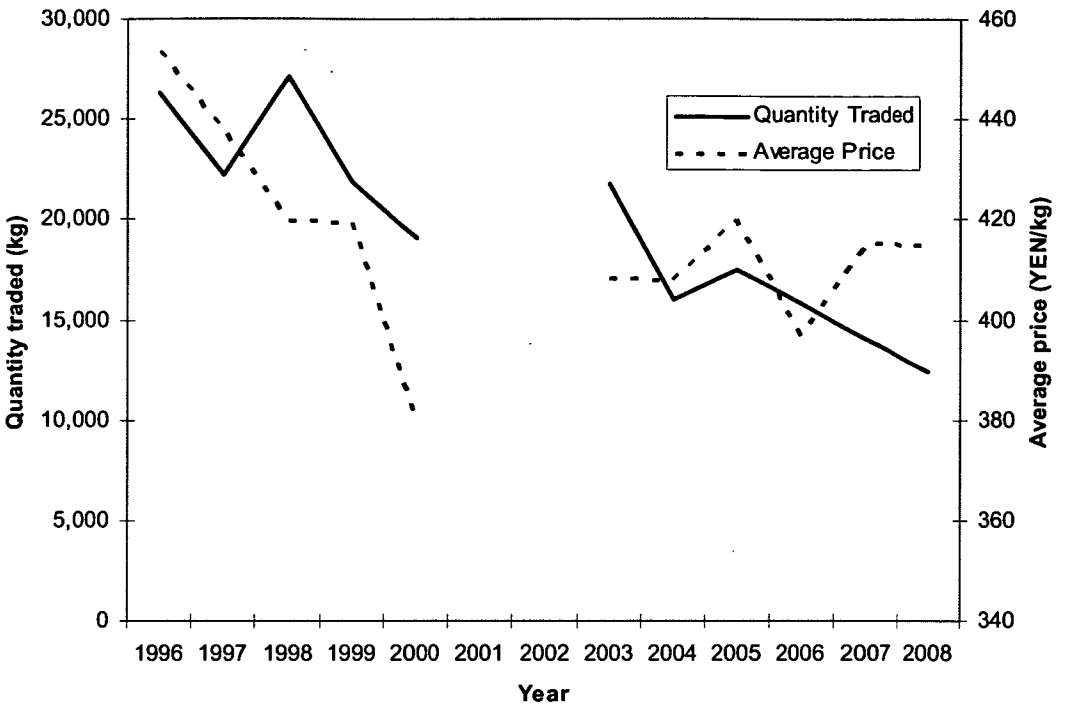


Figure 19: Quantity of krill traded and average price per kilogram in the Tokyo fish market from 1996 to 2008 (Tokyo Metropolitan Central Wholesale Market, 2008).

Availability of data on quantities and prices of krill traded in fish markets around the world can be both patchy in terms of frequency of trading events and unrepresentative of the true market value of krill. Several species can be traded under the "krill" product title and without full subscription rights to an individual market's trading data, it is not possible to consistently track this kind of market information. The quantities of krill traded in the markets examined here indicate that only relatively small quantities of krill are actually being traded in the traditional seafood markets, when compared to the actual quantity of krill that is coming out of the fishery.

The combination of these factors (small quantities, irregular trading, irregular relationships between quantities and prices, difficulty identifying exact species traded) indicates that the direct fish-market based trading of this species is not a reliable tool for detecting possible future trends in the krill fishery. This may not have been the case had more commercial data been available.

2.4.4 Krill Products

In lieu of reliable prices for actual raw krill product, it is useful to look to market prices for krill products for some indicator of the value of the krill resource. This information is very limited, both in terms of product range and markets across the world. Freely accessible information on sale prices for krill based meal and feed ingredients is virtually non-existent unless the buyer enters into direct negotiation with the supplier. Information on prices for krill pharma- and nutraceutical products is limited to markets for krill oil nutraceutical products.

As at July 2010, the average retail price per 500mg capsule for krill oil health supplements was US$0.70 with the average price for Neptune NKO® capsules being US$0.90 and the average price for Aker Superba™ capsules being US$0.48 (Table 2).

Table 2: Advertised retail prices for krill oil nutraceutical capsules from various online trading sites.

Brand	Company Source	Quantity	Purpose	Price (US$)	US$/Capsule
TwinLab	Neptune	60	Joint Health	39.99	0.67
OmegaGen	Neptune	60	General Health	65.00	1.08
Swisse	Neptune	50	Heart & cholesterol	47.95	0.96
Troo Health	Aker	60	General Health	29.20	0.49
Health Spark	Aker	60	General Health	44.93	0.75
Swanson	Aker	60	General Health	11.99	0.20

Figures that can be obtained for prices for any other krill-derived products are based on speculation and extrapolations by parties compiling reports on the value of the krill product and are therefore not presented here as a representation of the true value of krill products.

2.5 Summary

In terms of tracking development in the market, with reference to past and current mechanisms, analysis appears to have evolved from looking to the

countries that are fishing for the product and what they are doing in terms of R&D, to looking at the companies that are selling krill products. With limited or no information available on the movement of krill between the fisher and the product developer (except in the case of companies such as Aker and Krillsea Group where this is not an issue as they fish for their own raw product) it is not possible to use only the fishing countries as indicators of the development of the marketplace for krill. It has also now been established that traditional mechanisms used to track fisheries, such as fish market prices, cannot be applied to the krill fishery due to the lack of available of reliable, accurate information.

The development of krill products has diversified into new markets, the pharma- and nutraceutical markets, markets which are predicted to expand considerably in the coming years. However, krill is also still maintaining a place in its traditional markets of animal feed additives and food for human consumption. When combined, these traditional marketplaces for krill and the new and emerging marketplaces point towards a new level of investment in the marketplace not seen before. Companies now have products which have proven themselves in terms of quality and demand whereas in the early phases of the fishery, products were being developed without any real market niche to fill.

Given the now established changes occurring in the marketplace for krill, it is likely that there will be an associated increase in the fishery to accommodate increased demand for krill products. However, it has also been established in this Chapter that there is still a gap in the ability of managers and forecasters to predict the magnitude or the rate of increase of the fishery. As such, it is necessary to identify other tools that can be used to track the development of the krill fishery into the future.

Chapter Three: Management of the Krill Fishery

3.1 Introduction

The historic overexploitation of Antarctic species; fur and elephant seals 1700s and 1800s and whales in the 1900s (Agnew, 2008), did not bode well for future management of Antarctic fisheries resources (Edwards and Heap, 1981). Following the serious depletion of these stocks around the sub-Antarctic Islands of South Georgia, fishing fleets started to move southward and began the exploitation of Antarctic finfish species including mackerel icefish and marbled rockcod (Agnew, 2008; Constable *et al.*, 2000; Parkes, 2000). At the same time, fishing was also initiated for Antarctic krill. With a large and accessible biomass, krill presented an opportunity to fish one of the last unexploited marine biomasses in the world and exploratory catches of the species were taken in the late 1960s. By the late 1970s the krill fishery was well established.

With rising concerns over the possibility that krill, the keystone species of the Antarctic ecosystem, could meet the same fate as historically exploited stocks such as seals and whales, CCAMLR was adopted in 1980, entering into force in 1982. The CCAMLR Commission has been the body responsible for ensuring that krill stocks, and associated and dependent species, are not threatened by overfishing, ever since. The Commission, as of 2010, is responsible for managing commercial fisheries for four species in the Area including Patagonian toothfish, Antarctic toothfish, mackerel icefish and krill.

When the Convention was adopted in 1980, the krill fishery was the world's 24th largest fishery overall, and the largest crustacean fishery in the world (Nicol, 1991). In comparison to total global fisheries landings, the fisheries managed by CCAMLR were not globally significant in either quantity or value (Molenaar, 2000) but the importance of these fisheries, particularly the krill fishery, in terms of ecosystem effects, is significant. In terms of Southern Ocean fisheries, the krill fishery is, by weight, the largest fishery in the region.

It has been argued by Members at Commission meetings that because the current krill fishery is small in comparison to both the estimated biomass of the krill

stock and precautionary catch limits for the fishery, that regulatory measures that are applied to other fisheries in the Area need not be applied to the krill fishery (CCAMLR-XXV, paragraph 10.4; CCAMLR-XIII, paragraph 5.24; CCAMLR-IX, paragraph 8.9; CCAMLR-VIII, paragraph 4.6-4.9). The idea that the krill fishery is only small has come about because annual catches remain far below even the precautionary limits for the fishery and have even been well below the trigger level which has been set by the Commission to indicate when the fishery might be reaching a level where stricter regulatory measures are needed.

CCAMLR has two primary objectives in managing the krill fishery. Firstly, ensuring that overall krill biomass is not compromised and secondly, ensuring that krill biomass is adequate to meet the needs of land-based krill predators (Hewitt and Low, 2000). In order to achieve these objectives the Commission has adopted two approaches to management that are relatively novel in management of a fishery resource, the ecosystem and the precautionary approach. The Commission puts these management approaches into practice through the use of various management tools which are implemented through the adoption of Conservation Measures. Although there has not been a systematic approach to incorporating ecosystem considerations and precaution, the Commission has addressed a range of issues when considering the krill fishery and the overall effect of this is to give some practical effect to the principles in Article II of the Convention.

In order to address the issue of how well the Commission is placed to deal with an increase in krill catches, it is necessary to review how the Commission has managed the fishery to date and to take note of current shortcomings in the management of the fishery. As such, this Chapter will address the following questions:

- What elements of the Commission's management of the krill fishery incorporate the ecosystem approach and precaution?
- How well is the Commission placed to deal with an increase in krill catches?

- How has the Commission managed the krill fishery, to date?
- What are the shortcomings of the way the fishery is currently managed?

To address these questions, this Chapter will comment on the level of attention the Commission has given the issue of management of the krill fishery, given that the fishery provided the impetus for the negotiation of the Convention and will investigate how the Commission has managed the krill fishery in line with its Ecosystem Based Management (EBM) (also sometimes called Ecosystem Based Fisheries Management, or EBFM) and precautionary approaches to management. The application of the Scheme of International Scientific Observation (the Scheme) in the krill fishery will be used as a case study to investigate one of the mechanisms the Commission has for ensuring the orderly development of the krill fishery and will examine whether the Commission is using the Scheme to its full potential for fulfillment of its EBM and precautionary remits.

3.2 CCAMLR's Focus on Management of the Krill Fishery

Chapter Two established that krill catches in the Southern Ocean are likely to increase as a result of advances in krill product technologies. In recent years, the Commission's management of the krill fishery has not faced any significant challenges to its efficacy, given that krill catches have remained relatively low. However, with the krill fishery likely to undergo significant changes in its operation it is time to question how well placed the Commission is to deal with such changes.

Given that the Commission is responsible for managing four commercial fisheries in its Area, as well as protecting dependent and associated species that are connected to these fisheries it can be expected that, as a matter of necessity, the Commission's focus would be split accordingly. However, there has been commentary made on the low level of focus on krill by the Commission compared to other species (ASOC, 2006; Nicol, 1991) given that it is the largest fishery in the Area and that it precipitated negotiation of the Convention in the 1980s.

At the time of entry into force of the Convention, there were several finfish stocks in the Area that required urgent attention in terms of management due to declines in abundance and threats of overexploitation (Croxall *et al.*, 1992). In response to this, the Commission began by implementing a series of Conservation Measures, including area closures and gear restrictions, to immediately address these issues of overexploitation. The Commission then began to address implementation of EBM by setting up CEMP and the Working Group on the Development of Approaches to Management (WG-DAC). At the same time, the Commission was also acting to address high rates of seabird by-catch which had emerged as an issue at the 1989 Meeting of the Commission, shortly after longline fishing was first introduced in the Area.

The next issue that required the urgent attention of the Commission and, of particular focus in this thesis, was the development of the problem of IUU fishing for Patagonian toothfish, *Dissostichus eleginoides* (herein after referred to as toothfish) in the 1990s and the attention that was drawn away from the issue of management of the krill fishery and transferred onto development of regulatory measures to deal with this new threat to the Convention's purpose.

Awareness that IUU fishing was becoming a major problem in the CCAMLR Area did not appear to be recognised in Commission discussions until the Thirteenth meeting in 1994 (Molenaar, 2000). The Commission responded to the issue of IUU fishing with a series of Conservation Measures over the next 15 years aimed at increasing the regulation for toothfish fisheries including, *inter alia*, vessel monitoring requirements (Conservation Measure 10-04 [2007]), IUU vessel blacklists (Conservation Measures 10-06 and 10-07 [2006]), port inspections (Conservation Measure 10-03 [2005]) and most significantly the Catch Documentation Scheme (CDS) (Conservation Measure 10-05 [2006]) which aims to track the trade all toothfish taken from the Convention Area to ensure that traded fish are taken in line with CCAMLR regulations.

However, not only was the Commission concerned with the impact of IUU longline fishing on the target species, but it had serious concerns over the impact of this fishing on by-catch species, in particular seabirds such as albatross and

petrels (Agnew, 2008). Consequently, the Commission established an ad hoc Working Group on Incidental Mortality Associated with Longline Fishing (WG-IMALF) as early as 1993 and adopted further Conservation Measures aimed at reducing the by-catch of these species in longline fishing operations.

During this period the krill fishery developed, and although considerable scientific effort was devoted to establishing the sustainable management of this resource (e.g. CCAMLR 2000 Survey) the Commission's attention appears to have been directed elsewhere. In order for the Commission to ensure the orderly development of the krill fishery, in line with its ecosystem and precautionary approaches to management, it must be able to give adequate attention to developing its approach to management of the fishery. By assessing the amount of focus the Commission has given management of the krill fishery to date, and the amount of attention that has been diverted to other issues, we can gain some perspective on how the Commission will be placed to deal with an expanding krill fishery, and hence an increased need for further regulatory measures in the fishery.

3.2.1 Analysis of Commission Reports

In 1991 Nicol, noting that after nine meetings of the Commission no measures for regulating the krill fishery had been adopted, reviewed the way that the Commission and the Scientific Committee had dealt with krill (Nicol, 1991). Nicol's underlying argument was that the Commission and Scientific Committee had been ignoring the basic issue which underpinned the entire Convention – the management of the krill fishery. Nicol based his analysis of the deliberations of the Commission and Scientific Committee on the agenda items for the Meetings and the paragraphs contained in reports of the Meetings.

3.2.1.1 Methods

CCAMLR Commission reports from 1983 onwards were analysed to ascertain the extent of discussions relating to toothfish and krill. Methods employed by Nicol (1991) were reviewed and used as guidelines for identifying trends in the discussions of the Commission. In his 1992 note in response to criticism of his 1991 conclusions, Nicol acknowledged that the way he assessed the amount of

discussion that had taken place in the Scientific Committee reports may have resulted in an underestimation but that this could not be said for the assessment of the amount of discussion in the Commission reports. However, in order to eliminate this possibility, new guidelines for assessing the amount of discussion on management of the krill fishery that has taken place in the Commission to date, have been used, based on the concept of Nicol's 1991 method.

Each Commission report from 1983 onwards was analysed by counting the number of times krill or toothfish were referred to in each report. Occurrences of krill and toothfish were accounted for as follows:

- Krill occurrences included the use of krill and *Euphausia superba*;
- Toothfish occurrences included the use of toothfish, Patagonian toothfish, Antarctic toothfish, Dissostichus spp., *Dissostichus eleginoides*, *D.eleginoides*, *Dissostichus mawsoni* and *D.mawsoni*;
- Excluded occurrences in table of contents;
- Excluded occurrences in graph or table titles, or within graphs or tables;
- Excluded occurrences in footnotes; and
- Excluded occurrences occurring in any Conservation Measures which were included in Commission reports until the Commission's 17th meeting in 1998.

The methods employed aimed to remove any observer bias that might have occurred from making decisions on the legitimacy of recording an occurrence. Employing the tools listed above allowed the use of a method which would evenly weight any occurrence and therefore provide an accurate representation of the content of Commission discussions.

Only Commission reports were analysed, rather than Scientific Committee or Working Group reports. This approach was taken because it is the Commission that is the decision making body within the CCAMLR regime and therefore it is the reports from the Commission that are representative of the intentions and progress made under the Convention towards the conservation of Antarctic

marine living resources. It is important to note that the final Commission reports, in their published form, are agreed upon by all Members and thus the statements made in the reports reflect the views of every Member of the Commission.

3.2.1.2 Results

The primary method CCAMLR employs to track fisheries is through the submission of catch data from Members. Trends in catch data can be compared to trends in Commission discussions on krill (Figure 20), to examine how the Commission has responded to developments in the krill fishery. When the Commission was in its establishment phase in the early 1980s, krill catches were at their highest level but discussions on krill were not a priority (Nicol, 1991). In 1990 there was a small spike in discussions relating to krill (as highlighted on Figure 24). This spike occurred the year before the first Conservation Measure on precautionary catch limits for the fishery (32X) was adopted (in 1991), reflecting the preliminary discussions on krill management. Another small spike in krill discussions occurred in 1998/99 (as highlighted on Figure 20), the year prior to the CCAMLR 2000 biomass survey which was developed to set new catch limits for krill.

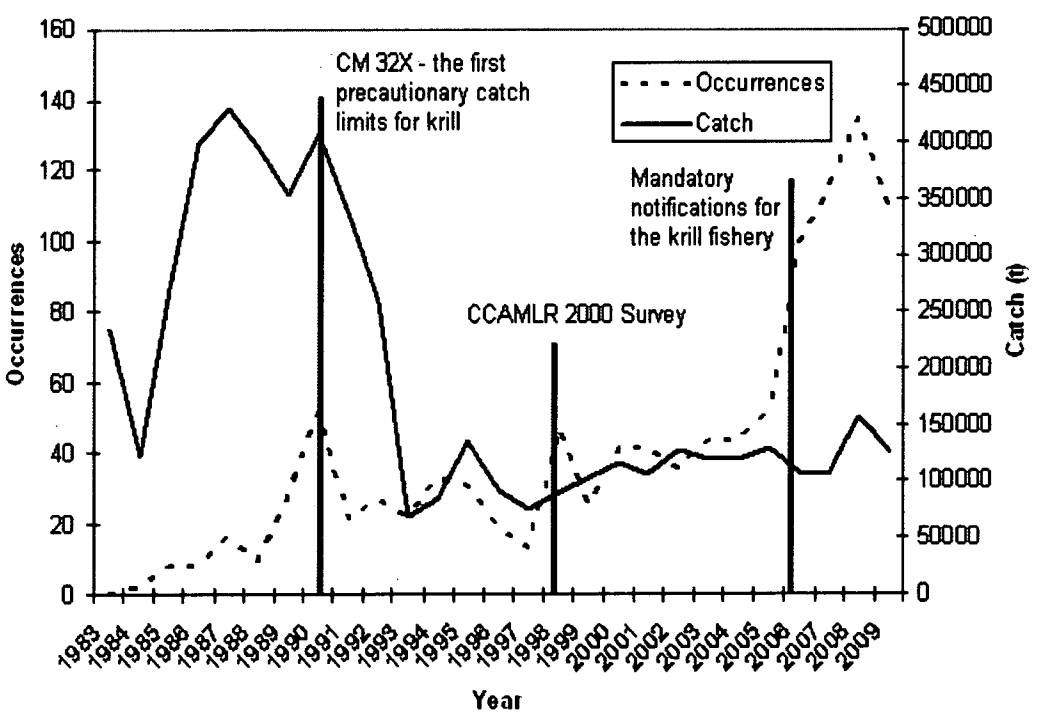


Figure 20: Number of references to krill made in Commission reports since 1983 and total catch of krill in the Convention Area during the same period.

Until the mid 1990s, both krill and toothfish were given similar attention by the Commission during its deliberations. By the mid 1990s, discussions concerning toothfish had increased dramatically, coinciding with the time that the issue of IUU fishing came the Commission's attention (Figure 21). At the same time, discussions pertaining to krill remained at a consistently low level by comparison. Discussions surrounding toothfish appeared to dominate the Commission's time until 2004 when they decreased at the same time that krill discussions began to increase. After 2005, discussions pertaining to krill have begun to dominate the Commission's discussions whilst those pertaining to toothfish have dropped below the level of krill discussions for the first time since the mid 1990s.

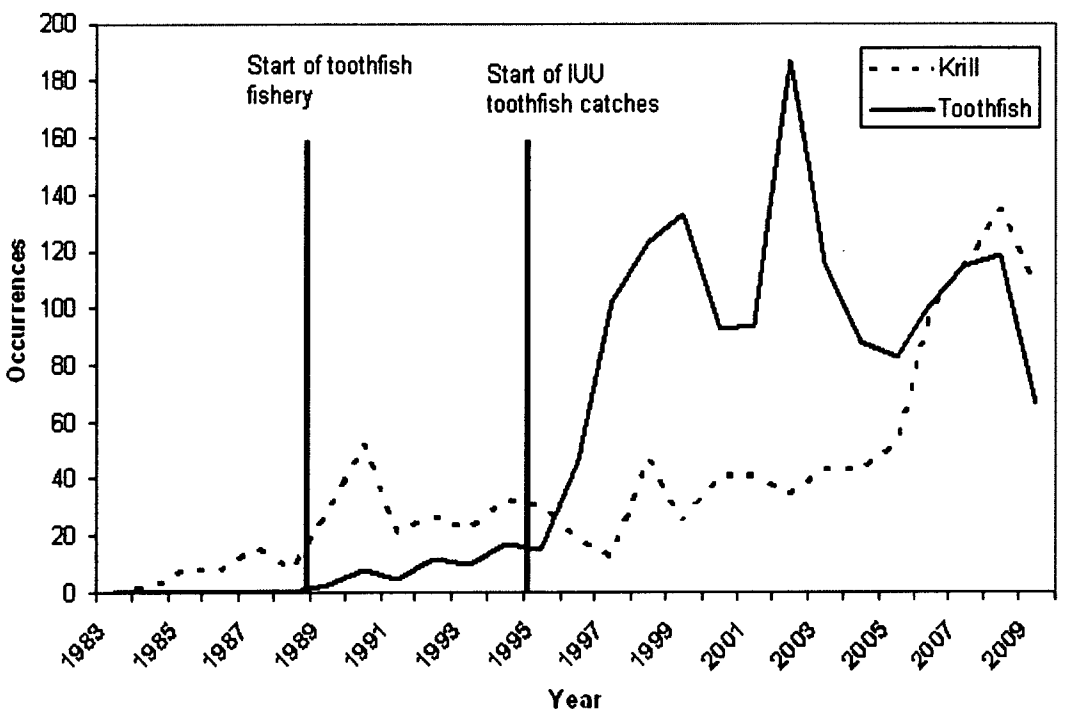


Figure 21: Number of times references to krill and toothfish occur in Commission Reports from 1983 to 2009.

After notifications became mandatory in 2006 (after being only voluntary from 2003) and it became apparent that there was increasing interest in the krill fishery (discussed in more detail in Chapter Four), discussions on krill in the Commission increased dramatically (as highlighted on Figure 20), indicating that the Commission responded quickly to information emanating from the notifications.

3.2.1.3 Discussion

Nicol's analysis of Commission's discussions (1991), whilst recognising that by 1991, the issue of management of the krill fishery was firmly on the Agenda for the Commission, also resulted in the following conclusions (Nicol, 1991):

- The number of paragraphs dealing with fish, in Commission reports, far exceeded paragraphs devoted to dealing with krill;
- The Commission had failed to achieve one of its primary objectives, to manage the krill fishery, after nine years of meetings;
- It was an anomaly for such a well established, and large (by weight), fishery to not be regulated; and
- Fishing nations needed to acknowledge the basic tenets of the Convention or risk the irrational use of the krill resource.

Nicol's analysis of the Commission and Scientific Committee reports, and subsequent conclusions about the Commission's management of the krill fishery, drew comments from other authors on the appropriateness of the conclusions that were drawn (Croxall *et al.*, 1992). In response to Nicol's findings, Croxall *et al.*, (1992) wrote that in comparison to other international fisheries conventions, CCAMLR had reached various landmarks (e.g. size and catch limits, closed seasons) faster than most and that it was not the fault of the workings of the Commission or Scientific Committee that had led to a paucity in krill-related regulatory measures, but rather resistance from krill fishing nations and subsequent blocking of consensus that was the hindrance. In response, Nicol (1992) noted that once the subject of management measures for the krill fishery had been raised, the Commission did act with due speed, enacting the first Conservation Measure within the next three years. However, Nicol (1992) also highlighted that when the fishery was in two of its expansion periods, and also during the crash of the fishery, the Commission did not appear to discuss these major developments (given what had appeared in Commission reports).

Analysis of Commission reports, using methods developed from Nicol's 1991 analysis, enables comment to be made on the amount of time it has taken the

Commission to develop its approach to management for the krill fishery. Although CCAMLR was established primarily to monitor and manage the krill fishery, krill was not mentioned in Commission reports until the Third Meeting in 1984. This apparent lag time in beginning discussions on krill occurred because early Commission meetings were dominated by administrative and procedural matters (Nicol, 1991; Howard, 1989).

During the period when the Commission was dealing with the IUU toothfish issue, it is apparent that the issue of management of the krill fishery was not receiving significant attention from the Commission. This is not to say that krill had been dismissed entirely but, rather, the Commission only had time to deal with immediate issues arising from the fishery and little time to develop measures which would enhance the precautionary management of the fishery. Issues such as development of a feedback management system and observers appeared to be on hold whilst the issue of IUU was being dealt with.

Since the introduction of mandatory notifications in 2006, and a drop in IUU toothfish catches, the Commission appears to have responded by refocussing discussions on the krill fishery, acknowledging that developments in the fishery will require regulatory measures for the krill fishery to, at the very least, come into line with those that apply to other fisheries in the Area.

Now that the krill fishery has been firmly on the Commission's agenda for a number of years it is appropriate to examine the range of measures it has taken to implement its ecosystem-based management mandate.

3.3 CCAMLR's Approach to Management of the Krill Fishery

CCAMLR was initially negotiated in response to increasing concern over the possible expansion of the fishery for Antarctic krill in the Southern Ocean (Molenaar, 2000; Triggs, 1987). This concern stemmed mainly from the fact that prior to CCAMLR there was no regulatory body responsible for management of the krill resource. Even at this early stage, it was recognised that a dramatic reduction in the size of krill stocks would have serious, and possibly irreversible,

effects on populations of krill predators, including penguins, seals, whales, fish and seabirds, cascading through the Southern Ocean food chain.

It was this concern for the Antarctic ecosystem as a whole, rather than krill as a single species, that led to the 'ecosystem approach' to management which was adopted by the Convention under Article II (Nicol, 1991). CCAMLR's ecosystem and precautionary approaches to management underpin the entire Convention's purpose: the conservation, including the rational use of, Antarctica's marine living resources (Chapter One).

At the time the Convention was negotiated it was recognised as a landmark achievement due to both its approach to management and its timing; CCAMLR adopted an Ecosystem Based Management (EBM) approach and was negotiated *prior* to overexploitation of the primary resource that it was responsible for managing (Boczek, 1983; Edwards and Heap, 1981). EBM, a relatively new approach in the field of natural resource management (Ruckelshaus *et al.*, 2008; Pikitch *et al.*, 2004; Constable, 2001), is part of an increasing trend towards consideration of broader, ecosystem-oriented factors (Sainsbury *et al.*, 2000) and CCAMLR is recognised as being the first management body to implement it (Fabra and Gascón, 2008; Howard, 1989).

An EBM approach requires the following factors to be accounted for when management decisions are made (Ruckelshaus *et al.*, 2008):

- Food-web interactions;
- Ecosystem dynamics;
- Human-induced change; and
- Naturally induced change and fluctuations.

In order for EBM to be successful, regulatory measures should (Pikitch *et al.*, 2004):

- Avoid degradation of ecosystems;

- Minimise risk of irreversible change to natural assemblages of species and ecosystem processes;
- Obtain and maintain long-term socioeconomic benefits without compromising ecosystems; and
- Generate knowledge of ecosystem processes sufficient to understand the likely consequences of human actions.

There are several key outcomes that need to be considered to ensure that EBM can achieve these objectives (Pikitch *et al.*, 2004):

- Management of impact of fishing activities on protected and endangered species, along with the ecosystem processes that are essential for their recovery;
- Protection of essential habitat, perhaps through ocean zoning;
- Reduction of excessive levels of by-catch; and
- Management of target species in the context of the overall state of the system.

In the CCAMLR context, EBM means that the complex relationships that exist between organisms and physical processes must be taken into account when management decisions are made. This approach also means that not only does the impact of the fishing activity on the target species need to be considered but so does the impact of the fishing activity on the numerous species that are dependent on or associated with that target species. Considering the vastness of the Area that CCAMLR is responsible for managing (approximately 35 million square kilometres), and the diverse range of organisms and ecosystem interactions that are taking place in that area, CCAMLR has a task unrivalled by other fisheries management bodies.

Often included in EBM is the principle of a precautionary approach to management. A precautionary approach to management requires that uncertainty shouldn't delay the implementation of regulatory measures for a fishery (Parkes, 2000) and where information is insufficient, strong, precautionary regulatory

measures that favour the ecosystem should be adopted (Pikitch *et al.*, 2004). In the CCAMLR context, the precautionary approach has the aim of minimising the risk of long-term adverse effects rather than delaying decisions until all necessary data are available (CCAMLR, 2010). Precaution is built in to all CCAMLR management decisions, from catch limits to by-catch reduction measures.

The precautionary approach was not developed by the Commission until the late 1980s when the Commission first began to use scientific evidence in the decision making process (Constable, 2002). It is sometimes thought that, although itself a standalone concept, the precautionary approach is also a significant component of the ecosystem approach (Fabra and Gascón, 2008). The ratification of the Convention can itself be seen to be a precautionary move for the conservation of Antarctic marine living resources (Parkes, 2000).

Whilst the first effective application of EBM and precautionary management approaches within CCAMLR is often thought to have occurred in 1991 when the first precautionary catch limits were set for krill (Agnew, 2008), as early as 1987 the Commission had established CEMP. The primary role of CEMP was to monitor the krill-dependent ecosystem to detect significant changes in the ecosystem, primarily by monitoring krill dependent predators (Agnew, 2008), and to distinguish between changes that are a result of fishing activities and those that are a result of environmental changes (Parkes, 2000; Agnew, 1997). The formation of WG-DAC at the 1986 and 1987 meetings of the Commission was also a significant step in the Commission's initial moves towards developing its approach to management. WG-DAC, previously called the Working Group on the Development of a Conservation Strategy, was established to (CCAMLR-V, paragraph 63):

> develop a process for defining a strategy for the progressive achievement of the objectives of the Convention, as set out in Article II.

3.3.1 Implementation of EBM and the Precautionary Approach in the CCAMLR Context

CCAMLR has moved towards EBM and precautionary management of the krill fishery by adopting a range of regulatory measures that take into account the needs of dependent and associated species. The Commission's management decisions take the form of Conservation Measures which are adopted only when consensus between all Members of the Commission has been achieved (consensus in the CCAMLR context can also be achieved through the absence of objection to a measure, see Turner *et al.*, 2008, for further discussion). Advice on proposed Conservation Measures is taken from the Scientific Committee and decisions are based on the best scientific information available at the time (Constable, 2002). Once a Conservation Measure is adopted it becomes legally binding on all Members of the Commission 180 days after notification (Article IX, 6b).

The Commission has adopted several Conservation Measures that aim to ensure that the krill fishery develops in line with its approach to management (Table 3). These measures require Members to comply with rules that are specifically aimed at ensuring both EBM and precautionary management principles are applied in the management of the krill fishery. In addition to these measures, the Commission has also adopted several measures which are commonly implemented by RFMOs to collect basic data from the fishery including catch and effort reporting requirements (23-02 and 23-06).

Each of the Conservation Measures included in Table 3 have been adopted to enhance the Commission's management framework for the krill fishery. Whilst each Measure has a distinct purpose, they are designed to not only compliment one another, thereby strengthening overall regulation of the fishery, but also to build on previous measures and be able to be altered in accordance with new information as it is made available to the Commission through the Working Groups and Scientific Committee. Some of these measures are specific to the krill fishery whilst others apply across all fisheries operating in the Area. To interpret the usefulness of each of the Measures which currently apply to the krill

fishery, the role that these Measures play in CCAMLR's management approach will be investigated.

Table 3: Conservation Measures applicable to the krill fishery that reflect the Commission's EBM and precautionary approaches to management.

Number	Adopted	Title	Effect
51-01	1991	Precautionary catch limitations on *Euphausia superba* in Subareas 48.1, 48.2, 48.3 and 48.4	• Highly precautionary catch level; • Trigger level; • Subdivision of catch; • Adopted prior to expansion of the fishery.
25-03	1991	Minimisation of the incidental mortality of seabirds and marine mammals in the course of trawling	• Restricts use of fishing gear; • Controls deployment of fishing gear; • Reduces level of incidental mortality.
33-01	1992	Limitation of the by-catch of *Gobionotothen gibberifrons*, *Chaenocephalus aceratus*, *Pseudochaenichthys georgianus*, *Notothenia rossii* and *Lepidonotothen squamifrons* in Subarea 48.3	• Conserves finfish stocks; • Fishing vessels must act to limit by-catch.
51-03	1992	Precautionary catch limitation on *Euphausia superba* in Division 58.4.2	• Highly precautionary catch level; • Division of catch; • Trigger level; • Observer requirement; Adopted prior to expansion of the fishery.
21-02	1993	Notification for exploratory fisheries	• Controls expansion of new fisheries; • Notification of fishing intentions.
51-02	1996	Precautionary catch limitation on *Euphausia superba* in Division 58.4.1	• Highly precautionary; • Division of catch; • Gear restrictions to reduce incidental mortality; • Adopted prior to expansion of the fishery.
10-04	1998	Automated satellite-linked vessel monitoring systems (VMS)	• Applied to krill fisheries in 2007; • Tracks fishing activities; • Will allow management of fishing activities within SSMUs.

21-03	2006	Notifications for krill fisheries	• Detailed information on intentions to fish for krill; • Details of fishing gear types, area to be fished, expected catch, type of vessel, numbers of vessels.
26-01	2006	General environmental protection during fishing	• Prohibits use and disposal of environmentally damaging plastics normally used in fishing activities; • Reduces entanglements and incidental mortality.
31-02	2007	General measure for the closure of all fisheries	• A fishery can be closed if stock is overexploited.
51-04	2008	General measures for exploratory fisheries for *Euphausia superba*	• Controls expansion of new fisheries; • Limits catch; • Notification requirement; • Observer requirement.
51-05	2008	Limits of the fishery for *Euphausia superba* in Subarea 48.6	• Controls distribution of catch across the Subarea; • Prevents taking of large catches from localised areas; • Protects land breeding predators.
51-06	2009	General measure for scientific observation in fisheries for *Euphausia superba*	• Partial Observer coverage mandatory for two seasons; • Enhances monitoring of fishery; • Increased biological data collection including by catch.
51-07	2009	Distribution of the trigger limit in the fishery for *Euphausia superba* in Subareas 48.1, 48.2, 48.3 and 48.4	• Distributes catch limit across Subareas; • Prevents taking of large catches from localised areas; • Protects land breeding predators.
91-03	2009	Protection of the South Orkney Islands southern shelf	• In line with Article II; • Designates an MPA; • Prohibits fishing to conserve biodiversity.

3.2.1.1 Precautionary Catch Limits

In 1991 the first Conservation Measure to directly regulate the krill fishery was adopted. Conservation Measure 32/X related to precautionary catch limits on krill in Area 48, and was set using outputs from the Krill Yield Model (KYM), discussed below (Miller, 2002), although these were subsequently modified when the Generalised Yield Model (GYM) was developed (Constable and de la Mare, 1995). Since adoption of this Conservation Measure, precautionary catch

limits have been set for the main fishing grounds within Area 48 on the basis of new data (Conservation Measure 51-01 [2006]) and for Divisions in Area 58 under Conservation Measures 51-02 (Division 58.4.1 – first set in 1996) and 51-03 (Division 58.4.2 – first set in 1992)].

Precautionary catch limits for Subareas 48.1, 48.2, 48.3 and 48.4 and Divisions 58.4.1 and 58.4.2 are set out in Conservation Measures 51-01 (2008), 51-02 (2008) and 51-03 (2008), summarised in Table 4. Conservation Measures 51-01 and 51-03 provide that trigger levels are to be applied to catches. A trigger level is a level of catch which must not be allowed to further proceed until tighter regulatory measures i.e. division of catch amongst smaller management units, have been established. Trigger levels are arbitrary catches which have been derived to ensure that catches are not taken from restricted areas. The trigger level of 620 000 tonnes set by 51-01, for example, was derived from the aggregate of the highest annual commercial catches taken from each of the Subareas in Area 48 (SC-CAMLR-XXVII, paragraph 3.33). These trigger levels are in place to ensure that the fishery develops in an orderly manner, with no irreversible impacts on predator species.

Table 4: Allocation of precautionary catch limits in the krill fishery.

Conservation Measure	First Adopted	Area/Division	Total Catch Limit (tonnes)	Trigger Level (tonnes)
51-01	1991	48.1, 48.2, 48.3, 48.4	3.47 million	620 000
51-02	1996	58.4.1	440 000	n/a
52-03	1992	58.4.2	2.645 million	452 000

An evolution of Conservation Measure 51-01 occurred in 2009 when Conservation Measure 51-07 was adopted, providing for the interim distribution of the trigger level catch amongst Subareas 48.1, 48.2, 48.3 and 48.4. This measure was adopted to avoid the trigger level catch being taken in one or two small areas, alleviating potential pressure on predator populations.

By 1994 the Commission had agreed on a set of decision rules on which all future decisions on precautionary catch limits for the krill fishery would be based, rather than the reactive mechanisms, which had led to Conservation Measure 32X (Constable *et al.*, 2000). For the ecosystem approach to function effectively in the CCAMLR context, the krill catch needs to be set at levels that allow relationships with predator species to remain unaffected by fishing activities, rather than at levels that only ensure stable recruitment of the krill population (Howard, 1989). This approach differs from traditional approaches used to manage fish stocks which have seen catch limits set at levels which will maximise catches over a period of time given different estimates of productivity of the harvested stock alone, known as Maximum Sustainable Yield (MSY) (Miller, 2002; Boczek, 1983; Frank, 1983).

These decision rules are based on the output of the GYM which estimates the proportion of unexploited biomass that can be caught each year and allows adjustments to fishing activities to be made when critical points are reached, as identified by the model, allowing decisions on management to be made in advance, in line with the precautionary approach (Hewitt and Low, 2000). When the decision rules are applied to the GYM, the option that results in the least impact - either on predator populations or on krill spawning biomass - is chosen as the catch level, (Constable *et al.*, 2000). As such, the decision rules are precautionary and ecosystem oriented in their not allowing biomass to drop below a level that would adversely affect other components of the ecosystem.

Prior to the development of these decision rules, the Commission had struggled with incorporating ecosystem assessments into management procedures (Constable, 2001; Agnew, 1997). A drawback of the model is that is doesn't specifically account for local and/or regional competition between krill fishing and krill predators, something that it is hoped will be addressed by the allocation of catch amongst Small Scale Management Units (SSMUs) (discussed in further detail below) (Hewitt and Low, 2000).

The adoption of the first precautionary catch limits for the krill fishery in Area 48, in 1991 (Conservation Measure 32X) is heralded as a significant achievement

in line with the precautionary approach (Fabra and Gascón, 2008). However, the adoption of Conservation Measure 31X (Notification that Members are considering Entering a New Fishery) in 1991 saw the first truly precautionary moves by the Commission (Parkes, 2000).

3.2.1.2 Controlling Development of the Krill Fishery

In 1991 Conservation Measure 31X (Notification that Members are Considering Entering a New Fishery) was adopted by the Commission, following discussions at the 1990 Commission meeting (CCAMLR-IX, paragraph 9.1-9.10). This measure stemmed from new fisheries being initiated in the Area before any information could be gathered on which to base Conservation Measures for ensuring the fisheries would comply with Article II of the Convention. The Commission, recognising the need to control the development of new fisheries whilst scientific data on the potential impacts of the new fishery could be gathered, adopted the measure which required Members to notify the Commission, in advance of the next meeting, of their intentions to initiate a new fishery to allow the Scientific Committee to advise the Commission on the potential impacts of the fishery on the fish stock in question, as well as on the ecosystem.

This measure was strengthened by the adoption of Conservation Measure 65XII (Exploratory Fisheries) in 1993. This Conservation Measure acted to control the rate at which a new fishery could develop (once the new fishery was established, after a period of one year, it would then be termed an exploratory fishery until the time that information enough to ensure that the fishery would be conducted inline with Article IX of the fishery could be gathered) (Parkes, 2000). The adoption of both these measures represented the Commission's attempts at ensuring that fisheries developed in line with the precautionary approach, allowing the Commission to monitor and control the rate at which new fisheries in the Area developed (Parkes, 2000). This was important given the consideration that new fisheries often develop very quickly and information from these new fisheries isn't usually available to managers until the fishery resource is already overexploited (Miller *et al.*, 2004).

In 2009 Conservation Measures 51-04 (General measure for exploratory fisheries for *Euphausia superba* in the Convention Area in the 2009/10 season) and 51-05 (Limits on the exploratory fishery for *Euphausia superba* in Statistical Subarea 48.6 in the 2009/10 season) were adopted to further control the development of new krill fisheries in the Area. Measure 51-04 controls developing ("exploratory") krill fisheries by closing a fishery once it reaches a specified catch limit and only allowing for 75% of the total catch limit to be taken within a certain range of land-breeding predator colonies.

By requiring Members to notify of their intentions to undertake exploratory fisheries for krill, the Commission took its initial steps to ensure that fishing activities could be properly assessed and their trajectories monitored. The Commission further built on the concept of gathering information from the fishery with the implementation of requirements for notifications for Members participating in the krill fishery.

3.2.1.3 Notifications

Conservation Measure 21-03 (Notifications of intent to participate in a fishery for *Euphausia superba*) was adopted in 2006, making it mandatory for Members to notify of their intention to fish for krill in the coming seasons, providing information on expected catch, area to be fished and expected products to be derived from catch (Annex 21-03/A). This Measure was to aid the Commission in tracking development of the krill fishery in light of increasing interest in the fishery and in the absence of other tools for tracking the fishery's development (CCAMLR-XXV, paragraph 12.24). Up until this point, the Commission had to rely on an informal and voluntary system whereby Members would verbally inform the Scientific Committee on their plans for krill fishing in the upcoming season which resulted in little substantial information being submitted to allow the Commission to monitor market interest or fishery trends (Croxall and Nicol, 2004; Nicol and Foster, 2002). The impact of this Measure on the Commission's ability to track developments in the krill fishery is discussed in more detail in Chapter Four.

This Measure requires Members to submit their notifications to the Commission prior to the WG-EMM meeting each year. This enables WG-EMM to consider the information contained within the notification, in particular the information on gear type/specifications and by catch mitigation devices, and to request further information (see WG-EMM-XXVIII, paragraphs 3.30-3.32) or make recommendations for alterations if it is deemed necessary. This Measure therefore allows the Commission to exercise control, and subsequently precaution, over the development of the krill fishery. It has also allowed the Commission to deal with applications from non Members e.g. the Cook Islands. Prior to this non-members such as Panama had fished with no notification and no reporting of catches.

3.2.1.4 Small Scale Management Units (SSMUs)

The need for SSMUs arose in Scientific Committee discussions surrounding the application of the first precautionary catch limits for the krill fishery in Area 48 under Conservation Measure 32X (SC-CAMLR-X, paragraphs 3.58-3.86). During discussions consideration was given to the considerable overlap between fishing grounds and krill predator foraging areas, particularly in the Antarctic Peninsula/Scotia Sea region (Agnew, 2008; Fabra and Gascón, 2008) with the majority of the krill catch being taken in a few small areas, close to breeding colonies (Hewitt and Low, 2000). There was concern that this overlap, both spatially and temporally, would result in a lack of krill resource availability for significant krill predators such as penguins, seabirds and seals (Constable, 2002).

In 1991, when the first Conservation Measure (32X) allocating a precautionary catch limit for Area 48 was adopted by the Commission, the need to consider distribution of precautionary catch limits across smaller spatial areas was recognised (CCAMLR-XXVIII, paragraph 12.63; Miller, 2002). In 1992 Conservation Measure 46/XI furthered this concept, allocating precautionary catch limits for Subareas in Area 48, to apply once a trigger level of 620 000 tonnes was reached. This Conservation Measure applied only for the 1992/93 and 1993/94 seasons at which point it would be reviewed and subject to the advice of the Scientific Committee. Conservation Measure 46/XI was not renewed at the 1994 Commission meeting as the Scientific Committee could not agree on how

the revised precautionary catch limit for Area 48 of 41 million tonnes, should be subdivided (CCAMLR-XIII, paragraph 8.4).

At the 2000 meeting the Commission once again addressed the need to further subdivide the precautionary catch in Area 48 over smaller spatial scales. As such, the precautionary catch for Area 48 was once again subdivided and allocated to Subareas (32/XIX – which changed to 51-01 in 2002). However, this Measure also noted that, on the advice of the Scientific Committee, the precautionary catch would be allocated amongst smaller management units once the trigger level was reached in the Area.

As a result the Commission, recognising the serious ecosystem wide effects that concentrated fishing effort such as this could have, has defined SSMUs to distribute the precautionary catch limit amongst. However, whilst the spatial boundaries of 15 SSMUs for Area 48 were established in 2002 (CCAMLR-XXI, paragraph 4.5), the subdivision of the precautionary catch limit across the SSMUs is yet to occur (the trigger level of 620 000 tonnes is yet to be reached in a single fishing season and consequently, the need to further subdivide the precautionary catch in order to ensure compliance with Conservation Measure 51-01 has not yet arisen). A number of candidate schemes have been proposed and discussed by the Scientific Committee and Working Groups (Plagányi, 2008; Watters *et al.*, 2008a; Watters *et al.*, 2008b). As at the 2009 meeting, there were six options open for consideration for allocating catch amongst the SSMUs (SC-CAMLR-XXVIII, paragraph 3.113) including:

1. the spatial distribution of historical catches by the krill fishery;
2. the spatial distribution of predator demand;
3. the spatial distribution of krill biomass;
4. the spatial distribution of krill biomass minus predator demand;
5. spatially explicit indices of krill availability that may be monitored or estimated on a regular basis; and
6. structured fishing strategies in which catches are rotated within and between SSMUs.

Hampering efforts to distribute the catch amongst the SSMUs is the lack of recognised scientific information on krill movements between the areas which in turn makes it difficult to define actual krill stocks (Miller, 2002).

A mechanism that is being discussed by the Commission to help progress the allocation of catch is the development of a feedback management procedure for the krill fishery (adaptive management whereby management measures are regularly adjusted based on ecosystem monitoring indices) (Fabra and Gascón, 2008; Nicol and de la Mare, 1993). This system would see management measures regularly changed in response to continually updated information from the ecosystem, aimed at detecting impacts from fishing and responding accordingly, before irreversible change occurs. Until there is agreement on a method for subdividing the precautionary catch across the SSMUs, in 2009 the Commission adopted an interim measure (Conservation Measure 51-07 [2009] Interim distribution of the trigger level in the fishery for *Euphausia superba* in Statistical Subareas 48.1, 48.2, 48.3 and 48.4) which divides the precautionary catch amongst four of the Subareas in Area 48.

3.2.1.5 Limiting By-catch

One of the key outcomes necessary for the proper implementation of EBM is recognised as being the reduction of excessive levels of by-catch in fishing operations (Pikitch *et al.*, 2004). As such, the Commission has adopted various Conservation Measures which aim to reduce the level of by-catch taken in krill fisheries, as well as to reduce the incidental mortality of seabirds and marine mammals in krill fishing operations.

Conservation Measures 25-03 (Minimisation of the incidental mortality of seabirds and marine mammals in the course of trawl fishing in the Convention Area) and 33-01 (Limitation of *Gobionotothen gibberifrons*, *Chaenocephalus aceratus*, *Pseudochaenichthys georgianus*, *Notothenia rossii* and *Lepidonotothen squamifrons* in Statistical Subarea 48.3), both adopted in the early 1990s represent early moves by the Commission to act to reduce by-catch and incidental mortality in all fishing operations, including krill. These measures restrict the use of certain types of fishing gear i.e. net monitor cables and require

vessels to act to reduce levels of by-catch by adapting shooting and hauling behaviours and setting catch limits for by-catch within a fishing season.

3.2.1.6 Other

Under Conservation Measure 148/XVII, CCAMLR required that all fishing vessels registered to member States have fully operational VMS by December 2000, excluding those vessels operating in the krill fishery. Vessel Monitoring Systems (VMS) involve the installation of tamper-proof satellite transponders on fishing vessels that continuously transmit positioning and navigational data as well as vessel information (including depth and fishing gear deployment information), making it possible to track the movement of these vessels. The information from vessels is transmitted to the vessel's flag state which is then required to submit the information to the Secretariat. The aim of VMS is to increase the capacity of regulatory bodies to undertake surveillance of fishing activities in the Southern Ocean (Bederman, 2000).

In 2007 the Commission, acting on advice from the Standing Committee on Implementation and Compliance (SCIC) (CCAMLR-XXVI, paragraph 8.13) revised Conservation Measure 10-04 (previously 148/XVII) to include the application of the Measure to vessels fishing for krill. However, vessels fishing for krill are excluded from the provisions of the Measure which require submission of VMS data by the flag state to the Secretariat. If VMS is to be used to assist in the management of the krill fishery, particularly once division of catches across SSMUs has occurred, this Measure will once again need to be revised to include krill in the data reporting requirement.

Several of the Conservation Measures listed in Table 4 as part of CCAMLR's EBM and precautionary approach to management of the krill fishery are general measures which allow for the protection of the marine environment during krill fishing operations. As the protection of ecosystem processes and essential habitats are key requirements of EBM (as discussed in *3.3.1*), these measures can be seen as significant tools developed to ensure the krill fishery develops in line with CCAMLR's approach to management.

Conservation Measure 26-01, first adopted in 2006, and Conservation Measure 91-03, first adopted in 2009, both act to minimise the impacts of fishing operations on species and ecosystems in the Area. 26-01 prohibits the use and disposal of plastics which are commonly used fishing activities and aims to reduce entanglements and mortalities associated with these plastics once they have entered the marine environment. 91-03 is a highly precautionary measure which designates a Marine Protected Area (MPA) in the region of the South Orkney Islands southern shelf. This measure affords protection to all aspects of the ecosystem in this region with the aim of protecting marine biodiversity, prohibiting fishing activities (other than those for CCAMLR-approved scientific research), dumping of wastes and transhipment activities.

Conservation Measure 31-02, adopted in 2007, is a highly precautionary tool adopted by the Commission which gives the CCAMLR Secretariat the power to close fisheries in the Area, in line with Article IX of the Convention. Closure of fisheries may be deemed necessary if catches exceed total catch limits during a fishing season or if other threats to the ecosystem are of concern.

3.3.1.7 Discussion

CCAMLR has often been lauded for being a progressive instrument in the management of marine resources given its unparalleled commitment to the ecosystem and precautionary approaches to management (Ruckelshaus *et al.*, 2008; Molenaar, 2001; Bederman, 2000; Parkes, 2000), particularly given that for any regulatory measures to be adopted, there must be consensus between 25 Members of the Commission. The Conservation Measures discussed here have been adopted over the past 19 years of CCAMLR's 28 years of operation and represent the Commission's cumulative efforts to ensure that the krill fishery in the Southern Ocean develops in line with its EBM and precautionary approaches to management.

Despite the considerable progress made by the Commission, the problem still remains, as was recognised as early as 1992 by Croxall *et al.*, of convincing some fishing nations of the need for practical Conservation Measures that are of a precautionary nature. There has been ongoing recognition in Commission

meetings over the past decade of the need to bring regulatory measures for the krill fishery into line with those for other fisheries in the Area (CCAMLR-XXVIII, paragraph 12.74; CCAMLR-XVII, paragraph 9.24). However, attempts to do this are often blocked by fishing nations at the consensus-requiring stage.

In particular, the need for mandatory 100% Observer coverage of the krill fishery and mandatory installation of VMS (until 2007) on krill fishing vessels are areas were consensus has been continually blocked by some fishing nations. Additionally, the Commission still faces the difficulty implementing and enforcing its decisions in the vast and remote Southern Ocean (Agnew, 2008) given that enforcement of Conservation Measures is under the control of Flag States and any penalties for transgressions of the Conservation Measures must be imposed by these Flag States (Parkes, 2000).

The novel management approaches taken by CCAMLR have set it apart from traditional RFMOs, making it a very progressive instrument (Fabra and Gascón, 2008; Molenaar, 2000). However, Ruckelshaus *et al.* (2008) recognise that, so far, the Commission has not clearly set out means by which scientific recommendations are integrated into policies which incorporate uncertainty. This may be a mechanism of the consensus decision making requirements of the Commission and the acknowledged difficulty of gaining support for tighter regulatory measures from fishing nations.

Problems which have challenged the Commission's effective management of finfish fisheries, such as IUU fishing for toothfish, have not yet eventuated in the krill fishery. Regardless of whether this is a result of catches being relatively low compared to precautionary limits or the current costs associated with operating in the distant-water, high value, low yield fishery, there needs to be management mechanisms in place to deal with this eventuation for the Commission to truly manage the fishery in a precautionary manner. Not only is this a unique situation for CCAMLR, but it is a unique situation for the large majority of fisheries around the world given that traditionally, new fisheries are quickly exploited and managers are only able to respond once a fishery has reached levels that threaten the future survival of the fish stock.

Although the Commission has made considerable progress on implementing many of the principles of EBM laid out in its charter, it continues to struggle with adopting a number of key elements despite scientific consensus being reached on their necessity through the Scientific Committee and Working Groups. The application of the CCAMLR Scheme of International Scientific Observation to the krill fishery will be examined as a case study of the difficulties the Commission faces in implementing elements of EBM, despite its mandate to do so.

3.4 The CCAMLR Scheme of International Scientific Observation and the Krill Fishery

At its 1992 Meeting, the Commission adopted a Scheme of International Scientific Observation (herein after referred to as the 'Scheme') in accordance with Article XXIV of the Convention which states that:

> In order to promote the objective and ensure observance of the provisions of this Convention, the Contracting Parties agree that a system of observation and inspection shall be established.

The aim of the Scheme is to gather scientific data from both fishing and research vessels so it can be used in the assessment and determination of fish stocks, in particular the population status of the target species, impacts of fishing on non-target species (by-catch) and the impact of fishing on dependent and related species.

Scientific Observers are a key element in the management of Southern Ocean fisheries, particularly due to difficulties associated with monitoring distant fishing fleets (Sabourenkov and Appleyard, 2005). An Observer has no enforcement capabilities; is present on a vessel only to collect information in an unbiased manner; and is not required to make report of any breaches whilst at sea. The role of the Observer on a vessel is outlined in Annex 1 of the Scientific Observers Manual as being:

to observe and report the operation of fishing activities in the Convention Area with the objectives and principles of the Convention on the Conservation of Antarctic Marine Living Resources in mind (Part 1:S1-3, CCAMLR, 2005a).

In order to fulfil this function the Observer must undertake a series of tasks including, *inter alia*:

- sampling catches for determining biological characteristics;
- record details of the vessel's operation such as fishing days and number of hauls;
- recording information pertaining to by-catch;
- recording interactions with seabirds and marine mammals;
- recording total catch, green weight, conversion factors and processed weight; and
- submitting reports, in the format approved by the Scientific Committee, to CCAMLR.

3.4.1 Application of the Scheme in the Krill Fishery

In 1995, the Commission endorsed the Scientific Committee's recommendation that 100% coverage by Observers should eventually become mandatory for all finfish fisheries in the Convention Area (Kock, 2000), as is now the case. Currently, the only fishery in the Convention Area for which it is not mandatory for an Observer to be present on a commercial vessel is the krill fishery (Kawaguchi and Nicol, 2007; Sabourenkov and Appleyard, 2005), a recognised drawback of the Scheme (Fabra and Gascón, 2008). Given the lack of scientific data from the fishery and the extensive area over which fishing operations are conducted, it has been suggested that mandatory application of the Scheme may also give the Commission one of its only avenues for ensuring compliance of fishing Members (Howard, 1989).

Currently, Observers are placed on krill fishing vessels in accordance with bilateral arrangements which are formed between the Designating Member (the

Member wishing to place an Observer on a vessel) and the Receiving Member (the Member who accepts the Observer on their vessel). The arrangements include principles pertaining to how the Observer is to be treated whilst on the vessel, the information that is to be provided to the Observer by the Receiving Member, arrangements for communications and transport of the Observer prior to and after their period of observation and the provision of copies of the final report (CCAMLR, 2005b).

Krill fishing vessels have operated with International Observers onboard in the past and many Members place Government-appointed Observers on their own krill vessels. International Observers submit their Observer Report and Scientific Observer Logbook (using the format outlined in the Scientific Observers Manual) to their Designating Member following their observation period, which in turn submits the Report to the Commission. Those vessels with Government-appointed Observers onboard do not necessarily submit their reports and logbook to the CCAMLR Secretariat.

On the numerous occasions when the need for mandatory 100% Observer coverage for the krill fishery has been discussed, the fact that some nations deploy Government-appointed Observers on their vessels has been given as a reason for Members not supporting the idea (CCAMLR-XXVII, paragraph 4.22). At the 2009 meeting of the Scientific Committee, Japan advised that it was working to towards being able to submit data from Government-appointed Observers to the Commission (SC-CAMLR-XXVIII, paragraph 6.27). Factors such as unnecessarily increasing operational costs for fishing vessels (CCAMLR-XXIV, paragraph 9.7) have also been cited as reasons for Members not supporting consensus on the issue of 100% Observer coverage for the fishery.

It is recognised (Kawaguchi and Nicol, 2007; Everson and de la Mare, 1996) that a common way for regulatory bodies to access information on a harvested marine resource is to gather this information directly from the fishery for that resource. Apart from catch and effort reporting requirements, the Scheme also allows for the collection of this information directly from the fishery. The Scientific Committee first called for more information from Observers in the krill fishery in

1998 (SC-CAMLR-XVII, paragraph 3.1). There have been many occasions since when the Scientific Committee has called for wider Observer coverage of the krill fishery and for various types of information from the fishery (Table 5).

Table 5: Information requested by the Scientific Committee from the krill fishery.

Scientific Committee Requested	Year	Report Reference
More Observers in the krill fishery	2009 2007 2006	SC-CAMLR-XXVIII, paragraph 6.28 SC-CAMLR-XXVI, paragraph 4.23 SC-CAMLR-XXV, paragraph 2.5
Data on by-catch	2006	SC-CAMLR-XXV, paragraph 2.5 and 2.10
Data on catch biological characteristics	2006	SC-CAMLR-XXV, paragraph 2.10
Information on gear configurations	2008 2006	SC-CAMLR-XXVII, paragraph 4.12 SC-CAMLR-XXV, paragraph 2.10
Vessel operational information, product types and conversion factors	2007 2006 2002 2001 1998	SC-CAMLR-XXVI, paragraph 4.24 SC-CAMLR-XXV, paragraph 4.18 SC-CAMLR-XXI, paragraph 4.8 SC-CAMLR-XX, paragraph 3.8 SC-CAMLR-XVII, paragraph 3.1
Accurate catch rates and standardised CPUEs	2007 2006 2002 1999	SC-CAMLR-XXVI, paragraph 4.24 SC-CAMLR-XXV, paragraph 2.10 SC-CAMLR-XXI, paragraph 3.4 SC-CAMLR-XVIII, paragraph 2.5
Interactions with seabirds and marine mammals/mitigation measures	2008 2006	SC-CAMLR-XXVII, paragraph 5.28 SC-CAMLR-XXV, paragraph 2.5 and 2.10

The 2006 version of the CCAMLR Scientific Observers Manual presents a list of research priorities, identified by the Scientific Committee, for conducting observations on commercial fishing vessels. For the krill fishery, including by-catch of fish, these priorities were:

1. observations of fishing operations
2. collection of haul-by-haul catch and effort data
3. representative length frequency distributions
4. representative sex and maturity stage distributions
5. observations on feeding intensity
6. observations of the by-catch of juvenile fish
7. observations of incidental mortality of predators (birds and seals)

At the 2005 Meeting of the Scientific Committee it was noted that due to changes in the pattern of the krill fishery, in particular a shift in the timing of the season of the fishery, the inconsistency of the information currently recorded in Observer reports from the krill fishery seriously hinders the collection of information on *current* trawling methods (SC-CAMLR-XXIV, paragraph 4.6). As a result, the Scientific Committee advised the Commission that developments in the krill fishery in terms of products and harvesting technologies:

> will require changes in the type of data and reporting formats required from the fishery and in the level of observer coverage (SC-CAMLR-XXIV, paragraph 4.11).

Sabourenkov and Appleyard (2005) documented a history of the operation of the International Scheme of Scientific Observation across all fisheries, noting that although Observer coverage in the krill fishery is currently voluntary, coverage in the fishery had risen from 8% in 2000 to 67% in 2004. Sabourenkov and Appleyard commented that most Observers on krill fishing vessels are Government-appointed Observers but it is important to note that reports from Government-appointed Observers are rarely submitted to the Commission and, up until 2005, no reports from Government-appointed Observers had been submitted.

In 2008 the Scientific Committee agreed that 100% observer coverage was necessary but the Commission has been unable to reach consensus on this matter (SC-CAMLR-XXVII, paragraphs 6.22-6.33). Given the ongoing debate within

the Commission over mandatory 100% Observer coverage in the krill fishery and the ongoing need for data from the fishery to assist in monitoring the fishery and its effects on the ecosystem, it is necessary to determine how useful information in Observer reports can be for achieving this. In making the argument for 100% Observer coverage, it is also necessary to highlight the paucity in information across different areas and seasons, as well as fishing methods, that the Secretariat receives. This is primarily due to the low number of Reports and logbook data submitted because the Observer program is not mandatory – an issue first highlighted by the Scientific Committee in 1999 (SC-CAMLR-XVIII, paragraph 3.20) and still the case today.

Only if sufficient useful and meaningful information can be extracted from these reports can the Scheme truly enhance the Commission's understanding of the operation of the krill fishery and therefore allow the Commission to manage the fishery in line with its EBM and precautionary approach to management.

3.4.1.1 Methods

This analysis considers only information presented in Observer Report forms that have been submitted to the CCAMLR Secretariat up to June 2006, the first being in 2000. Scientific Observations had taken place on krill fishing vessels prior to 2000 but reports were not submitted to the Secretariat in the format of a Scientific Observers Report as required under the Scheme. These reports were instead submitted to WG-Krill and WG-EMM as Background Papers and as such, are not included in this analysis. Additionally, information recorded in the logbooks of the Observers Reports is not included in this analysis.

All figures are based solely on the information provided in the Observer Reports submitted in the format specified under the Scheme as the aim of this method is to examine the information that has been submitted to the Secretariat in this form and to determine its usefulness to the Commission. This is not an analysis of information that has been provided in the Commission in any other format, for example statistical bulletins. When the term Observer/s is used in this analysis, it refers to both Government-appointed and International Observers. When this is not the case, it has been specified.

Also note that one International Observer Report from a cruise which took place in 2006 was not available at the time of this analysis and information from this observed cruise, and later cruises, is not included in this analysis.

3.4.1.2 Results

A total of 32 Scientific Observer Reports had been received by the Secretariat up to June 2006 (Figure 22), of which 27 were the result of the Scheme. The first International Observer Report from the krill fishery was submitted to the Secretariat in 2000. The first Report from a Government-appointed Observer Report was received in 2005. Since 2000 there has been a steady increase in the number of reports submitted, until 2006 when the number halved from the previous year. From 2000 to June 2006, there were only five reports from Government-appointed Observers submitted, representing only 16% of total Observer Reports submitted. The number of days covered by Government-appointed Observers and International Observers in the period of analysis can be seen in Figure 23.

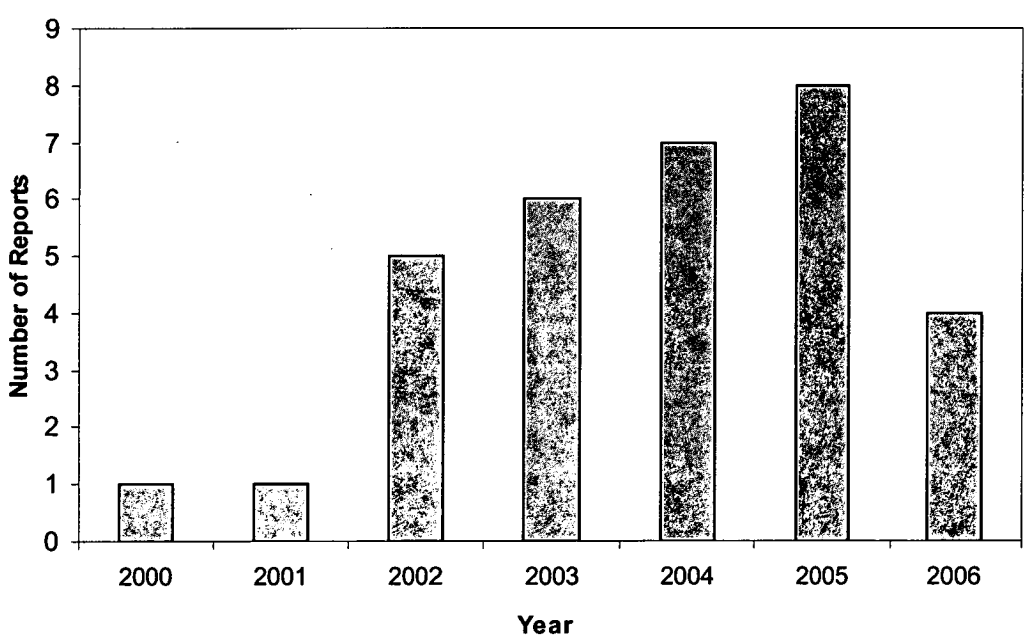


Figure 22: Number of Observer Reports received by the Secretariat in the format specified under the International Scheme for Scientific Observation.

In the years towards the end of the period of analysis, there was very limited coverage of summer months, with June, July and August being covered by

Observers most frequently. The summer months were not covered by any of the Observers who had submitted reports (Figure 24).

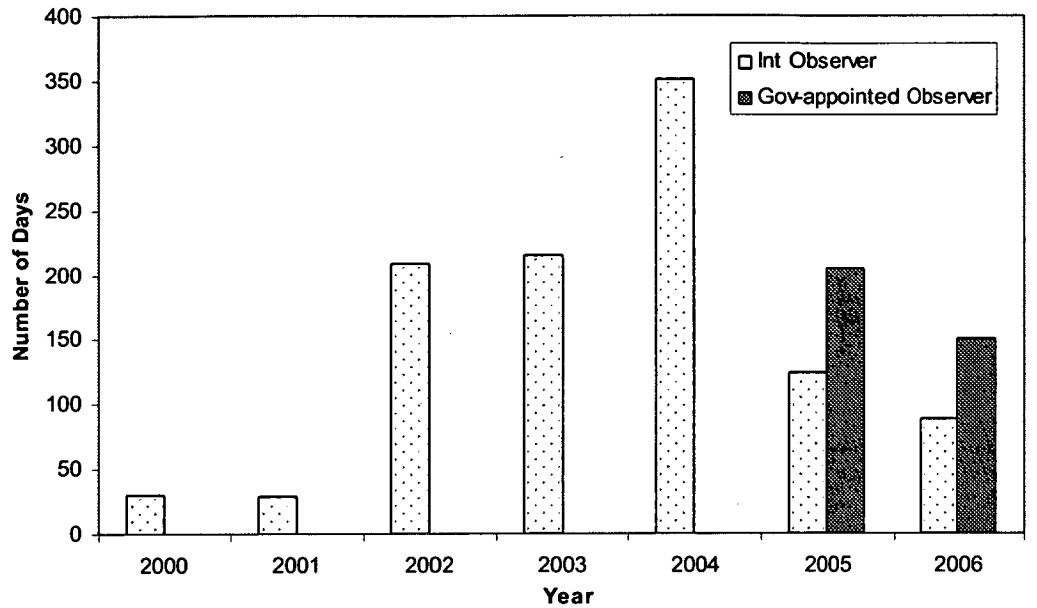


Figure 23: Number of days International and Government-appointed Observers have been present on krill fishing vessels.

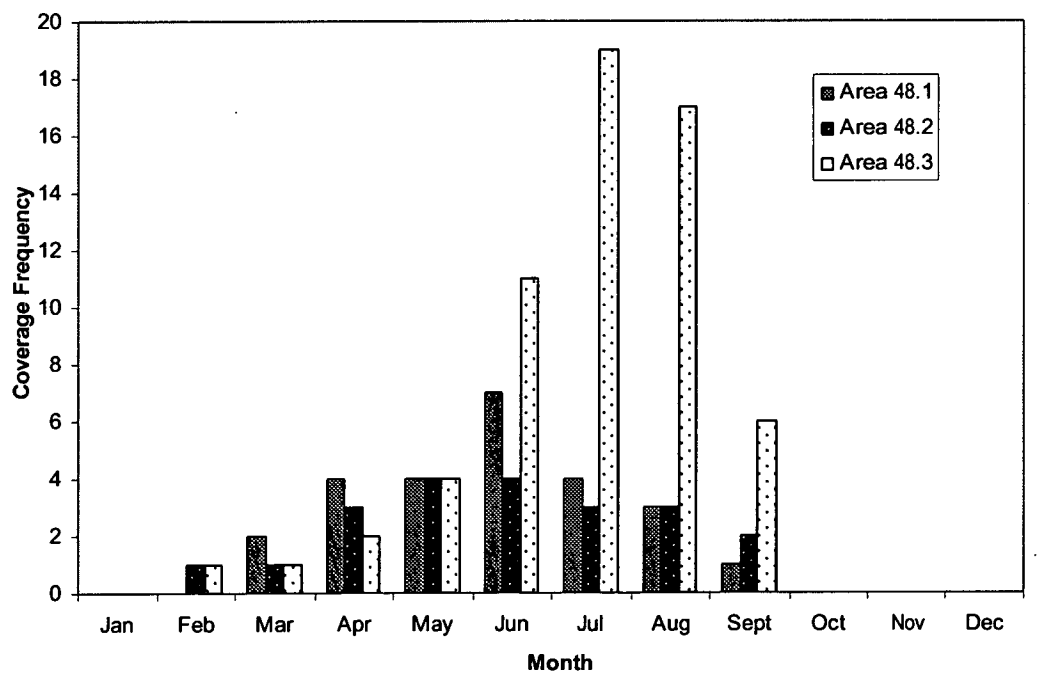


Figure 24: Number of times months have been covered by an Observer in each Subarea for which Observer Reports have been received. Note that Observer Report from 2000 is not included as the Report did not specify which Subarea the cruise operated in.

Areas 48.1, 48.2, and 48.3 were the only Subareas where Observers were present in the period of analysis, where Observer Reports had been submitted to the Commission. Comparing the months that were covered by Observers most frequently with the areas where observation had taken place, it can be seen that Area 48.3 was accorded the most observation, with this occurring in the winter months. Area 48.2 had the least coverage out of the three areas which had coverage.

Analysis of the content of the Observer Reports highlighted numerous issues in both the type of data reported and the format and frequency with which it was reported. Examples of these inconsistencies and how they can affect the usefulness of Observer Reports are given below (Table 6). Inconsistencies in the way information is reported makes it extremely difficult to easily compare information between reports and, consequently, to compile information that is representative of what is truly happening in the fishery. These inconsistencies exist despite standard forms and sampling guidelines being provided (Sabourenkov and Appleyard, 2005) to ensure that the information being collected by Observers would be as effective as possible in aiding management decisions.

Table 6: Summary of findings from analysis of Observer Reports from the krill fishery submitted to the Secretariat up until June 2006.

Information	Issue	Resulting Problem
Vessel specifications	Units of capacity of freezers and hold inconsistent	Compromises ability to assess capacity of vessels to expand operations
VMS	Response to presence/absence of VMS inconsistent	Limits monitoring and surveillance capabilities
Fishing gear	Types and sizes of nets (e.g. mesh size, length, materials) reported inconsistently	Difficult to calculate CPUE for comparisons between vessels
Processing	Different methods of calculating	Lack of information on

information	green and processed weights and catch estimations	true biomass being removed
Conversion factors	Frequency of reportage and methods used to calculate factors	Data that does not represent the true operational nature of the fishery
Biological data	Frequency of reportage and sampling methods	Reduced quantity and quality of information for stock assessments
By-catch	Frequency of data collection, unclear information on methods used to determine by-catch	Unable to determine true impact of fishery on species being taken as by-catch
Marine mammal interactions	Frequency of reporting on mitigation measures and entanglements	Incomplete information on impact of fishery on marine mammals

This analysis of the 32 reports submitted under the CCAMLR Scheme of International Observation between 2000 and June 2006 revealed that there were numerous inconsistencies in the information reported by Observers. Few reports were submitted each year with a maximum of eight submitted in 2005. Very little information was reported from seasons other than winter. The areas observed were heavily biased to Subarea 48.3. Information on fishing gear suggested great differences between vessels. Aspects of operational procedures were reported sporadically and inconsistently. Similarly, because of the differences in the information reported in individual Observer's Reports it would be difficult to assess the level of by-catch of larval fish or of vertebrates.

3.4.1.3 Discussion

As deployment of Observers in the krill fishery is not mandatory, there is only very patchy information submitted to the Secretariat on the operation of the fishery. Having two Observers on each vessel (as is required in fisheries for *Dissostichus* spp. under Conservation Measure 41-01 [2006]) would allow for

more (or total) observation of all trawls and would increase information on catch sizes and by-catch. Problems with lack of information recorded on by-catch have been encountered in the fishery; for example, when an Observer on board a Japanese vessel did not have direct access to the catches and as such, the reported low level of juvenile by-catch could not be assumed to be accurate (SC-CAMLR-XXI, paragraph 3.5).

For the Scientific Committee to make use of information from Observers, reports must be submitted to the Secretariat, and must be in a consistent format. Government-appointed Observer's reports are rarely submitted and analyses from these reports are also rarely submitted to WG-EMM. It is extremely difficult to assess the quality of the information in Government-appointed Observer's Reports because they do not follow a common format. From information available, there is inconsistency of information recorded by Government-appointed vs. International Observers. However, only five reports had been submitted by Government-appointed Observers, up to June 2006, so it is difficult to make a definitive statement on the quality of information recorded by Government-appointed Observers versus the quality of information recorded by International Observers.

Aside from the issue of submission of reports from Government-appointed Observers is the need to standardise the quality of data collected by these Observers so that the data is useful and relevant to the needs of the Commission. Discussions at the Technical Group for At-Sea Operations (TASO) have highlighted the need for a CCAMLR-led accreditation system for all Observers to ensure data acquired is of a consistent quality (Kawaguchi, 2009).

An official template for Observer's Reports is available from the CCAMLR website (www.ccamlr.org/pu/e/sc/obs/logbooks.htm). However, on many occasions, sections of reports were deleted from the form. Deletion of a section of the form cannot be assumed to equate to a 'no' answer for that section. Forms need to be designed so that sections cannot be deleted and observers need to be compelled to answer all sections – whether it be as a 'no' or 'N/A', as this is valuable and valid information when analysing these reports.

Comparing information in the Observer's Report to information in the Statistical Bulletin is difficult due to different values i.e. fishing days/fishing hours; Catch per Unit Effort (CPUE) and gear types being reported. Some attempt needs to be made to standardise information so that cross-comparisons can be made.

The aim of CCAMLR's Scheme of International Scientific Observation is to gather scientific data, from both fishing and research vessels, so that this information can be used in the assessment of fished stocks, in particular the population status of the target species, and in the determination of the impact of fishing on target species as well as on dependent and related species. It has become apparent from this analysis that for the krill fishery, this information is not available given the current mode of operation of the Scheme.

In order to ensure that the Scheme can be flexible and can adapt to changes in the types of information the Commission requires in order to ensure the orderly development of the krill fishery, there is a need for the Scientific Committee to have the ability to review both the coverage of the Scheme, spatially and temporally, and the types and quality of data that are being submitted. For the Scheme to be applied to allow precautionary management of the fishery, the Commission needs to ensure that the Scheme has as much coverage as early as possible in its early stages of application, allowing the Commission to make alterations to the Scheme before opportunities for collection of substantial amounts of data are lost.

From the analysis of information submitted to date it is apparent that it would not be possible to address any of the priority research topics that have been identified by the Scientific Committee without consistent reporting of data on krill (and by-catch) from the Scheme. Information required should be agreed by the Scientific Committee and should be consistent across all observations to allow for comparability between Observer Reports, it should not be up to the discretion of the Designating Member to decide what data should be collected by the Observer under the terms of a bilateral arrangement.

There is also a need to improve the way in which information is recorded and submitted to CCAMLR by Scientific Observers. This includes:

- Standardisation of reporting in the Observer Report;
- Standardisation of values between Observer Forms and fine scale catch and effort data reported in the Statistical Bulletin;
- Training of Observers to ensure consistency despite language barriers;
- Improvements in accessibility of Observer Reports, their associated logbooks, information on which/how many vessels have National Observers onboard; and
- Submission to the Commission of past Government-appointed Observer Reports so that the information collected by them becomes of value.

In order for the Scheme to achieve its aims for the krill fishery it will have to be applied in a fashion that produces consistent results, over the entire temporal and spatial scale of the fishery, it will have to be representative of the different types of gear and vessels being used and the products being produced and it will have to produce information that is compatible with information being submitted to the Secretariat by other channels (e.g. annual catch and effort data). The development of SSMUs will require feedback of comprehensive fishery-dependent information at an appropriate scale and this is most effectively obtained from Scientific Observers on krill fishing vessels (Sabourenkov and Appleyard, 2005). It is difficult to see how the Commission will be able to extract information that will be of use in managing the krill fishery without 100% coverage of observers on all krill vessels.

At the 2007 meeting of WG-EMM, this analysis was submitted as a background paper (Foster *et al.*, 2007) (Appendix 1). The paper prompted the Working Group to ask the Secretariat to prepare a summary of Observer data from the krill fishery from the 2006/07 season for it to review (WG-EMM-XXVI, paragraph 4.58). Most importantly, the Working Group acknowledged that the quality of

summary information recorded by Observers could be improved, particularly in terms of consistency and completion of all sections of the report form (WG-EMM-XXVI, paragraph 4.59). Additionally, the Working Group also requested that consultations with experts begin in order to enhance reporting requirements on technical gear configurations (WG-EMM-XXVI, paragraph 4.6).

Following these discussions in WG-EMM, the form for notifications on intention to fish for krill was also updated to include information on gear types (CCAMLR-XXVII, paragraph 4.31) so that potential impacts associated with this information could be properly assessed by the Scientific Committee prior to the fishing taking place. Additionally, in 2008, sampling requirement for Observers were also updated (CCAMLR-XXVII, paragraph 4.31) to ensure that information from across as many fishing areas as possible could be collected, maximising the distribution of data, and consequently its usefulness for analysis of the fishery.

As a result of the continuing inability of the Commission to reach consensus on the matter of mandatory 100% Observer coverage for the krill fishery, in 2009 Conservation Measure 51-06 (General measure for scientific observation in fisheries for *Euphausia superba*) was adopted. This measure is in force only for the 2009/10 and 2010/11 seasons and requires that all vessels fishing for krill have one, if not two Observers appointed in accordance with the Scheme, on board. The measure sets target levels for Observer coverage of fishing voyages and hauls and will be reviewed at the 2010 Commission meeting. This measure represents a small step towards mandatory 100% Observer coverage for the krill fishery.

3.5 Conclusions

It has frequently been stated in the published literature that in order for the Commission to understand the dynamics of the largest fishery under its management and to ensure that the krill fishery develops in an orderly fashion, the Commission must act to bring management of the krill fishery into line with management measures applied to other fisheries in the Area (Croxall and Nicol, 2004; Miller, 2002). Management decisions must be sensitive to developments in the worldwide demand for krill and to the changes in the fishery that are likely to

occur as a result (Hewitt and Low, 2000). To this date, some significant regulatory measures proposed by the Scientific Committee to work towards this goal, have been blocked in Commission meetings.

For example, the introduction of a Conservation Measure making 100% Observer coverage mandatory for the krill fishery, as recommended by the Scientific Committee, has been blocked at several meetings (CCAMLR-XXVI, paragraph 4.22; CCAMLR-XXIV, paragraph 9.7). Whilst the blocking of this measure has not yet had serious ramifications for the krill fishery due to the current low level of harvesting, for CCAMLR to manage the fishery in a truly precautionary manner, the introduction of 100% Observer coverage is vital.

It has been suggested that it has been the need for consensus that has allowed Members with fishing interests, with a traditional resistance to restrictions on fishing, to block more stringent regulation of the krill fishery (Croxall *et al.*, 1992), an inherent problem of the approach that is recognised in the published literature (Bederman, 2000; Edwards and Heap, 1981). However, it is also argued that the need for consensus encourages compromise between Members (Kock, 2007) and therefore increases the likelihood of compliance with Conservation Measures. Others argue that the rule of consensus may balance the Commission's dual role of conservation and rational use (Fabra and Gascón, 2008) by allowing for a higher degree of compromise. Conversely, it has also been suggested that consensus presents problems in balancing fishing and non-fishing nation's interests (Hewitt and Low, 2000) and may lead to a lowest common denominator in terms of the Conservation Measures that are adopted (Fabra and Gascón, 2008; Bederman, 2000).

Given the combined factors of scientific uncertainty and current changes in the operation of the fishery that will see an expansion in catches, it is of increasing concern that consensus amongst Members will be increasingly difficult to obtain and may impinge on the Commission's ability to prevent overharvesting of the krill resource. It is recognised that the Commission has faced difficulties in defining and implementing its approach to management in terms of actual operational requirements (Hewitt and Low, 2000) and that the development of

the Commission's management approach for the fishery has been delayed by the need for it to act to prevent the decimation of toothfish stocks in the Area.

Additional to suggestions that the requirement for consensus may be hindering tighter regulatory measures for the fishery, it has also been argued that whilst the theory behind EBM is sound, the theory has not yet been well tested due to the relative infancy of the approach (Ruckelshaus *et al.*, 2008). In fact, due to the lack of instances where EBM is used in fisheries management, case studies of the level of success of the approach are very rare (Hewitt and Low, 2000). However, an evaluation of 14 RFMOs in place across overlapping distribution ranges for albatross, clearly showed that CCAMLR had performed the best in terms of participation and transparency, target fish data and assessment, target fish management and status, combating IUU fishing, commitment to reducing by-catch, by-catch data collection and by-catch mitigation (Small, 2005).

The development of CCAMLR's approach to management can be seen documented in the many Conservation Measures which have been adopted by the Commission over the years of its operation. In some instances, the Commission has needed to manage fisheries in a reactive manner, particularly in the first decade of its operation when finfish stocks such as icefish and toothfish were threatened by fishing activities (Constable, 2000). The continuing issues associated with the application of the Scheme to the krill fishery are representative of the struggles the Commission has faced, and will continue to face, in ensuring that the fishery develops in a manner which is consistent with its management approach. However, a unique opportunity for CCAMLR to mange a fishery in a truly precautionary manner, in an EBM context, now exists with the krill fishery.

In order for CCAMLR to take advantage of this opportunity, the Commission needs to build on the management framework (as identified in this Chapter) for the fishery that has been constructed since CCAMLR's inception. The opportunity to make both 100% Observer coverage and full application of VMS to the krill fishery mandatory provide two examples of moves that could be made

now to enhance CCAMLR's precautionary and EBM approaches to the krill fishery.

Chapter Four: Current Tools for Detecting Trends in the Krill Fishery

4.1 Introduction

Traditional mechanisms used to track the trends of developing fisheries, including fish market quantity and prices of trade, do not exist for the krill fishery. As a result managers of the fishery are not currently able to predict either the magnitude, or the rate, at which the fishery may develop. In order for CCAMLR to ensure that the krill fishery develops in line with its EBM and precautionary approach to management, the Commission needs to have the capacity to forecast changes in the fishery so that management decisions can be made in advance to ensure the protection of krill, as well as dependent and associated species.

There have been numerous occasions when the Scientific Committee, supported by the Commission, has requested information from Members on krill fishing operations and krill markets in order to be better informed of developments in the fishery (Table 7). However, despite these repeated requests, very little information has been submitted by Members (SC-CAMLR-XVII, paragraph 2.5; SC-CAMLR-XVIII, paragraph 2.6; SC-CAMLR-XIX, paragraph 2.5) with commercial-in-confidence issues often cited as reasons for non-submission (CCAMLR-XXII, paragraph 4.38).

This Chapter will identify the tools CCAMLR currently has for monitoring trends in the krill fishery. These include catch data that has been routinely submitted to the Commission since the inception of CCAMLR and data from notifications of intention to fish which were, until 2006, submitted voluntarily to the Commission but since this point, have been made mandatory (see discussion of Conservation Measure 21-03 in section 3.2.2.3). Additional to these traditional sources of data, the Commission, in 2009, took on the krill patent database as a source of information for tracking developments in the krill fishery. Relevant information that can be garnered from these three tools will be presented here and will be analysed to highlight trends in, and across, each tool.

Table 7: Information requested by the Scientific Committee on the economics of the Antarctic krill fishery.

Information Requested	Year	Report Reference
Past and current krill market information.	1998	SC-CAMLR-XVII, paragraph 2.6
Past and current market prices for krill products.	1999	SC-CAMLR-XVIII, paragraph 2.7
Past and current market prices for krill products.	2000	SC-CAMLR-XIX, paragraph 2.4
Updated information on krill processing, market developments, economic analyses.	2001	SC-CAMLR-XX, paragraph 2.4
Information on economics of the fishery and market developments.	2001	SC-CAMLR-XX, paragraph 3.8
Information on commercial market prices, economic marketing and technological information and demand for aquaculture feeds.	2002	SC-CAMLR-XXI, paragraph 4.11
Ability to predict trends in the fishery still hampered by a lack of information on technological and economic developments.	2004	SC-CAMLR-XXIII, paragraph 4.17
Noted change in pattern of fishery operation in regards to participants, products composition and harvesting technologies.	2005	SC-CAMLR-XXIV, paragraph 4.11
Noted that new products, particularly oil and pharmacological products, appear to be driving interest in the fishery.	2007	SC-CAMLR-XXVI, paragraph 4.9
Information on how publicly available information in trade press etc may be used to inform WG deliberations.	2008	SC-CAMLR-XXVII, paragraph 4.9

4.2 Information Submitted to CCAMLR

CCAMLR gathers information from the krill fishery on a near real-time basis through the provisions of Conservation Measures for catch and effort data reporting. Under Article IX (1) of the Convention, the Commission has the function of:

- acquiring catch and effort statistics on harvested populations; and
- analysis, dissemination and publication of the information referred to above.

To fulfill this remit, CCAMLR collects fisheries landing data for all fisheries operating in the Southern Ocean and makes this information publicly available through its Statistical Bulletin. By requesting submission of data from Members for catches pre-dating the Convention (CCAMLR-II, Annex E), CCAMLR has a record of krill catches dating back to the 1970s. Catch data for fisheries in the CCAMLR Area are submitted electronically to the Commission in accordance with the various Conservation Measures listed in Table 8.

Table 8: Conservation Measures regulating types, methods and frequency of submission of fishery data to the Commission Secretariat.

Number	First Adopted	Title
23-02	1992	Ten-day catch and effort reporting
23-03	1991	Monthly catch and effort reporting
23-04	1989	Fine-scale catch and effort data
23-05	1992	Fine-scale biological data
23-06	2002	Data reporting for krill fisheries
24-01	1992	Application of measures to research

CCAMLR uses this information to track fisheries both through fishing seasons and throughout the life of a fishery. Within a fishing season, the Secretariat can monitor catch and effort to estimate when a fishery will reach the allowable catch for that season, and can close fisheries accordingly (CCAMLR, 2009a). Information is also used in stock assessments (Kock, 2000), yield models for

setting future catch limits and tracking developments in operational aspects of the fishery, for example, trawl times and CPUE.

Monitoring past trends in a fishery is one method of making projections of likely future catches. However, making such projections based *only* on past catches is flawed, particularly in a fishery such as that for krill, which is one of the last remaining underexploited fish stocks in the world. Recognising the potential for the krill fishery to expand (due to stock size and low catches relative to precautionary catch limits) the Commission, in 2006, implemented further measures to allow tracking of developments in the fishery: mandatory notifications of intention to fish (Conservation Measure 21-03). Now CCAMLR has two mechanisms for tracking developments in the krill fishery: submission of fishing data and mandatory notifications. A third mechanism has been adopted as a result of the work presented in this thesis and will be discussed in section 4.3 below.

4.2.1 Catch and Effort Data

CCAMLR catch and effort data from krill fisheries is submitted to the Secretariat in line with provisions in Conservation Measures 23-02, 23-03 and 23-06. The following data on catch statistics is compiled from CCAMLR Statistical Bulletin Volume 20 (Database Version, 2010). Analysis of catch and effort data from the Statistical Bulletin indicates four important features of the krill fishery today

First, catches of krill have increased significantly ($p \leq 0.05$) at a steady rate over the past 16 years, almost doubling from 68 000 tonnes in 1993 to 126 000 tonnes in 2009 (Figure 25). Prior to this, catches had fluctuated and had reached much higher levels at various stages (as discussed in Chapter One). Despite the sustained and significant increase in catches over the past 16 years, the fishery has been more stable than at any other point in its history.

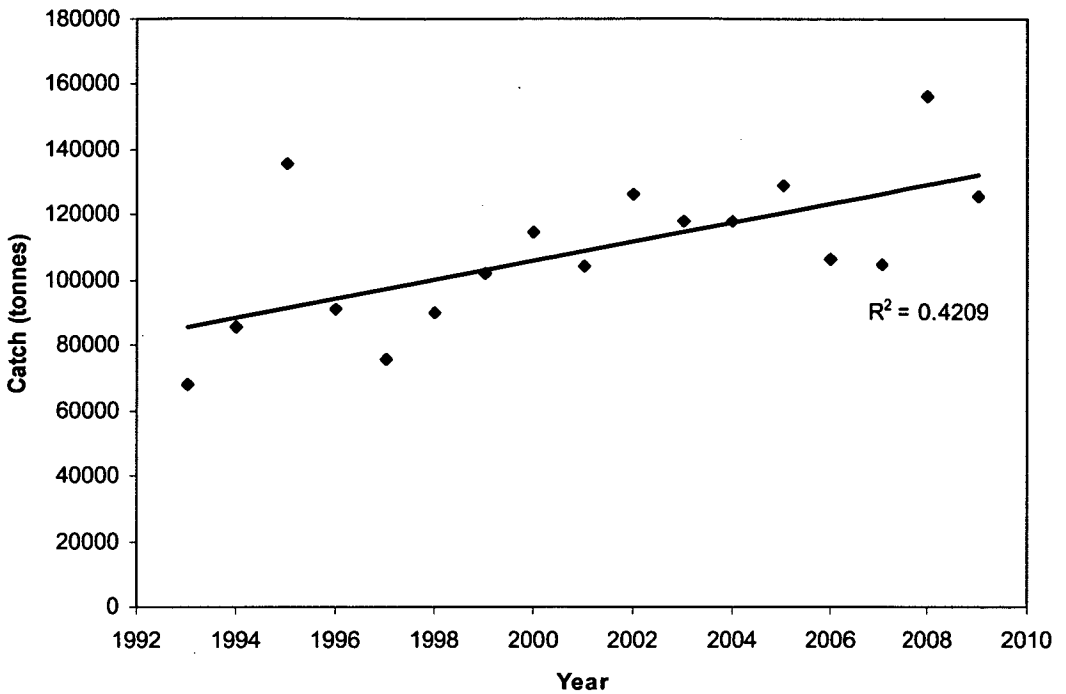


Figure 25: Linear regression of total catch of krill in the CCAMLR Convention Area from 1993 to 2009 (CCAMLR, 2010).

Second, the majority of krill have been caught in Area 48 with almost 100% of catches from the past 15 years being taken in this Area. Large catches had been taken in Area 58 in the 1970s and early 1980s but since 1997 there has been no reported catch from any Area but Area 48 (excepting very small catches in Area 41 in 1998 and 2006 amounting to no more than 117 tonnes).

Third, within Area 48, over the life of the fishery, most krill have been taken from Subareas 48.1, 48.2 and 48.3 (Figure 26). In total, less than 1% of all catches from Area 48 have been taken from outside these Subareas. From 2007 to 2009, the majority of krill was taken in Subarea 48.2, when compared to Subareas 48.1 and 48.3.

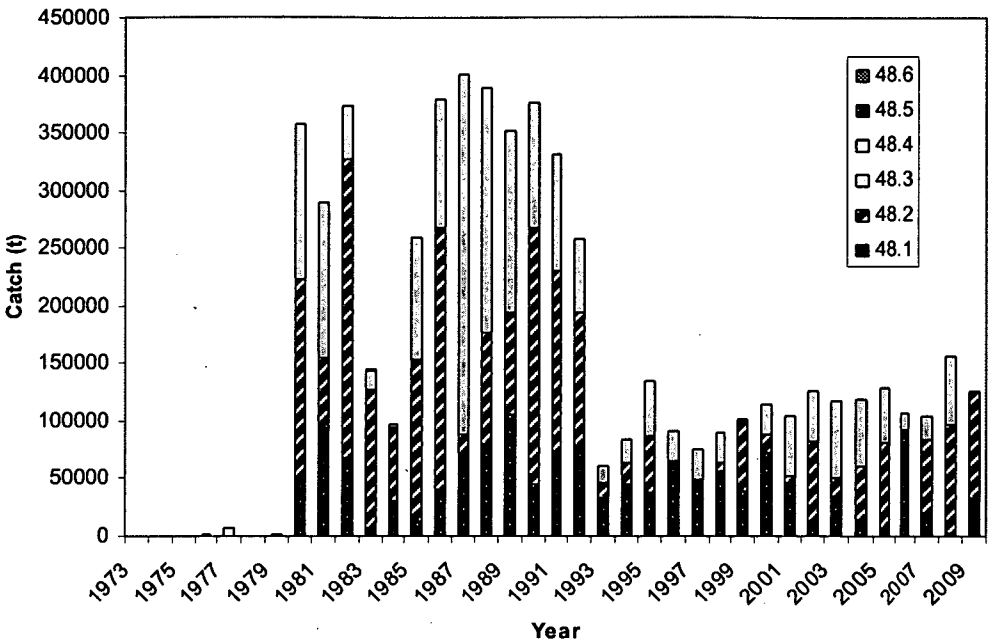


Figure 26: Distribution of krill catches from Area 48 across Subareas (CCAMLR, 2010).

Lastly, in fishing seasons in the early days of the fishery, krill catches were taken over summer and autumn months, decreasing into winter and being lowest in spring months (Figure 27). In recent years krill catches have shown a trend with lowest catches over summer, increasing into the autumn and winter months, peaking in late Autumn, with very little fishing activity in Spring (Figure 28).

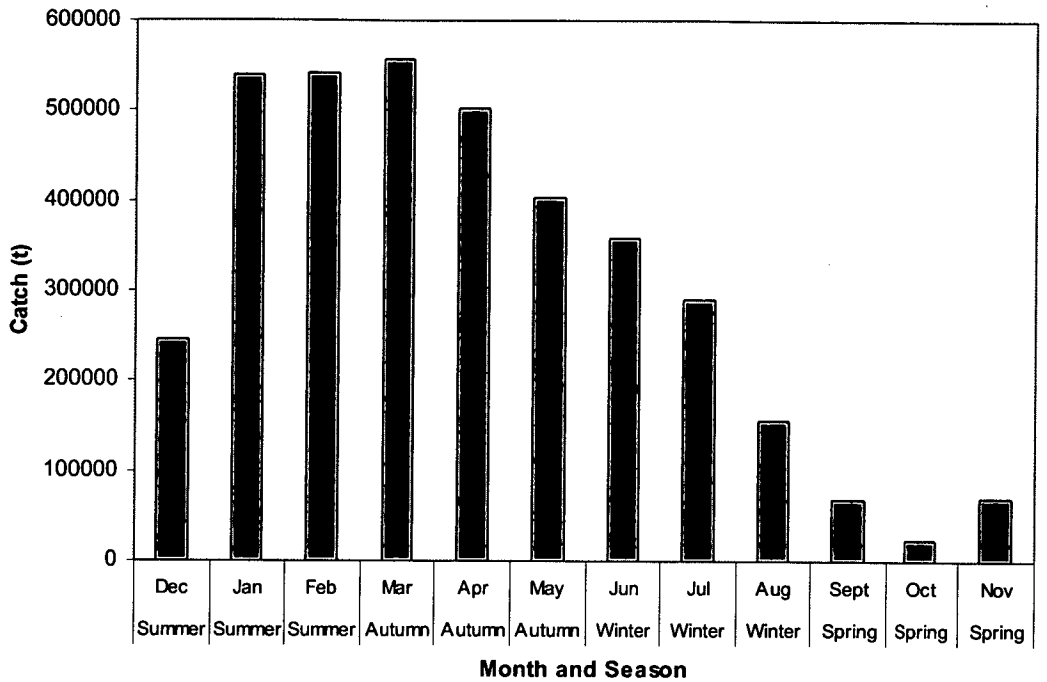


Figure 27: Distribution of krill catches across months and seasons from 1973 to 1993 (CCAMLR, 2010).

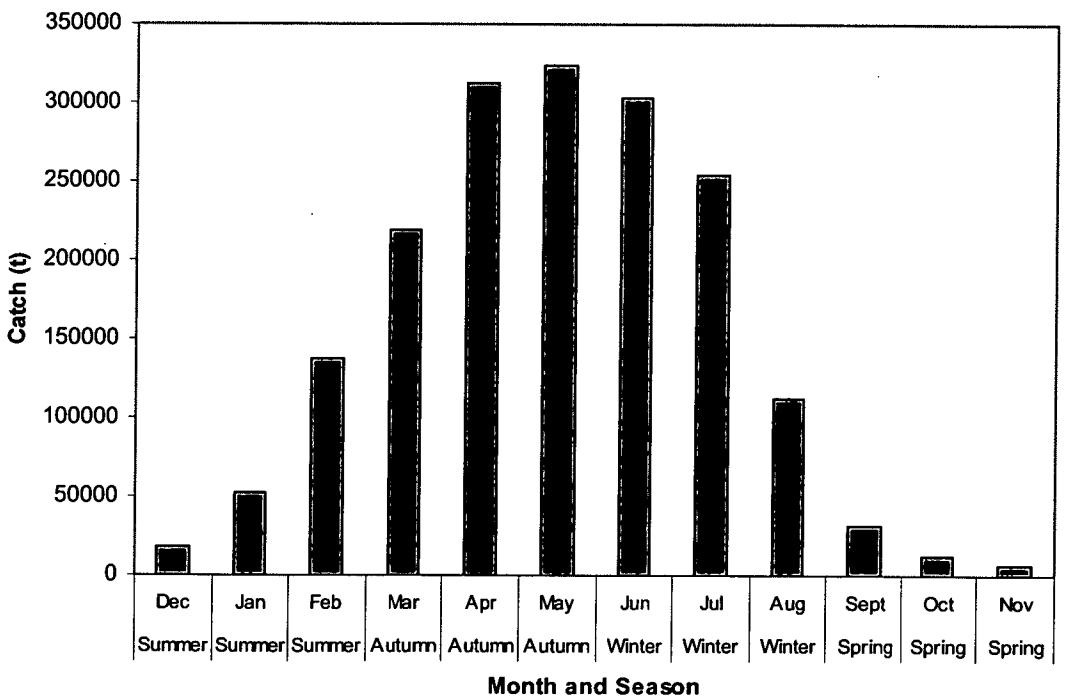


Figure 28: Distribution of krill catches across months and seasons from 1994 to 2009 (CCAMLR, 2010).

Generally, fishery data submitted to CCAMLR indicates some temporal and spatial shifts in the fishery over time which have been attributed to shifts in sea-ice extent (Kawaguchi and Nicol, 2007). Overall, despite small fluctuations on a year-to-year basis, the fishery has been showing a steady rate of increase over the past 15 years.

4.2.2 Notifications Data

Historical catch data for krill (Figure 29) clearly illustrates the fluctuations that have occurred in the fishery since its inception. These fluctuations, along with an absence of knowledge on the drivers of the fishery, have made it difficult for the Commission to make projections about the likely future of the fishery. In 2006 the Commission adopted Conservation Measure 21-03 (Notifications of intent to participate in a fishery for *Euphausia superba*), in order for the Commission to be better informed of likely future catches and the forces that will drive them, discussed in Chapter Three. Prior to this, Members would submit information on their likely fishing operations in Member Activity Statements, including intended level of catch and number of vessels expected to operate in the fishery. In 2003 the Commission endorsed a voluntary notification procedure for the krill fishery (CCAMLR-XXII, paragraphs 4.37-4.39), which eventually led to the mandatory notifications required under Conservation Measure 21-03. For the purposes of tracking information submitted on notifications, information has been extracted from both the Member Activity Statements and the formal notifications from 2003 onwards.

Since Conservation Measure 21-03 was adopted there has been a marked change in the number and type of notifications being made to the Commission. There has been a marked increase in the tonnage of krill notified since the scheme was adopted (Figure 29). There is also a large discrepancy between the level of catch notified by Members and the actual catch that has occurred and notified catches have been considerably higher than actual catches for the duration of this scheme. In the last season (2009) notified catches were 360% higher than actual catches. Whilst it can be seen in Figure 29 that actual catches have not come close to reaching the trigger level of 620 000 tonnes for Area 48, notified catches actually exceeded this trigger level for the 2008 season.

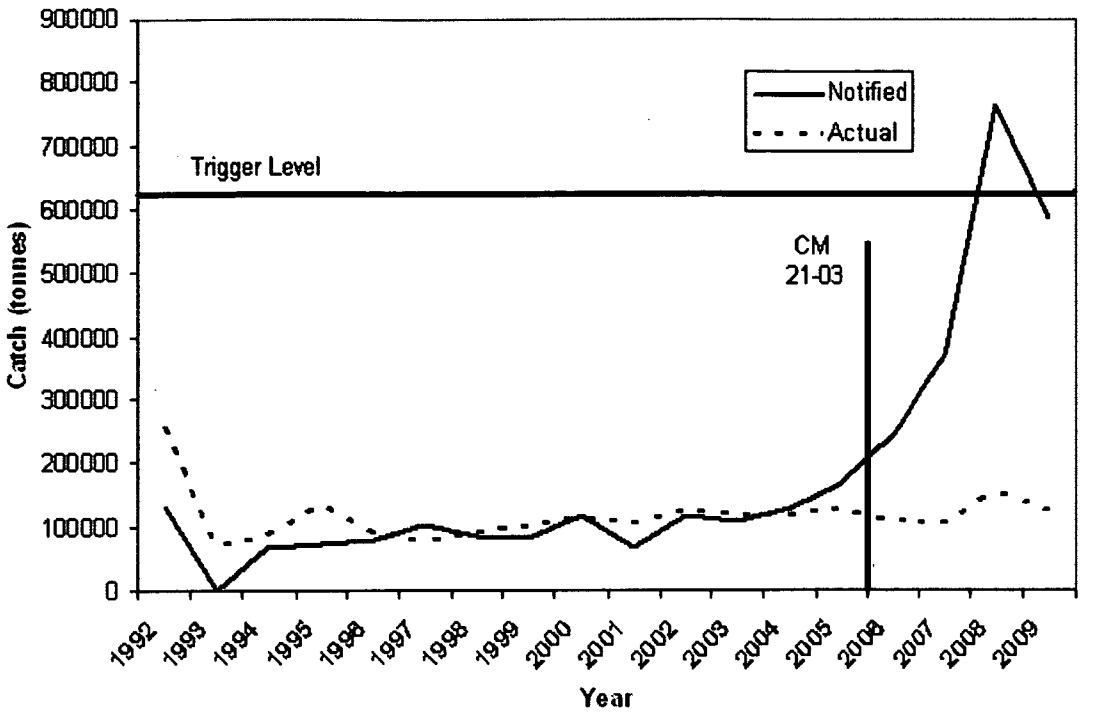


Figure 29: Krill catch and notification data from 1992 to 2008 (CCAMLR, 2010). Note that mandatory notifications data was not required until the 2006 season.

In the 14 years prior to mandatory notifications, actual catches were higher than notified catches in 65% of cases, meaning that information on planned krill fishing activities for coming seasons that was being submitted to the Commission by Members would have led to an underestimation of the amount of krill being removed from the Area. Since 2006, notifications have been, on average, 280% higher than actual catches.

There has been some discussion at Commission meetings that the discrepancy between notified and actual catches makes the notification process ineffective (CCAMLR-XXVII, paragraphs 8.13-8.21; CCAMLR-XXVI, paragraph 3.25). The primary concerns raised with this issue included an incorrect assumption of if, or when, the trigger level may be reached, as well as a concern over the increased workload for the Secretariat in processing notifications that were not accurate. In order to prevent excessive notifications it was proposed by some Members that a fee be associated with lodging notifications and that a penalty

apply for those vessels that notified but didn't fish (CCAMLR-XXVII, paragraph 8.19).

On several occasions the Scientific Committee has recognised the need for Members to provide more than intention to fish and expected catch level information to allow the Committee access to as much information as possible for formulating advice on how to allow for orderly development of the fishery. It was recognised that additional information would allow the Committee to track the fishery in terms of product types being derived, areas and seasons of fishing operations and gear types and specifications.

As such, since 2006, Members submitting notifications for krill fishing operations have been required to also submit information on types of products to be derived from catches, including the proportion of catch that will go into different products, as well as the number of vessels from each country expected to participate in the fishery. Until notifications became mandatory, there was only very patchy information of this nature being submitted to the Commission via Member Activity Statements. Information on what products are coming out of the fishery and how many different vessels, and what companies they are operating on behalf of, has the potential to help the Commission track the direction the fishery may take in terms of potential markets and level of interest and diversification of participation.

The main fishing nations (in terms of level of catch and consistency of participation in krill fishing activities) of Japan, Poland, Korea, Norway and Ukraine have submitted information to meet these requirements for the past four seasons. On the basis of this information, meal, frozen and raw products make up most of the products emanating from the krill fishery.

Japan has notified that the same proportion of its catches will go to raw, boiled, meal and peeled krill products since notifications became mandatory. Japan has notified the same number of vessels participating in the fishery each year over the same period and level of intended catch has also remained stable. Notifications from Poland (Figure 30) show a diversification from traditional

raw, meal and peeled products to include frozen krill and oil products. Notifications on intended catch levels have been variable but the number of vessels notified to participate in the fishery each year has remained the same.

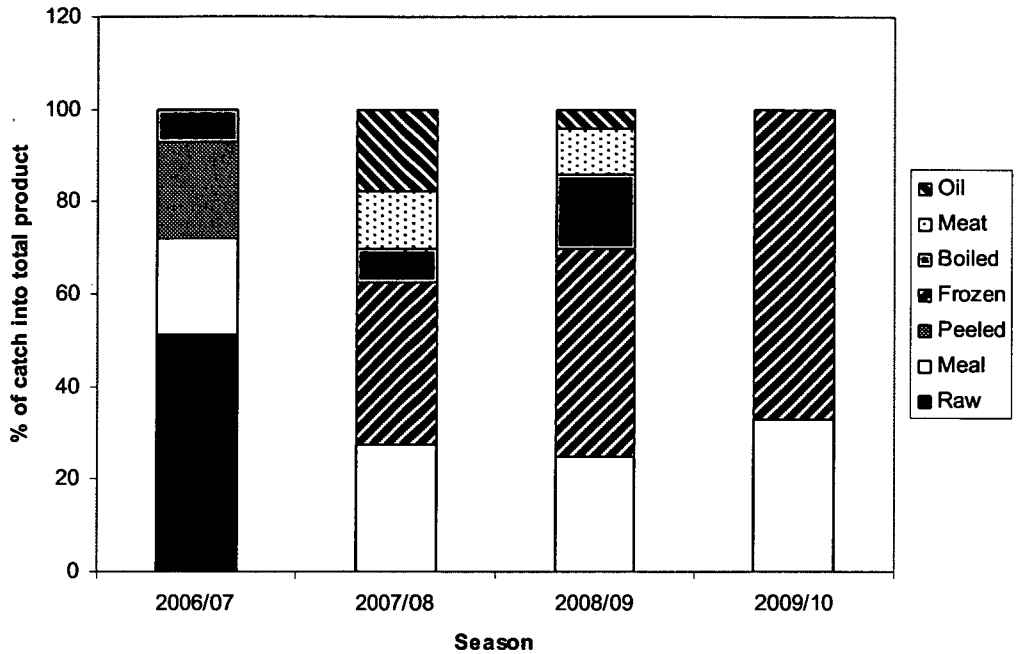


Figure 30: Products to be derived from catches from Poland as reported in notifications.

In terms of quantity, Korea's notifications have increased steadily but the number of vessels notified to participate in the fishery has remained stable. There have not been any notable changes in the types of products being derived from catches with meal being notified every season and frozen and meal products being notified in alternating seasons.

Level of intended catch from Norway has been at a consistently high level since it started fishing operations. There has been a marked diversification in the types of products being taken by Norwegian vessels with a shift from just meal (and unknown) product to products including shells, hydrolysates, lipids and proteins (Figure 31). The number of Norwegian vessels notified to participate in each season's fishing activities has fluctuated. It must be noted that Norway has recently entered into partnerships with companies specialising in the extraction

and purification of oils from krill meal base, suggesting that down stream processing of products may not represent the initial intent for the product.

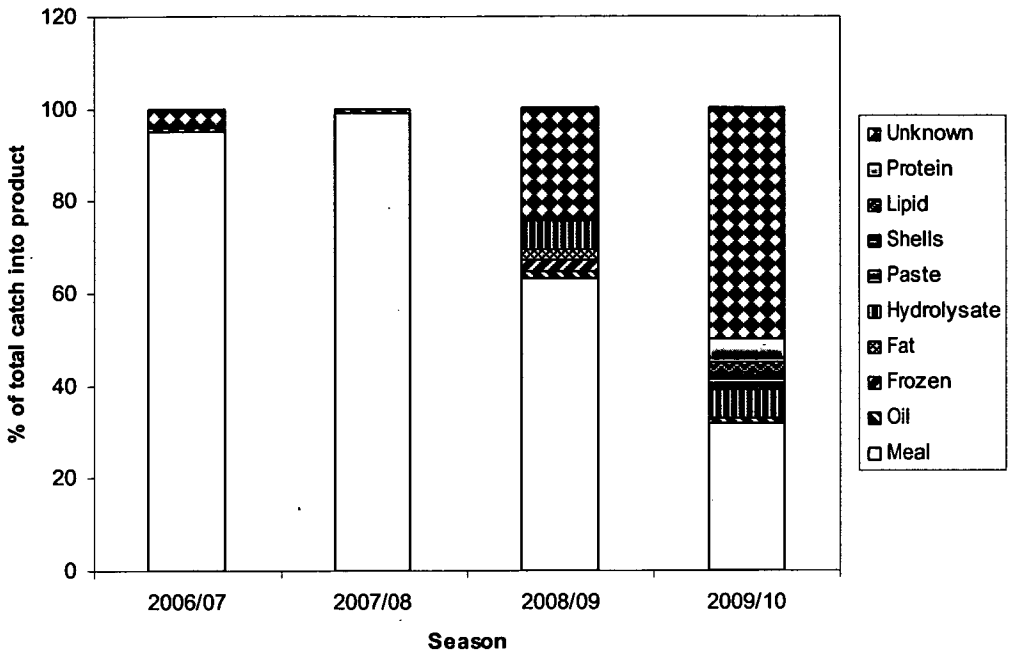


Figure 31: Products to be derived from catches from Norway as reported in notifications.

The types of products being notified by Ukraine (Figure 32) has become less diverse each season and has moved away from off-the-shelf products such as krill paste and canned krill and has moved towards products including meat, meal and boiled krill. The level of notified catch from Ukraine has been variable since 2006 with a general downwards trend, a trend which is also mirrored in the number of vessels expected to participate in the fishery each season.

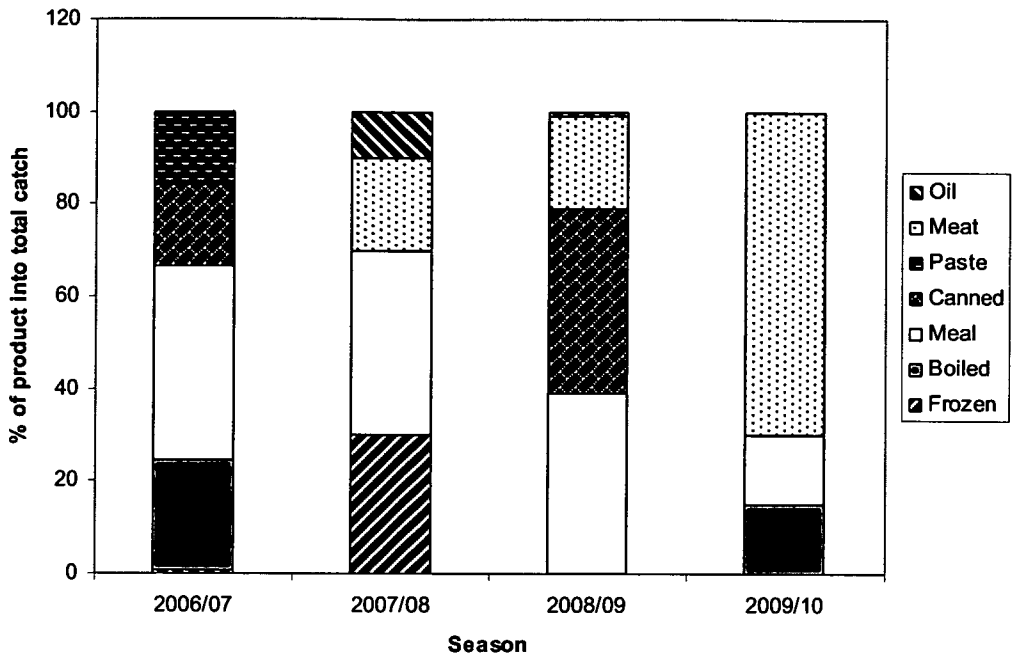


Figure 32: Products to be derived from catches from Ukraine as reported in notifications.

Overall, there appears to have been a shift away from the traditional, Soviet era products of canned krill and krill paste for use in the human food market. Notifications now indicate that the products now emanating from the fishery are those products that were identified in Chapter Two as being likely to fill new market niches for krill and krill products. These include hydrolysates, proteins, lipids and oils which will be mainly used in the pharma- and nutraceutical markets. 'Commercial in confidence' interests of companies flagged to Member countries have often been cited as reasons for non-submission of information on product types and other fishing plans. The information presented in the above Figures illustrates that such data can be used by the Commission to track where interest in the fishery is coming from. Knowing which products krill are being targeted for, and subsequent tracking of market demand for these products, can give some indication of possible trends in demand for the product and hence trends in the fishery.

4.2.3 Discussion

Despite Members' concerns that the notification procedure may not be truly representative of the actual catch level for the coming season, the notification process does provide the Commission with valuable information on interest in the krill fishery (CCAMLR-XXVI, paragraph 4.35). The mandatory notification requirement under Conservation Measure 21-03 means that if a member does not notify their intention to fish, they are prohibited to from doing so in the coming season. As such, the Commission has recognised that increasing notifications, both in terms of catch and participation, represent increasing interest in krill and krill products that is likely to result in an increase in actual catches in coming years. The notification procedure also provides the Commission with invaluable information on proposed fishing techniques and gear specifications so that the Scientific Committee can review and control, if necessary, fishing methods employed in the fishery to ensure that they are not going to be damaging to the ecosystem.

The discrepancy between notified and actual catches may be due to fishing nations not wanting to restrict their fishing activities whilst they continue to develop and refine fishing techniques and continue product development. Attempts have been made to ensure that notifications are more useful by asking Members to provide more detailed information, such as product types to be derived from catches. It is likely that as krill catches increase, the gap between notified and actual catches will decrease and notifications will become a more reliable indicator of potential trends in the fishery.

The Commission currently uses two primary tools for monitoring and predicting trends in the fishery for Antarctic krill: reports of annual catches and notifications of intent to participate in the fishery. Catches reported by Members involved in the fishery have shown only a slight upward trend since the 2000/01 season. Notifications of intent to fish, however, have risen dramatically over the past five seasons from a notified catch of around 67 000 for the 2000/01 season to a notified catch of over 750 000 for the 2007/08 season, a catch level exceeding the trigger level of 620 000, set by the Commission for Area 48.

4.2.4 Summary

Since notifications for intention to participate in the krill fishery became mandatory in 2006, the amount of information being submitted to the Secretariat on fishing operations has increased substantially. The Commission now has information on expected catch levels, vessel names and specifications, gear types, products to be derived from catches, and areas and months to be fished. Combined with catch and effort data which is mandatorily submitted to the Commission, the Commission now has two tools that can be used to track developments in the krill fishery.

Given the current disconnect between actual and notified catches and the downstream processing of krill that occurs after the krill is sold-on, notification data can, at best, give only indications of where interest in the fishery lies. On several occasions the Scientific Committee has recognised the need for Members to provide the Committee and WG-EMM with more information than simply catch levels and intention to fish, in order to provide the SC with the best possible information for formulating advice on how to maintain an orderly development of the fishery and to ensure CCAMLR objectives are met.

Information on past and current krill market prices, products and other market drivers has been requested on several occasions by the Scientific Committee (Table 7). In response to such requests, limited information has been provided by some Members but there is no requirement for systematic submission of such data and no acknowledged methodology for obtaining it. In order to identify more real trends in the fishery, it is necessary to look beyond CCAMLR to other areas that may be potentially used as tools to predict future trends.

4.3 Patent Database

A patent is a right granted for any device, substance, method or process which is new, inventive and useful, is legally enforceable and gives the owner the exclusive right to commercially exploit the invention for the life of the patent. (IP Australia, 2010). Once an Applicant has patented a technology, that Applicant has exclusive rights to exploit that technology. Records of patents that have been granted are kept in publicly accessible online databases and contain all

information necessary for distinguishing each patent as unique including description of methods, ingredients and research results. This means that others can access the information in the patent and can use that information as the basis for further research into the development of a similar technology. Patents are generally applied for when the applicant sees a future commercial gain from the development of the patented product. Under Australian law, a patent gives the Applicant control over and protection of the patented technology for 20 years (IP Australia, 2010).

There have been many studies which have used publicly available patent databases to investigate rates of technological change and patenting activity occurring in different industries (Gupta and Manchikanti, 2010; Hidalgo *et al.*, 2010; Ninan and Sharma, 2006; Basberg, 1981). Patents and patent databases are also increasingly being used for detecting investor interest in emerging technologies (Schiermeier, 2010) and for identifying products and technologies relating to particular ingredients (Darby, 2010). Whilst using patents to predict commercialisation and emerging technologies is still an emerging technique (Pilkington, 2004) the information contained within the patents can be used to gather simple information for answering basic questions such who, what, where, when and why, for example:

- Who: under the title of Applicant(s) or Inventor(s) both the name of the Company who "owns" the patent, and often the name of individuals involved in the developing the product/technology, are cited;
- What: detailed information on what product/technology is involved in the patent is given in the Title, Description and Claims sections of the patent.
- Where: in the Applicant(s) and Inventor(s) titles, the country of both is given alongside the names;
- When: information on when the patent was first lodged and when it was granted is available under the Publication date, Application Number and Priority Number titles; and
- Why: the Classification assigned to the patent by patent offices describes the intended area of application for the patent.

As a response to continued calls for information on trends in the market for krill a paper on detecting trends in the krill fishery was submitted to WG-EMM in 2002 (Nicol and Foster, 2002). This paper outlined the prospect of using publicly available patent databases to construct a database of krill-specific patents from which trends in products types, countries and companies with a potential interest in participating in the krill fishery could be identified. Both the Working Group (WG-EMM-XXI, 2.47-2.48) and the Scientific Committee (SC-CAMLR-XVII, 4.9-4.11) recognised the importance of the information presented in the paper in providing insight into developments in the industry that could lead to future expansion of the krill fishery. The analyses in this paper were subsequently published (Nicol and Foster, 2003).

Analysis of the krill patent database constructed in 2002 indicated a number of trends relevant to the deliberations of the Scientific Committee:

1) A total of 376 krill-related patents were lodged from 1934-2002;
2) Traditional fishing nations, particularly Japan, had lodged most patents in the early half of the data set;
3) There was an increasing trend in the later years for non-traditional fishing nations being involved;
4) The majority of patents were directed at the use of krill for human consumption, with the next most numerous being those directed at uses in the production of feed and bait; and
5) There was an increasing trend in the later years for patents directed at using krill for medical uses.

The database which was first constructed in 2002 has been reconstructed using more refined techniques and has been updated to include data up until March 2009. A preliminary analysis of this database was presented to the Scientific Committee in 2009 (Foster *et al.*, 2009) (Appendix 2). The full results of the analysis of this newly updated krill patent database are presented here.

4.3.1 Methods

In the 2002 WG-EMM paper the krill patent database was constructed using patents from the European, Japanese and United States patent offices. The database has now been updated (Appendix 3) to include all krill related patents from 1976-March 2009, but only the EPO and USPTO databases were used in the patent search. This alteration in the scope of databases searched is because the EPO and USPTO are recognised as the primary Patent Offices with which to lodge patents to obtain the best scope for coverage of new technologies, and are thus readily searched. The updated database was constructed after extensive consultation with patent and Intellectual Property (IP) professionals at IP Australia, to ensure the highest degree of coverage and reliability of data as possible.

The databases were searched (using the patent search engine at http://ep.espacenet.com/?locale=en_EP and http://patft.uspto.gov/) using key search phrases to include all issued patents containing the phrases "krill" and/or "Euphausia superba" in the Title or Abstract. This search method means that patents referring only obliquely to krill in a reference or example are excluded from the total patents, therefore avoiding over-representation of krill-related patents. However, a noted drawback of this search method is that some patents which are known to apply to krill technologies but do not mention krill in their Title or Abstract, are excluded from the patent total (for example the patent lodged by Aker Biomarine ASA in 2008 (WO2008048107) relating to the continuous pumping system). Even though some technologies, such as that presented in Aker's 2008 patent, may not pertain directly to a marketable krill product, they do represent significant investment by the Assignee in the krill industry (to lodge and maintain a patent is a costly process) and therefore are an indicator of likely future activity in the krill product marketplace. All patents were crossed-checked by investigation of the International Patent Documentation Centre (INPADOC) Patent family (which indicates other countries/patent offices with which the patent has been lodged) to ensure no duplication, again minimising over-representation of patents. It is worth noting that because of the time between lodging an application and the granting of a patent, and the

subsequent appearance of this patent in the database, the last year in any time series always underestimates the number of patents lodged for that year.

Patents identified as being krill-related have been sorted into four main categories with each category representing several different but related groupings of patents. In order to categorise patents two main methods were employed. Firstly, many patents clearly state the intended purpose of the patented technology. When this was clear, patents were classified using this description. However, in some patents the intention is ambiguous and so a second method was employed to classify these patents. The International Patent Classification (IPC) system identifies the purpose of each patent and then classifies it accordingly using codes that define its classification.

The 'processing' category accounts for patents relating to processing, harvesting, packaging, peeling and preservation techniques as well as patents relating to the extraction of chitin. These smaller categories were grouped together under 'processing' as they represent technologies and processes that have been developed to allow the capture and use of krill. 'Aquaculture' includes patents related to fishing and aquaculture feed and bait (or attractant) technologies, and patents relating to the extraction and/or use of hydrolysates and pigments. These smaller categories were grouped together as they represent the use of krill in products and technologies that are primarily used in aquaculture-related products. The 'human' category refers to patents related to food for human consumption, and those patents encompassing medical and enzyme related technologies and products used in the treatment of human medical conditions. Finally, the 'other' encompasses all other patents, primarily those related to the use of krill in industrial procedures and includes pest control devices and products, which do not fit into the other three categories described above.

4.3.2 Results

A total of 812 krill related patents have been lodged from 1976-March 2009. This represents a substantial increase from the 376 patents which were identified in the 2002 database (Figure 33). The number of patents lodged since 1999 totalled 351 (43% of total patents) as opposed to around 230 (28% of total

patents) patents lodged in the two previous 10 year periods. There has been a notable increase in the rate of patent lodging since 2000.

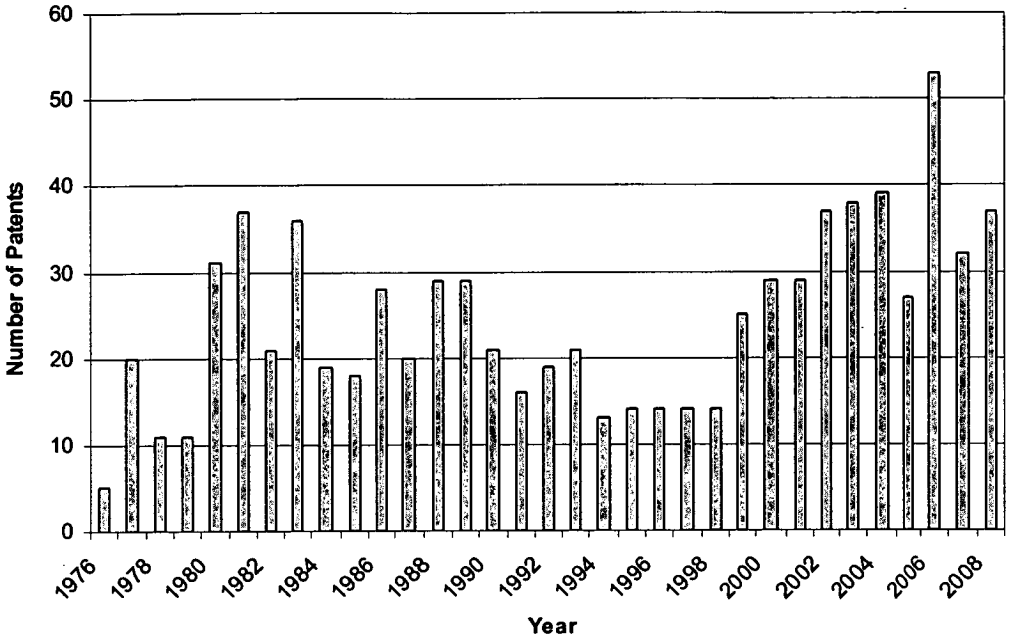


Figure 33: Number of krill-related patents lodged from 1976 to 2009.

The composition of the technologies the patents represent shows an obvious trend (Figures 34 to 37). Patents related to processing dominated applications from the 1976-1986 period (50% of total patents) and showed a marked decline thereafter (only 11% of total patents from 1987-2009). In contrast, patents for Aquaculture and Human Uses for krill markedly increased in the 1999-2009 period (89% of total patents), having represented only 61% of total patents from the 1976 to 1998 period.

The period in the krill fishery from 1979-1986 was dominated by problems related to the processing of fluoride in krill, making the product unfit for human consumption (see discussion in section 1.3). The dominance of patents related to processing during this period reflects the work done by the industry to develop new technologies to overcome these processing problems.

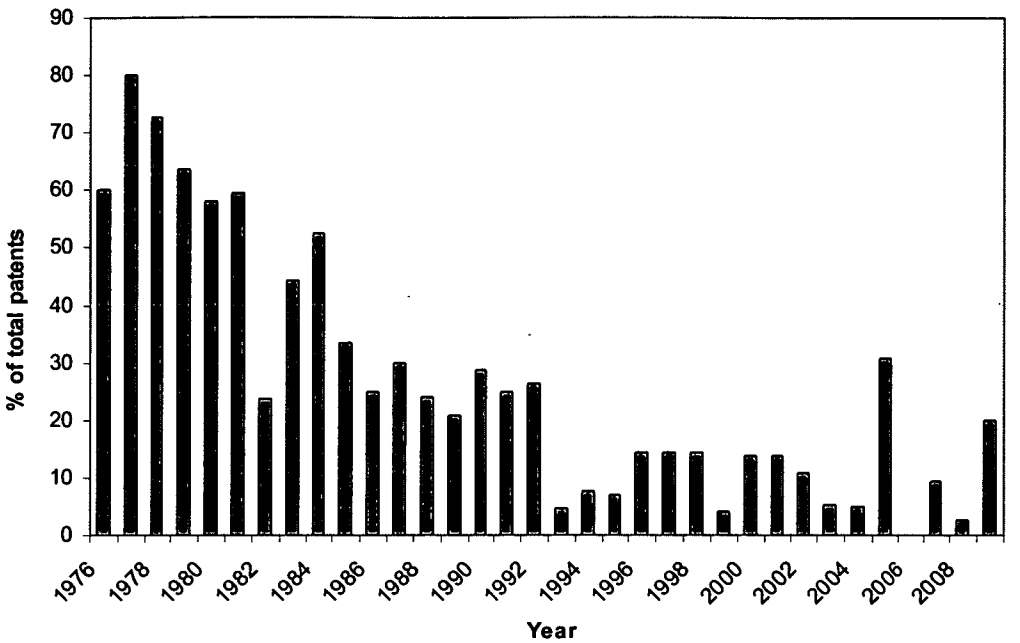


Figure 34: Patents related to uses of krill for Processing purposes, 1973-2009.

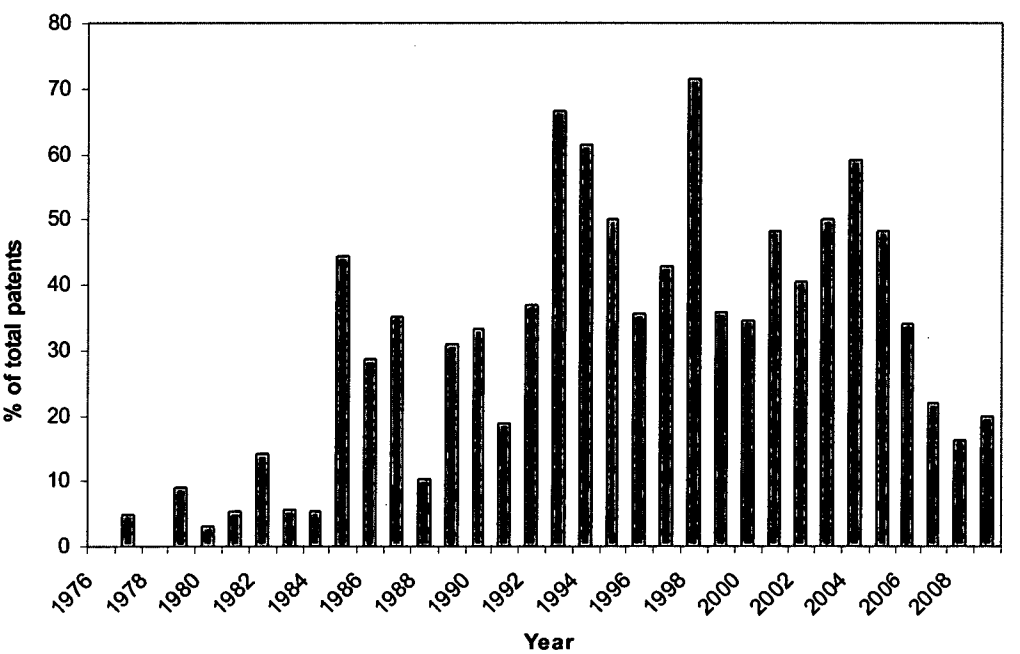


Figure 35: Patents related to uses of krill for Aquaculture purposes, 1973-2009.

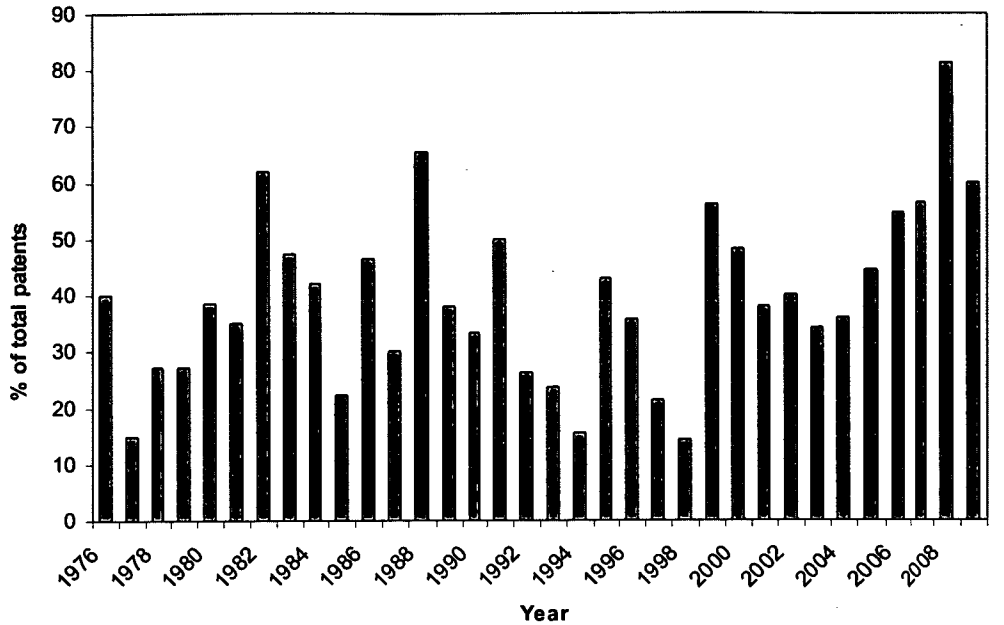


Figure 36: Patents related to uses of krill for Human Use purposes, 1973-2009.

A clear trend of an increase in patents relating to Medical Use is evident when the Human Use category is subdivided into patents relating to technologies/products for Food and those relating to Medical Uses (Figure 37).

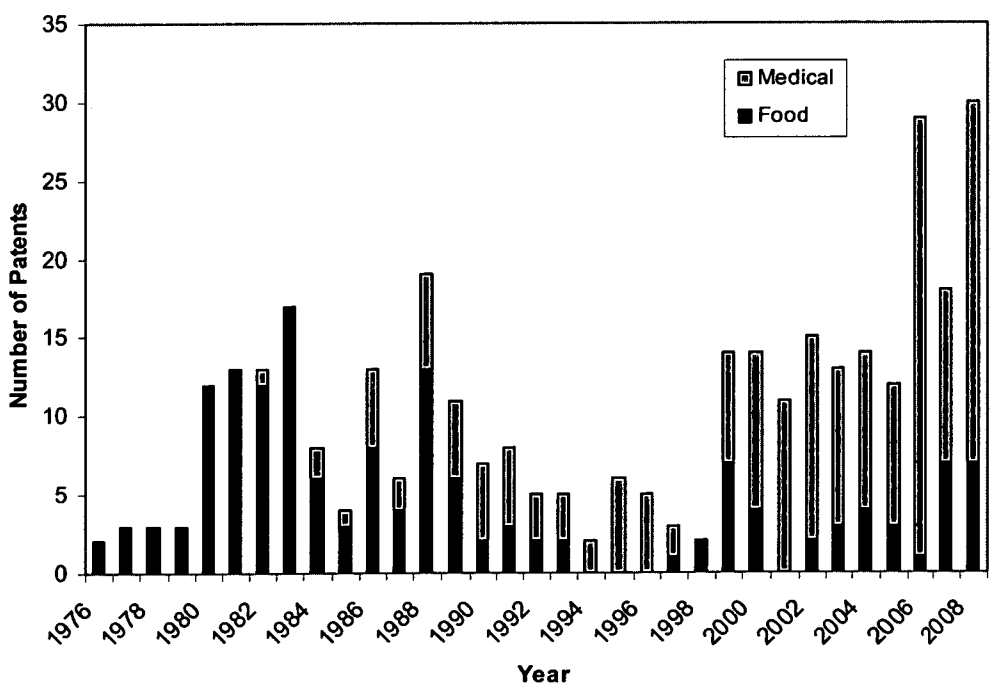


Figure 37: Krill-related patents lodged from 1976 to 2009, categorised into Food and Medical Uses.

Patents relating to Medical Uses represented only 4% of total patents in 1976-1986 but 38% in the period from 1999-2009. In contrast, patents relating to Food technologies/products have declined; they represented 35% of patents from 1976-1986 compared to only 11% of patents lodged from 1999-2009.

This patent database can also be used to analyse the patent activity of different countries. The most "patent active" countries over the life of the database are Poland, Canada, USA and Japan. Predictably, Japan, the most persistent fishing nation, has been the most active country, with Japanese companies lodging 49% of the total patents, and companies from the USA lodging 21%, Poland lodging 7% and Canada lodging 4% of total patents. If this information is broken down to identify trends over the period of the database, it can be seen (Figure 38) that the proportion of patents lodged by Japan is showing a downwards trend mirroring their reduced involvement in the fishery, whilst the proportion of total patents lodged by USA and Canada, neither of who actually fish for krill, is showing an upwards trend.

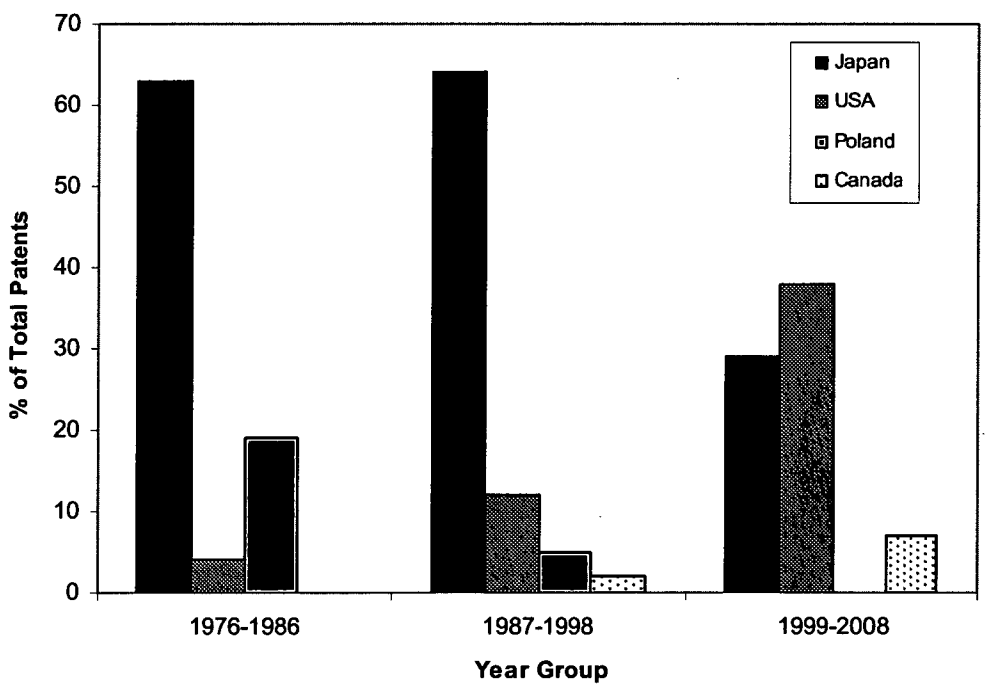


Figure 38: Percentages of total patents lodged by most "patent active" countries, in year groups representing phases in the fishery's history.

The Commission currently has two primary mechanisms for tracking developments in the krill fishery: catches and catch notifications. Over the past ten years, both indicators have shown significant upward trends (Figure 25 and Figure 39), suggesting an increase in the level of the fishery in the future. Analysis of results from this study indicates that there has also been a significant upward trend in the number of krill-related patents (Figure 40).

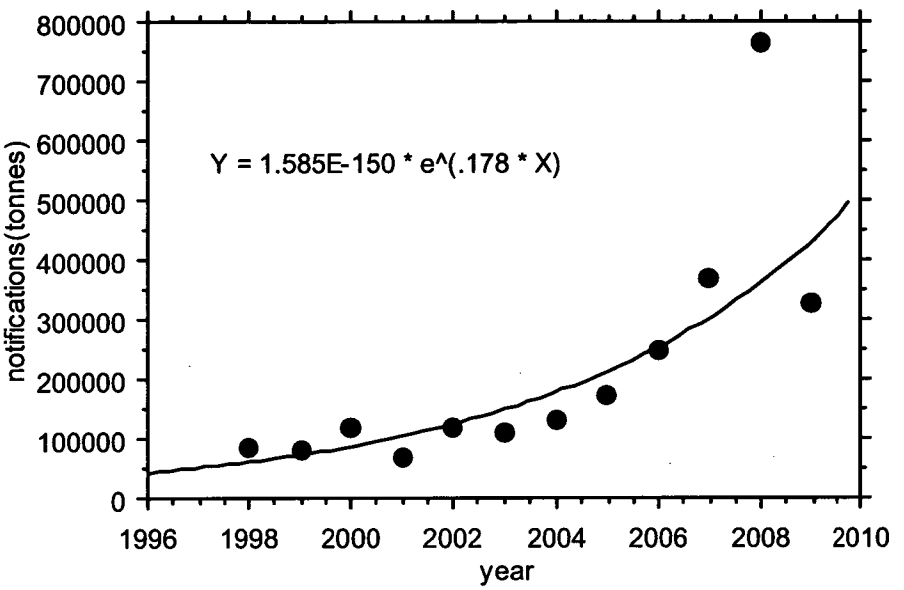


Figure 39: Notifications per year for the last decade. The observed increase is significant ($p<0.002$).

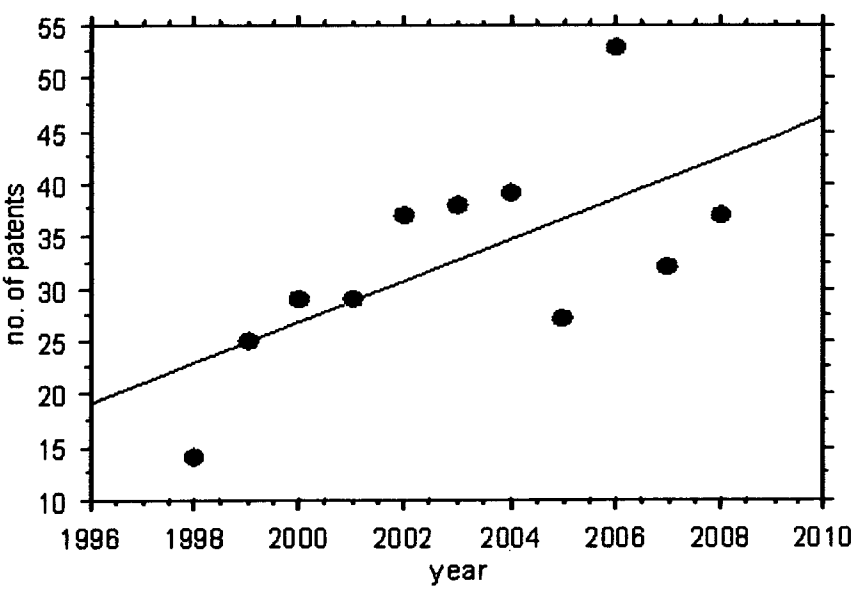


Figure 40: Number of patents lodged per year for the last decade. The observed increase is significant ($p<0.03$).

Thus, all three indicators show a similar and statistically significant upwards trend over the last 10 years and the patent data reinforces the information from the catch and notification data.

4.3.3 Discussion

There has been an increase in the rate of patent applications related to krill over recent years. Since the 2002 study the nature of patents has shifted slightly with a further decrease in patents relating to Processing Technologies/Products, an increase in the proportion of patents relating to Human Use and a slight decrease in the proportion of patents relating to Aquaculture technologies/products. This is further supported by evidence that the number of patents relating to Feed/Bait technologies/products is showing a steep downward trend whilst the number of patents relating to Medical Uses shows an upward trend. It is also evident from analysis of this database that there is increasing patent activity from current non-krill fishing nations, such as USA and Canada, and decreasing patent activity from fishing nations such as Japan and Poland.

The krill patent database indicates some interesting shifts in the types of krill-related products and technologies that are being patented. Applying for and maintaining a patent represents a considerable investment by the person/s and/or company lodging the application. The krill patent database is a useful tool for tracking where money is being invested in terms of krill-related R&D and can therefore be used by the Commission to track likely developments in the krill fishery.

This analysis was submitted to the Scientific Committee in 2009 by the Delegation of Australia (Foster *et al.*, 2009) as an update to the database was that was submitted by Nicol and Foster (2002) to WG-EMM in 2002. After discussion of the paper, the Scientific Committee agreed that the patent database could provide an excellent additional source of information to augment the Scientific Committee's data on trends in the krill fishery (SC-CAMLR-XXVIII, paragraph 4.10). As a result, the Scientific Committee agreed that it would be useful if the patent database could be maintained by the Secretariat to provide annual updates on these trends (SC-CAMLR-XXVIII, paragraph 4.12).

4.3.4 Summary

The database confirms increasing patent activity from the USA and Canada, neither of whom currently fish for krill. It also confirmed decreasing patent activity from those that do fish, including as Japan and Poland. In this respect it is important for the Commission to note that there appears to be heightened interest in the krill industry from Members who are not necessarily directly involved in fishing activities. As such, it will be increasingly important for the Commission to develop means by which to monitor the economic drivers of the fishery, rather than having to rely solely on information contained in notifications from fishing Members.

Trends in the krill fishery are currently informed by data on annual catches and by the annual notification procedure. There has been considerable discussion within the Scientific Committee over the utility of these sources of information to detect trends, and of the need to obtain more information from the krill industry. The patent database provides an additional tool that can be used detect trends in the krill fishery by examining both the number and type of patents related to krill that are lodged annually.

4.4 Conclusions

Obvious correlations exist between what is known about product development, and advancement in harvesting and processing techniques in the early experimental and developmental phases of the fishery (see Chapter Two) and what is shown in the patent database in terms of technologies patented during the same period. Additionally, synergies can also be identified between the countries known to fish in this period and the countries from which the patents from the same period were originating.

Tools currently used by the Commission to track the krill fishery, that is, catches, notifications and the krill patent database, all indicate that the krill fishery is increasing in terms of catches and participation. Patent activity is at its highest level ever and the krill industry has been shown to be diversifying in terms of product range and focus – as well as the countries showing interest in fishing for krill.

These tools give the Commission reliable options for tracking the krill fishery. However, the demand for krill and krill products is also driven by a broader marketplace where the demand for these products is driven by competition and supply of products competing to fill similar market niches. As such, it is important that the Commission looks beyond the direct market for krill in order to keep track of trends in the wider marketplace that may affect the demand for krill.

Chapter Five: Other Indicators for Future Developments in the Krill Fishery

5.1 Introduction

After examining the potential market niches that krill and krill products are likely to fill in the future, Chapter Two highlighted the absence of reliable information for tracking the development of the krill fishery. Whilst the CCAMLR catch data from the fishery, discussed in Chapter Four, does allow tracking of the fishery, it is the notifications and krill patent database which have the capacity to be used to make projections for the future of the fishery. Given the range of market niches that have been identified for krill and krill-related products, it is important to look beyond the fishery itself to the broader marketplace to gain some perspective on other potential drivers of the krill fishery.

As such, this Chapter will review other tools that have the potential to be used as indicators for monitoring trends in the krill fishery. The tools presented here emanate primarily from the marketplace and include competing commodities and published literature. Competing commodities represent other products and fish resources which are likely to compete with krill for market share, in particular for use in fish meal and other animals feeds. The published scientific literature represents research that has been undertaken in a particular field that has been peer reviewed to ensure the integrity of the research presented. The krill patent database highlighted an increase in products being patented in the fields of human medical and aquaculture uses. Given that research for product development is often a collaboration between industry and academic research institutions, it is likely that much of the research that has gone into the development of these products would be presented in the published scientific literature.

5.2 Competing Commodities

Chapter Two established the niches for krill and krill products that are currently evolving in the marketplace. The use of krill in pharma- and nutraceuticals for treatment of human medical conditions is currently undergoing rapid changes, the use of krill in aquaculture and animal feed products continues to develop and

the use of krill in the more traditional roles of human consumption markets continues. The nature of the marketplace naturally dictates that krill and krill products will compete with other products for a share of the market. By looking at trends in the availability and price of products with which it is most likely to compete, possible trends in the future demand for krill and krill products can be identified.

5.2.1 Trends in Production and Trade of Competing Commodities

Chapter Two indicated that the commodities most likely to compete with krill and krill-derived products in the marketplace, in terms of demand for quantity, are meals and oils for use in aquaculture and agriculture feeds. Other market niches likely to be filled by krill and krill products, as identified in Chapter Two, represent low yield, high value markets, for example krill oil for medical uses. Fishmeal and fish oil are traded frequently and in large quantities in markets across the world. Affecting the availability and price of these two commodities is the price and availability of the raw materials that go into them i.e. small pelagic fish. The availability and price of small pelagic fish is affected by seasons, stock sizes, operating costs in the fishery and demand for the product. Soy-based meals and oils are also worthy of consideration as potential competitors in the meal and oils sectors. Although, as discussed in Chapter Two, krill derived meals and oils have numerous competitive advantages over soy and regular fish-based meals and oils, these products have traditionally dominated the market in this area.

Information on trade of these commodities is collated by the FAO and is frequently reported and commented on by various industry organisations for example FAO's Globefish, the International Fishmeal and Fish Oil Organisation (IFFO), and Aquafeed (providing information on the commercial aquaculture feed sector). The information contained in this section uses raw FAO data and commentary from industry organisations such as the ones mentioned above.

5.2.1.1 Fishmeal and Fish Oil

Over the past 35 years there has been an upwards trend in the price and quantity of fishmeal (Figure 41) traded in the global marketplace. Over this time there have been fluctuations in both price and quantity traded. Over the past decade,

the quantity of fishmeal traded, whilst fluctuating, has not continued increasing. A closer look at the trends of the past eight years (Figure 42) indicates that for the past four years, the price of fishmeal as been higher than ever before and has risen sharply in the past two years. Figure 42 also illustrates that, even though overall soymeal prices are lower than those for fishmeal, prices of soymeal over the past eights years have followed a similar trend to those of fishmeal.

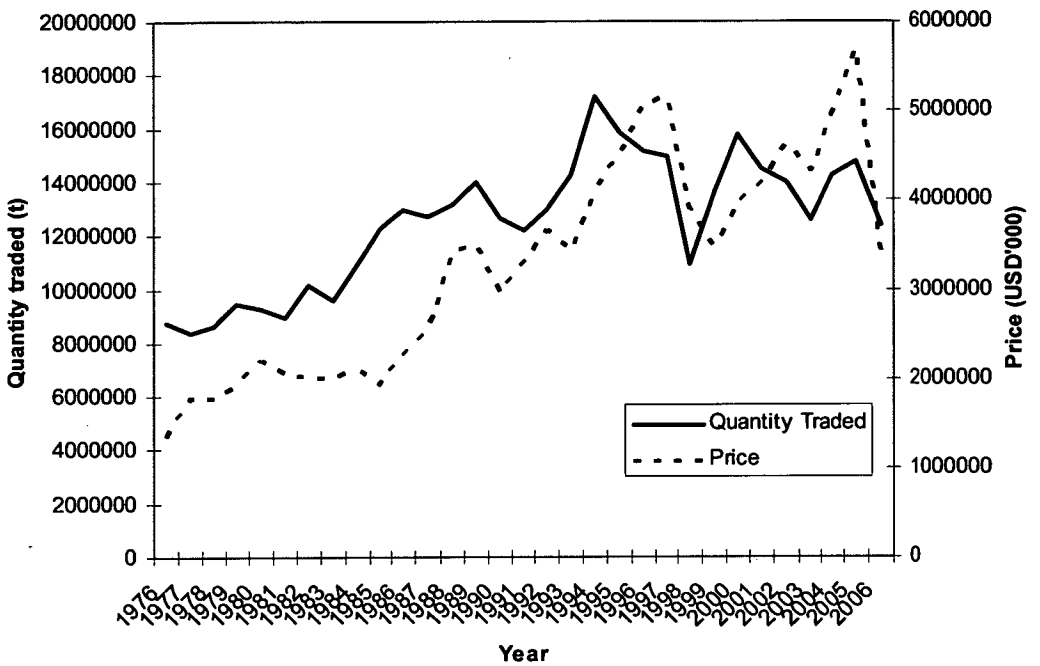


Figure 41: Quantity and value of fishmeal traded globally from 1976 to 2006 (FAO, 2010).

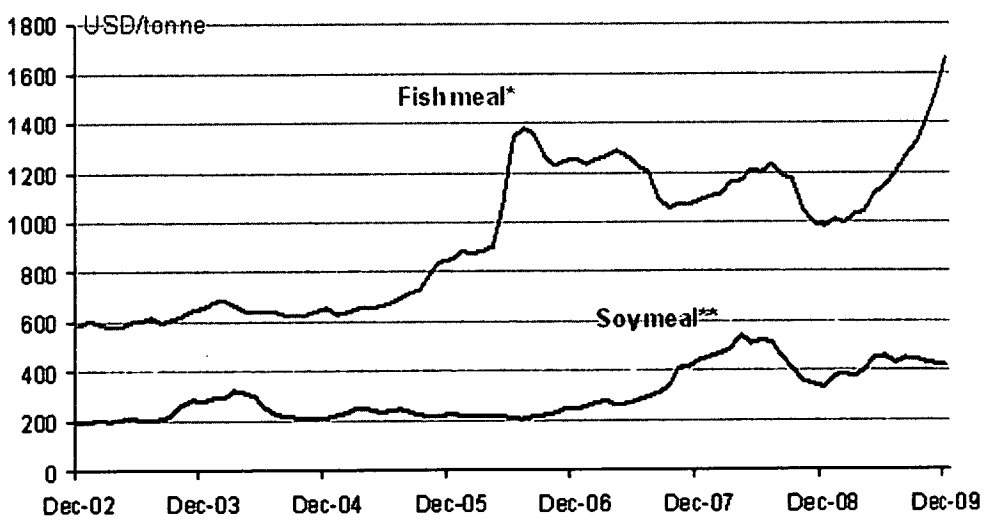


Figure 42: Fishmeal and soymeal prices December 2002 to December 2009 (Globefish, 2010). Not adjusted for inflation.

Over the past 35 years there has been an increase in the price of fish oil being traded and large fluctuations in the quantities being traded (Figure 43). Overall, there has been only a slight increase in the quantity of fish oil in the marketplace since 1976. A closer examination of the last eights years indicates a steady upwards trend in the price of fish oil with a spike in prices in 2007 and 2008, a trend closely followed by prices for soybean meal (Figure 44).

The global oil price nearly tripled from early 2007 to late 2008 as a result of the onset of the Global Financial Crisis (GFC) (OPEC, 2010). The Organisation of the Petroleum Exporting Countries (OPEC) reported that the 'basket price' of oil (average price of a "basket" of seven different oils, used to monitor world oil market conditions) rose sharply in early 2007 and plunged in late 2008 (Figure 45) as part of this price fluctuation. A similar trend in the price of fish oil, and a similar, if less extreme, trend in the price of fishmeal for the same period is evident in Figures 42 and 44. There have been links drawn between the onset of the GFC and rising commodity prices (Conway, 2008) with soaring energy and food costs, combined with global shortages in supply, leading to the fluctuations seen in fishmeal and fish oils as well as soymeal and soybean oils. It is recognised by industry bodies, that the price of fish oil traditionally appears to track world oil prices (Globefish, 2010).

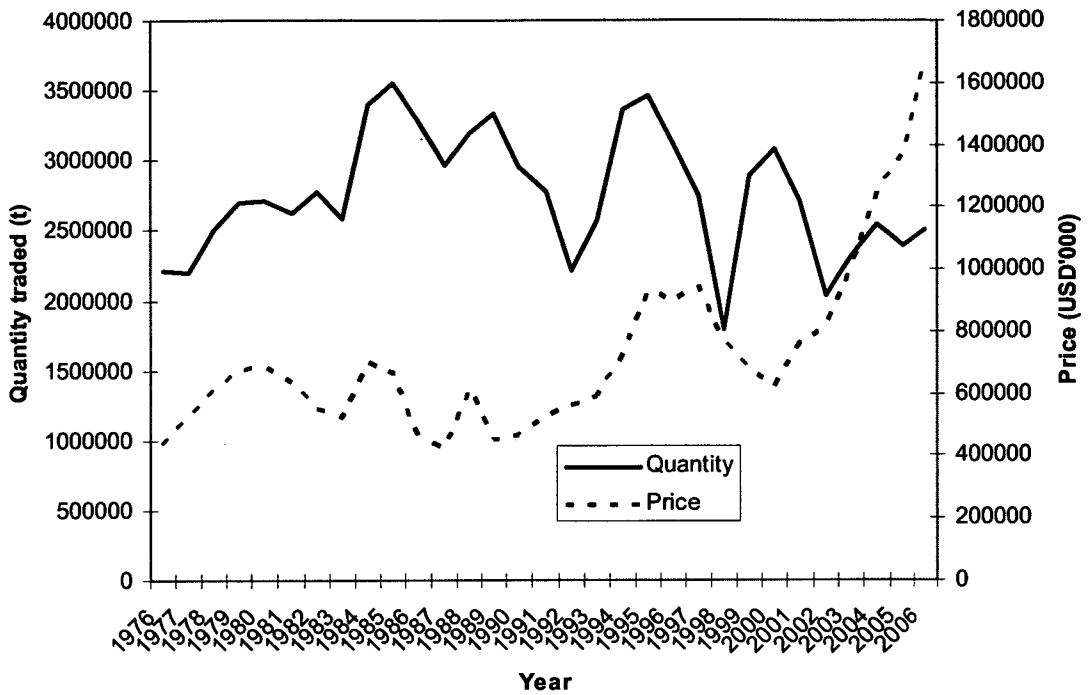


Figure 43: Quantity and value of fish oil traded globally from 1976 to 2006 (FAO, 2010). Not adjsuted for inflation.

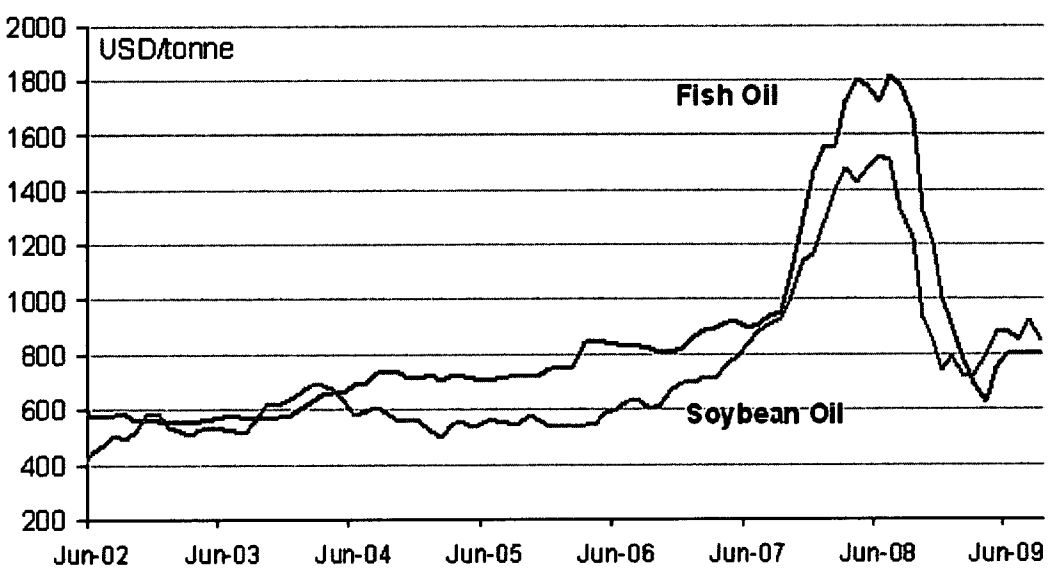


Figure 44: Fish oil and Soybean oil prices from June 2002 to June 2009 (Globefish, 2010). Not adjsuted for inflation.

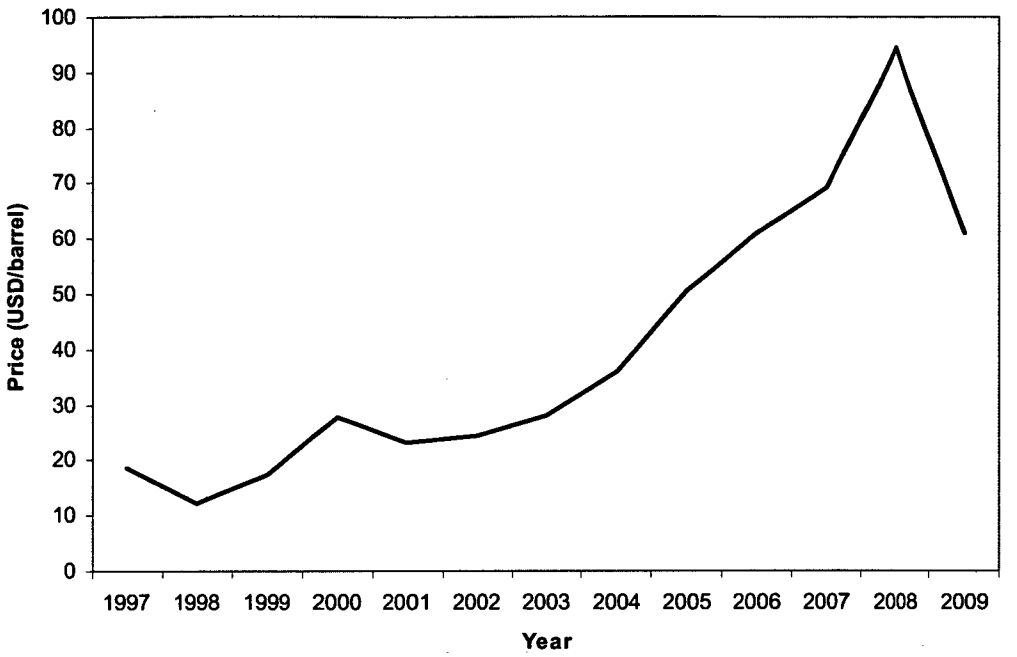


Figure 45: OPEC basket price for world oil from 1997 to 2009 (OPEC, 2010).

The quantities and prices of the commodities that have been investigated here suggest that the market for fishmeals and fish oils is entering a new phase where there is an increase in both the amount of fishmeals and fish oils that are being traded and the prices they are commanding. Soymeal and soybean oil prices appear to be tracking the same trends as those of fishmeal and fish oils suggesting that there is a market-wide increase in demand and prices for commercial feed products and ingredients. Projections from industry bodies suggest that prices for fish oil will certainly continue to increase (Globefish, 2010) whilst the quantity of fishmeal being produced will decline and prices will increase, in a trend started many years ago (Globefish, 2010). If these projections hold true, and both demand for the product and prices continue to increase, it is likely that alternative products will be investigated with the possibility of becoming feasible competitors in the marketplace.

5.2.1.2 Indicator Species

Small pelagic fish constitute up to half of the total landing of all marine species globally and often make up the bulk of the fish biomass (Fréon *et al.*, 2005). Identified by Tacon (2005) as the principal species constituting the majority of

fishmeals produced world over are species including the Peruvian anchovy (anchoveta), Atlantic herring, Blue whiting, Capelin, Chilean jack mackerel, European pilchards (sardines) and Californian pilchards. The fourteen species identified by Tacon (2005) accounted for 87% of the total capture fisheries landings which were destined for reduction into meals in 2003. Skretting, a world leader in the supply of fish feed to the capture fisheries market, had an inclusion rate of 47.4% Peruvian anchovy, 25.7% Blue whiting and 5.4% herring in their fish meals produced in 2007 (Skretting, 2008).

Based on the demonstrated importance of sardines, herring, anchovies and other small pelagics to the production of fish meals and oils, this study has chosen three of these species as indicator species i.e. species chosen to represent trends in catch, price, trade and utilisation of small pelagic species in fish meals. According to FAO figures from 2006 (Figure 46) anchoveta, Blue whiting and Atlantic herring were amongst the five top marine capture fisheries for this year. As such, these three species will be used as illustrative only, rather than analytical indicator species, for use in this tool.

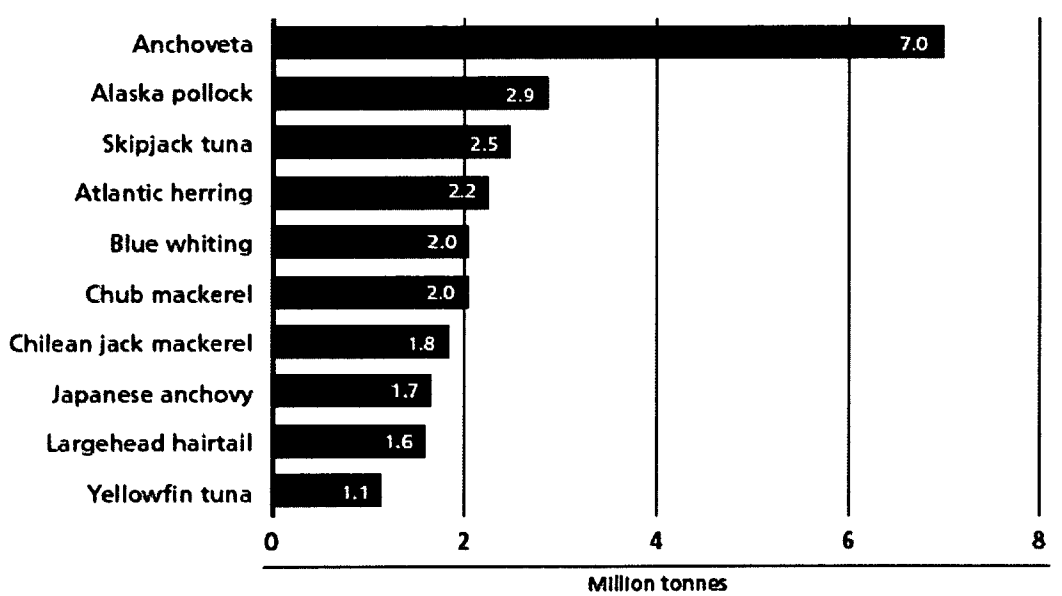


Figure 46: Marine capture fisheries production: top ten species in 2006 (FAO, 2008).

By examining the trends in quantity and value of trade of these species globally, trends in the availability of these species for inclusion in fish meals can be identified. Tracking these trends may provide a useful tool for making predictions about the fishery for krill given that they are not only representative of krill in terms of ecosystem roles, but they are being targeted for use in fishmeals and production of fish oils, two markets where krill is likely to establish a marketshare in the future.

The Peruvian anchovy (*Engraulis ringens*), reaching a maximum size of 20cm, forms large surface swarms off the Peruvian and northern Chilean coast. The anchoveta has been targeted by fish meal and oil producers since the 1950s and stock size and health is largely dependent on environmental factors, namely the occurrence of El Niño events when stock sizes decrease markedly due to the influx of warm, nutrient poor waters as a result of heavy rains and disrupted upwelling events. As early as the 1970s it was apparent that anchoveta stocks needed careful management to ensure over-exploitation in El Niño years did not decimate stocks.

Referred to by the FAO (2009) as the most heavily exploited fishery in the world, the stock has been classified by FAO as over exploited (being exploited above a level believed to be sustainable in the long term with no potential room for further expansion and a high risk of depletion/collapse). Landings of anchoveta reached over 7 600 000 in 2007, dropping from over ten million tonnes in 2005 (Figure 47). As can be seen in Figure 47, landings of anchoveta fluctuate dramatically, coinciding with El Niño years. Production of fishmeal from anchoveta (Figure 48) has more than halved from mid-2000 highs of 800 000 – 120 000 tonnes. The irregular catches of anchoveta, mainly due to stock size fluctuations as a result of El Nino events makes supply of the species patchy, limiting stable production.

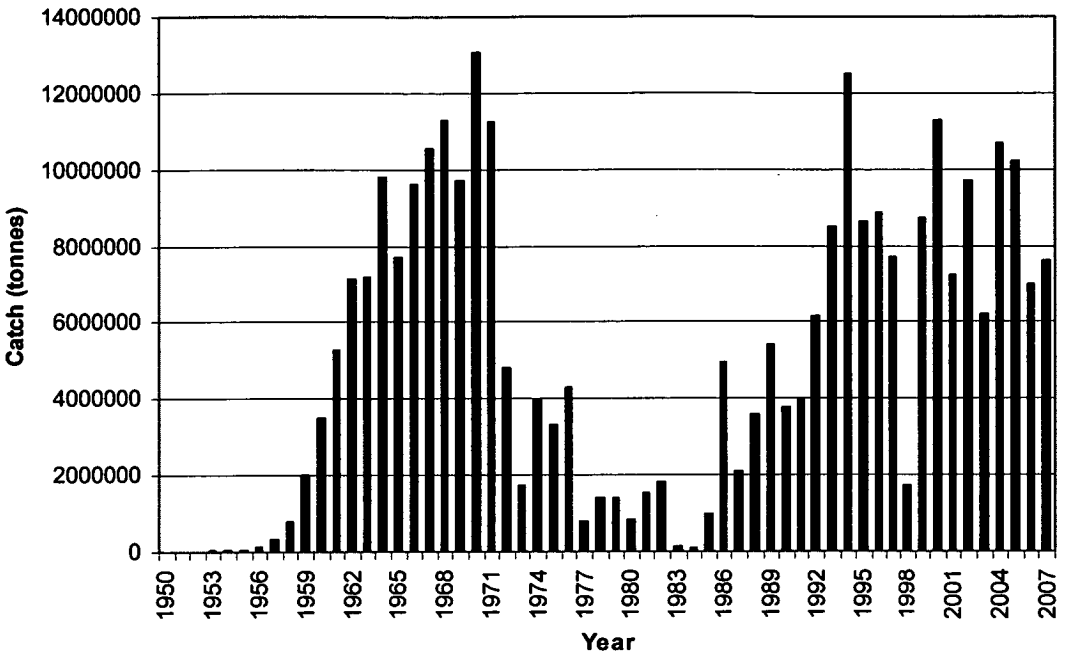


Figure 47: Landings of Peruvian anchovy from 2005 to 2007 (FAO Fishstat, 2007).

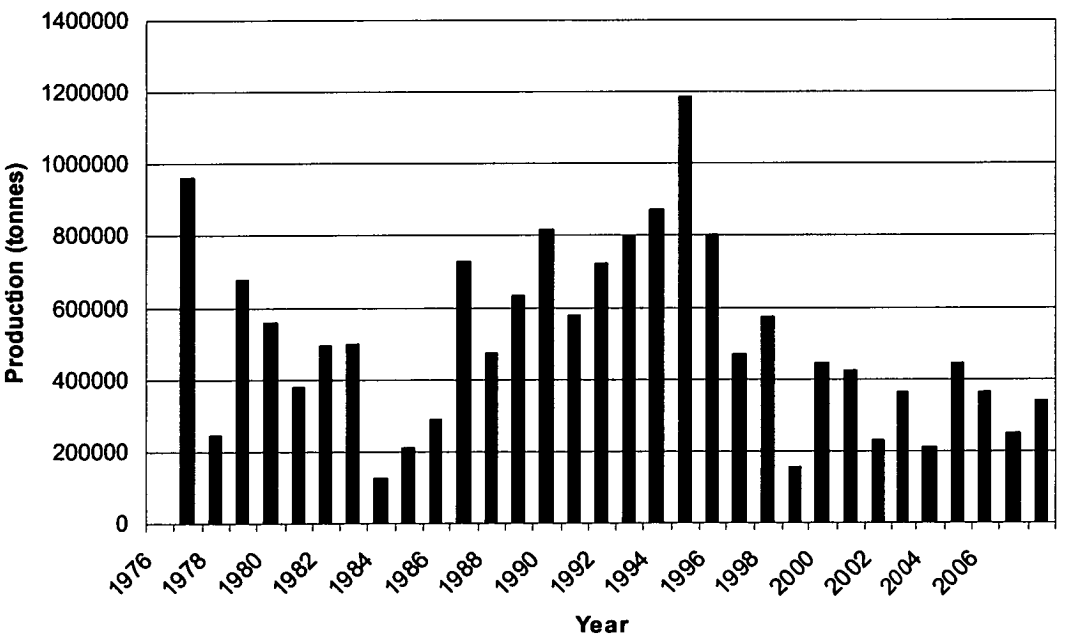


Figure 48: Production quantity of anchoveta meal from 1976 to 2007 (FAO Fishstat, 2007).

Blue whiting (*Micromesistius poutassou*) is a highly commercial, northern hemisphere species, growing to an approximate maximum size of 50cm. The fishery exists primarily in the Northeast Atlantic and off the Southern and South coasts, respectively, of Greenland and Canada (Fishbase, 2009). Blue whiting form surface aggregations during daylight hours but migrates to become a bottom dweller at night.

Blue Whiting is classified as an overexploited fishery (being exploited above a level believed to be sustainable in the long term with no potential room for further expansion and a high risk of depletion/collapse) in the Northeast Atlantic with catches peaking at around 2 500 000 tonnes in 2004 and slowly decreasing to 1 600 000 tonnes in 2007 (Figure 49). Following the downwards trend of landings from 2005 is the quantity of fishmeal being produced from this species (Figure 50).

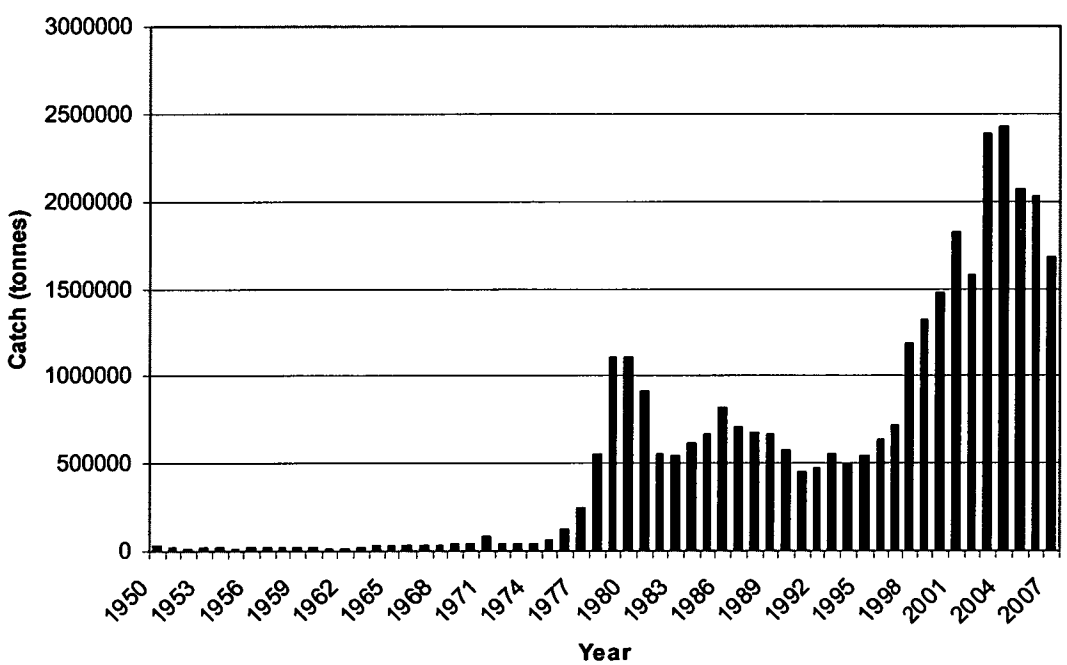


Figure 49: Landings of Blue whiting from 1950 to 2007 (FAO Fishstat, 2007).

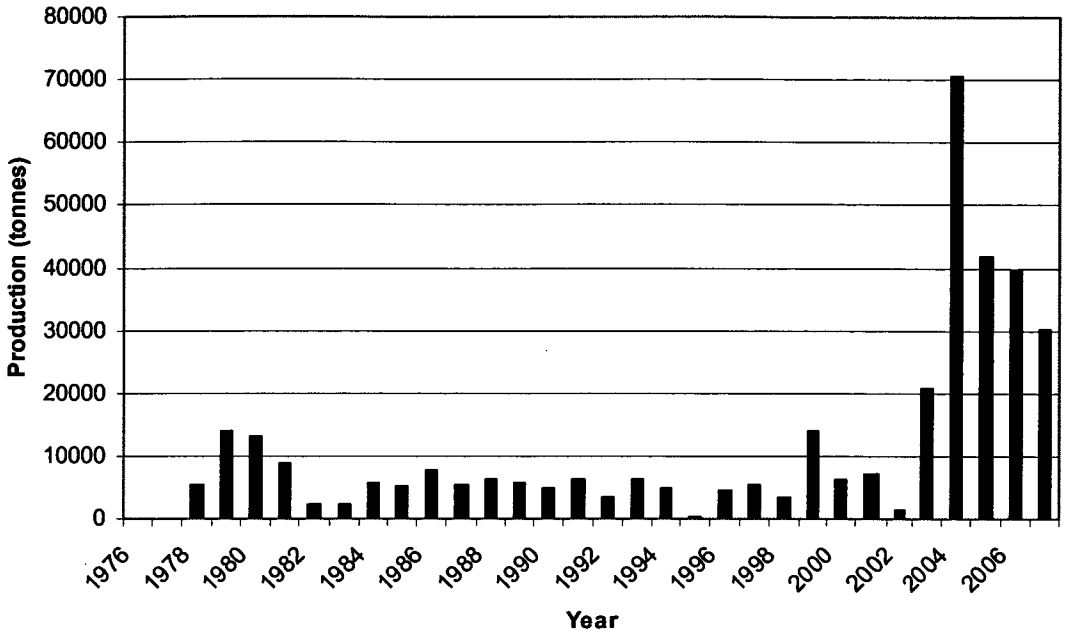


Figure 50: Production quantity of Blue whiting meal from 1979 to 2007 (FAO Fishstat, 2007).

Atlantic herring (*Clupea harengus*) is a small (maximum size of 40cm), schooling pelagic North Atlantic species of which all size classes are targeted with small size classes being targeted in the nearshore fishery and larger size classes in a distant water fishery. Aggregations are usually targeted feeding in summer months, and in overwintering and spawning aggregations (Indiseas, 2008).

This small pelagic was heavily fished species during the 1970s when overfishing of the northern hemisphere species resulted in a huge reduction in catches, effectively a "collapse" of the fishery. Catches recovered into the 1990s with current catches stabilised at approximately 2 250 000 tonnes from 2005 (Figure 51). This fishery is classified as fully exploited (operating at or close to an optimal yield level with no expected room for further expansion) by the FAO (FAO, 2006).

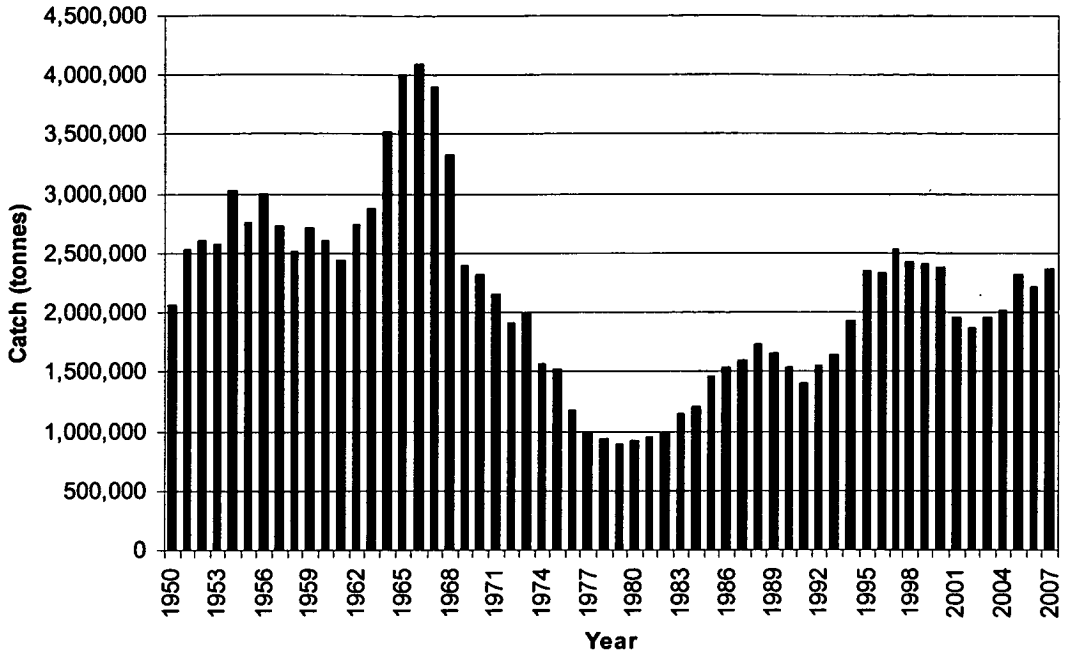


Figure 51: Landings of Atlantic herring from 1950 to 2007 (FAO Fishstat, 2007).

5.2.2 Summary

Of the fourteen species identified in Tacon's (2005) report as forming the bulk of the world capture fisheries landings destined for reduction, seven species are fully exploited (no room for expansion), five are over exploited (high risk of stock depletion/collapse) and one species has various stocks ranging from under exploited (room for expansion in production) to recovering (catches increasing after having being seriously depleted). Of the three indicator species chosen for this tool, two are classified as overexploited and one as fully exploited. Catches of Chilean jack mackerel, Capelin, Atlantic horse mackerel, Norway pout, Sandeels and Gulf menhaden have all dropped considerably over the past decade.

Given the declines in the species most commonly used to fulfil demand for fishmeal and fish oil, there will be an increasing need to source raw product for these commodities from other fish stocks or terrestrial sources, such as soy crops, in the near future.

5.3 Other Tools

5.3.1 Published Scientific Literature

Companies developing technologies and/or products invest substantial amounts of capital in research and development. Often private companies will partner with established research institutions, including universities, to conduct necessary research. For example, research by Aker into the effects of its dietary krill oil product for treating various metabolic diseases was undertaken by scientists from the Heart Research Institute in Sydney (Tandy *et al.*, 2009). The outcomes of R&D activities are sometimes published in what is known as the scientific literature (peer-reviewed scientific papers published in journals specific to the field of the research). Given the amount of R&D that has occurred, and is continuing to take place, in the development of krill-related products and technologies in recent years, published literature may give an indication of developing interests in the krill marketplace.

A search of online database Current Contents Connect (ISI), a multidisciplinary online database that collates all published material from the world's leading scholarly journals from 2008 to present, resulted in a list of over 600 academic publications that contained "Euphausia superba" in the topic for the period 2000 to 2009. Each publication was categorised according to the area of research to which it applied. The main categories used were 'aquaculture', 'medical', 'functional foods', 'management' and 'scientific research'.

Articles were classified as 'aquaculture' if they related to research into the use of krill in feeds or feeding experiments. 'Medical' articles were those that specifically stated that the intention of the research was aimed at medical applications. Those articles classified as 'functional foods' were directly related to technologies and methods for the incorporation of krill into foods to enhance the health benefits associated with those foods, these articles generally appearing in journals related to food research and technologies. 'Management' articles were those clearly relating directly to the management of krill stocks in the Southern Ocean and lastly, all articles pertaining to topics such as biology, ecology, distribution, abundance, reproduction, predation and acoustic technologies were classified as 'scientific research'.

Those articles in the 'scientific research' category consistently accounted for between 80% and 96% of all articles for each year, accounting for 91% of all 606 articles from 2000 to 2009. The remaining four categories only accounted for a total of 9% of all articles found for the 2000-2009 period.

Linear regression (Figure 52) indicated that there was a significant positive trend in the categories of 'management' ($p \leq 0.05$) and 'functional foods' ($p \leq 0.05$). The categories of 'aquaculture' and 'medical' did not show any significant trends. It must be noted that the proportion of total articles that these four categories accounted for (9%) was very low in comparison to the 'scientific research' articles.

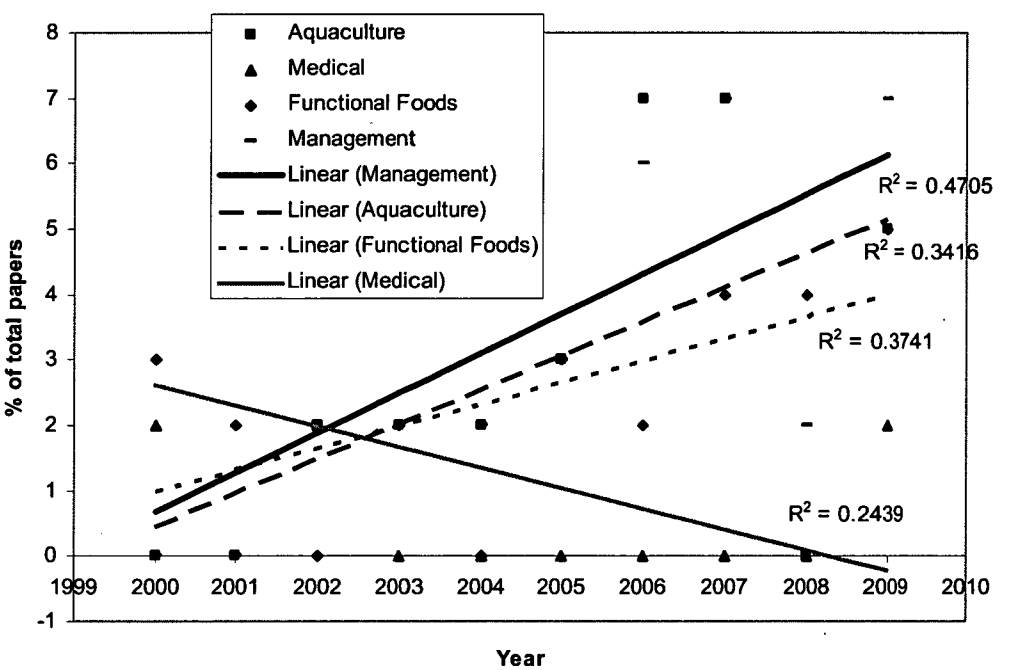


Figure 52: Linear regression of results from the 'aquaculture', 'medical', functional foods' and 'management' categories from the Current Contents Connect search.

During collection and analysis of this data, several problems associated with using published scientific research as a tool for predicting trends in the fishery were identified. Firstly, not all R&D undertaken by companies will be published in the scientific literature due to commercial-in-confidence. Secondly, results

from R&D are often published as basic scientific findings on properties or composition of krill rather than as being obviously for commercial use. Lastly, there can be a time lag of several years before results are made available in the published literature. Analysis of data from the literature search indicated that, overall, published scientific literature does not provide a reliable mechanism for identifying future trends in the krill fishery.

Whilst developments in the krill industry are reported in trade press publications (increasingly online) and the results of R&D can appear as papers in the published scientific literature, using these sources of information as indicators of developments in the krill fishery is not feasible. However, they can be used to provide qualitative information on the development of the fishery and can provide important information on factors affecting the industry, including product development and industry participation.

5.4 Conclusions

Information available from tracking price and availability trends in competing commodities can provide managers with a broad picture of the dynamics of the marketplace in which krill products will compete. Trends in commodities which are likely to compete with krill in the marketplace such as fishmeal and fish oils and forecasts from key industry bodies suggest that prices for both these commodities will increase over the coming years as a result of reduced supply. This reduced supply may be a factor of the overexploited state of those fish stocks commonly used to supply the raw materials for these commodities. By monitoring the marketplace for these commodities, managers of the krill fishery will be able to keep track in shifts in the wider marketplace that could affect the demand for the krill resource.

Chapter Six: Conclusions

6.1 Introduction

Antarctic krill (*Euphausia superba*) has long been recognised as the keystone species of the Antarctic food web and consequently is a resource that should be managed cautiously. After initial developments in the krill fishery in the 1970s that raised concerns over impacts of unregulated harvests, Antarctic Treaty Parties negotiated the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). This instrument charged the Commission with responsibility for managing these resources using an ecosystem-based approach, centered on krill. The fishery for krill has been operating at a commercial level since the 1960s, evolving considerably since its inception. However, over the past ten years the fishery has undergone a particularly significant period of change, both in terms of operation and participation. These changes have raised concerns amongst the scientific community that the Commission needs to be prepared for an increase in krill catches in the CCAMLR Area and needs to ensure that the fishery develops according to its approach to management.

This thesis has addressed several key objectives, building on the primary aim of providing an overview CCAMLR's management of krill. These objectives centered on analysis of the development of the fishery, the management of the fishery to date and identifying tools to assist the Commission in tracking development of the fishery. A brief summary of the key findings of this study is presented here.

6.2 Development of the Southern Ocean Krill Fishery

Over the past ten years, the development of krill products has diversified into new markets, namely for high-value pharma- and nutraceuticals. The entry of new operators into the marketplace and the shift in product focus has resulted in an increase in the amount of publicly available information being provided by these companies as they advertise their products to compete for market share. Markets for these new pharma- and nutraceutical products are predicted to expand considerably in the coming years. Krill is also maintaining a place in its traditional markets of animal feed additives and food for human consumption.

When combined, these traditional marketplaces and the new and emerging marketplaces for krill point towards a new level of investment in the marketplace not yet seen in the fishery's history.

The developing demand for krill products suggests that the fishery has become low-yield, high-value in nature. That is, relatively small quantities of high quality raw krill resource are being manufactured to yield small quantities of high value product. This is evident in the types of products that krill is being made into with fishmeal being marketed for value-adding purposes rather than as a bulk meal component and pharma- and nutraceutical products requiring high quality product in relatively small quantities. These products do not require large volumes of krill but rather, require high quality raw krill which technology can now deliver through the continuous pumping system being used by newer entrants into the fishery i.e. Aker Biomarine. These products command a higher price than more traditional products in the food and aquaculture/bait markets. This low-yield, high-value feature of the marketplace in which krill will compete will likely result in slower development of the fishery, rather than a sudden explosion in catches as has been seen in small pelagic species which have been fished as bulk fishmeal ingredients in the past.

Unless something drastic happens in the chain of supply and demand for fishmeal and fish oil commodities, which is not likely given the very steady changes that have been occurring in the fishmeal markets over the past 40 years, it is highly unlikely that there will be any rapid expansion in the krill fishery to unprecedented levels over the next decade, at least. However, if the intensive fishing of small pelagics for inclusion in fishmeal and fish oil continues and forces the stocks to decline to the point where they become commercially unviable, there may be room for krill to become a more viable option for inclusion in these commodities. By monitoring the marketplace for these commodities, managers of the krill fishery can keep track of shifts in the wider marketplace that could affect the demand for krill.

Given these changes that are occurring in the marketplace for krill now, it is likely that there will be an associated increase in the size of the fishery to

accommodate increased demand for krill products. In order for the Commission to ensure the fishery develops in an orderly manner, it needs to be able track developments in the fishery, both in terms of changes in catches and developments in the marketplace for krill that will affect the demand for the resource. The tools currently used by the Commission to track the fishery: catch data, notification data, and the krill patent database that has recently been adopted, indicate emerging trends in the operation of the fishery. All three tools show a similar and statistically significant trend of increased interest in the krill fishery over the last 10 years, with information from the patent data reinforcing information from the catch and notification data.

Patent activity is at its highest level ever and the krill industry has been shown to be diversifying in terms of product range and focus – as well as the countries showing interest in fishing for krill. Patents act as a surrogate measure of interest in krill because they are applied for when the Applicant sees the possibility of future commercial gains from the technology and needs to protect their intellectual property rights and their R&D. However, the disconnect between countries involved in increased patenting activities and those countries which are actually fishing for krill indicates a paucity of information on the supply chain of krill from fisher to end-product developer. The Commission needs to establish connections with industry bodies to ensure this information is available to the Commission and can be used to both understand and track developments in the fishery into the future.

The krill patent database and the results of examination of Observer reports submitted under the CCAMLR Scheme of International Scientific Observation were key outcomes of this study. The research and results from both these processes were submitted to the Scientific Committee and WG-EMM, along with recommendations to utilise the information presented. Both papers had a significant impact, with the Commission adopting the krill patent database as a tool for tracking developments in the krill fishery and effecting changes in the collection of information through the Observer Scheme and notification procedure.

6.3 Management of the Southern Ocean Krill Fishery

The development of CCAMLR's approach to management is documented in the Conservation Measures which have been adopted by the Commission over the years of its operation. The regulatory controls enacted by these Conservation Measures largely follow the Commission's EBM and precautionary approach to management of the krill fishery. Whilst precautionary catch limits, the setting of trigger levels on these catches and controlled expansion of the fishery through exploratory fishing regulations represent the work of the Commission consistent with its precautionary approach to management, by-catch reduction mechanisms and general environmental protection measures represent measures in line with EBM.

However, some significant regulatory measures that would enhance the EBM and precautionary based management of the fishery that have been proposed by the Scientific Committee have been blocked in Commission meetings. In particular, continuing issues associated with the application of the CCAMLR Scheme of International Scientific Observation to the krill fishery are representative of the struggles the Commission has faced, and will continue to face, in ensuring that the fishery develops in a manner which is consistent with its management approach.

The blocking of management measures has been a consequence of the consensus decision making process. Until now, with only small, incremental increases in krill catches, tighter regulatory measures for the fishery have not been seen as necessary by some fishing nations. However, the relevance arguments presented by those Members who do not support 100% mandatory observer coverage for the krill fishery is diminishing as notifications begin to exceed trigger levels and actual catches approach these trigger levels. Whilst the absence of consensus on key management measures for the krill fishery can be seen as a failure of process within the Commission, it has not, and will not, result in over-harvesting of the krill resource in the short term. In the krill context, lack of consensus may have slowed down the process of adopting tighter regulatory measures for the fishery but it has not stopped the process which began with the establishment of precautionary catch limits in 1991.

Given the combined factors of scientific uncertainty and imminent expansion in catches, it is of increasing concern that the need for consensus amongst Members may impinge on the Commission's ability to adopt Conservation Measures that will allow the fishery to develop in an orderly manner.

6.4 Conclusions

Management of the krill fishery to date has been sufficient to ensure protection of krill stocks, and the populations of those species that are dependent on krill. However, up until this point in time, krill stocks have not been under significant pressure from fishing activities. Now, evidence from this research points towards an expansion in the krill fishery and the Commission must respond by implementing tighter regulatory measures to ensure that it develops in line with its approach to management. A first step towards achieving this would be for the Commission to act to bring management of the krill fishery into line with management measures applied to other fisheries in the Area.

Application of the CCAMLR Scheme of International Scientific Observation to the krill fishery must be made mandatory for all krill fishing vessels. The use of Government-appointed Observers is unhelpful to the Commission if reports from these Observers are not conveyed to the Commission in full. Data on by-catch, size, length and age frequency and fishing operations which can be gleaned from these reports would be invaluable to the Commission for management purposes. Only 100% coverage of the fishery using International Observers would ensure that all information collected by Observers was being passed on to the Commission.

Additionally, the full provisions of Conservation Measure 10-04 (Automated satellite-linked Vessel Monitoring Systems [VMS]) need to be applied to the krill fishery. Currently, the krill fishery is excluded from the provisions of this Measure requiring Members to submit VMS information to the Commission as well as the flag state. As this Measure is currently applied to the krill fishery, flag states are not required to forward VMS reports or messages emanating from krill fishing vessels fishing on to the Commission. With the eventuation of SSMUs

and the increasing likelihood that trigger levels for some Subareas in Area 48 will be reached and/or exceeded in coming seasons, it will be of critical importance that the Commission has access to up-to-the-minute information on the locations and operations of krill fishing vessels in those areas.

Future management decisions by the Commission *must* be sensitive to developments in the worldwide demand for krill and to the changes in the fishery that are likely to occur as a result. The future success of the Commission's approach to management is dependent not only on its science-based EBM but also on the existence of an industry that is a willing participant in the process. Recent developments, such as the MSC certification of one of the krill fishing vessels, indicates that there may be a move towards a more co-operative approach to the conservation and management of krill. This can only be good for the industry, for CCAMLR and for the Antarctic ecosystem.

References

Adelung, D., Buchholz, F., Culik, B. And Keck, A. (1987). Fluoride in tissues of krill *Euphausia superba* Dana and *Meganyctiphanes norvegica* M. Sars in relation to the moult cycle. Polar Biology **7**:43-50.

Agnew, D.J. (2008). Fisheries management and Conservation in the Antarctic: National and International Regimes and the Problem of Implementation. American Fisheries Society Symposium **49**:1667-1679.

Agnew, D.J. (1997). Review: The CCAMLR Ecosystem Monitoring Programme. Antarctic Science **9**(3):235-242.

Aker. (2010a). www.akerbiomarine.com. Accessed 23rd July, 2010.

Aker. (2010b). 2010 Q1 Report. AkerBioMarine, Norway.

Aker. (2010c). 2010 Q2 Report. AkerBioMarine, Norway.

Aker. (2009a). 2009 Annual Report. Aker BioMarine, Norway.

Aker. (2009b). 2009 Q3 Presentation. Aker BioMarine, Norway.

Aker. (2007). 2007 Q4 Report. Aker BioMarine, Norway.

Arthi, V. (2009). Omega 3 Concentrates – Window of Opportunities. Frost & Sullivan Market Insight, 27 August 2009. http://www.frost.com/prod/servlet/market-insight-top.pag?docid=178244151 Accessed 2nd November, 2009.

ASOC. (2006). Improving monitoring and control of the krill fishery. CCAMLR-XXV/BG27.

Baker, A. de C., Boden, B.P. and Brinton, E. (1990). *A practical Guide to the Euphausiids of the world.* British Museum – Natural History, London. 96pp.

Basberg, B. (1981). Patents, innovations and technological developments in Norwegian Whaling, 1880-1968. World Patent Information **3**(1):19-22.

Batetta, B., Griinari, M., Carta, G., Murru, E., Ligresti, A., Cordeddu, L., Giordano, E., Sanna, F., Bisogno, T., Uda, S., Collu, M., Bruheim, I., Di Marzo, V. and Banni, S. (2009). Endocannabinoids may mediate the ability of (n-3) fatty acids to reduce ectopic fat and inflammatory mediators in obese zucker rats. The Journal of Nutrition **139**(8):1495-1501.

Bederman, D.J. (2000). CCAMLR in crisis: A case study of marine management in the Southern Ocean. In: Scheiber, H.N. (Editor). *Law of the Sea: Common heritage and Emerging Challenges.* Publications on Ocean development, Volume 34, p. 169-196.

Boczek, B.A. (1983). The protection of the Antarctic Ecosystem: A study in International Environmental Law. Ocean Development and International Law **13**(3):347-425.

Bridges, K.M., Gigliotti, J.C., Altman, S., Jaczynski, J. and Tou, J.C. (2010). Determination of digestibility, tissue deposition and metabolism of the Omega-3 fatty acid content of krill protein concentrate in growing rats. Journal of Agricultural and Food Chemistry **58**:2830-2837.

Buchholz, F. (2003). Experiments on the physiology of Southern and Northern krill *Euphausia superba* and *Meganyctiphanes norvegica*, with emphasis on moult and growth - A Review. Marine and Freshwater Behaviour and Physiology **36**(4): 229-247.

Budzinski, E., Bykowski, P. and Dutkiewicz, D. (1985). Possibilities of processing and marketing of products made from Antarctic krill. *FAO Fisheries Technical Paper*. No.268. Rome: FAO. 46p.

Bunea, R., Farrah, K.E. and Deutsch, L. (2004). Evaluation of the effects of Neptune Krill Oil on the clinical course of hyperlipidemia. Alternative Medicine Review **9**(4):420-428.

Bustos, R., Romo, L., Yáñez, K., Díaz, G. and Romo, C. (2003). Oxidative stability of carotenoid pigments and polyunsaturated fatty acids in microparticulate diets containing krill oil for nutrition of marine fish larvae. Journal of Food Engineering **56**:289-293.

CCAMLR. (2010). *Statistical Bulletin*, Vol. 22 (Database Version).

CCAMLR. (2009a). www.ccamlr.org. Accessed 1st October, 2009.

CCAMLR. (2009b). Summary of notifications for krill fisheries in 2009/10. WG-EMM 09/7.

CCAMLR-XXVIII. (2009). Report of the Twenty-eighth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-XXVII. (2008). Report of the Twenty-seventh Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-XXVI. (2007). Report of the Twenty-sixth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-XXV. (2006). Report of the Twenty-fifth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-XXIV. (2005a). Report of the Twenty-forth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR. (2005b). Text of the CCAMLR Scheme of International Scientific Observation: Part 10 to the text of the Convention on the Conservation of Antarctic Marine Living Resources. CCAMLR *Basic Documents*. CCAMLR, Hobart.

CCAMLR-XXII. (2003). Report of the Twenty-second Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-XXI. (2002). Report of the Twenty-first Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-XIX. (2000). Report of the Nineteenth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-XVII. (1998). Report of the Seventeenth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-XIII. (1994). Report of the Thirteenth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-IX. (1990). Report of the Ninth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-VIII. (1989). Report of the Eight Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-V. (1986). Report of the Fifth Meeting of the Commission. CCAMLR, Hobart.

CCAMLR-II. (1983). Report of the Second Meeting of the Commission. CCAMLR, Hobart.

Chandrasekar, B., Troyer, D.A., Venkatraman, J.T. and Fernandes, G. (1996). Tissue specific regulation of transforming growth factors beta by oemga-3

lipid-rich krill oil in autoimmune murine lupus. Nutrition Research **16**(3):489-503.

ColdSea. (2009). http://www.norwegiankrilloil.com/index.php/coldseakrill. Accessed 27th July, 2010.

Constable, A.J. (2002). CCAMLR Ecosystem Monitoring and Management: Future Work. CCAMLR Science **9**:233-253.

Constable, A.J. (2001). The ecosystem approach to managing fisheries: achieving conservation objectives for predators of fished species. CCAMLR Science **8**:37-64.

Constable, A. J. and W. K. de la Mare. (1995). A generalised model for evaluating yield and the long term status of fish stocks under conditions of uncertainty. CCAMLR Science: 31-54.

Constable, A.J., de la Mare, W.K., Agnew, D.J., Everson, I. and Miller, D. (2000). Managing fisheries to conserve the Antarctic marine ecosystem: practical implementation of the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). ICES Journal of Marine Sciences **57**: 778-791.

Conway, E. (2008). George Soros: rocketing oil price is a bubble. www.telegraph.co.uk. Telegraph 26th May 2008. Accessed 1st October, 2010,

Cool Antarctica. (2008). www.coolantarctica.com. Accessed 12th June, 2008.

Croxall, J.P. and Nicol, S. (2004). Management of Southern Ocean fisheries: global forces and future sustainability. Antarctic Science **16**(4):569-584.

Croxall, J.P., Everson, I. and Miller, D.G.M. (1992). Management of the Antarctic krill fishery. Polar Record **28**(164):64-66.

Czeczuga, B. (1984). Studies on carotenoproteins in animals. X. *Euphausia superba* Dana 1852 (*Crustacea, Euphausiacea*). Polish Polar Research **5**(1-2):121-127.

Darby, A. (2010). Australia selling whale products in spite of ban. www.theage.com.au. The Age 16th June. Accessed 20th July, 2010.

Davis, D.A. and Arnold, C.R. (2000). Replacement of fish meal in practical diets for the pacific white shrimp, *Liptopenaeus vannamei*. Aquaculture **185**:291-298.

Deutsch, L. (2007). Evaluation of the effect of Neptune Krill Oil on chronic inflammation and arthritic symptoms. Journal of the American College of Nutrition **26**(1):39-48.

Duan, J., Jiang, Y., Cherian, G. and Zhao, Y. (2010). Effect of combined chitosan-krill oil coating and modified atmosphere packaging on the storability of cold-stored lingcod (*Ophiodon elongates*). Food Chemistry **122**(4):1035-1042.

Eddie, G.C. (1977). The Harvesting of Krill. Southern Ocean Fisheries Survey Programme. Rome, FAO, GLO/SO/77/2. 76p.

Edwards, D.M. and Heap, J.A. (1981). Convention on the Conservation of Antarctic Marine Living Resources: A Commentary. Polar Record **20**(127):353-362.

Enzymotec. (2010). Enzymotec Profile. http://www.npicenter.com/images/profile/Enzy/Enzymotec%20Profile.pdf. Accessed 4th August, 2010.

Everson, I. (2000). The Southern Ocean. In: Everson I. (Ed) *Krill: biology, Ecology and Fisheries*. Blackwell Science Ltd, Oxford. p. 63-79.

Everson, I. (1977). The Living Resources of the Southern Ocean. Southern Ocean Fisheries Survey Programme. Rome: FAO, GLO/SO/77/1. 156p.

Everson, I. and de la Mare, W.K. (1996). Some thoughts on precautionary measures for the krill fishery. CCAMLR Science **3**:1-11.

Fabra, A. and Gascón, V. (2008). The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) and the Ecosystem Approach. The International Journal of Marine and Coastal Law **23**:567-598.

FAO. (2010). Fisheries Commodities and Trade. http://www.fao.org/fishery/statistics/global-commodities-production/en.

FAO. (2009). http://www.fao.org/fishery/species/3393/en. Accessed 5th October, 2009.

FAO. (2008). The State of World Fisheries and Aquaculture. FAO Fisheries and Aquaculture Department. FAO, Rome. 178p.

FAO Fish Stat Plus. (2007). Food and Agricultural Organisation universal software for fishery statistical time series.

FAO. (2006). Review of the State of World Marine Fisheries Resources. ftp://ftp.fao.org/docrep/fao/007/y5852e/Y5852E23.pdf.

FAO. (2004). Protein Sources for the Animal Feed Industry. In: *FAO Animal Production and Health Proceedings*. Expert consultation and Workshop, Bangkok, 29 April to 3 May, 2002. FAO, Rome. 349p.

Färber-Lorda, J., Beier, E. and Mayzaud, P. (2009). Morphological and biochemical differentiation in Antarctic krill. Journal of Marine Systems **78**:525-535.

Fereidoon, S. and Wanasundara, U.N. (1998). Omega-3 fatty acid concentrates: nutritional aspects and production technologies. Trends in Food Science and Technology **9**:230-240.

Fernholm, B. and Rudback, G.T. (1989). Marine resource management of the Antarctic. Ambio **18**(1):68-70.

FIS. (2009). Krill oil product to be marketed in Europe. http://fis.com/fis/worldnews/worldnews.asp?l=e&ndb=1&id=34910. Accessed 27th July, 2010.

Fishbase. (2009). www.fishbase.org. Accessed 2nd July, 2010.

Floreto, E.A.T., Brown, P.B. and Bayer, R.C. (2001). The effects of krill hydrolysate-supplemented soy-bean based diets on the growth, colouration, amino and fatty acids profiles of juvenile American lobster, *Homarus americanus*. Aquaculture Nutrition **7**:33-43.

Foster, J., Nicol, S. and Kawaguchi, S. (2009). The use of patent databases to detect trends in the krill fishery. CCAMLR, SC-CAMLR-XXVIII/BG/15.

Foster, J., Nicol, S. and Kawaguchi, S. (2007). Information on krill in reports from the CCAMLR Scheme of International Observation and its utility for management. CCAMLR, WG-EMM-07/22.

Frank, R.F. (1983). The Convention on the Conservation of Antarctic Marine Living Resources. Ocean Development and International Law Journal **13**(3):291-345.

Fréon, P., Cury, P., Shannon, L and Roy, C. (2005). Sustainable exploitation of small pelagic fish stocks challenged by environmental and ecosystem changes: A Review. Bulletin of Marine Science **76**(2):385-462.

Gaber, M.M.A. (2005). The effect of different levels of krill meal supplementation of soybean-based diets on feed intake, digestibility, and chemical composition of juvenile Nile Tilapia *Oreochromis niloticus, L.* Journal of the World Aquaculture Society **36**(3):346-353.

Gigliotti, J.C., Jaczynski, J. and Tou, J.C. (2008). Determination of the nutritional value, protein quality and safety of krill protein concentrate isolated using an isoelectric solubilization/precipitation technique. Food Chemistry **111**:209-214.

Giogios, I., Grigorakis, K., Nengas, I., Papasolomontos, S., Papaioannou, N. and Alexis, M.N. (2009). Fatty acid composition and volatile compounds of selected marine oils and meals. Journal of the Science of Food and Agriculture **89**:88-100.

Globefish. (2010). www.globefish.org/fish-oil-and-fishmeal-market-reports.html. Accessed 2nd July, 2010.

Grantham, G.J. (1977). The Utilization of Krill. Southern Ocean Fisheries Survey Programme. Rome: FAO, GLO/SO/77/3. 61p.

Güner, S., Dincer, B., Alemdag, N., Colak, A. and Tüfekci, M. (1998). Proximate composition and selected mineral content of commercially important fish species from the Black Sea. Journal of the Science of Food and Agriculture **78**(3):337-342.

Gupta, R. and Manchikanti, P. (2010). Analysis of patenting trends of antifungal drugs in the product patent regime in India. World Patent Information **32**:135-140.

Hamovitch, E. (2001). Tapping Krill. Montreal Business Magazine July-August:86-87.

Harvard. (2009). http://www.hsph.harvard.edu/nutritionsource/what-should-you-eat/protein-full-story/index.html#1. Harvard School of Public Health. Accessed 13th October, 2009.

Hasan, M.R., Hecht, T., De Silva, S.S. and Tacon, A.G.J. (2007). Study and analysis of feeds and fertilizers for sustainable aquaculture development. *FAO Fisheries Technical Paper*. No.497. Rome, FAO. 510p.

Heffernan, D.A. (1987). The Australian Biology Dictionary. Longman Cheshire Pty Ltd, London.

Heller, L. (2010). Enzymotec krill gets Novel Food status. 18th May, 2010. NUTRAingredients.com.

Hewitt, R.P. and Low, E.H.L. (2000). The Fishery on Antarctic Krill: Defining an Ecosystem Approach to Management. Reviews in Fisheries Science **8**(3):235-298.

Hildago, A., Molero, J. and Penas, G. (2010). Technology and industrialization at the take-off of the Spanish economy: New evidence based on patents. World Patent Information **32**:53-61.

Howard, M. (1989). The Convention on the Conservation of Antarctic Marine Living Resources: A five-year review. International and Comparative Law Quarterly **38**: 104-149.

IFFO. (2008a). The healthiest omega-3s EPA and DHA are found mainly in fish oil and fishmeal. http://www.iffo.net/downloads/77.pdf. International Fishmeal and Fish Oil Organisation. Accessed 2nd August, 2010.

IFFO. (2008b). The importance of dietary EPA & DHA omega-3 fatty acids in the health of both animals and humans. http://www.iffo.net/intranet/content/archivos/75.pdf. International Fishmeal and Fish Oil Organisation. Accessed 2nd August, 2010.

Indiseas. (2008). http://www.meece.eu/indiseas.html. Accessed 20th March, 2010.

IP Australia. (2010). www.ipaustralia.gov.au. Accessed 27th September, 2010.

Jackson, A. (2006). Fish In - Fish Out (FIFO) Ratios Explained. http://www.iffo.net/intranet/content/archivos/100.pdf. International Fishmeal and Fish Oil Organisation. Accessed 21st July, 2010.

Jacquet, J. and Pauly, D. (2010). Seafood stewardship in crisis. Nature **467**(2):28-29.

Kalinowski, C.T., Izquierdo, M.S., Schuchardt, L.E. (2007). Dietary supplementation time with shrimp shell meal on red porgy (*Pagrus pagrus*) skin colour and carotenoid concentration. Aquaculture **272**:451-457.

Karlsen, Ø., Suontama, J. and Olsen, R.E. (2006). Effect if Antarctic krillmeal on quality of farmed Atlantic cod (*Gadus morhua* L.). Aquaculture Research **37**(16):1676-1684.

Karlstam, B., Vincent, J., Johansson, B. and Bryno, C. (1991). A simple purification method of squeezed krill for obtaining high levels of hydrolytic enzymes. Preparative Biochemistry **21**:237-256.

Kassis, N.M., Beamer, S.K., Matak, K.E., Tou, J.C. and Jaczynski, J. (2010). Nutritional composition of novel nutraceutical egg products developed with omega-3-rish oils. LWT – Food Science and Technology **43**:1204-1212.

Kawaguchi, S. (2009). Implementation of CCAMLR Observer Program on Krill Fisheries. CCAMLR, WG-TASO-09/07.

Kawaguchi, S. and Nicol, S. (2007). Learning about Antarctic krill from the fishery. Antarctic Science **19**(2):219-230.

Kidd, P.M. (2009). Integrated brain restoration after Ischemic Stroke – Medical management, risk factors, nutrients, and other interventions for managing inflammation and enhancing brain plasticity. Alternative Medicine Review **14**(1):14-35.

Kim, S-K., Takeuchi, T., Akimoto, A., Furuita, H., Yamamoto, T., Yokoyama, M. and Murata, Y. (2005). Effect of taurine supplemented practical diet on growth performance and taurine contents in whole body and tissues of juvenile Japanese flounder *Paralichthys olivaceus*. Fisheries Science **71**:627-632.

Kock, K-H. (2007). Antarctic Marine Living Resources – exploitation and its management in the Southern Ocean. Antarctic Science **19**(2):231-238.

Kock, K-H. (2000). http://www.ccamlr.org/pu/e/e_pubs/am/toc.htm. Viewed 19th June, 2007.

Kock, K-H., Reid, K., Croxall, J. and Nicol, S. (2007). Fisheries in the Southern Ocean: an ecosystem approach. Philosophical Transactions of the Royal Society B **362**: 2333-2349.

Kofuji, P.Y.M., Hosokawa, H. and Masumoto, T. (2006). Effects of dietary supplementation with feeding stimulants on yellowtail *Seriola quinqueradiata* (Temminck & Schlegel; Carangidae) protein digestion at low water temperatures. Aquaculture Research **37**:366-373.

KrillSea. (2010). www.krillsea.no. Accessed 2nd August, 2010.

Lyubimova, T.C., Naumov, A.G. and Lagunov, L.L. (1973). Prospects of the utilisation of krill and other unconventional resources of the world ocean. Journal of the Fisheries Research Board of Canada **30**(12/2):2196-2201.

Maguire, J.-J., Sissenwine, M., Csirke, J., Grainger, R. and Garcia, S. (2006). The state of world highly migratory, straddling and other high seas fishery resources and associated species. *FAO Fisheries Technical Paper.* No. 495. Rome: FAO. 84p.

Marr, J. (1962). The natural history and geography of the Antarctic krill (*Euphausia superba*). Discovery Reports. Vol. XXXII, p. 33-464.

Makintosh, N.A. (1973). *Distribution of post-larval krill in the Antarctic.* Discovery Reports. Cambridge University Press, London. Vol. XXXVI, p.95-156.

Mauchline, J. (1980). The biology of mysids and euphausiids. Advances in Marine Biology **18**:1-681.

McElroy, J.K. (1984). Antarctic Fisheries. History and prospects. Marine Policy **8**(3):239-259.

McElroy, J.K. (1982a). P15: The Production and Use of Krill Meal: A Techno-Economic Appraisal. Centre for the Economics and Management of Aquatic Resources, University of Portsmouth, UK.

McElroy, J.K. (1982b). Krill – still an enigma. Marine Policy **6** (3):238-239.

McElroy, J.K. (1981a). P10: The Market for Krill. Centre for the Economics and Management of Aquatic Resources, University of Portsmouth, UK.

McElroy, J.K. (1981b). P11: The Economics of Harvesting Krill. Centre for the Economics and Management of Aquatic Resources, University of Portsmouth, UK.

McElroy, J.K. (1980). Economic evaluations of krill fishing systems. In: Connell, J.J. (Ed). *Advances in Fish Science and Technology.* Fishing News Books, Blackwell Scientific Publications Ltd. London. P. 314-322.

Melrose, J., Hall, A., Macpherson, C., Bellenger, C.R. and Ghosh, P. (1995). Evaluation of digestive proteinases from the Antarctic krill *Euphausia superba* as potential chemonucleolytic agents. *In vitro* and *in vivo* studies. Archives of Orthopaedic and Trauma Surgery **114**:145-152.

Miller D.G.M. (2002). Antarctic krill and ecosystem management—from Seattle to Siena. CCAMLR Science **9**:175–2002.

Miller, D.G.M. (1991). Exploitation of Antarctic marine living resources: A brief history and a possible approach to managing the krill fishery. South African Journal of Marine Science **10**:321-339.

Miller D.G.M, Sabourenkov E.N, Ramm D.C. (2004). Managing Antarctic marine living resources: the CCAMLR approach. International Journal of Marine and Coastal Law **19**:317–363.

Miller, D.G.M. and Hampton, I. (1989). Biology and Ecology of the Antarctic Krill. BIOMASS Scientific Series **9**. 166p.

Molenaar, E.J. (2000). CCAMLR and Southern Ocean Fisheries. The International Journal of Marine and Coastal Law **16**(3):465-499.

Moreira, A.C., Muller, A.C.A., Pereira, N. and Antunes, A. (2006). Pharmaceutical patents on plant derived materials in Brazil: Policy, law and statistics. World Patent Information **28**:34-42.

Moretti, V.M., Mentasti, T., Bellagamba, F., Luzzana, U., Caprino, G.M., Giani, I. and Valfrè, F. (2006). Determination of astaxanthin stereoisomers and colour attributes in flesh of rainbow trout (*Oncorhynchus mykiss*) as a tool to distinguish the dietary pigmentation source. Food Additives and Contaminants **23**(11):1056-1063.

MSC. (2010). www.msc.org. Marine Stewardship Council. Accessed 3rd August, 2010.

Naczk, M., Synowiecki, J. and Sikorski, Z.E. (1981). The gross chemical composition of Antarctic krill waste. Food Chemistry 7:175-179.

Naylor, R.L., Goldburg, R.J., Primavera, J.H., Kautsky, N., Beveridge, M.C.M., Clay, J., Folks, C., Lubchenco, J., Mooney, H. and Troell, M. (2000). Effect of aquaculture on world fish supplies. Nature **405**:1017-1024.

Neptune Technologies and Bioressources. (2010a). www.neptunebiotech.com. Accessed 2nd August, 2010.

Neptune Technologies and Bioressources. (2010b). First Quarter Report 2010.

Neptune Technologies and Bioressources. (2009). 2009 Annual Report.

Neptune Technologies and Bioressources. (2008). www.neptunebiotech.com. Accessed 16th April, 2008.

Nichols, P.D. (2007). Fish oil sources. In: Breivik, H (Editor) *Long-Chain Omega-3 Speciality Oils*. The Oily Press, England.

Nichols, P.D. and Nelson, M.M. (2007). Marine oils in Australasia. In: O'Connor, J (Chairman) *Handbook of Australasian Edible Oils*. Oils and Fats Specialist Group of NZIC, Auckland, New Zealand.

Nichols, P.D., Virtue, P., Mooney, B.D., Elliott, N.G. and Yearsley, G.K. (1998). Seafood the good food: the oil (fat) content and composition of Australian commercial fishes, shellfishes and crustaceans. FRDC Project 95/122.

Nicol, S., Foster, J. and Kawaguchi, S. (2011). The fishery for Antarctic krill – recent developments. Fish and Fisheries, 7th February, 2011.

Nicol, S. (1992). Management of the krill fishery; was CCAMLR slow to act? Polar Record **28**(165):155-157.

Nicol, S. (1991). CCAMLR and its approaches to management of the krill fishery. Polar Record **27**(162):229-236.

Nicol, S. and Foster, J. (2003). Recent trends in the fishery for Antarctic krill. Aquatic Living Resources **16**:42-45.

Nicol, S. and Foster, J. (2002). Detecting trends in the krill fishery. CCAMLR, WG-EMM-XXI-02/25.

Nicol, S., Forster, I. and Spence, J. (2000). Products Derived from Krill. In: Everson I. (Ed) *Krill: biology, Ecology and Fisheries*. Blackwell Science Ltd, Oxford. p. 262-283.

Nicol, S. and Endo, Y. (1997). Krill fisheries of the world. *FAO Fisheries Technical Paper*. No.367. Rome: FAO. 81p.

Nicol, S. and De la Mare, W. (1993). Ecosystem management and the Antarctic krill. American Scientist **81**(1):36.

Nicol, S. and Hosie, G.W. (1993). Chitin Production by Krill. Biochemical Systematics and Ecology **21**(2):181-184.

Ninan, S. and Sharma, A. (2006). Cross-sectional analysis of patents in Indian fisheries sector. World Patent Information **28**:147-158.

NuGO. (2010). Nutrigenomics Organisation. www.nugo.org. Accessed 29th July, 2010.

Nutraingredients. (2004). Fish oils have good future, suggests recent supplier expansions. http://www.nutraingredients.com/Consumer-Trends/Fish-oils-have-good-future-suggests-recent-supplier-expansions. Accessed 4th November, 2009.

Oehlenschläger, J. and Schreiber, W. (1981). A Functional Protein Concentrate (FKPC) from Antarctic Krill (*Euphausia superba*, Dana 1850). Lebenschmittel-Untersuchung und-Forschung **172**:393-398.

OPEC (2010). OPEC: Annual Report 2009. Organisation of the Petroleum Exporting Countries, Austria.

Opstad, I., Suontama, J., Langmyhr, E and Olsen, R.E. (2006). Growth, survival and development of Atlantic cod (*Gadus morhua* L.) weaned onto diets containing various sources of marine protein. ICES Journal of Marine Science **63**:320-325.

Parkes, G. (2000). Precautionary fisheries management: the CCAMLR approach. Marine Policy **24**:83-91.

Pikitch, E.K., Santora, C., Babcock, E.A., Bakun, A., Bonfil, R., Conover, D.O., Dayton, P., Doukakis, P., Fluharty, D., Heneman, B., Houde, E.D., Link, J., Livingston, P.A., Mangel, M., McAllister, M.K., Pop, J. and Sainsbury, K.J. (2004). Ecosystem-Based Fishery Management. Science **305**:346-347.

Pilkington, A. (2004). Technology portfolio alignment as an indicator of commercialisation: an investigation of fuel cell patenting. Technovation **24**:761-771.

Pitcher, T.J. (2008). The sea ahead: challenges to marine biology from seafood sustainability. Hydrobiologia **606**:161-185.

Plagányi, É.E. and Butterworth, D.S. (2008). Conditioning SMOM using the agreed calendar of observed changes in predator and krill abundance: a further step in the observed changes in predator and krill abundance: a further step in the development of a management procedure for krill fisheries in Area 48. CCAMLR WG-EMM-08/44.

Rehbein, H. (1980). Composition and properties of krill fingers. In: Connell, J.J. (Ed). *Advances in Fish Science and Technology*. Fishing News Books, Blackwell Scientific Publications Ltd. London. P. 311-314.

Ruckelshaus, M., Klinger, T., Knowlton, N. And DeMaster, D.P. (2008). Marine Ecosystem-based management in Practice: Scientific and Governance Challenges. Bioscience **58**(1):53-63.

Sabourenkov, E.N. and Appleyard, E. (2005). Scientific Observations in CCAMLR Fisheries – Past, Present and Future. CCAMLR Science **12**:81-98.

Sainsbury, K.J., Punt, A.E. and Smith, A.D.M. (2000). Design of operational management strategies for achieving fishery ecosystem objectives. ICES Journal of Marine Science **57**:731-741.

Samocha, T.M., Davis, D.A., Saoud, I.P. and Debault, K. (2004). Substitution of fish meal by co-extruded soybean poultry by-product meal in practical diets for the Pacific white shrimp, *Litopaenaeus vannamei*. Aquaculture **231**:197-203.

Savage, G.P. and Foulds, M.J. (1987). Chemical composition and nutritive value of Antarctic krill (*Euphausia superba*) and southern blue whiting (*Micromesistius australis*). New Zealand Journal of Marine and Freshwater Research **21**:599-604.

SC-CAMLR-XXVIII. (2009). Report of the Twenty-eighth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XXVII. (2008). Report of the Twenty-seventh Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XXVI. (2007). Report of the Twenty-sixth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XXV. (2006). Report of the Twenty-fifth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XXIV. (2005). Report of the Twenty-fourth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XXIII. (2004). Report of the Twenty-third Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XXII. (2003). Report of the Twenty-second Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XXI. (2002). Report of the Twenty-first Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XX. (2001). Report of the Twentieth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XIX. (2000). Report of the Nineteenth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XVIII. (1999). Report of the Eighteenth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XVII. (1998). Report of the Seventeenth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-XVI. (1997). Report of the Sixteenth Meeting of the Scientific Committee. CCAMLR, Hobart.

SC-CAMLR-X. (1991). Report of the Tenth Meeting of the Scientific Committee. CCAMLR, Hobart.

Schiermeier, Q. (2010). Green patents corralled. Nature **465**(6):21.

Shahidi, F. and Wanasundara, U.N. (1998). Omega-3 fatty acid concentrates: nutritional aspects and production technologies. Trends in Food Science and Technology **9**:230-240.

Sidhu, G.S., Montgomery, W.A., Holloway, G.L., Johnson, A.R. and Walker, D.M. (1970). Biochemical composition and nutritive vale of krill (*Euphausia superba* Dana). Journal of the Science of Food and Agriculture **21**:293-296.

Siebert, G., Kühl, J and Hannover, R. (1980). Nutritional experiments with krill. In: Connell, J.J. (Ed). *Advances in Fish Science and Technology.* Fishing News Books, Blackwell Scientific Publications Ltd. London. P. 332-334.

Siegel, V. (2005). Distribution and population dynamics of *Euphausia superba*: summary of recent findings. Polar Biology **29**(1):1-22.

Skretting. (2008). Revealing Our Commitment to Sustainable Aquaculture. http://www.skretting.com.au/internet/SkrettingAustralia/webInternet.nsf/wprId/97C337D45F48D1DDC125751200108EC9?OpenDocument. Accessed 25th March, 2008.

Small, C.J. (2005). Regional Fisheries Management Organisations: their duties and performance in reducing bycatch of albatrosses and other species. Cambridge, UK: Birdlife International.

Smith, D.M., Tabrett, S.J., Barclay, M.C. and Irvin, S.J. (2005a). The efficacy of ingredients included in shrimp feeds to stimulate uptake. Aquaculture Nutrition **11**:263-272.

Smith, D.M., Williams, K.C. and Irvin, S.J. (2005b). Response of the tropical spiny lobster *Panulirus ornatus* to protein content of pelleted feed and to a diet of mussel flesh. Aquaculture Nutrition **11**:209-217.

Soevik, T. and Braekkan, O.R. (1979). Fluoride in Antarctic Krill (*Euphausia Superba*) and Atlantic Krill (*Meganyctiphanes norvegica*). Journal of the Fisheries Research Board of Canada **36**:1414-1416.

Suontama, J., Kiessling, A., Melle, W., Waagbø, R. and Olsen, R.E. (2007). Protein from Northern krill (*Thysanoessa inermis*), Antarctic krill (*Euphausia superba*) and the Arctic amphipod (*Themisto libellula*) can partially replace fish meal in diets to Atlantic salmon (*Salmo salar*) without affecting product quality. Aquaculture Nutrition **13**:50-58.

Sydney Fish Market (2008). Krill Report. Sydney Fish Market Pty. Ltd. Sydney, Australia.

Tacon, A.G.J. and Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. Aquaculture **285**:146-158.

Tacon, A.G.J. (2005). Salmon aquaculture dialogue: state of information on salmon aquaculture feed and the environment. International Aquafeed **8**:22-37.

Tandy, S., Chung, R.W.S., Wat, E., Kamili, A., Berge, K., Griinari. M. and Cohn, J.S. (2009). Dietary krill oil supplementation reduces hepatic steatosis, glycaemia, and hypercholesterolemia in high-fat-fed mice. Journal of Agricultural and Food Chemistry **57**:9339-9345.

Tenuto-Filho, A. and Alvarenga, R.C.C. (1999). Reduction of the bioavailability of fluoride from Antarctic krill by calcium. International Journal of Food Science and Nutrition **50**:297-302.

Tenuto-Filho, A. (1993). Fluorine removal during production of krill paste and protein concentrates. Acta Alimaentaria **22**:269-281.

Tokyo Metropolitan Central Wholesale Market (2008). http://www.shijou.metro.tokyo.jp/torihiki/.

Tou, J.C., Jaczynski, J. and Chen-Chen, Y. (2007). Krill for human consumption: nutritional value and potential health benefits. Nutrition Reviews **65**(2):63-77.

Triggs, G.D. (1987). Introduction to: Part II. The Antarctic Treaty Regime: protecting the marine environment. In: Triggs, G.D. (Editor). *The Antarctic Treaty Regime*. Cambridge, Cambridge University Press, p.113-115.

Turner, J., Jabour, J. and Miller, D. (2008). Consensus or Not Consensus: That Is the CCAMLR Question. Ocean Yearbook **22**:117-157.

UNCED. (1992). Report of the United Nations Conference on Environment and Development. Rio de Janeiro, 3 to 14 June, 1992. United Nations General Assembly, New York.

United Nations Population Division. (2009). http://esa.un.org/unpp/. Accessed 13th October, 2009.

Voronia, N.M. (1983). Biomass and production of Antarctic krill (*Euphausia superba* dana). Oceanology **23**(6):760-762.

WG-EMM-XXVIII. (2009). Report of the Working Group on Ecosystem Monitoring and Management. CCAMLR, Hobart.

WG-EMM-XXVI. (2007). Report of the Working Group on Ecosystem Monitoring and Management. CCAMLR, Hobart.

WG-EMM-XXI. (2002). Report of the Working Group on Ecosystem Monitoring and Management. CCAMLR, Hobart.

Watters, G.M., Hinke, J.T. and Hill, S. (2008a). Developing four plausible parameterizations of Foosa (a so called reference set of parameterizations) by conditioning the model on a calendar of events that describes changes in the abundances of krill and their predators in the Scotia Sea. CCAMLR WG-EMM-08/13.

Watters, G.M., Hinke, J.T. and Hill, S. (2008b). A risk assessment to advise on strategies for subdividing a precautionary catch limit among small-scale management units during stage 1 of the staged development of the krill fishery in Subareas 48.1, 48.2 and 48.3. CCAMLR WG-EMM-08/30.

Yanase, M. (1981). Chemical Composition of the exoskeleton of Antarctic krill. Bulletin of Tokai Regional Fisheries Research Laboratories **83**:1-6.

Yoshitomi, B., Masatoshi, A. and Syun-ichirou, O. (2007). Effect of total replacement of dietary fish meal by low fluoride krill (*Euphausia superba*) meal on growth performance of rainbow trout (*Oncorhynchus mykiss*) in fresh water. Aquaculture **266**:219-225.

Zhu, B. and Wang, X. (1989). A study of fluoride and biochemical components in Antarctic krill (*Euphausia superba*). In: Kung, G. (Editor). Proceedings of the International Symposium on Antarctic Research. China Ocean Press, Tianjin, China, p. 277-283.